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RESEARCH ARTICLE

Energy-efficient techniques for IoT application on resource-aware fog computing paradigm

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Abstract
During the rapid emergence of the IoT environment, computing is widespread in all domains and undergoes tiny changes on an everyday basis that lead to momentous shifts in the development and deployment of applications. Network infrastructure can be utilized efficiently in large volumes of data by deploying the applications. IoT applications constitute different types of modules that run together with interdependency and run on the cloud conventionally in the data center. The research study proposes a framework for a resource-aware fog computing paradigm using a module mapping algorithm, lower bound algorithm, application module, network node and resource-aware algorithm. Fog computing is employed for deploying IoT applications that are sensitive to latency. The incoming data is processed by fog computing by utilizing the available resources by reducing the amount of data sent to the server. The optimum performance can be achieved by connecting the appropriate sensor node to the parent node. The proposed algorithm reduces energy consumption and latency. Comparative analysis is performed for the proposed and conventional fog computing paradigm.

Keywords: Resource aware, IoT application, Fog computing paradigm, Latency, network, Energy efficient technique.

Introduction

One of the most exciting new developments that could have a huge impact on our society is the internet of things (IoT). Many of the items in our environment can be integrated with the Internet and communication can be made easier without the involvement of human beings and the IoT approaches a critical mass in development [Atlam, H. F., & Wills, G. B., 2019]. The primary objective of the IoT is to decrease the amount of data entry done by humans by using various kinds of sensors for gathering data from the surroundings and enabling autonomous data processing and storage [Sharma, V., Malhotra, S., & Hashmi, M., 2018; Atlam, H. F., Walters, R. J., Wills, G. B., & Daniel, J., 2021].

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The inability of current cloud platforms to handle and store the growing volume of IoT data traffic [Singhal, A. K., & Singhal, N., 2021] is a problem that impacts all IoT systems. Applications related to health care [Santos, G. L., Takako Endo, P., Ferreira da Silva Lisboa Tigre, M. F., Ferreira da Silva, L. G., Sadok, D., Kelner, J., & Lynn, T., 2018], multimedia [Mann, Z. A., 2022], and vehicular/drone applications [Yu, C., Lin, B., Guo, P., Zhang, W., Li, S., & He, R., 2018; Mahmood, Z., & Ramachandran, M., 2018] that are latency-sensitive may experience a comparatively significant delay when connecting to a distant cloud through congested networks. Moreover, uploaded IoT data may have less privacy as a result of cloud centralization [Margariti, S. V., Dimakopoulos, V. V., & Tsoumanis, G., 2020]. Although cloud computing provides benefits, the traditional network architecture of cloud computing is under threat from the impending IoT ecosystem due to the rapid growth of ubiquitous mobile and sensing devices and technological advancements. The IoT applications and their requirements lead to the emergence of fog and cloud computing paradigms for overcoming the aforementioned issues and the requirements will meet with latency-sensitive communication, network processing efficiency and dynamic scalability [Fersi, G., 2021; Bhambri, P., Rani, S., Gupta, G., & Khang, A. (Eds.), 2022].

Fog is a layer that sits between the cloud and IoT levels, made up of processing power, memory and a network that has geographically dispersed servers. Fog servers when compared with cloud servers can be situated closer to the IoT

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devices and can produce lower reaction rates and are hence capable of supporting the majority of latency-sensitive IoT applications [Bermbach, D., Pallas, F., Pérez, D. G., Plebani, P., Anderson, M., Kat, R., & Tai, S., 2018]. Even though fog servers have far less processing and storage power than the cloud [Skarlat, O., Karagiannis, V., Rausch, T., Bachmann, K., & Schulte, S., 2018], their greater quantity and geographic distribution enable network congestion in the cloud can be reduced by fog by supporting a high volume of Internet of Things applications. Local fog servers can indeed handle an IoT application completely without allowing IoT data to spread to clouds or fog further out into the network.

A vast number of geographically dispersed and heterogeneous Fog Servers are situated in an intermediary layer between IoT devices and Cloud servers according to the Fog computing paradigm [Goudarzi, M., Palaniswami, M., & Buyya, R., 2019, Yousefpour, A., Fung, C., Nguyen, T., Kadiyala, K., Jalali, F., Niakanlahiji, A., & Jue, J. P., 2019]. As shown in Figure. 1, distributed field switches (FSs) such as Nvidia Jetson platform, Rasberry Pis, nano servers, femtocells, core routers, regional servers, base stations for small-cell and switches provide storage resources and heterogeneous computing for running of different types of applications in IoT devices.

The constraints may be overcome by cloud computing with the use of edge and fog computing [Atieh, A. T., 2021]. Since cloud computing cannot be fully replaced by edge computing or fog computing, they are not replacements for it. On the other hand, the three technologies can cooperate to provide enhanced response times, dependability, and latency. Location awareness is also made possible by the edge devices' and the fog layer's geo-distributed architecture.

The location of processing power and intelligence is one of the main distinctions between fog and edge computing.

Many nodes are used in fog computing to connect the cloud to the end devices that contain intelligence. These assigned smart nodes serve as access points or base stations [Karagiannis, V., & Schulte, S., 2020]. Away from the cloud, the relocating intelligence can be processed by fog computing with internet of things data close to the data sources. After that, it can use cloud resources more efficiently than it could with individual devices (only if necessary). For example, Data processing can be assisted by fog computing in the IoT gateway or fog node by moving the intelligence and resource allocation in the network architecture to the local area network position [Naha, R. K., Garg, S., Georgakopoulos, D., Jayaraman, P. P., Gao, L., Xiang, Y., & Ranjan, R., 2018].

Integration of the internet of things with fog computing brought new business possibilities using fog as a service. In this scenario, a service provider establishes a network of fog node sales as a landlord throughout the geographical footprint from various types of vertical industries to several tenants. Local computing, networking, and storage

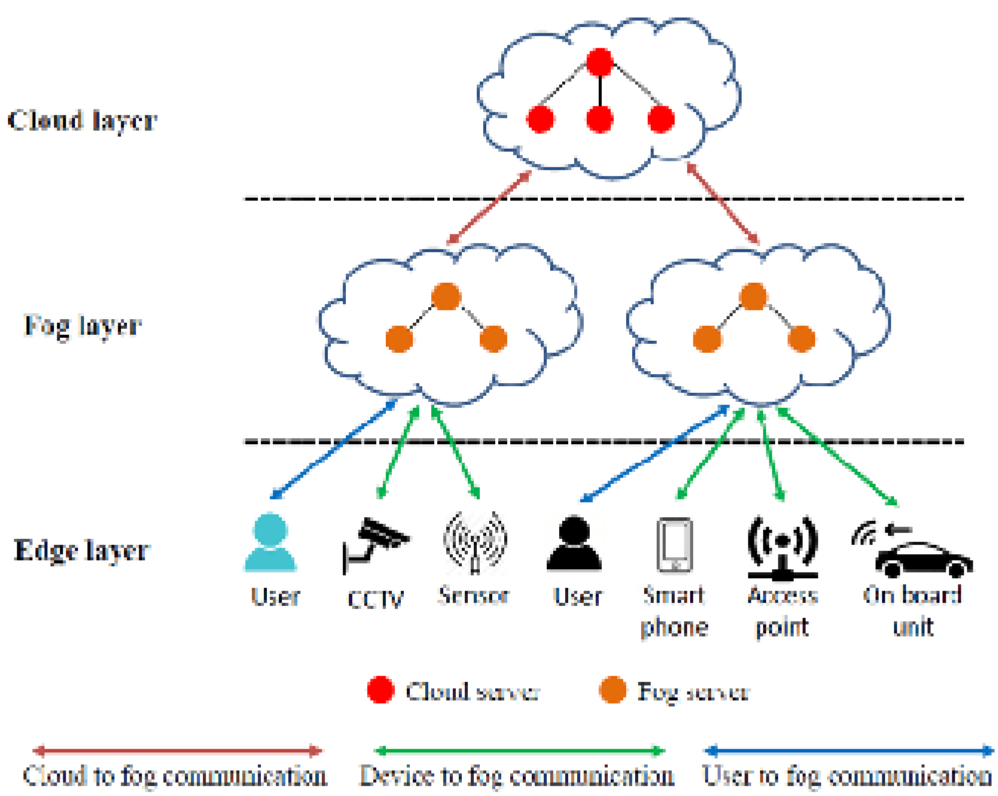

Figure 1: Fog computing architecture

capabilities are hosted by each fog node [Coutinho, A., Rodrigues, H., Prazeres, C., & Greve, F., 2018]. New business models are made possible by FaaS by providing services to clients. In contrast to cloud computing, the primary objective is to run the big business with the construct of resources and to manage massive information centers FaaS allows both small- and large-scale businesses to run and deploy computing, control services and storage at various levels of for satisfying the diverse range of clientele [Srirama, S. N., 2024].

The idea behind edge computing is to transfer an edge gateway's intelligence, processing power, and communication capabilities directly to the devices. It usually focuses more on the IoT device side and does not interact with any type of cloud-based services. Mobile services are one example, which require extremely low latency and instantaneous access to a radio network. One way to transmit communication and processing of resources from edge computing to cloud platforms is through edge computing. This is done by enabling fog services to minimize latency and give users quick message delivery [Deng, S., Zhao, H., Fang, W., Yin, J., Dustdar, S., & Zomaya, A. Y., 2020].

The authors used fog computing architecture to develop an electronic healthcare system [Hassan, S. R., Ahmad, I., Ahmad, S., Alfaify, A., & Shafiq, M., 2020]. Additionally, the authors assessed their suggested fog-based method using cloud-based employment. The researchers proposed a multi-tier fog computing system to deliver smart services to the end consumers [Ammad, M., Shah, M. A., Islam, S. U., Maple, C., Alaulamie, A. A., Rodrigues, J. J., & Tariq, U., 2020]. The fog nodes use the limited resources at their disposal to process the information that the edge nodes have detected. The sensing frequency of the sensor installed on an edge node determines how much data it can produce. Fog nodes must have enough computational power to analyze the data produced by the connected edge nodes in order for applications to be implemented on the fog architecture efficiently. Consequently, the effective deployment of applications on the fog architecture depends in large part on the resource allocation approach. We have provided a load-aware resource allocation technique in this post. The suggested approach allows resources to fog nodes in proportion to the load that their connected edge devices produce.

By bringing cloud services and utilities to the edge network, fog computing seeks to meet the demands of applications that are latency-sensitive and processing real-time data as well as dispatching. According to the quality of service (QoS) criteria, computing is dynamically distributed among the network components and cloud platforms in this new paradigm.

When combined, these two models can provide a productive interaction between the cloud and fog, especially when it comes to meeting the requirements of applications that are latency-sensitive. The proposed framework develops the advanced resource-aware fog computing paradigm by considering the constraints such as iterations in the fog layer that attempt to place the modules towards the cloud computing paradigm using the available resources with the fog layer then it iterates towards the cloud paradigm. This is due to the device allocation with the network edge that is closer like gateways access points and routers typically which is not more powerful when compared to the host modules with heterogeneous applications in the IoT ecosystem.

Problem Statement

Without a doubt, more research will be required to address the issues raised by the changing fog-cloud architecture. The primary aim of the research study is to utilize the network resources efficiently and to minimize the application latency. The proposed framework requires few changes in the applications which is to be deployed and developed the gaps can be addressed by formulating the framework with module mapping of applications and efficient resource allocation in the fog computing paradigm. In this work, we offer an alternative method of approaching the issue from the standpoint of application deployment, with the ultimate goal of serving the interests of all stakeholders involved in the Internet of Things ecosystem. Our solution to the issue takes into account the following:

- The deployment strategy for the upcoming and future Internet of Things applications is in the fog-cloud architecture, which is sensitive to latency.
- Effective use of the network infrastructure's resources.

Study Objective

The goal of this fog computing research is to provide edge network utilities and cloud services, meeting the demands of applications sensitive to latency and enabling the processing of real-time data and distribution.

Literature Review

Research on fog computing is still in its infancy because it is a relatively new paradigm. Determining the architecture's applicability in the context of the internet of things [Sarkar, S., Wankar, R., Srirama, S. N., & Suryadevara, N. K., 2019] and evaluating it [Martinez, I., Hafid, A. S., & Jarray, A., 2020] are among the continuing tasks. The development of fog-based internet of things applications, its scalability for wide-scale geographic distribution [Yu, Y., Bu, X., Yang, K., Wu, Z., & Han, Z., 2018; Beraldi, R., Canali, C., Lancellotti, R., & Mattia, G. P., 2020], and a context-aware analytics platform for real-time data in the fog as additional factors.

Definition of Fog

Fog is an extremely visualized network node that offers storage capabilities and processing of end devices (Internet of Things). Fog nodes near IoT devices, especially at the network edge, can offer IoT applications low-latency computing support. Fog nodes appear anywhere hierarchically between the remote cloud and the IoT layer, while usually being at the network edge [Al-Khafajiy, M., Baker, T., Waraich, A., Al-Jumeily, D., & Hussain, A., 2018]. This architecture configuration lowers the amount of data that reaches cloud servers and enables fog to fulfill a large number of IoT requests [Laghari, A. A., Jumani, A. K., & Laghari, R. A., 2021]. Fog is designed to serve IoT applications that are latency-sensitive and require modest resources, as cloud computing is still necessary for applications that require long-term storage and heavy computing [Mostafa, N., Al Ridhawi, I., & Aloqaily, M., 2018]. Fog is defined as a non-trivial extension of the Cloud that primarily consists of the following features: i) Interaction with the cloud and support for online analytics ii) federation and interoperability iii) interactions with real-time applications iv) heterogeneity v) the predominance of wireless access vi) large volume of nodes vii) mobility support viii) widely distributed geographic distribution ix) location awareness and low latency. Consequently, IoT data processing is offered by fog nodes with energy awareness, time awareness, activity awareness and location awareness [Hazra, A., Rana, P., Adhikari, M., & Amgoth, T., 2023].

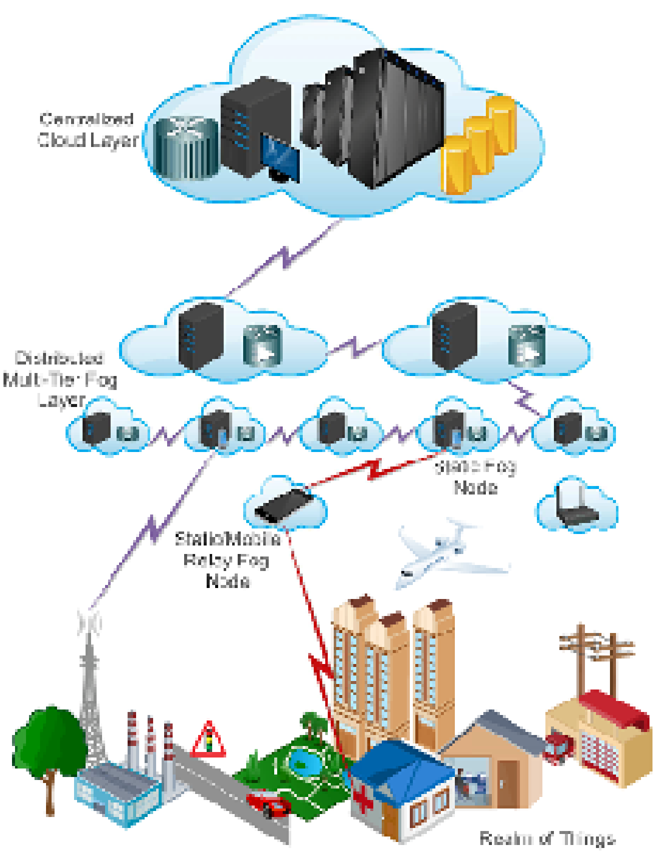

Figure 2: Multi-tier fog layer

Data routing in fog frequently adheres to a path computing method, whereby data is sent to nodes progressively larger than the cloud. As a result, a hierarchical architecture, similar to that shown in Figure 2, can be used to express the IoT, fog, and cloud layers.

Fog servers are physically dispersed to be in greater proximity to IoT, resulting in the network configuration shown in Figure 3. An IoT application can connect to any fog node directly or via a network access point because every fog server has a network connection.

Difficulties with the Cloud of Things

Cloud to IoT connection has numerous advantages. For example, IoT resources can be managed and it can be offered more economical and effective IoT services. Furthermore, it offers quick integration of sophisticated data processing and affordable installation and deployment streamlining the processing and the flow of IoT data [Saroa, M. K., & Aron, R., 2018].

The CoT paradigm is not simple; in addition, it presents a few complex difficulties for the IoT devices that the conventional centralized cloud computing framework is unable to handle. These difficulties include latency, capacity limitations, devices with limited resources, network failure with sporadic connectivity, and increased security [Atlam, H. F., Alenezi, A., Hussein, R. K., & Wills, G. B., 2018]. Furthermore, the centralized cloud model is inappropriate for IoT applications when inadequate internet access or time-sensitive processes are present. Milliseconds can be extremely important in various situations including medical care and telemedicine. A similar situation applies to vehicle-to-vehicle communication, where the centralized cloud approach's latency cannot be tolerated in order to prevent collisions or accidents [Donassolo, B., Fajjari, I., Legrand, A., & Mertikopoulos, P., 2019]. To address these issues, latency and capacity constraints can be enhanced using the cloud computing paradigm [Ai, Y., Peng, M., & Zhang, K., 2018]. Fog computing is a novel technique that Cisco proposed to alleviate most of these issues [Mahmud, R., Kotagiri, R., & Buyya, R., 2018].

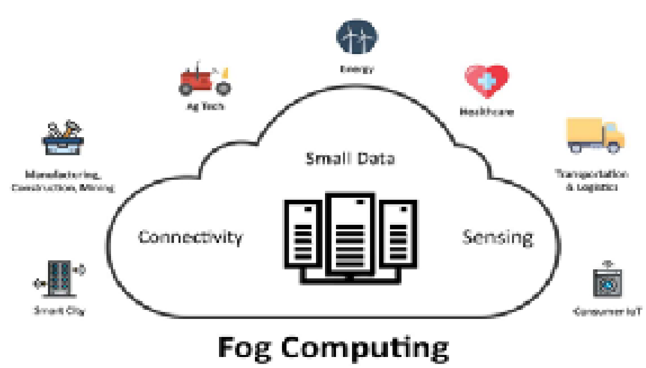

Figure 3: Fog computing facilitates a wide range of IoT applications to enhance customer service

IoT and fog computing

There are significant obstacles to the Internet of Things applications in the existing centralized cloud computing architecture. For example, it is unable to support time-sensitive Internet of Things applications like video streaming, gaming and augmented reality [Flinn, J., 2022]. Additionally, because it is a centralized approach, it does not have location awareness. Fog computing can help with these problems.

Fog computing serves as a link between IoT devices and massive Storage services and cloud computing. Fog computing, according to Cisco [Ketu, S., & Mishra, P. K., 2022], acts as a component in the cloud computing paradigm which brings the edge network to the closer cloud paradigm between their conventional cloud servers and end devices it can offer networking resources, storage and processing in a highly virtualized model [Alatoun, K., Matrouk, K., Mohammed, M. A., Nedoma, J., Martinek, R., & Zmij, P., 2022]. The majority of the data produced by these IoT items and devices need to be processed and analyzed in real time So that the IOT application's efficiency can be improved [Keshari, N., Singh, D., & Maurya, A. K., 2022]. The real-time problem with IoT devices will be solved by fog computing, which will extend cloud networking, processing, and capabilities for storage down to the network's edge and offer safe and effective IoT applications [Mani, S. K., & Meenakshisundaram, I., 2020]. Through the access and proxy points positioned in accordance with the tracks and long highways, real-time communication can be facilitated efficiently with the capabilities of the fog computing paradigm among different types of IoT applications including linked automobiles. For applications that require low latency including video streaming augmented reality and gaming fog computing paradigm can be considered the ideal option [C. da Silva, R. A., & S. da Fonseca, N. L., 2019].

Through the integration of the IoT with fog computing, we can benefit at a greater level in the number of IoT applications. In order to lower latency, real-time interactions can be facilitated by fog computing between IoT devices, particularly for time-sensitive IoT applications. Furthermore, fog computing's capacity to support sensor networks on a large scale is one of its key advantages. This is because the number of IoT devices is constantly increasing and will soon reach billions. As Figure 4 illustrates, fog computing can be quite advantageous for a range of IoT applications.

Many of the shortcomings of current computer architectures rely completely on end-user devices and cloud computing connected to the Internet of Things can be effectively addressed using fog computing.

Methodology

The methodology on resource awareness of computing paradigm for IoT applications to provide services and utilities to the edge computing network by enabling real-time data processing and distribution.

Fog computing is an emerging concept that connects edge devices deficient in resources with resourceful servers

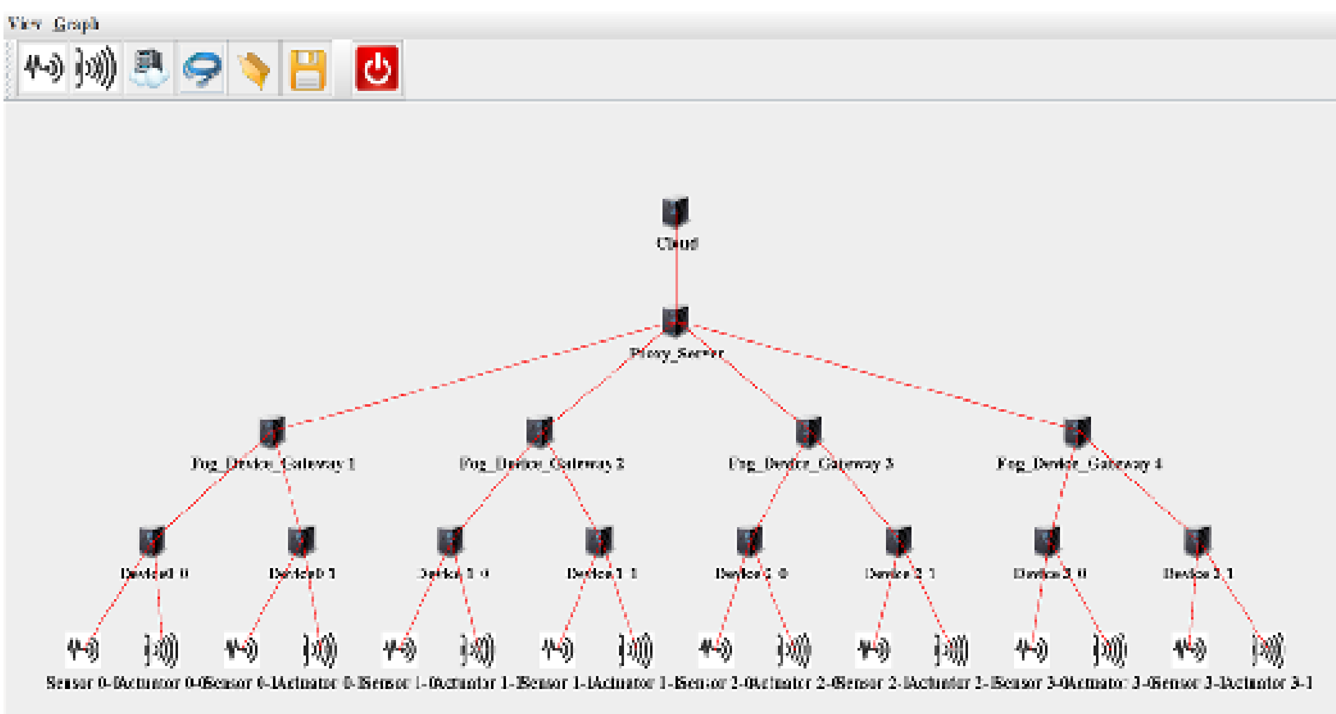

Figure 4: Evaluation of the proposed algorithm

through resource-aware fog devices by the implementation of IoT applications the architecture provides resourceful servers for delivering limited processing capabilities in a centralized manner using fog devices that are adjacent to sensor nodes. Due to its decentralized manner of resource distribution using the proposed architecture, it will be more effective in large-scale implementation. It offers minimum latency, reduced network load and the mobility for implementation of IoT applications. Dynamic fog computing environment comprised of devices with various available capabilities for data processing. These parameters limit the functionality of processing in the fog device such as RAM and CPU. The i_{th} fog node is represented as f_i then the node's processing capability can be expressed as;

$$P_c\left(f_i\right)=\left\langle CPU_i, RAM_i\right\rangle \qquad Eq.(3.1)$$

The sum of individual capabilities for data processing that are available at each fog device can be expressed as;

$$N=\sum_{i=1}^{M} P_c\left\{f_i\right\} \qquad Eq.(3.2)$$

Where the total number of fog modes can be represented as M in the network. The transmitted information by the sensor nodes and sent to connect to the parent fog device. The available resources at the fog device can be used for task execution related to data when it is sensed by an edge node. The form devices are connected to the parent node for delivering the sensed information for instant processing. The sensed data which is to be processed by the fog device depending upon the information volume at each device connected can be expressed as;

$$L(f_i)=\sum_{\forall I_i \in E_i} S\left(I_i\right) \qquad Eq.(3.3)$$

The optimum performance of the fog computing paradigm can be achieved by the connected devices based on the available resources with the parent device. The computational capacity of the network mode can be bounded by a general finite constraint set and it is represented as a set of 3 basic attributes such as bandwidth, RAM and CPU. The proposed algorithm adds more number of attributes in nodes with more storage capacity. Hence, the network node is represented as n_i in the infrastructure i.

$$Cap\left(n_i\right)=\left\langle CPU_i, RAM_i, Bandwidth_i\right\rangle \qquad Eq.(3.4)$$

The set of available resources in IoT infrastructure can be represented as;

$$N=\left\{n_i\right\} \qquad Eq.(3.5)$$

N can be written as two mutually exclusive subsets N_C and N_F.

N_C is a Cloud layer set of network nodes

N_F is a Fog layer set of network nodes

$$N_F \cap N_C=\phi \qquad Eq.(3.6)$$

$$N_F \cup N_C=N \qquad Eq.(3.7)$$

The developed application for deployment in fog computing architecture is based on the "Distributed Data Flow Model". It has distributed components to provide better results with the use of multi-component applications. The event and periodic-based edges are the two possible types.

The function of module mapping can be represented as M,

$$\mathrm{M}: V \rightarrow N \qquad Eq.(3.8)$$

during the deployment application for placement of the application module in the network node and it can be written as;

$$\forall\left(v_i, n_i\right) \in M \left| \begin{array}{l} Cap\left(n_i\right) \geq Req\left(v_i\right) \\ \qquad \forall v_i \in \bar{V} \\ \qquad \forall n_i \in N \end{array} \right. \qquad Eq.(3.9)$$

The integrated algorithms are proposed for enabling application modules for resource-aware placement in IoT and fog computing paradigms.

Algorithm 1: Module mapping algorithm

Input

Application module V Set of network node N

Output

Module mapping on the network nodes

1. function MODULEMAP (AppModule Modules [], NetworkNode nodes [])
2. Sort(modules[]), Sort (nodes[]) in ascending order
3. Map < AppModule,NetworkNode[] > module map
4. int low = 0, high = nodes.size -1; start
5. for; start = 0 to module.size do
6. int I = LOWERBOUND (modules[start],nodes[],low,high
7. if (I ! = -1) then
8. module map.insert(modules[start],nodes[i]);
9. Cap (node[i] = Cap (node[i]) – Req(modules[start];
10. Sort (nodes[]); in ascending order
11. low = i+1
12. else

moduleMap.Insert(modules[start],nodes[nodes.size-1])
end if
end for
return (module map);
end function

Algorithm 2: Lower bound algorithm

function LOWERBOUND (AppModule Modules [], NetworkNode nodes [],int low,int high)
int mid = $\frac{(low+high)}{2}$; length = nodes
while (True) do
Networknode x = node[mid];
if Compare (x,module) = = 1 then
mid-1 = high
if (low>high) then return mid;
end if
else
mid + 1= low;
if (high<low) then
return (length-1>mid)?mid+1; -1);
end if
end if
mid $=\frac{(low+high)}{2}$;
end while
end function

Algorithm 3: Comparison of application module and network nodes

function Compare (AppModule a NetworkNode b)
if (a.CPU≤ b.CPU && a.RAM≤b.RAM && a.Bandwidth ≤b.Bandwidth then return 1;
end if
return -1;
end function

Algorithm 4: ***Resource-aware algorithm for fog computing algorithm***

Edge devices $I_i \in$ Layer 3, Fog devices $f_i \in Layer\,2$
for each I_i do
if ($R_i < R_{limit}$)
add I_i to $K_L = \{\}$
end
else
add I_i to $K_H = \{\}$
end
end
for each f_i do
for I_i to K_H do
if ($P_c(f_i) < S(I_i)$)
add I_i to $E_i = \{\}$
$P_c(f_i) = P_c(f_i) - S(I_i)$;
end
else
for $I_i \in K_L$ do
if ($P_c(f_i) < S(I_i.)$)
add I_i to $E_i = \{\}$
$P_c(f_i) = P_c(f_i) - S(I_i)$
end
end for
end
end for
end for

Results and Discussion

The proposed resource-aware fog computing approach for module mapping can be compared with the conventional paradigm in terms of response rate. The different types of integrated algorithms effectively manage the connection between parent devices and edge nodes by considering the available resources for processing in the fog layer and sensed data volume at end devices. The framework allocates the edge device appropriately in the network after a thorough search of the edge layer with each fog device. The processing load can be balanced on fog nodes based on the computational resources by sensing the rate of sensors under fog nodes.

The network configuration is tabulated in Table 1 with specifications like random access memory rate, per execution, downloading capacity, uploading capacity and processing power. The intelligence surveillance is implemented on the proposed framework of resource allocation fog computing paradigm. The evaluations are carried out by performing the comparative analysis with the traditional fog paradigm and the proposed framework by creating different types of scenarios on multiple scales by considering the parameters for observation like end-to-end delay network consumption and cost of processing.

Comparison of energy consumption

The power consumption, utilization of the network and delay response time of the application using the placement approaches for resource allocation can be compared with the proposed fog computing framework with the conventional resource allocation methods. The results of the simulation show that the proposed framework has a highly significant influence on the utilization of network energy consumption and response time across the various network topologies used.

The proposed framework has favorable outcomes in the resource allocation of the fog computing paradigm with effective model mapping and it has a high impact on end-to-end latency as shown in Table 2. Table 3 shows the consumed energy between the two different types of placement

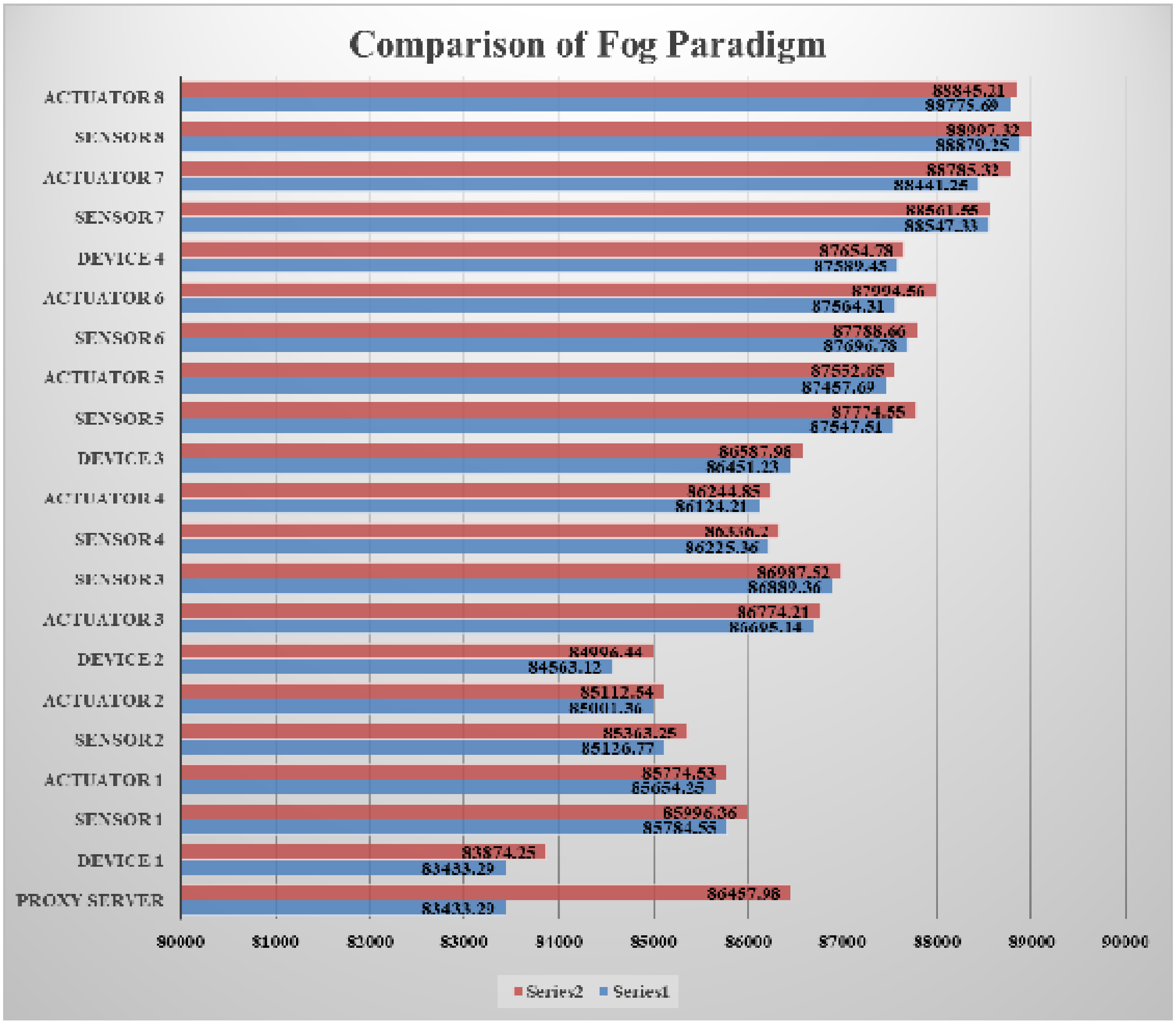

Figure 5: Comparative analysis of energy consumption

strategies. The proposed framework aims to balance the energy consumption at low-cost and high-cost sites. The comparison of consumed energy has been evaluated using some components between the conventional and the proposed fog computing paradigm. Then the graph was plotted between sensors and actuators and device and energy consumed.

Table 1: Network configuration

Specifications	*Fog_Device_ Gateway X*	*Cloud server*	*Device X-X*	*Proxy Server*
Random Access memory	3072	35840	1024	5120
Downlink	8000	10000	50	8000
Uplink	8000	1000	100	8000
MIPS	6000	20000	2000	8000

Comparison of network energy consumption

In the cloud computing paradigm, the server will process all the sensed information and it can be implemented in the system with increased latency that is directly proportional to the quantity of connected sensors in the cloud computing paradigm. However, the data processing is performed by the fog nodes in the fog computing paradigm at the

Table 2: Network configuration

Cloud energy consumed		*Latency (ms)*
Cloud Server	Proxy server	150
Proxy server	Fog_Device-Gateway_X	15
Fog_Device-Gateway_X	Device X-X	3
Device X-X	Sensor_X-X	1
Device X-X	Actuator_X-X	2

Table 3: Consumed energy

	Traditional	*Proposed fog paradigm*
Cloud	1619320.37	1619320.37
Proxy Server	83433.29	86457.98
Device 1	83433.29	83874.25
Sensor 1	85784.55	85996.36
Actuator 1	85654.25	85774.53
Sensor 2	85126.77	85363.25
Actuator 2	85001.36	85112.54
Device 2	84563.12	84996.44
Actuator 3	86695.14	86774.21
Sensor 3	86889.36	86987.52
Sensor 4	86225.36	86336.20
Actuator 4	86124.21	86244.85
Device 3	86451.23	86587.98
Sensor 5	87547.51	87774.55
Actuator 5	87457.69	87552.65
Sensor 6	87696.78	87788.66
Actuator 6	87564.31	87994.56
Device 4	87589.45	87654.78
Sensor 7	88547.33	88561.55
Actuator 7	88441.25	88785.32
Sensor 8	88879.25	88997.32
Actuator 8	88775.69	88845.21

intermediate level by reducing the information volume that should be processed by the cloud server and it advances the processing time. The primary objective is to reduce the stress of the organization with minimal resources on edge hubs that can be compared with the data seen by the edge hub with the number of sensors associated. Through inspection of sensors present in the edge gadgets, the proposed framework calculates the volume of information that enters the fog devices. The graph shows the comparison of overall energy consumption between the proposed and traditional framework which is illustrated in Figure 5.

Conclusion

The proposed framework of the research study balances the available resources effectively using a fog computing platform and the information sensed volume and generated in the edge network. The expected outcomes can be achieved by the proposed framework to manage the connection between edge devices and fog nodes. The framework estimates detected information in the edge nodes by assigning it to the parent fog device that has resources available in the fog computing platform. The efficient management of processing resources and sense to load in the network reduces the network consumption and latency of the system. This intelligence survey system using the distributed application of a camera network can be implemented on various cases for comparing the conventional fog architecture with the proposed algorithm. The findings of the comparative analysis show that the integrated algorithm reduces the network consumption delay and cost consumption.

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References

Ai, Y., Peng, M., & Zhang, K. (2018). Edge computing technologies for the Internet of Things: a primer. *Digital Communications and Networks*, *4*(2), 77-86. https://doi.org/10.1016/j.dcan.2017.07.001

Alatoun, K., Matrouk, K., Mohammed, M. A., Nedoma, J., Martinek, R., & Zmij, P. (2022). A novel low-latency and energy-efficient task scheduling framework for the Internet of medical things in an edge fog cloud system. *Sensors*, *22*(14),5327.https://doi.org/10.3390/s22145327.

Al-Khafajiy, M., Baker, T., Waraich, A., Al-Jumeily, D., & Hussain, A. (2018). IoT-fog optimal workload via fog offloading. In *2018 IEEE/ACM international conference on utility and cloud computing companion (UCC companion)* (pp.359-364).IEEE. https://doi.org/10.1109/ucccompanion.2018.00081.

Ammad, M., Shah, M. A., Islam, S. U., Maple, C., Alaulamie, A. A., Rodrigues, J. J., & Tariq, U. (2020). A novel fog-based multi-level energy-efficient framework for IoT-enabled smart environments. *IEEE Access*, *8*, 150010-150026. https://doi.org/10.1109/access.2020.3010157 .

Atieh, A. T. (2021). The next generation cloud technologies: a review on distributed cloud, fog and edge computing and their opportunities and challenges. *ResearchBerg Review of Science and Technology*, *1*(1), 1-15.https://orcid.org/0000-0003-0494-5282.

Atlam, H. F., & Wills, G. B. (2019). An efficient security risk estimation technique for Risk-based access control model for IoT. *Internet of Things*, *6*, 100052. https://doi.org/10.1016/j.iot.2019.100052.

Atlam, H. F., Alenezi, A., Hussein, R. K., & Wills, G. B. (2018). Validation of an adaptive risk-based access control model for the Internet of Things. *International Journal of Computer Network and Information Security*, *14*(1), 26. https://doi.org/10.5815/ijcnis.2018.01.04.

Atlam, H. F., Walters, R. J., Wills, G. B., & Daniel, J. (2021). Fuzzy logic with expert judgment to implement an adaptive risk-based access control model for IoT. *Mobile Networks and Applications*, *26*(6),2545-2557. https://doi.org/10.1007/s11036-019-01214-w.

Beraldi, R., Canali, C., Lancellotti, R., & Mattia, G. P. (2020). Distributed load balancing for heterogeneous fog computing infrastructures in smart cities. *Pervasive and*

Mobile Computing, *67*,101221. https://doi.org/10.1016/j.pmcj.2020.101221 .

Bermbach, D., Pallas, F., Pérez, D. G., Plebani, P., Anderson, M., Kat, R., & Tai, S. (2018). A research perspective on fog computing. In *Service-Oriented Computing–ICSoC 2017 Workshops: ASOCA, ISyCC, WESOACS, and Satellite Events, Malaga, Spain, November 13–16, 2017, Revised Selected Papers* (pp. 198-210). Springer International Publishing. https://doi.org/10.1007/978-3-319-91764-1_16.

Bhambri, P., Rani, S., Gupta, G., & Khang, A. (Eds.). (2022). *Cloud and fog computing platforms for the Internet of Things*. CRC Press. https://doi.org/10.1201/9781003213888

C. da Silva, R. A., & S. da Fonseca, N. L. (2019). On the location of fog nodes in fog-cloud infrastructures. *Sensors*, *19*(11), 2445. https://doi.org/10.3390/s19112445.

Coutinho, A., Rodrigues, H., Prazeres, C., & Greve, F. (2018). Scalable fogged for fog computing emulation. In *2018 IEEE Symposium on Computers and Communications (ISCC)* (pp. 00334-00340). IEEE. https://doi.org/10.1109/iscc.2018.8538484 .

Deng, S., Zhao, H., Fang, W., Yin, J., Dustdar, S., & Zomaya, A. Y. (2020). Edge intelligence: The confluence of edge computing and artificial intelligence. *IEEE Internet of Things Journal*, *7*(8),7457-7469. https://doi.org/10.1109/jiot.2020.2984887

Donassolo, B., Fajjari, I., Legrand, A., & Mertikopoulos, P. (2019). Fog-based framework for IoT service provisioning. In *2019 16th IEEE Annual Consumer Communications & Networking Conference (CCNC)* (pp. 1-6). IEEE. https://doi.org/10.1109/ccnc.2019.8651835

Fersi, G. (2021). Fog computing and Internet of Things in one building block: A survey and an overview of interacting technologies. *Cluster Computing*, *24*(4),2757-2787. https://doi.org/10.1007/s10586-021-03286-4.

Flinn, J. (2022). *Cyber foraging: Bridging mobile and cloud computing*. Springer Nature. https://doi.org/10.1007/978-3-031-02481-8.

Goudarzi, M., Palaniswami, M., & Buyya, R. (2019). A fog-driven dynamic resource allocation technique in ultra-dense femtocell networks. *Journal of Network and Computer Applications*, *145*,102407. https://doi.org/10.1016/j.jnca.2019.102407

Hassan, S. R., Ahmad, I., Ahmad, S., Alfaify, A., & Shafiq, M. (2020). Remote pain monitoring using fog computing for e-healthcare: An efficient architecture. *Sensors*, *20*(22), 6574. https://doi.org/10.3390/s20226574.

Hazra, A., Rana, P., Adhikari, M., & Amgoth, T. (2023). Fog computing for next-generation internet of things: fundamental, state-of-the-art and research challenges. *Computer Science Review*, *48*, 100549. https://doi.org/10.1016/j.cosrev.2023.100549.

Karagiannis, V., & Schulte, S. (2020). Comparison of alternative architectures in fog computing. In *2020 IEEE 4th International Conference on Fog and Edge Computing (ICFEC)* (pp. 19-28). IEEE. https://doi.org/10.1109/icfec50348.2020.00010 .

Keshari, N., Singh, D., & Maurya, A. K. (2022). A survey on Vehicular Fog Computing: Current state-of-the-art and future directions. *Vehicular Communications*, *38*, 100512.https://doi.org/10.1016/j.vehcom.2022.100512.

Ketu, S., & Mishra, P. K. (2022). Cloud, fog and mist computing in IoT: an indication of emerging opportunities. *IETE Technical Review*, *39*(3),713-724. https://doi.org/10.1080/02564602.2021.1898482.

Laghari, A. A., Jumani, A. K., & Laghari, R. A. (2021). Review and state of art of fog computing. *Archives of Computational Methods in Engineering*, *28*(5), 3631-3643. https://doi.org/10.1007/s11831-020-09517-y.

Mahmood, Z., & Ramachandran, M. (2018). Fog computing: Concepts, principles and related paradigms. *Fog computing: concepts, frameworks and technologies*, 3-21. https://doi.org/10.1007/978-3-319-94890-4_1.

Mahmud, R., Kotagiri, R., & Buyya, R. (2018). Fog computing: A taxonomy, survey and future directions. *Internet of everything: algorithms, methodologies, technologies and perspectives*,103-130. https://doi.org/10.1007/978-981-10-5861-5_5.

Mani, S. K., & Meenakshisundaram, I. (2020). Improving quality-of-service in fog computing through efficient resource allocation. *Computational Intelligence*, *36*(4),1527-1547. https://doi.org/10.1111/coin.12285.

Mann, Z. A. (2022). Decentralized application placement in fog computing. *IEEE Transactions on Parallel and Distributed Systems*, *33*(12),3262-3273. http://dx.doi.org/10.1109/TPDS.2022.3148985.

Margariti, S. V., Dimakopoulos, V. V., & Tsoumanis, G. (2020). Modeling and simulation tools for fog computing—a comprehensive survey from a cost perspective. *Future Internet*, *12*(5),89. https://doi.org/10.3390/fi12050089.

Martinez, I., Hafid, A. S., & Jarray, A. (2020). Design, resource management, and evaluation of fog computing systems: a survey. *IEEE Internet of Things Journal*, *8*(4), 2494 - 2516. https://doi.org/10.1109/jiot.2020.3022699.

Mostafa, N., Al Ridhawi, I., & Aloqaily, M. (2018). Fog resource selection using historical executions. In *2018 third International Conference on Fog and Mobile Edge Computing (FMEC)* (pp. 272-276). IEEE. https://doi.org/10.1109/fmec.2018.8364078 .

Naha, R. K., Garg, S., Georgakopoulos, D., Jayaraman, P. P., Gao, L., Xiang, Y., & Ranjan, R. (2018). Fog computing: Survey of trends, architectures, requirements, and research directions. *IEEE Access*, *6*, 47980-48009.https://doi.org/10.1109/access.2018.2866491.

Santos, G. L., Takako Endo, P., Ferreira da Silva Lisboa Tigre, M. F., Ferreira da Silva, L. G., Sadok, D., Kelner, J., & Lynn, T. (2018). Analyzing the availability and performance of an e-health system integrated with edge, fog and cloud infrastructures. *Journal of Cloud Computing*, *7*,1-22. https://doi.org/10.1186/s13677-018-0118-3.

Sarkar, S., Wankar, R., Srirama, S. N., & Suryadevara, N. K. (2019). Serverless management of sensing systems for fog computing framework. *IEEE Sensors Journal*, *20*(3),1564-1572. https://doi.org/10.1109/jsen.2019.2939182

Saroa, M. K., & Aron, R. (2018). Fog computing and its role in the development of smart applications. In *2018 IEEE Intl Conf on Parallel & Distributed Processing with Applications, Ubiquitous Computing & Communications, Big Data & Cloud Computing, Social Computing & Networking, Sustainable Computing & Communications (ISPA/IUCC/BDCloud/SocialCom/SustainCom)* (pp.1120-1127).IEEE. https://doi.org/10.1109/BDCloud.2018.00166.

Sharma, V., Malhotra, S., & Hashmi, M. (2018). An emerging application-centric RFID framework based on new web technology. In *2018 IEEE International Conference on RFID Technology & Application (RFID-TA)* (pp. 1-6). IEEE. DOI:10.1109/RFID-TA.2018.8552742.

Singhal, A. K., & Singhal, N. (2021). Cloud computing vs fog computing: a comparative study. *International Journal of Advanced Networking and Applications*, *12*(4), 4627-4632. https://doi.org/10.35444/ijana.2021.12403.

Skarlat, O., Karagiannis, V., Rausch, T., Bachmann, K., & Schulte, S. (2018). A framework for optimization, service placement, and runtime operation in the fog. In *2018 IEEE/ACM 11th International Conference on Utility and Cloud Computing (UCC)* (pp. 164-173). IEEE. https://doi.org/10.1109/ucc.2018.00025.

Srirama, S. N. (2024). A decade of research in fog computing: relevance, challenges, and future directions. *Software: Practice and Experience*, *54*(1),3-23. https://doi.org/10.1002/spe.3243.

Yousefpour, A., Fung, C., Nguyen, T., Kadiyala, K., Jalali, F., Niakanlahiji, A., & Jue, J. P. (2019). All one needs to know about fog computing and related edge computing paradigms: A complete survey. *Journal of Systems Architecture*, *98*, 289-330. https://doi.org/10.1016/j.sysarc.2019.02.009.

Yu, C., Lin, B., Guo, P., Zhang, W., Li, S., & He, R. (2018). Deployment and dimensioning of fog computing-based internet of vehicle infrastructure for autonomous driving. *IEEE Internet of Things Journal*, *6*(1), 149-160. http://dx.doi.org/10.1109/JIOT.2018.2875750.

Yu, Y., Bu, X., Yang, K., Wu, Z., & Han, Z. (2018). Green large-scale fog computing resource allocation using joint benders decomposition, Dinkelbach algorithm, ADMM, and branch-and-bound. *IEEE Internet of Things Journal*, *6*(3),4106-4117, https://doi.org/10.1109/jiot.2018.2875587.