**International Journal of Informatics and Communication Technology (IJ-ICT)**
Vol. 15, No. 1, March 2026, pp. 332~342
ISSN: 2252-8776, DOI: 10.11591/ijict.v15i1.pp332-341


# Towards efficient fog computing in smart cities: balancing energy consumption and delay

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**Article Info**

***Article history:***

Received Mar 29, 2025
Revised Oct 20, 2025
Accepted Nov 5, 2025

***Keywords:***

Cloud computing
Delay
Energy efficiency
Fog computing
Internet of things

**ABSTRACT**

In this work, we propose fog-based energy-delay optimization (F-EDO) approach and benchmark its performance against the cloud-based energy-delay optimization (C-EDO) method, focusing on energy consumption and delay. Unlike previous studies that optimize energy or delay separately, F-EDO minimizes both metrics simultaneously, achieving up to 52.2% energy savings with near-zero delay. Additionally, increasing the number of users also leads to energy savings. This is due to the optimized placement of fog servers at the access layer which reduces network energy consumption compared to C-EDO. F-EDO also significantly reduces delay, with negligible delay compared to C-EDO due to fog servers are placed closer to the users which minimized the transmission distances. Besides, the results also show that the energy saving in F-EDO compared to the C-EDO increased as the processing capacity of the processing server increased while maintaining its minimal delay. Overall, F-EDO proves to be a more energy-efficient and lower-delay solution for IoT networks, offering a better alternative to cloud-based offloading.

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## 1. INTRODUCTION

The development of smart city technologies is driven by the integration of advanced solutions that focus on scalability, resource management and real-time analytics. At the core of this transformation is the intersection of technology and urban planning in order to optimize resources, enhance public services, and improve the quality of life for residents. The advancement of the internet of things (IoT) has become a key enabler for smart cities [1], [2] as it allows seamless communication between devices and systems [3]. The integration of IoT with cloud and fog computing enhanced data processing capabilities while supporting real-time decision-making [4], [5]. This is because, cloud computing offers scalable and high processing and storage capabilities while fog computing brings these capabilities closer to the network edge, hence reducing the latency and improving responsiveness [6], [7]. Together, these technologies form the foundation for sustainable, efficient urban ecosystems that will define the cities of tomorrow.

Fog computing technologies have become a key enabler in transforming urban infrastructures. This enables real-time monitoring and analytics across various sectors including public safety, healthcare, and transportation [8], [9]. A systematic mapping approach in [7] highlights how fog computing improves the efficiency of data processing and scalability. A multitier fog computing model has been proposed in He *et al.* [10] to optimize resource allocation by placing the computation closer to the edge network, thus enhancing the speed of decision-making while reducing the reliance on cloud systems. Abdali *et al.* [11], the researchers propose a categorization method for managing the massive IoT data to improve the responsiveness of smart city services. This is done by classifying the fog computing applications into real-time and near-real-time domains. Benomar *et al.* [4], the researchers introduce a fog-based architecture for the industrial IoT (IIoT) environment, where the fog layer is used to perform the data aggregation through singular value decomposition (SVD). The results show that the proposed architecture reduces the network traffic while reducing energy consumption. Additionally, the architecture was tested in a real-world case study involving the monitoring of induction motors, demonstrating improved packet delivery ratio (PDR) and reduced latency compared to traditional methods.

Meanwhile, in the transportation sector, vehicular fog computing (VFC) enhances urban mobility through edge computing. Tang *et al.* [12], the researchers use three-layer architectures in VFC to improve task offloading by using roadside units (RSUs) and centralized schedulers for task allocation. The results show that response latency is reduced while the efficiency of the system is improved compared to the traditional models. Case studies in [13] also show the transformative effects of fog computing on public transportation, thus supporting the pursuit of sustainability goals in smart cities. In addition to this, the National Strategic Smart City Program (NSSP) in South Korea also outlined the importance of connectivity in smart cities such as the 5G and other advanced technologies to enhance the services in the urban area including transportation, governance and education [14]. In Ji *et al.* [15], an A-VIoT framework is used to manage real-time video data for smart city applications such as surveillance and emergency response. The results show that the framework reduced the bandwidth limitation and energy consumption of the network.

With the growing number of IoT devices in smart cities, efficient task management and fog offloading are essential to maintain system performance. Several researchers have focused on hybrid computing models that combined fog computing architecture with other technologies to optimize resource utilization. For instance, in Ali *et al.* [16], a volunteer-supported fog computing (VSFC) model, the integration of traditional fog computing with volunteer computing is proposed to reduce the latency, energy consumption and network usage. This model has gained popularity in several cities including Helsinki and Singapore where fog computing has been used to improve public transportation besides promoting the sustainability effort. Meanwhile, the FogFlow framework introduced in Tang *et al.* [12] simplifies the orchestration of IoT services in smart cities by enabling elastic service deployment across cloud and edge environments. The framework improves operational efficiency, including throughput and latency, while supporting standard interfaces for interoperability. However, it does not provide a unified approach for optimizing both energy consumption and latency. In Khazael *et al.* [17], a new architecture for complex event processing (CEP) in smart city monitoring applications has been proposed to address challenges posed by multi-tenant edge devices with limited resources. The architecture integrates a publish-subscribe architectural pattern with software-defined networking (SDN) technology aiming to enhance communication efficiency while supporting the quality of service (QoS) requirements. Besides, the architecture facilitates the distributed processing of event notifications and employs a centralized coordination mechanism to calculate the optimal route and head selection. The results show significant improvements in energy consumption and network traffic. Meanwhile, in [9], load balancing and resource management have been improved by integrating the SDN with machine learning. Omoniwa *et al.* [18] proposed a FECIoT framework that allows IoT devices to offload computational tasks to more capable devices to optimize overall resource utilization. The results reveal that the proposed framework improves the service provisioning at the edge, and minimizes the delay and bandwidth demand. Additionally, the oneM2M-based Fog Computing architecture proposed in [19] shows a significant reduction of the transmission times for high-resolution image data, thus improving the efficiency of smart city applications.

To the best of our knowledge, existing research focuses either on optimizing energy efficiency or reducing network delay independently. Also, they does not provide a comprehensice solution that balances both metrics. This gap is critical, as smart city applications require both low energy consumption and minimal delay to provide QoS to the users. Therefore, our work addresses this by introducing an mixed-integer linear programming (MILP)-based fog-based energy-delay optimization (F-EDO) model which optimize the number and placement of fog servers to minimize the energy consumption while reduing the network delay.

## 2. RESEARCH METHOD

In this work, we evaluate our model in terms of energy consumption and the network delay in a real-world urban setting, Bandaraya Malacca, Malaysia to ensure that our optimization results align with practical smart city environments. Twelve point of interest within Bandaraya Malacca covering an approximate size area of 0.23km$^2$ as shown in Figure 1 have been selected as candidate locations to place the fog server. Note that, we obtained the location of the twelve points of interest using the GPS coordinates from Google Maps and calculate the inter-node distance using MATLAB. This step is important to ensure the optimal selection of the location to place the fog server based on the given number of users.

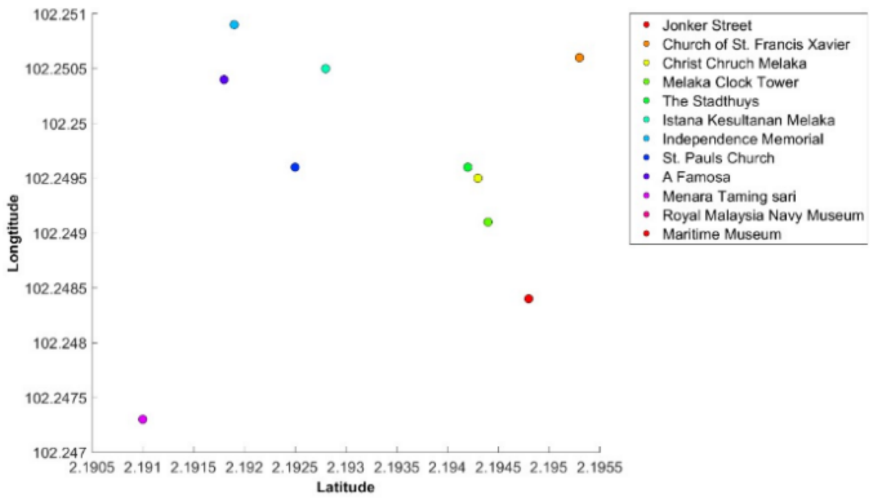


Figure 1. Twelve point of interest within Bandaraya Malacca

Figure 2 shows the architecture of the proposed fog computing which consists of four layers. The first layer is the IoT layer, comprised of IoT devices such as mobile phone, and laptop. The second layer is the access layer. It consists of WiFi access points for gathering data from IoT devices, fog servers for processing the data and access switches connect the access points and the fog servers. Each selected point of interest is equipped with a WiFi access point, access switch and a fog server. Also, in this work, the communication between WiFi access points is allowed as long as they are within their communication range of 300m. The third layer is the metro layer which acts as an intermediary between the access and the upper layer. The fourth layer is the core layer that serves as the network backbone for high-speed data transmission and cloud connectivity. However, it is worth to note that, in this work we focus only on layer 1 and layer 2 as these layers are directly involved in local data processing and fog computing operation. Meanwhile, to evaluate the performance between the proposed fog computing architecture, we used traditional approach where the processing is performed at the cloud layer which is layer 4.

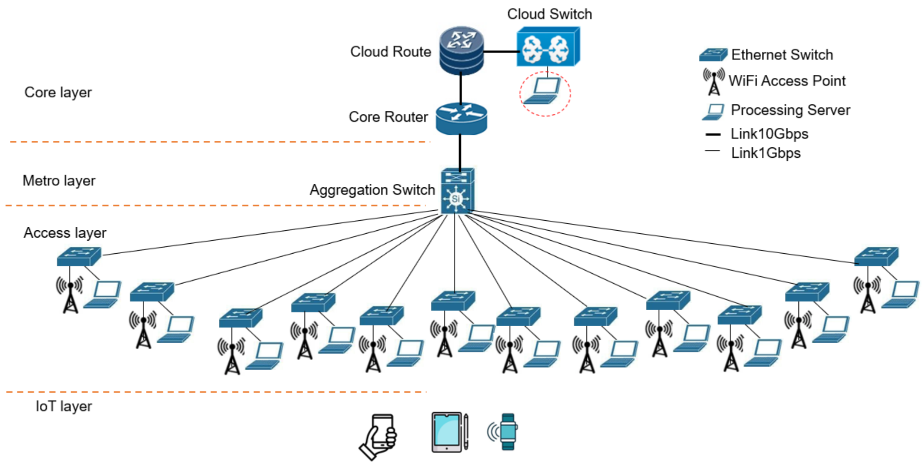


Figure 2. Fog architecture for smart city application

To minimize the energy consumption of the networking equipment and processing as well as minimize the delay we develop a new MILP model to optimize the number and location of the fog servers. MILP is considered in this work as it provides a flexible and scalable framework to solve complex optimization problem in the network. Note that, in this work, we only consider propagation delay as the delay parameter in the network. MILP is chosen in this work as it provides flexibility to solve large and complex optimization problem. The MILP optimization for our proposed architecture is performed using the AMPL software with CPLEX 22.1.2 solver, running on 2.1 GHz CPU.

In the following, we show the mathematical model for the F-EDO approach that is used to minimize both the energy and delay in the network. In addition to this, we also show the mathematical model for the cloud-based energy-delay optimization (C-EDO) approach, where the processing is performed at the cloud layer. Note that, for both models, we did not consider the energy consumption of the IoT devices. Also, the power consumption profile considered in this work for all equipment is composed of idle power and load-dependent power as shown in Figure 3. Table 1 shows some of the parameter used in this work including the set, power consumption and capacity of the networking and processing equipment.

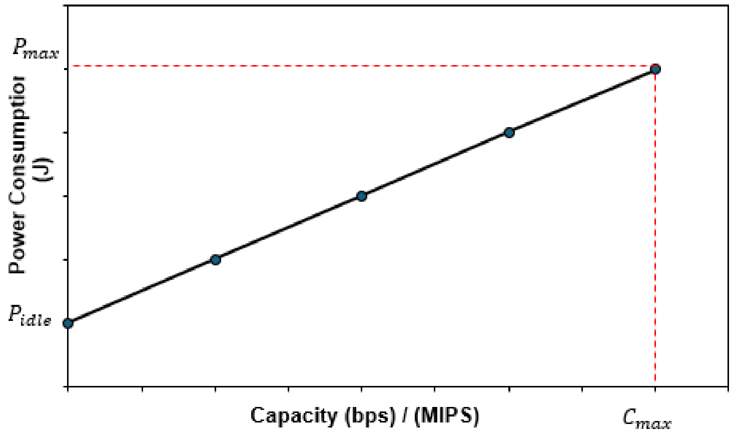


Figure 3. Power profile for networking and processing equipment

Table 1. Sets and parameters used in MILP model

| Set | Description | |
|---|---|---|
| $FN$ | Set of fog server | |
| $IoT$ | Set of IoT group | |
| $AP$ | Set of Access Point | |
| $ETH$ | Set of Ethernet Switch | |
| $AS$ | Set of Aggregation Switch | |
| $AR$ | Set of Aggregation Router | |
| $CR$ | Set of Core Router | |
| $CLR$ | Set of Cloud Router | |
| $CLS$ | Set of Cloud Switch | |
| $N$ | $IoT \cup AP \cup ETH \cup AS \cup AR \cup CR \cup CLR \cup CLS$ | |
| Parameter | Description | Value |
| $IAP$ | Idle power consumed by Access Point | 7.872 W [20] |
| $EAP$ | Energy per bit of Access Point | 7.173 J/Gbits [19] |
| $IES$ | Idle power consumed by Ethernet Switch | 0.57 W [21] |
| $EES$ | Energy per bit of Ethernet Switch | 0.184 J/Gbits [20] |
| $IAS$ | Idle power consumed by Access Switch | 47.7 W [22] |
| $EAS$ | Energy per bit of Access Switch | 0.6898 J/Gbits [21] |
| $IAR$ | Idle power consumed by Aggregation Router | 112.85 W [21] |
| $EAR$ | Energy per bit of Aggregation Router | 0.8125 J/Gbits [21] |
| $ICLR$ | Idle power consumed by Cloud Router | 122.85 W [21] |
| $ECLR$ | Energy per bit of Cloud Router | 0.8125 J/Gbits [21] |
| $ICLS$ | Idle power consumed by Cloud Switch | 54.54 W [21] |
| $ECLS$ | Energy per bit of Cloud Switch | 0.6313 J/Gbits [21] |
| $IFog$ | Idle power of Intel XeonE5-2420 | 57 W [23] |
| $EFog$ | Power per MIPS of Intel XeonE5-2420 | 1111 $\mu W/MIPS$ [22] |
| $CFog$ | Maximum capacity of Intel XeonE5-2420 | 34.2 kMIPS [22] |
| $Mips$ | Size of MIPS per User | 1000 MIPS |
| $D$ | Size of Data per User | 0.001 Gbit |
| $U_i$ | Number of users per IoT group | 10 |

### 2.1. F-EDO

The total energy consumption of the network is composed of energy consumed by the networking equipment, $N_e$ and energy consumed by the processing server, $P_e$. The energy consumption of the networking equipment, $N_e$ consists of the energy consumed by the access point, $AP_e$ and ethernet switch, $ES_e$, aggregation switch, $AS_e$, aggregation router, $AR_e$, core router, $CR_e$, cloud router, $CLR_e$ and cloud switch, $CLS_e$, as show in (1)-(3). The $AP_e$, $ES_e$, $AS_e$, $AR_e$, $CR_e$, $CLR_e$ and $CLS_e$, is calculate based on the number the devices it used, $X_i$ and the amount of traffic that traverse to it, $T_i$ as in (2) to (8), respectively.

$$N_e = AP_e + ES_e + AS_e + AR_e + CR_e + CLR_e + CLS_e \tag{1}$$

$$AP_e = \sum_{i \in APT} (X_i . IAP + T_i . EAP) \tag{2}$$

$$ES_e = \sum_{i \in ETH} (X_i . IES + T_i . EES) \tag{3}$$

$$AS_e = \sum_{i \in ETH} (X_i . IAS + T_i . EAS) \tag{4}$$

$$AR_e = \sum_{i \in ETH} (X_i . IAR + T_i . EAR) \tag{5}$$

$$CR_e = \sum_{i \in ETH} (X_i . ICR + T_i . ECR) \tag{6}$$

$$CLR_e = \sum_{i \in ETH} (X_i . ICLR + T_i . ECLR) \tag{7}$$

$$CLS_e = \sum_{i \in ETH} (X_i . ICLS + T_i . ECLS) \tag{8}$$

Meanwhile, the energy consumption of the processing equipment, $F_e$ is based on the number the server is used, $Z_i$ and the amount users, $w_{ij}$ and MIPS per user, $Mips$ the server served as shown in (9).

$$F_e = \sum_{i \in FN} Z_i . IFog + \sum_{i \in IoT} \sum_{j \in FN} w_{ij} . Mips * EFog \tag{9}$$

The delay in the network, $D_t$ is calculate based on the delay occurred in wired. $D_w$ and wireless, $D_{wl}$. Note that, as the delay is in microseconds, therefore to ensure the balance between the energy consumption and delay, we multiply the latency by a factor of $M$ as shown in (10). Note that, $M$ is a big number.

$$D_t = \sum_{i \in IoT} \sum_{j \in FN} (D_w + D_{wl}) . M \tag{10}$$

The objective function of the model is to minimize the energy consumption of networking equipment and processing and delay as in (11).

$$Objective\ Function = Minimize\ (N_e + P_e + D_t) \tag{11}$$

Subject to,

$$\sum_{j \in Nm[i]: i <> j} L_{ij}^{sd} - L_{ji}^{sd} = if\ i = s\ then\ L_{sd}\ else\ if\ i = d\ then\ -L_{sd}\ else\ 0$$
$$\forall s \in IoT, \forall d \in FN, \forall i \in N, s \neq d \tag{12}$$

Constraint (12) is used to ensure the flow conservation of the total incoming and outgoing traffic from a node are equal.

$$w_{sd} \leq U_s . Y_d$$
$$\forall s \in IoT, \forall d \in FN, s \neq d \tag{13}$$

$$\sum_{d \in FN: s \neq d} w_{sd} = U_s$$
$$\forall s \in IoT \tag{14}$$

Constraint (13) is to assign users in IoT group, $U_s$ to the server, $w_{sd}$ if only the fog server is used, $Y$ while constraint (14) is to ensure all users are assign to the server.

$$\sum_{s\in IoT:s\neq d} w_{sd}.MIPS \leq CF_d.Z_d$$
$$\forall d \in FN \quad (15)$$

$$Y_d \leq Z_d$$
$$\forall d \in FN \quad (16)$$

Constraint (15) is to determine the number of fog server required, $Z_d$ based on the number of users, $w_{sd}$ per MIPS and the capacity of the server, $CF_d$. Meanwhile, constraint (16) is to ensure that $Z_d$ will be 1 or more if the selected server is powered on.

$$L_{sd} = w_{sd}.D$$
$$\forall s \in IoT, \forall d \in FN, s \neq d \quad (17)$$

$$\sum_{s\in IoT}\sum_{d\in FN}\sum_{j\in Nm[i],i\neq j} L_{ij}^{sd} = T_i$$
$$\forall i \in N \quad (18)$$

$$\sum_{s\in IoT}\sum_{d\in FN} L_{ij}^{sd} \leq Link_{ij}$$
$$\forall i \in N, \forall j \in Nm[i], i \neq j \quad (19)$$

Constraint (17) calculates the total traffic, $L_{sd}$ based on the association between the user in IoT to the fog server, $w_{sd}$ and the size of data per user, $D$. Meanwhile, constraint (18) is to calculate the total traffic traversing each node, $T_i$ based on the size of traffic from the IoT group, s to the fog server, d using link $i$ and $j$, $L_{ij}^{sd}$. Constraint (19) is to limit the size of from traversing the link ij from the IoT group to fog server, $L_{ij}^{sd}$ does not exceed the maximum limit of the link, $Link_{ij}$.

$$T_i \leq C_i$$
$$\forall i \in AP \quad (20)$$

$$X_i \geq T_i$$
$$X_i \leq M.T_i$$
$$\forall i \in N \quad (21)$$

Constraint (20) is to ensure, the traffic served by the access point, $T_i$ does not exceed its maximum capacity, $C_i$ which is 0.45 Gbps. Meanwhile, constraint (21) is to determine the node that is used to serve the traffic, $X_i$. Note that the $X_i$ is the binary number where it will be 1 if the node is used to serve the traffic, else 0.

$$P_{ij}^{sd} \geq L_{ij}^{sd}$$
$$P_{ij}^{sd} \leq M.L_{ij}^{sd}$$
$$\forall s \in IoT, \forall d \in FN, i \in N, j \in Nm[i], i \neq j \quad (22)$$

$$\sum_{i\in N}\sum_{j\in Nm[i]\ i\neq j} P_{ij}^{sd}.Distr_{ij} = Dr_{sd}$$
$$\forall s \in IoT, \forall d \in FN \quad (23)$$

$$\sum_{i\in N}\sum_{j\in Nm[i]\ i\neq j} P_{ij}^{sd}.Distw_{ij} = Dw_{sd}$$
$$\forall s \in IoT, \forall d \in FN \quad (24)$$

Constraint (22) is a binary value to determine the paths that is used to send the traffic from the IoT group to the fog server, $P_{ij}^{sd}$. This is based on the traffic traversing the link $i$ and $j$ from IoT group to the fog server, $L_{ij}^{sd}$. Constraint (23) and (24) is to determine the distance the traffic travel from the IoT group to the fog server for wired connection, $Dr_{sd}$ and wireless connection, $Dw_{sd}$ respectively. The distance is based on the binary indicator of the path used to send the traffic from the IoT group to the fog server, $P_{ij}^{sd}$ and the distance for wired, $Distr_{ij}$ and wireless connection, $Distw_{ij}$.

$$Dr_{sd} = Dr_{sd}/Sr$$
$$\forall s \in IoT, \forall d \in FN \quad (25)$$
$$Dw_{sd} = Dw_{sd}/Sw$$

$$\forall s \in IoT, \forall d \in FN \quad (26)$$

Constraint (25) and (26) is to calculate the delay occurred in wired, $Dr_{sd}$ and wireless, $Dw_{sd}$ medium to transmit data from IoT group to fog server, respectively. This calculation is based on the total distance of data traversing the medium and the speed of light. For wired medium, the speed of light, $S_r$ is 2.7 x $10^8$ m/s while wireless, $S_w$ is 3 x $10^8$ m/s.

### 2.2. C-EDO

In this work, a C-EDO is used to benchmark the proposed F-EDO in terms of its energy efficiency and delay. In C-EDO, the server is located at the cloud. Therefore, the (1)-(26) are used in C-EDO while the parameter of candidate location of server, $FN$ is change to be only at the cloud switch.

## 3. RESULTS AND DISCUSSION

The results and analysis of the proposed F-EDO is presented in this section. In the first scenario, we allow more than one processing server to be deployed at each candidate location. Also, we consider ten users per IoT group. To benchmark F-EDO, we compared its performance in terms of its energy consumption and delay with the C-EDO where the processing is performed in the cloud. Note that, in this work, each IoT group is located at the access point, hence the delay is calculated from the access point to the fog server. However, the propagation delay for transmitting traffic from the access point to a fog server located at the same location is considered negligible.

The results in Figure 4 show that, F-EDO achieves up to 52.2% energy saving compared to the C-EDO. This is mainly contributed by the energy consumption of the networking equipment. In F-EDO, the fog server is located at the access layer, which optimizes energy consumption by activating only the networking devices at the access layer. Meanwhile in C-EDO, the servers are located at the core layer, resulting in more energy consumption in the upper layer. The results also reveal that, the energy consumption of the processing in F-EDO is higher than in C-EDO. This is because in F-EDO, fog servers are placed within local access networks in order to reduce the propagation time. This is shown in Figure 5 where F-EDO maintain negligible delays while the delay in C-EDO is approximately 0.15ms. This proves that cloud-based architectures are fundamentally limited by distance-related latencies, making fog computing the superior choice for real-time IoT applications.

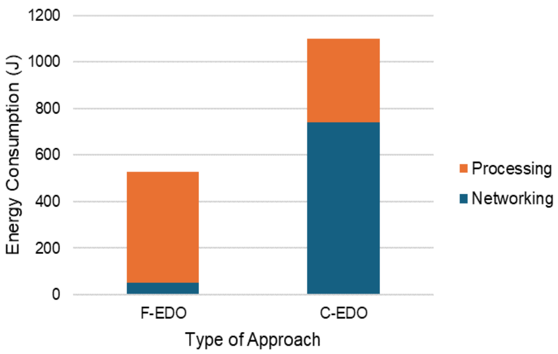


Figure 4. Energy consumption of the networking and processing equipment

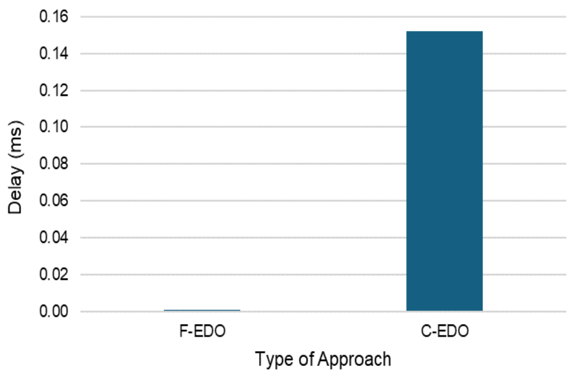


Figure 5. Delay in the network for F-EDO and C-EDO

We also evaluate the performance of F-EDO by increasing the number of users per IoT group to 20 and 30. The results in Figure 6 show that increasing the traffic increase the total energy consumption in both F-EDO and C-EDO. However, the results reveal that F-EDO remains more energy-efficient than C-EDO with 43.2% and 33.4% for 20 and 30 users per IoT group, respectively. It is worth noting that, the reduction in energy saving with increasing traffic in F-EDO is because of the increasing energy consumption of the processing server as shown in Figure 6 as higher user demands require additional fog servers to maintain low delay. Meanwhile, results in Figure 7 show the delay occurred in F-EDO is negligible while higher delay occurs in C-EDO for all IoT group size. This is due to the same reason as explained earlier which is the proximity of fog servers in F-EDO to the user. The results also indicate that, the delay in C-EDO remain constant, as the location of the servers are always at the cloud.

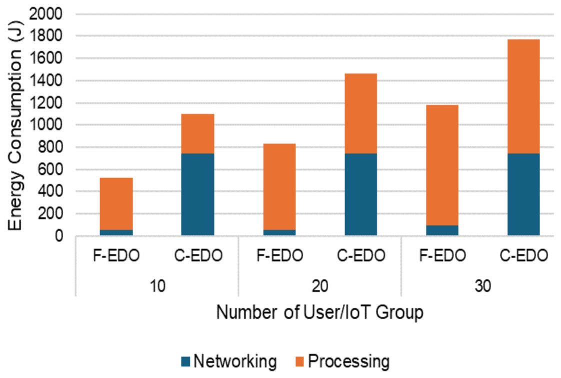


Figure 6. Energy consumption of networking and processing equipment with difference number of users/IoT group

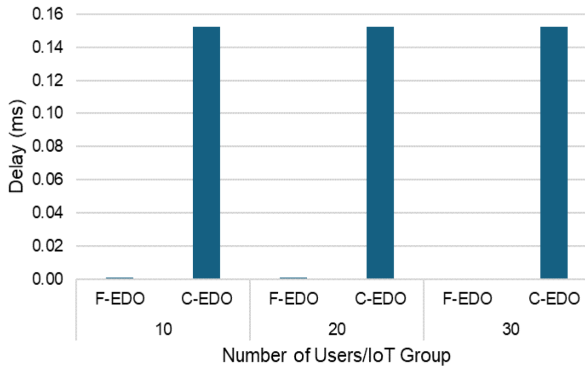


Figure 7. Delay in the network with difference number of users/IoT group

Additionally, we evaluate the performance of F-EDO using different type of processing servers that has different processing capabilities as shown in Table 2. In this scenario we consider the 30 users per IoT group to evaluate the performance of the F-EDO.

Table 2. Input parameters for processing servers

| Server | *IFog* | *EFog* | *CFog* |
|---|---|---|---|
| Intel X5675 [24] | 57 W | 517 µW/MIPS | 73.44 kMIPS |
| Nvidia T4 GPU [25] | 45 W | 27.7 µW/MIPS | 1,080 kMIPS |

Figure 8 shows that, as the processing capability of the server increases, energy consumption in both F-EDO and C-EDO decreases. This reduction is mainly due to the decrease energy consumption of the processing as fewer fog servers are utilized to serve users as shown in Figure 9. Furthermore, Figure 10 demonstrates that, the delay in F-EDO remains negligible while in C-EDO the delay remains the same regardless of the processing capability of the server.

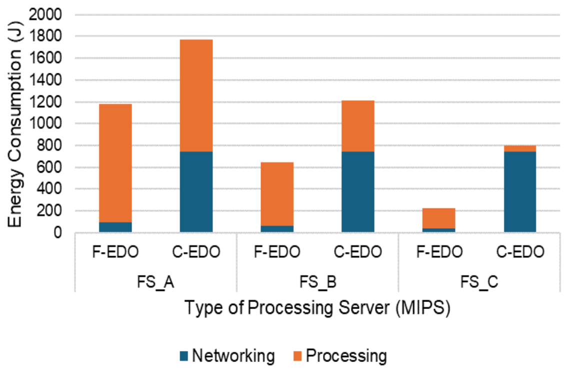


Figure 8. Energy consumption of networking and processing equipment with different type of processing server

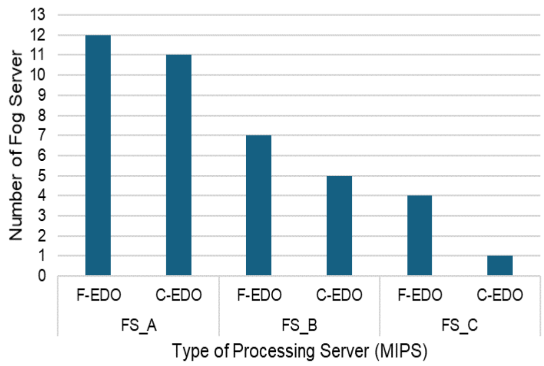


Figure 9. Number of utilized fog server for different type of processing servers

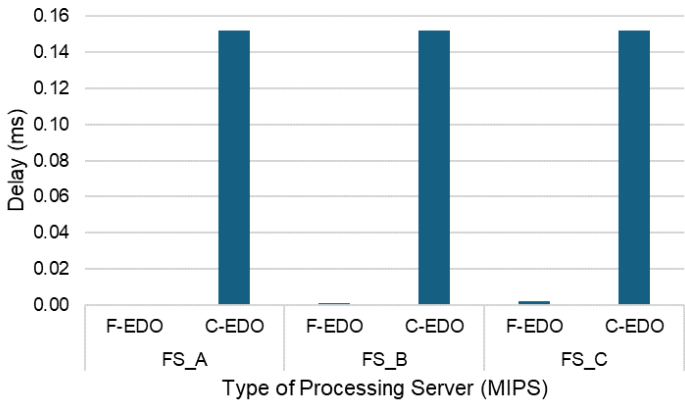


Figure 10. Delay in the network with different type of processing server

## 4. CONCLUSION

In this work, we proposed the F-EDO approach and benchmarked its performance against the C-EDO method in terms of energy consumption and delay. Our findings demonstrated that F-EDO outperforms C-EDO in energy efficiency with up to 52.2% energy savings. These saving are also observed when the number of users increases. This is due the location of fog servers in F-EDO is optimized at the access layer, which reduces network energy consumption compared to the cloud-based servers in C-EDO. Furthermore, F-EDO significantly reduces delay, with negligible delay compared to the C-EDO due to the longer transmission distance to the cloud. The results also reveal that, the performance of both approaches improved with higher processing capabilities of the servers where the F-EDO maintains negligible delay regardless of the server's processing capability. Overall, the F-EDO approach proves to be a more energy-efficient and lower-delay solution for IoT networks, hence offering a better alternative to cloud-based offloading.

## FUNDING INFORMATION

This research is fully supported by the FRGS grant, FRGS/1/2023/ICT08/UTEM/03/1. The authors fully acknowledged the Ministry of Higher Education (MOHE) and Universiti Teknikal Malaysia Melaka (UTeM) for the approved fund which makes this important research viable and effective.

## AUTHOR CONTRIBUTIONS STATEMENT

This journal uses the Contributor Roles Taxonomy (CRediT) to recognize individual author contributions, reduce authorship disputes, and facilitate collaboration.

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C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

**CONFLICT OF INTEREST STATEMENT**

The authors state no conflict of interest.

**DATA AVAILABILITY**

The authors confirm that the data supporting the findings of this study are available within the article.

**REFERENCES**


[1] E. H. Houssein, M. A. Othman, W. M. Mohamed, and M. Younan, "Internet of things in smart cities: comprehensive review, open issues, and challenges," *IEEE Internet of Things Journal*, vol. 11, no. 21, pp. 34941–34952, 2024, doi: 10.1109/JIOT.2024.3449753.

[2] A. Kirimtat, O. Krejcar, A. Kertesz, and M. F. Tasgetiren, "Future trends and current state of smart city concepts: A survey," *IEEE Access*, vol. 8, pp. 86448–86467, 2020, doi: 10.1109/ACCESS.2020.2992441.

[3] L. U. Khan, I. Yaqoob, N. H. Tran, S. M. A. Kazmi, T. N. Dang, and C. S. Hong, "Edge-computing-enabled smart cities: a comprehensive survey," *IEEE Internet of Things Journal*, vol. 7, no. 10, pp. 10200–10232, 2020, doi: 10.1109/JIOT.2020.2987070.

[4] Z. Benomar *et al.*, "A fog-based architecture for latency-sensitive monitoring applications in industrial internet of things," *IEEE Internet of Things Journal*, vol. 10, no. 3, pp. 1908–1918, 2023, doi: 10.1109/JIOT.2021.3138691.

[5] P. Charalampidis, E. Tragos, and A. Fragkiadakis, "A fog-enabled IoT platform for efficient management and data collection," *IEEE International Workshop on Computer Aided Modeling and Design of Communication Links and Networks, CAMAD*, vol. 2017-June, 2017, doi: 10.1109/CAMAD.2017.8031527.

[6] I. Martinez, A. S. Hafid, and A. Jarray, "Design, resource management, and evaluation of fog computing systems: a survey," *IEEE Internet of Things Journal*, vol. 8, no. 4, pp. 2494–2516, 2021, doi: 10.1109/JIOT.2020.3022699.

[7] M. Burhan *et al.*, "A comprehensive survey on the cooperation of fog computing paradigm-based IoT applications: layered architecture, real-time security issues, and solutions," *IEEE Access*, vol. 11, pp. 73303–73329, 2023, doi: 10.1109/ACCESS.2023.3294479.

[8] R. Kumari, K. Kaur, G. Chhabra, S. Bharany, and K. Kaushik, "Systematic mapping study on edge and fog computing in smart cities: a comprehensive review," *Proceedings of International Conference on Communication, Computer Sciences and Engineering, IC3SE 2024*, pp. 771–777, 2024, doi: 10.1109/IC3SE62002.2024.10593518.

[9] M. R. Rezaee, N. A. W. Abdul Hamid, M. Hussin, and Z. A. Zukarnain, "Fog offloading and task management in IoT-fog-cloud environment: review of algorithms, networks, and SDN application," *IEEE Access*, vol. 12, pp. 39058–39080, 2024, doi: 10.1109/ACCESS.2024.3375368.

[10] J. He, J. Wei, K. Chen, Z. Tang, Y. Zhou, and Y. Zhang, "Multitier fog computing with large-scale iot data analytics for smart cities," *IEEE Internet of Things Journal*, vol. 5, no. 2, pp. 677–686, 2018, doi: 10.1109/JIOT.2017.2724845.

[11] T. A. N. Abdali, R. Hassan, A. H. M. Aman, and Q. N. Nguyen, "Fog computing advancement: concept, architecture, applications, advantages, and open issues," *IEEE Access*, vol. 9, pp. 75961–75980, 2021, doi: 10.1109/ACCESS.2021.3081770.

[12] C. Tang, X. Wei, C. Zhu, Y. Wang, and W. Jia, "Mobile vehicles as fog nodes for latency optimization in smart cities," *IEEE Transactions on Vehicular Technology*, vol. 69, no. 9, pp. 9364–9375, 2020, doi: 10.1109/TVT.2020.2970763.

[13] Agus Supriyanto and Joko Santoso, "Application of edge computing for realtime data processing in smart cities," *International Journal of Information Engineering and Science*, vol. 1, no. 2, pp. 13–18, 2024, doi: 10.62951/ijies.v1i2.89.

[14] J. Yang, Y. Kwon, and D. Kim, "Regional smart city development focus: the south korean national strategic smart city program," *IEEE Access*, vol. 9, pp. 7193–7210, 2021, doi: 10.1109/ACCESS.2020.3047139.

[15] W. Ji, J. Xu, H. Qiao, M. Zhou, and B. Liang, "Visual IoT: enabling internet of things visualization in smart cities," *IEEE Network*, vol. 33, no. 2, pp. 102–110, 2019, doi: 10.1109/MNET.2019.1800258.

[16] B. Ali, M. Adeel Pasha, S. U. Islam, H. Song, and R. Buyya, "A volunteer-supported fog computing environment for delay-sensitive IoT applications," *IEEE Internet of Things Journal*, vol. 8, no. 5, pp. 3822–3830, 2021, doi: 10.1109/JIOT.2020.3024823.

[17] B. Khazael, H. T. Malazi, and S. Clarke, "Complex event processing in smart city monitoring applications," *IEEE Access*, vol. 9, pp. 143150–143165, 2021, doi: 10.1109/ACCESS.2021.3119975.

[18] B. Omoniwa, R. Hussain, M. A. Javed, S. H. Bouk, and S. A. Malik, "Fog/edge computing-based IoT (FECIoT): Architecture, applications, and research issues," *IEEE Internet of Things Journal*, vol. 6, no. 3, pp. 4118–4149, 2019, doi: 10.1109/JIOT.2018.2875544.

[19] S. S. D. Xu, C. H. Chen, and T. C. Chang, "Design of oneM2M-based fog computing architecture," *IEEE Internet of Things Journal*, vol. 6, no. 6, pp. 9464–9474, 2019, doi: 10.1109/JIOT.2019.2929118.

[20] S. B. W. Connectivity, "Cisco small business 500 series wireless access points single point setup," pp. 1–8, 2013.

[21] NETGEAR, "NETGEAR 200 series," pp. 1–2, 2015.

[22] I. S. B. M. Isa, T. E. H. El-Gorashi, M. O. I. Musa, and J. M. H. Elmirghani, "Energy efficient fog-based healthcare monitoring infrastructure," *IEEE Access*, vol. 8, pp. 197828–197852, 2020, doi: 10.1109/ACCESS.2020.3033555.

[23] "Intel Xeon Processor E5-2420 (15M Cache, 1.90 GHz, 7.20 GT/s Intel QPI) Product SpecificationsIntel Xeon Processor E5-2420 (15M Cache, 1.90 GHz, 7.20 GT/s Intel QPI) Product Specifications," 2019. https://ark.intel.com/content/www/us/en/ark/products/64617/intel-xeon- processor-e5-2420-15m-cache-1-90-ghz-7-20-gt-s-intel-qpi.html (accessed Oct. 26, 2019).

[24] "Intel Xeon Processor E5-2680 (20MCache, 2.70 GHz, 8.00 GT/s Intel QPI) Product Specifications.," 2019. https://ark.intel.com/content/www/us/en/ark/products/64583/intel- xeon-processor-e5-2680-20m-cache-2-70-ghz-8-00-gt-s-intel-qpi. html (accessed Oct. 26, 2019).

[25] Nvidia, "Tensor cores in NVIDIA Volta architecture | NVIDIA," *Nvidia.Com*, 2018. https://www.nvidia.com/en-us/data-center/tensorcore/ (accessed Oct. 16, 2019).

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