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Reliable Resource Allocation and Management for IoT Transportation Using Fog Computing

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Abstract: Resource allocation in smart settings, more specifically in Internet of Things (IoT) transportation, is challenging due to the complexity and dynamic nature of fog computing. The demands of users may alter over time, necessitating more trustworthy resource allocation and administration. Effective resource allocation and management systems must be designed to accommodate changing user needs. Fog devices don't just run fog-specific software. Resource and link failures could be brought on by the absence of centralised administration, device autonomy, and wireless communication in the fog environment. Resources must be allocated and managed effectively because the majority of fog devices are battery-powered. Latency-aware IoT applications, such as intelligent transportation, healthcare, and emergency response, are now pervasive as a result of the enormous growth of ubiquitous computing. These services generate a large amount of data, which requires edge processing. The flexibility and services on-demand for the cloud can successfully manage these applications. It's not always advisable to manage IoT applications exclusively in the cloud, especially for latency-sensitive applications. Thus, fog computing has emerged as a bridge between the cloud and the devices it supports. This is typically how sensors and IoT devices are connected. These neighbouring Fog devices control storage and intermediary computation. In order to improve the Fog environment reliability in IoT-based systems, this paper suggests resource allocation and management strategy. When assigning resources, latency and energy efficiency are taken into account. Users may prioritise cost-effectiveness over speed in a fog. Simulation was performed in the iFogSim2 simulation tool, and performance was compared with one of the existing state-of-the-art strategy. A comparison of results shows that the proposed strategy reduced latency by 10.3% and energy consumption by 21.85% when compared with the existing strategy.

Keywords: Internet of Things; fog computing; transportation; latency; energy consumption

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1. Introduction

The "Internet of Things" IoT communicates everyday objects to the Internet and one another to improve communication between entities and people. In the linking process, sensors, actuators, and controllers are frequently utilized [1]. Since its debut, cloud computing has been used for hosting and delivering subscription-based computing and application services. It can also be used by CPSs (Cloud Printing Services) with IoT capabilities to run their own programmes. Customers can access storage and virtualized computing instances in cloud data centres through data and computing servers [2].

These data centres and the IoT devices are still separated by a distance. Because of this, data and orders must be transported across longer distances, which slows down how quickly cloud-based programmes can provide their services [3]. Network congestion is common even if a sizable number of IoT devices are linked and starting data-driven dialogues with remote applications. Additionally, cloud data centres are under more computational stress. IoT-enabled CPSs discover that the cloud-based application execution model cannot deliver the services they require [4]. Massive volumes of data are constantly being produced by sensors, communication systems, mobile devices, and social networks in the IoT environment, leading to a novel type of network design. The IoT ecosystem is characterised by a dispersed, challenging, and dynamic environment that presents several technical challenges. Latency, connectivity, competence, cost, power, scalability, and dependability are a few of the technical difficulties [5]. The Fog computing environment is a cutting-edge processing model that makes use of the computation power of fog devices to bring application services to clients more quickly and more efficiently. Some convergent-structured devices can act as fog nodes, giving users access to processing, storage, and networking resources. Convergent structured devices differ from traditional computational devices in terms of shape, structure, and functionality. They include computation-aware vehicles, drones with data processing and storage capabilities, and mobile edge devices. These types of nodes are significantly important in the context of IoT transportation. In the (IoT-Fog-Cloud) processing model, fog devices communicate with the cloud to carry out complex computation and long-term archiving [6]. To connect IoT devices to standard cloud computing data centres, which are commonly but not always situated at the network's edge, fog computing is a highly virtualized platform [7]. Fog computing is a scenario in which several dissimilar, ubiquitous, decentralised, wireless, and occasionally autonomous devices connect and cooperate with one another and the network. These duties include supporting fundamental network functions and creating new services and applications that can be used in a sandbox [8]. Cloud computing has more processing power and storage capacity than fog computing. Therefore, effective resource allocation is crucial in fog computing. Numerous studies on resource distribution in the fog computing paradigm have been done as a result. The growth process heavily depends on the transportation industry. Transportation needs are influenced by a variety of factors, such as the availability of commodities, travel patterns, logistics, etc. As a result, connecting consumers to the supply chain team through logistics now includes transportation as a crucial and fundamental component. IoT integration helps to build a centralised network that can efficiently handle and maintain goods, resources, and purchase orders, increase the distance travelled by the vehicle, locate safer and better routes in emergency situations, and boost the profitability of the transportation industry. Consider an IoT-based transportation system where the environment is made up of various sensors, devices, and cars. Data is produced by sensors in a variety of devices, including speed sensors, cameras, temperature sensors, vehicle tracking sensors, and GPS sensors. We can use applications to aid in making wise decisions in this circumstance. This includes suggesting the best methods to save gasoline or providing real-time traffic details in emergency scenarios, such as when nearing an emergency vehicle or an accident. Therefore, many applications require real-time computation in order to create an IoT-based transportation environment. Several parameters, including speed, distance traveled, road quality, driving habits, traffic sensors, climate, and other factors, are necessary to accomplish a particular application goal. Because of the real-time nature of the application environment and the need for low latency, it is not practical to rely completely on the cloud for processing. An intermediary computing and storage node, or "Fog device", is required to reduce latency. By utilising many Fog devices, it is possible to execute programmes close to consumers with minimum latency. Additionally, this lessens the load placed on the cloud's application processing infrastructure and network traffic. The Fog environment's complexity and dynamic nature make it difficult to assign resources for user applications. Applications are not only run on fog devices. Resource and link failures as well as latency may result from decentralised administration, device autonomy, and wireless communication in a fog environment [9].

Resource management, which involves optimizing the use of different resources including bandwidth, processing power, and energy, is essential for IoT transportation in order to reduce latency and energy consumption. In IoT transportation, latency reduction is crucial since it makes sure that data is transferred promptly and effectively. This is particularly important for autonomous vehicle applications, as real-time data is required to guarantee the safety of passengers and other road users. IoT transportation systems can lessen latency by controlling resources like computing power and bandwidth, which can shorten the time it takes for data to be transmitted. Another important factor in IoT transportation is energy consumption. Batteries, which have finite lives and require periodic replacement or recharging, power many IoT devices. The amount of energy needed to transfer data can be decreased by IoT transportation systems by maximizing the use of resources like processing power and wireless connectivity. This may result in longer battery life, fewer replacements being necessary, and cheaper running expenses. Conclusively, efficient resource management in IoT transportation is crucial for cutting down on latency and energy usage. IoT transportation systems may send data rapidly, effectively, and with little energy use by maximizing the utilization of diverse resources. This could enhance the performance, dependability, and security of IoT transportation systems.

In recent years, the IoT has become increasingly popular in transportation, leading to an increase in connected devices and cloud workload. Traditional clouds have been struggling with issues such as bandwidth, energy consumption, delay, and latency due to the increased workload. Fog computing offers a solution to bandwidth, delay, and latency issues in cloud computing. In transportation-related IoT, data management is crucial for preventing accidents and collecting data. To improve transportation-related IoT fog computing, there is a need to minimize latency, maximize energy efficiency, and provide an efficient resource allocation and management mechanism. All of these requirements make it necessary to contribute to the development of fog computing. Therefore, a new framework for resource allocation and management in an IoT transportation fog environment has been suggested to address the above-mentioned challenges.

The contributions of this research work are highlighted below:

- We suggested a trustworthy framework for resource management and allocation in IoT transportation utilizing fog computing.
- We took into account latency and energy efficiency when evaluating performance.
- We used ifogSim2 simulator for the evaluation of latency and energy consumption.

The remaining part of the paper is organized as follows: The latest related work in the literature is presented in Section 2. In Section 3, system design and modelling are described. In Section 4, the algorithm of R2AM is presented along with a diagram. Evaluation methods are presented in Section 5. In Section 6, the experimental setup is defined. The results are presented in Section 7, and the conclusion and future work are presented in Section 8.

2. Related Work

The literature review is undertaken in accordance with the resource allocation, simulation, cloud and fog computing infrastructure, IoT transportation, and cloud and fog computing infrastructure tools.

In [10], the rapid growth of geo-distributed and ubiquitous devices is evident, with billions of such devices expected to emerge soon. In [11], it is highlighted that the enormous amount of data generated by smart devices requires reliable network infrastructures, which is often a point of conflict. The data gathered by smart settings can be used to enhance their performance and evolution. The data is transferred to cloud servers for further processing and then sent back to the devices via existing cloud infrastructures. Despite this, the cloud paradigm has been considered in its early stages.

In [12], the term “cloud computing” is well explained by the “National Institute of Standards and Technology” (NIST) as an computing architecture that allows multiple computer resources to be allocated to users in the form of facilities. Software applications and system centers are considered as providing services in a data center. However, there are certain limitations in cloud, such as the requirement to transmit data from every sensor towards a data center, process the data, and then transferred instructions to actuators over a network. This limitation is due to the fact that sensors and actuators are often located on the same physical devices. This can result in increased communication time and inaccurate control information, which can be a significant disadvantage.

In [1], fog computing can be utilized by service providers to transfer processing from cloud data centers to the network edge. This reduces operational costs and energy usage in data centers, while improving the quality for users. Additionally, the cost of fog nodes has decreased, making it easier to connect with mobile and power-restricted end-user devices due to fog's location awarenesss [13]. Fog computing can be used in various contexts to maximize the reliability of particular information management systems, for example bridge and road monitoring, supply chain monitoring, healthcare monitoring, and water pipe network monitoring.

In [14], the gaps in cloud computing can be addressed by using edge and fog computing. Edge and fog computing do not entirely replace cloud computing but rather can be combined with it to achieve greater dependability, latency, and response times.

In [1], the ability to determine location is enabled by the widespread distribution of edge devices and the fog layer. Unlike edge computing, where both the processing capacity and intelligence are located in one place, in fog computing, they are situated in two distinct locations. In fog computing, there are multiple nodes located between the end devices and the cloud, each of which contains intelligence.

In [15], Fog computing can be advantageous by utilizing the Local Area Network (LAN) position within the network architecture, allowing for the shifting of intelligence through "data computation in a fog node or an IoT gateway". In [2], Edge computing involves the transfer of intelligence, processing power, and interoperability from an edge gateway to devices directly. Unlike some cloud-based services, it is typically associated with the "IoT device side". As [16] highlights, certain mobile services require a radio network with very low delay and real-time accessibility. With the introduction of "edge computing", as mentioned in [17], data computation and communication are moved from the cloud to a "Local Area Network" LAN. This results in faster message delivery for users and smoother service operation.

In [18], the ILP of optimizing the fog computing platform to handle numerous requests was recognized. Our team proposed a DQN-based method to tackle this NP-hard problem effectively, and the results showed that our approach achieved success rates that were close to optimal, surpassing the state-of-the-art techniques.

In [19], the study focused on driver behavior in two scenarios and found that even small changes, such as a pedestrian mock-up crossing the path in a different direction (scenario 1L or 1R), could have a significant impact on the parameters that influence driving behavior, particularly in impending crisis situations. The study concluded that driver response time, time to accident, and road risk level were all linked. The study's previous findings were also used to demonstrate that under the tested conditions, response time increased linearly with TTC.

In [20], big data and IoT are increasingly significant in daily life, with big data technologies simplifying preprocessing and allowing for higher-level analysis of preprocessed data. The s-ITS framework is established when processed traffic data is exposed to big data and IoT methods. The suggested framework promotes the development of effective transportation systems by utilizing big data technologies, smart parking, and vehicle tracking. By analyzing vehicle movement, the system can help determine traffic levels in a particular area, and energy-saving techniques can be incorporated into the ITS system to improve its efficiency in dealing with current traffic scenarios.

In [21], the study proposes a method for resource contribution in fog nodes using blockchain technology. The framework's resource model was created using a differential game and considered important parameters and profits, demonstrating that fog node resource optimization can be accomplished.

In [22], resource allocation in fog computing is a challenging and essential subject. The study proposes a dynamic resource sharing technique based on PTPN for fog computing that improves the efficiency of fog resource utilization and meets users' QoS requirements. Consumers can choose the most suitable resources from a pool of pre-allocated resources based on factors such as price, time cost, and reliability estimation, similar to the purchasing mode on the internet.

In [23], the study explores the use of fog computing in smart manufacturing where real-time data processing is crucial for detecting anomalies and addressing device failures. The delivery of computing resources to the terminal devices is defined as "containers" based on specific problems. The study analyzes the work scheduling process to optimize fog node resource utilization and presents a new task scheduling method and a resource reallocation mechanism.

In [24], the study proposes a new task scheduling approach (I-FASC) for fog computing, taking into account task and resource characteristics. The enhanced genetic algorithm (I-FA) that considers the mechanism of explosion radius recognition of fireworks which is utilized for optimizing the scheduling process. The study performs load simulation and certification using two sets of tests in a short time to analyze task scheduling in fog computing and present some findings.

In [25], the study introduces a new energy-aware technique based on a unique meta-heuristic algorithm called the marine-predator-algorithm (MPA). The solutions are evaluated based on six performance criteria: make-span, expenditures, energy consumption, flow time, and emission of carbon dioxide rate. As stated in [26], these designated smart nodes can function as base stations. "Fog computing is capable of processing IoT data in close proximity to the source by extracting intelligence from the cloud". Subsequently, it can make more efficient use of cloud resources (only when needed). Table 1 shows the analysis of existing studies.

Table 1. The analysis of existing studies.

References	Environment	Technology	Contribution	Limitations
[1]	Fog environment	Edge computing	Resource Assignment	Not Energy Efficient
[2]	Fog Environment	Fog Computing	Application Management	Not Latency-Aware
[12]	Smart cities	Fog computing	Mobile Crowd Sensing Technology	Not Latency-Aware
[15]	Fog Environment	Fog Computing	Resource Assignment	Not Energy Efficient
[19]	emergency traffic	Collision-free transportation	Analysis of collision avoidance	Not Energy Efficient
[20]	IoT Environment	Big data	Intelligent Transportation System	Not Energy Efficient
[24]	Fog Environment	Fog Computing	Task Scheduling Algorithm	Not Latency-Aware
[25]	Fog Environment	Fog Computing	Marine Predators Algorithm for Task Assignment	Not Energy Efficient

3. System Design and Model

Figure 1 shows the proposed "Reliable Resource Allocation and Management" (R2AM) strategy framework for Transportation through IoT Network using fog computing. At a high level, IoT devices submit user requests to fog level nodes for data transmission from edge devices to fog devices. Fog level nodes validate and manage all application requests while cloud nodes are responsible for permanently storing the data. The fog level nodes have all the necessary fog resources installed, and the decentralized decision system (DDS) is deployed on this layer.

Several fog servers are set up to provide resource organization services to all resources, and they have a higher configuration than fog devices. Fog devices are connected through a medium of communication to form clusters on the cloud level node. The application's parameters are used to process all data on the fog level node layer, and the cloud layer acts as a centralized system for sending data to the cloud after processing it.

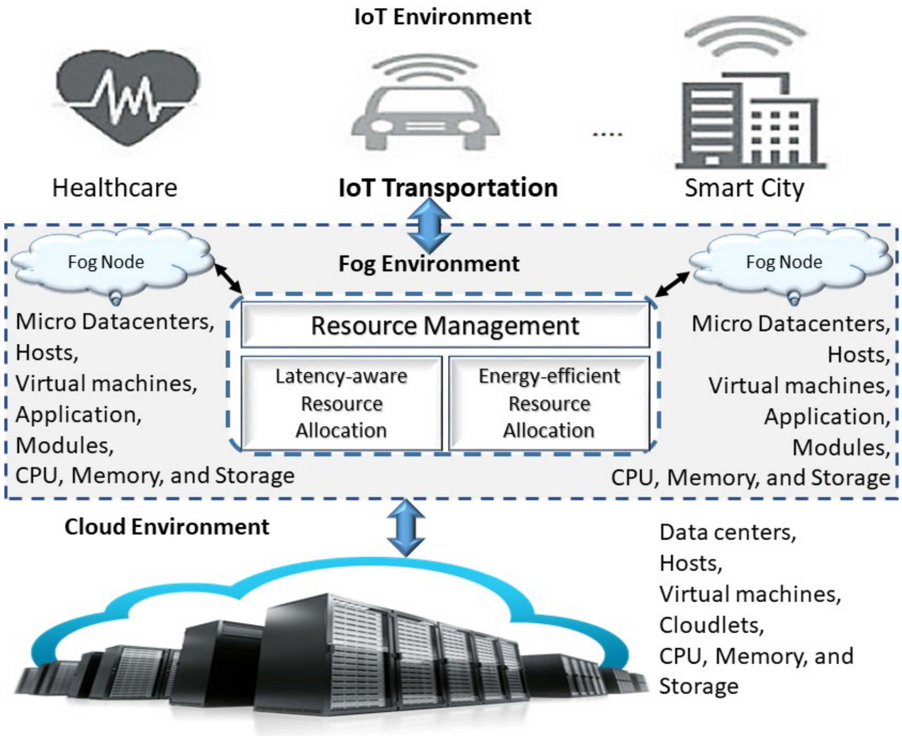

Figure 1. Proposed Model of R2AM.

4. Algorithm for R2AM

The proposed R2AM technique is outlined in Algorithm 1, which presents the process of the R2AM strategy in pseudo code. Initially, the data from IoT devices is placed in a queue for later use, while information from fog nodes is stored in queue2. The fog nodes are then ranked in decreasing order based on their processing time, and the IoT data are allocated to the fog nodes in accordance with the sorted list. The outcomes of the IoT data are delivered back once they have been processed successfully. Table 2 shows the list of abbreviations and used notations in the algorithm.

Algorithm 1: R2AM Strategy

```
Input: DIot
Output: Ra
  Procedure R2AM ( )
  Queue1 ← GetIoTData ( )
  Queue2 ← GetFogNodes ( )
  for (each IoT Data in Queue1) do
      Fpt ← FogNodeProcessingTime ( )
      Sort Fpt in descending order for F1 to Fn
      F1 ≥ F2 ≥ F3 . . . Fn
      Minpt ← integer.max
      Foga ← null
      if (Fpt ≤ Minpt) then
              Fpt ← Minpt
              Fpt ← DIoT
              Foga ← Fpt
        end if
   end for
   Return Result (Ra)
   end Procedure
```

Table 2. List of abbreviations and used notations.

Symbol	Definition
R2AM	Reliable Resource Allocation and Management
CPS	Cloud Printing Service
IoT	Internet of Things
CDC	Crowd-sensed Data Collection
DDS	Decentralized Decision System
DIoT	Data of IoT devices
R_a	Resource Allocation
Queue1	Stores information about total IoT data
Queue2	Stores information about total Nodes
F_{pt}	Fog Computing Processing Time
Min_{pt}	Fog Computing with Minimum Processing Time
Fog_a	Fog Assigned

5. Evaluation Method

This section describes the evaluation method in detail. It includes details about the simulation tool, application modeling, and performance evaluation parameters.

5.1. Simulation Tool

The proposed R2AM strategy's performance is evaluated using the simulation tool iFogSim2 [26,27], an upgraded version of iFogSim [27] that provides additional features such as mobility, microservices management, and clustering in fog and edge computing environments. With the ability to handle service transfer for several smart devices, iFogSim2 is the suitable simulation environment for evaluating the proposed model. iFogSim2's components provide a range of simulation scenarios, including mobility, clustering, and microservices, which can be used alone or in combination. Additionally, iFogSim2 has been enhanced with various test scripts and studies to improve its functionality and support new strategies

5.2. Application Modeling

The proposed R2AM technique's efficiency is demonstrated using the Crowd-sensed Data Collection (CDC) application, which is highly relevant to IoT transportation. CDC is a process in which sensors connected to the internet collect data in a mobile crowd-sensing scenario. This type of data is essential for traffic signal collection and road system design in urban areas. Vehicular crowd-sensing is another method of data collection where sensors on mobile vehicles sense and transmit the data in real-time, enabling real-time decision-making. CDC uses Directed Acyclic Graph (DAG) based modeling and consists of two microservices, namely, a NGINX microservice and a processing microservice. The NGINX microservice functions as a webserver gateway, receiving data generated by the vehicular network and transmitting it to the processing microservice. The processing microservice sanitizes and extracts features to produce the necessary results [28]. CDC can increase road safety by providing timely information on accidents through incident control or updating mechanisms.

5.3. Performance Evaluation Parameters

Latency and energy consumption are key performance evaluation parameters for the proposed research strategy. In a transportation IoT environment [29–37], minimizing latency and reducing energy consumption are critical aspects.

Latency: Refers to the delay that occurs in a system during the computation of a task. It is typically calculated by adding the processing delay and the transmission delay [29,30]. Latency is measured in milliseconds (MS), and its formula is given by Equation (1).

$$Latency = Processing_{Delay} + Transmission_{Delay} \tag{1}$$

Energy consumption: Refers to the total power utilized by all devices in a system, including processing, sensing, and transmitting devices [29–37]. It is typically measured in joules and can be calculated using the following equation (Equation (2)).

$$Energy\ Consumption = Power_{Processing} + Power_{Sensing} + Power_{Transmitting} \tag{2}$$

6. Experimental Setup

The iFogSim2 simulation environment [26,27] was used to evaluate the proposed strategy. Specifically, a simulation of a CDC application was performed on a PC with an Intel Core i5 2.60 GHz CPU, 8 Gigabytes of RAM, and MS Windows 10 64-bit operating system. The simulation focused on comparing the R2AM strategy to the SMP (Scalable Microservice Placement) strategy [26], using performance evaluation parameters such as latency and energy consumption.

7. Results

This section presents the findings of a simulation that was conducted to assess how data transmission can be improved to minimize both latency and energy consumption. The simulation was performed after outlining the system components and technique.

7.1. Latency

To evaluate its performance with respect to latency for CDC applications, the proposed R2AM strategy was simulated. Figure 2 displays the latency of the CDC application, which illustrates that the proposed R2AM strategy has lower latency compared to the SMP strategy. Specifically, the simulation results indicate that the proposed R2AM strategy has less latency.

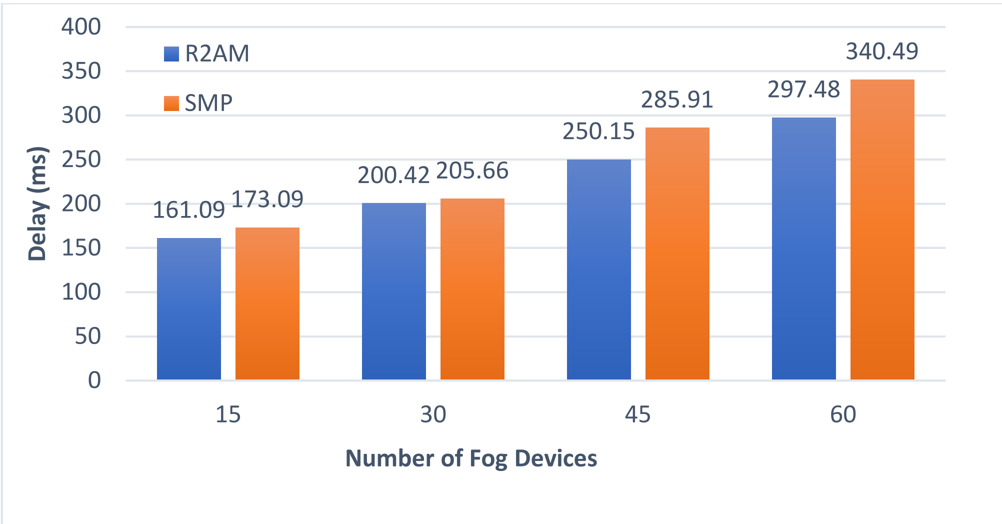

Figure 2. Latency comparison of proposed and existing strategies.

7.2. Energy Consumption

In order to assess its energy consumption for CDC applications, the proposed R2AM strategy was simulated. The results of the simulation, shown in Figure 3, indicate that the R2AM strategy has a lower energy consumption compared to the existing SMP strategy. Specifically, the simulation demonstrated that the proposed R2AM strategy has the minimum energy consumption.

The proposed strategy delivers superior results with regard to energy consumption. This is because the strategy dynamically allocates resources with minimal processing time, and when tasks require less processing time, they consume less energy.

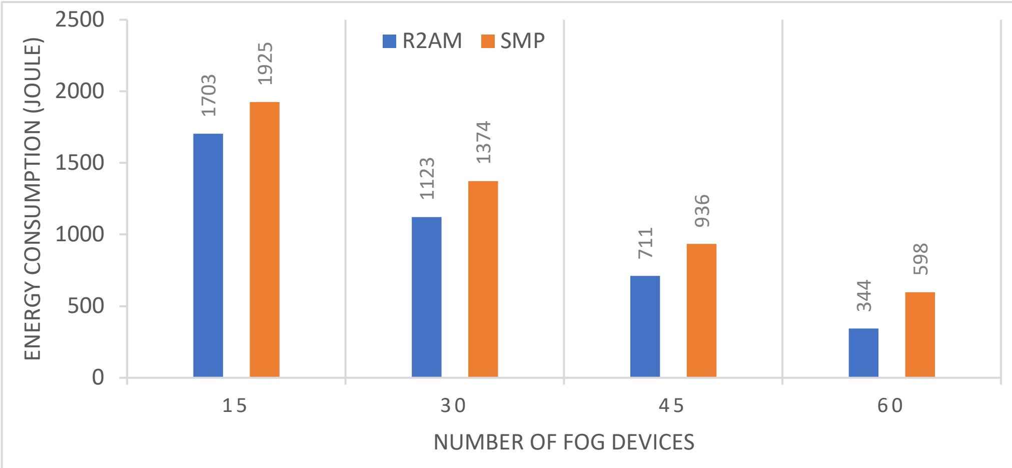

Figure 3. Energy Consumption comparison of proposed and existing strategies.

8. Conclusions

In recent years, the IoT has become increasingly popular in transportation, leading to an increase in connected devices and cloud workload. Traditional clouds have been struggling with issues such as bandwidth, energy consumption, delay, and latency due to the increased workload. Fog computing offers a solution to bandwidth, delay, and latency issues in cloud computing. In transportation-related IoT, data management is crucial for preventing accidents and collecting data. To improve transportation-related IoT fog computing, there is require to minimize latency, maximize energy efficiency, and provide an efficient resource allocation. To address the challenges presented by the requirements of IoT transportation systems, contributing to the development of fog computing has become essential. A new framework, called Reliable Resource Allocation and Management (R2AM), has been proposed to manage resource allocation in IoT transportation using fog computing. Under this proposed strategy, data from IoT devices is queued for storage and processing, while fog nodes are placed in a separate queue. All available fog nodes are then sorted based on processing time, and IoT data is assigned to them according to the order in the list. The results of this process are returned upon successful execution.

The proposed R2AM strategy was compared to the existing SMP strategy through simulation in the ifogSim2 simulation environment. The results show that the proposed strategy was able to reduce latency by 10.3% and energy consumption by 21.85% compared to the existing strategy. However, there is a potential for execution failure due to limited communication device range, which was not considered in the proposed strategy. The authors aim to address this in future work by proposing a fault-tolerant and reliable resource assignment for IoT transportation. Additionally, the authors plan to improve the proposed strategy by incorporating more number of evaluation parameters and making the comparison with other relevant and recent methods.

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Data Availability Statement: We ran simulations to see how well the proposed approach performed. Any questions concerning the study in this publication are welcome and can be directed to the lead author (Haseeb Ullah Atiq) upon request.

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