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iJIM International Journal of Interactive Mobile Technologies

iJIM | eISSN: 1865-7923 | Vol. 18 No. 3 (2024) | OPEN ACCESS

https://doi.org/10.3991/ijim.v18i03.42813

PAPER

A New WRR Algorithm for an Efficient Load Balancing System in IoT Networks under SDN

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ABSTRACT

The Internet of Things (IoT) connects various smart objects and manages a vast network using diverse technologies, which present numerous challenges. Software-defined networking (SDN) is a system that addresses the challenges of traditional networks and ensures the centralized configuration of network entities to manage network integrity. Furthermore, the uneven distribution of IoT network load results in the depletion of IoT device resources. To address this issue, traffic must be distributed equally, requiring efficient load balancing to be ensured. This requires the development of an efficient architecture for IoT networks. The main goal of this paper is to propose a novel architecture that leverages the potential of SDN, the clustering technique, and a new weighted round-robin (N-WRR) protocol. The objective of this architecture is to achieve load balancing, which is a crucial aspect in the development of IoT networks as it ensures the network's efficiency. Furthermore, to prevent network congestion and ensure efficient data flow by redistributing traffic from overloaded paths to less burdened ones. The simulation results demonstrate that our N-WRR algorithm achieves highly efficient load balancing compared to the simple weighted round-robin (WRR), and without the application of any load balancing method. Furthermore, our proposed approach enhances throughput, data transfer, and bandwidth availability. This results in an increase in processed requests.

KEYWORDS

clustering, load balancing, Internet of Things (IoT) network, open flow, software-defined network (SDN), weighted round robin

1 INTRODUCTION

The Internet of Things (IoT) enables diverse smart devices to autonomously connect with each other at any time and in any location [1] [2]. Moreover, they have extensive connectivity at the network, software, and application levels to detect and extract substantial amounts of information and data from various heterogeneous systems, which is a complex task.

Tamri, R., Antari, J., Iqdour, R. (2024). A New WRR Algorithm for an Efficient Load Balancing System in IoT Networks under SDN. *International Journal of Interactive Mobile Technologies (iJIM)*, 18(3), pp. 45–59. https://doi.org/10.3991/ijim.v18i03.42813

Article submitted 2023-07-05. Revision uploaded 2023-08-02. Final acceptance 2023-11-08.

The Internet of Things systems are composed of heterogeneous hardware and software technologies, which encompass various details to consider, such as data transmission, connectivity, longevity, compatibility, norms, and standards. This presents several challenges in [3] [4] to managing infrastructure, including the vast amount of generated data and organizations across different domains, as illustrated in Figure 1.

Moreover, the IoT network is characterized by its large, mobile, and dynamic size. It consists of heterogeneous devices that change their topology and connectivity. Any malfunction of supporting IoT devices or network outage may cause catastrophic effects, such as data corruption or loss during transmission or storage. This highlights the need for multiple tools and solutions to coordinate and centralize the network systems.

Consequently, in the literature, several researchers [5] [6] have proposed new architectures, gateway solutions [7], and various IoT platforms [8]. Their aim is to introduce solutions that guarantee compatibility at every level of the IoT architecture stack.

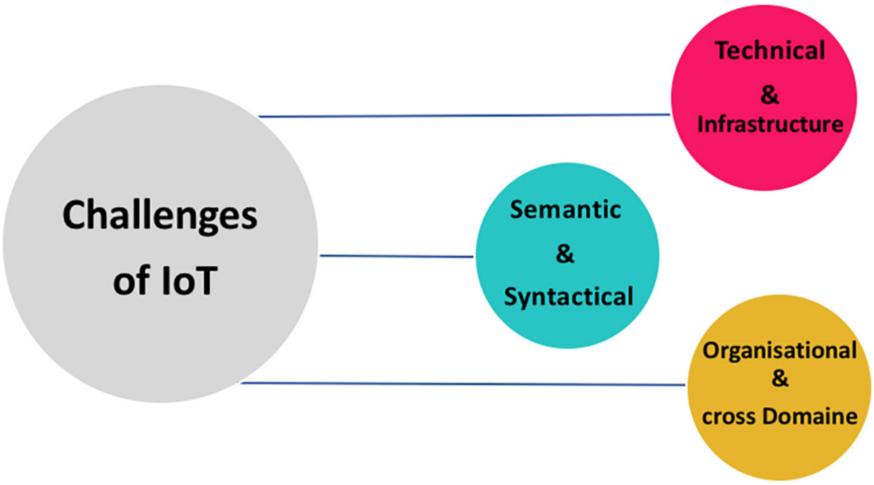

Fig. 1. The challenges in IoT

Software-defined networking (SDN) technology is one of the solutions at the network layer that has gained significant attention [9] [10] [11]. Thanks to the numerous features offered, it is now possible to manage the entire network through a programmable centralized controller. This evolution of SDN into a programmable and scalable networking framework allows for addressing certain limitations of the IoT network [12] [13]. The controller has a global view of the network, enabling it to manage network flows more efficiently and dynamically adapt to network conditions [14] [15]. The SDN technology consists of three separate layers, as shown in Figure 2: the data plane, control plane, and application plane. The programming interfaces, such as the southbound interface and the northbound interface, enable communication between the SDN controller and the data plane as well as the application plane. Additionally, there is an east-west interface for communication between multiple controllers.

The primary characteristics of the three layers of the SDN architecture are:

- The data plane, also known as the infrastructure layer, consists of physical devices that route and forward network traffic (data network) using the OpenFlow (OF) protocol. This protocol is shared with the controller and is the most widely used standardized protocol by SDN controllers.

- The Control plane is based on the SDN controller, which has a global view of the network and infrastructure equipment. SDN enables efficient custom configuration and optimized routing through predefined policies, providing reliable connectivity.
- The application plane consists of several programmable services and applications that enable network administrators to configure and manage the entire network.

Therefore, implementing a centralized architecture based on SDN in an IoT environment enables IoT devices to benefit from SDN technology's advantages. It allows for automated and isolated management of the complexity of the data plane layer, eliminating the need to reprogram or reconfigure any device [16] [17]. This approach also facilitates the addition of new devices to the network at any time, reducing standardization issues [17] and ensuring compatibility at this level.

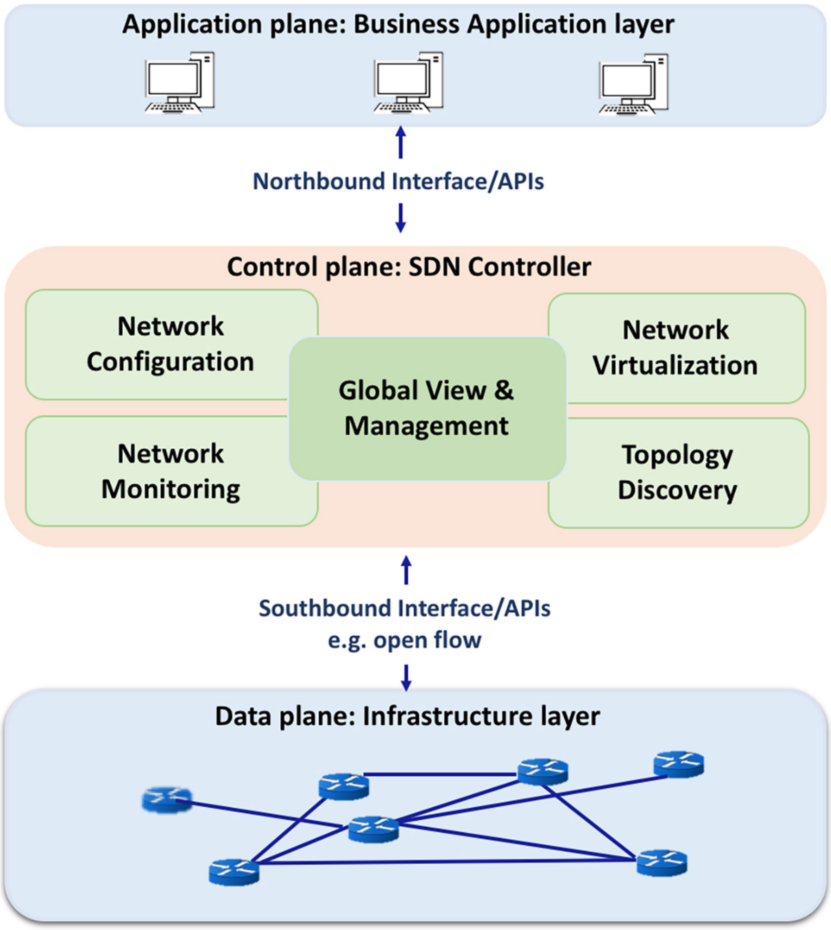

Fig. 2. The SDN architecture

Furthermore, the data generated by IoT devices is continuously growing and evolving, leading to an increased demand for various services and resources. This necessitates the need to balance the load in order to meet the high requirements of the IoT network, such as high performance, lower latency, high throughput, and high availability [18] [19]. In traditional networks, load-balancing algorithms do not adequately address the virtualization of network operations and rapid scaling.

Software-defined networking overcomes all these limitations and enables the improvement of network services and performance compared to traditional networks. Nevertheless, developing efficient load balancing remains the main concern in research associated with SDN [18] [15] [20].

Additionally, clustering allows for reducing communication overhead by selecting a cluster head (CH) that enables only the necessary devices to participate in processing and communication. In the literature, several researchers [21] [22] [23] [20] [24] have investigated the use of clustering techniques to enhance resource utilization in a range of IoT applications, aiming to improve the performance of network equipment. The researchers [25] presented a survey that describes the application of clustering in IoT networks and the potential for migrating existing wireless sensor network (WSN) clustering techniques to IoT networks.

In this paper, we propose an enhanced algorithm based on weighted round-robin (WRR) to improve the load-balancing mechanism named New weighted round-robin (N-WRR). The "N-WRR" algorithm is implemented in the SDN controller within an architecture based on clustering.

The main objectives of this paper are as follows:

- To ensure network compatibility in the IoT architecture, a centralized SDN controller [26] [27] [14] [16] is utilized to manage heterogeneous IoT devices within a clustering structure.
- Develop a new algorithm, referred to as N-WRR, to distribute load balancing among CHs in our architecture.
- Utilize the SDN controller to achieve faster and more extensive re-clustering, a concept that has not yet been explored or studied [13].

The Mininet-WiFi emulator and the OpenDaylight controller are utilized to conduct the experiments. A comparative study was conducted to evaluate the throughput, response delay, bandwidth, and total number of requests processed for three different methods: N-WRR, simple WRR, and a third method without applying any load balancing.

The rest of the paper is structured as follows: Section II provides background information and related works that demonstrate the significance of SDN, clustering, and load balancing technologies for IoT. In Section III, we describe the design of the proposed architecture. The simulation scenario is described in Section IV. The evaluation and performance analysis are presented in Section V. Finally, Section VI draws conclusions and outlines some future research directions.

2 BACKGROUND AND RELATED WORKS

The Internet of Things involves physical objects or things that are characterized by limited resources in terms of processing power, storage, and volatile memory. To preserve these resources, [25] [28] clustering plays an important role in IoT by addressing significant challenges and [24] [25] ensuring network stability [28]. Clustering involves multiple nodes and devices forming a cluster, with local interactions being controlled by a CH. The CH aggregates and fuses all collected data.

However, traffic in cluster-based IoT has increased significantly. The network must manage multiple cluster members (CMs) with a single CH, which is very challenging [29]. Additionally, IoT objects and things are characterized by non-homogeneity. SDN [34], thus enables the administration of cluster-based IoT networks and facilitates the enhancement of network services and performance, thereby mitigating issues related to compatibility and resource limitations in IoT devices.

Furthermore, researchers conducted a comparative study that presents arguments regarding the management and performance of SDN-based networks versus non-SDN-based networks (traditional networks) [13]. In this context, the Table 1 presents a comparison of arguments for SDN-based IoT versus non-SDN-based IoT (traditional networks).

Furthermore, load management is necessary to regulate the increasing traffic on the network. In this sense, Sunil et al. [18] emphasized the importance of load balancing and the significant role of SDN for IoT applications in the years to come.

Additionally, the literature presents various algorithms that can efficiently perform load balancing among networks, including the random strategy [30], round-robin, WRR [31], dynamic load balancing, and flow statistic load balancing [31]. For this purpose, the authors in [31] analyzed various algorithms used for SDN-based load balancing. In these studies, various parameters of load balancing, such as throughput, response time, and availability, are utilized to compare the performance of these algorithms. The simulation results indicate that the WRR load balancing approach outperforms round-robin and dynamic load balancing. Moreover, in 2019, [32] incorporated a WRR algorithm for load balancing in the SDN controller. The simulation results indicate that the utilization of the WRR algorithm is highly efficient compared to the standard SDN approach (i.e., without employing the WRR algorithm). The WRR algorithm enhances bandwidth availability and data transfer size, thereby reducing latency in software-defined networking.

Table 1. SDN-based IoT vs. non-SDN based IoT

Metric	SDN-Based IoT	Non SDN-Based IoT
Quality of Service (QoS)	The SDN controller manages and takes care of QoS provisioning for the entire network	Each node is responsible for provisioning QoS
Management	The whole network is administered by the controller	The nodes cooperate with each other in order to administer the network
Routing	The controller determines and decides the routing nodes	The nodes work together to build routing decisions
Energy-Efficiency	The controller has a global view of the network, which allows it defines any node's active time.	The nodes collaborate themselves by sending broadcast messages to their neighbors in order to obtain the locations of devices. That increases the energy consuming for each node.
Configuration	Central software monitoring. Configuration mostly completed remotely.	Configuration is done directly and individually for network devices.
Novelty	Novel alteration of the network becomes simple as network modification could be added to the existing infrastructure. Does not need to review the entire processing of the network.	A simple adjustment or modification will require a severe study and understanding of the structural design of the entire network. Innovation is possible, but complicated to implement.
Maintenance	Quick maintain, as it is easy to execute new services or network upgrades without disrupting the entire network.	Difficult to support as a small change in the network could affect the entire network.

3 PROPOSED ARCHITECTURE

3.1 Motivation

The number of packets transmitted in a network at a given point in time defines the network traffic. Efficient traffic management ensures optimal solutions for various challenges, such as load balancing, reducing network congestion, bandwidth management, and energy consumption. Moreover, effective and thorough analysis of network traffic can enhance network performance [33]. SDN allows for easy control to configure complex networks through a programmable and flexible interface [34]. The SDN controller makes packet routing decisions. Generally, it periodically gathers status information for each device, connections, links, and other networking components. Therefore, when new devices are added to the network, this information helps in updating the network policy. Our proposal combines various technologies such as SDN, clustering, and the N-WRR algorithm for load balancing to implement a cluster-based architecture to ensure efficient load balancing and guarantees high performance in the data plane layer.

3.2 Architecture

Our proposed architecture consists of two layers: the control layer and the infrastructure layer (data plane layer), as shown in Figure 3. The infrastructure layer is comprised of various IoT devices grouped into clusters. Each cluster contains several CMs connected to and managed by their CH. On the other hand, the control layer consists of an SDN controller that separates the control plane from the data plane (infrastructure layer). SDN has a global view of the entire network, enabling it to gather precise information about the flow and establish appropriate network policies for configuring each CH through a secure channel using the OF protocol. The controller also gathers the load information of all the CHs and is responsible for grouping the CMs into clusters based on the load and performance of each CH. Each CH accepts incoming data streams from the different CMs and relays them along a predefined path that has already been calculated and established based on the rules defined by the SDN controller. However, the high volume of communications between CHs and CMs, as well as between SDNs and CHs to pass network data, leads to the depletion of the CHs' resources. To address this situation, the authors in [32] proposed a straightforward algorithm-based WRR, outlined in algorithm 2 and described in Figure 5, for load balancing. The algorithm's performance is evaluated based on throughput and delay parameters. In the following paper, we propose an improved version of the WRR algorithm that enhances the results obtained in [32].

Furthermore, the proposed algorithm enables load balancing to prevent overloading and the inability to process at the level of the less powerful CHs. The N-WRR algorithm, as shown in algorithm 1 and described in Figure 4, is based on the weighting principle of the WRR algorithm. It aims to benefit from the various advantages of the algorithm in order to address the problem at hand.

In this architecture, the N-WRR is installed on the SDN controller to enable network administrators to assign a predefined weight value to each CH based on various criteria, such as the ability to manage traffic according to their resources.

This means that the CH with the higher weight receives a greater proportion of requests and traffic, allowing for efficient use of resources in the network.

In the proposed architecture, the N-WRR is based on a multiple queuing model and multiple CHs that process requests. To prevent delays in processing requests from IoT devices, our system utilizes multiple CHs, with each cluster assigned a weight to manage a limited number of requests from the CMs within its cluster. In the event that one of the CH reaches the maximum number of requests being processed and receives an additional request, the SDN checks the number of requests being processed at each CH. The CH with the fewest number of requests being processed is then responsible for processing the request from its neighboring CH, as outlined in algorithm 1.

Moreover, CHs have a high number of interactions with the CMs, other CHs, and the SDN controller to manage network data, which depletes their energy. If that is the case, a new CH needs to be selected to manage the network traffic. In this case, if a new additional device is added, SDN checks if it is an eligible trusted IoT device and if it performs more than the existing CHs. The current node is elected as a new CH and replaces the CH with lesser performance, as explained in Figure 6. This resolves the problem of re-clustering, which has not yet been considered and studied [13].

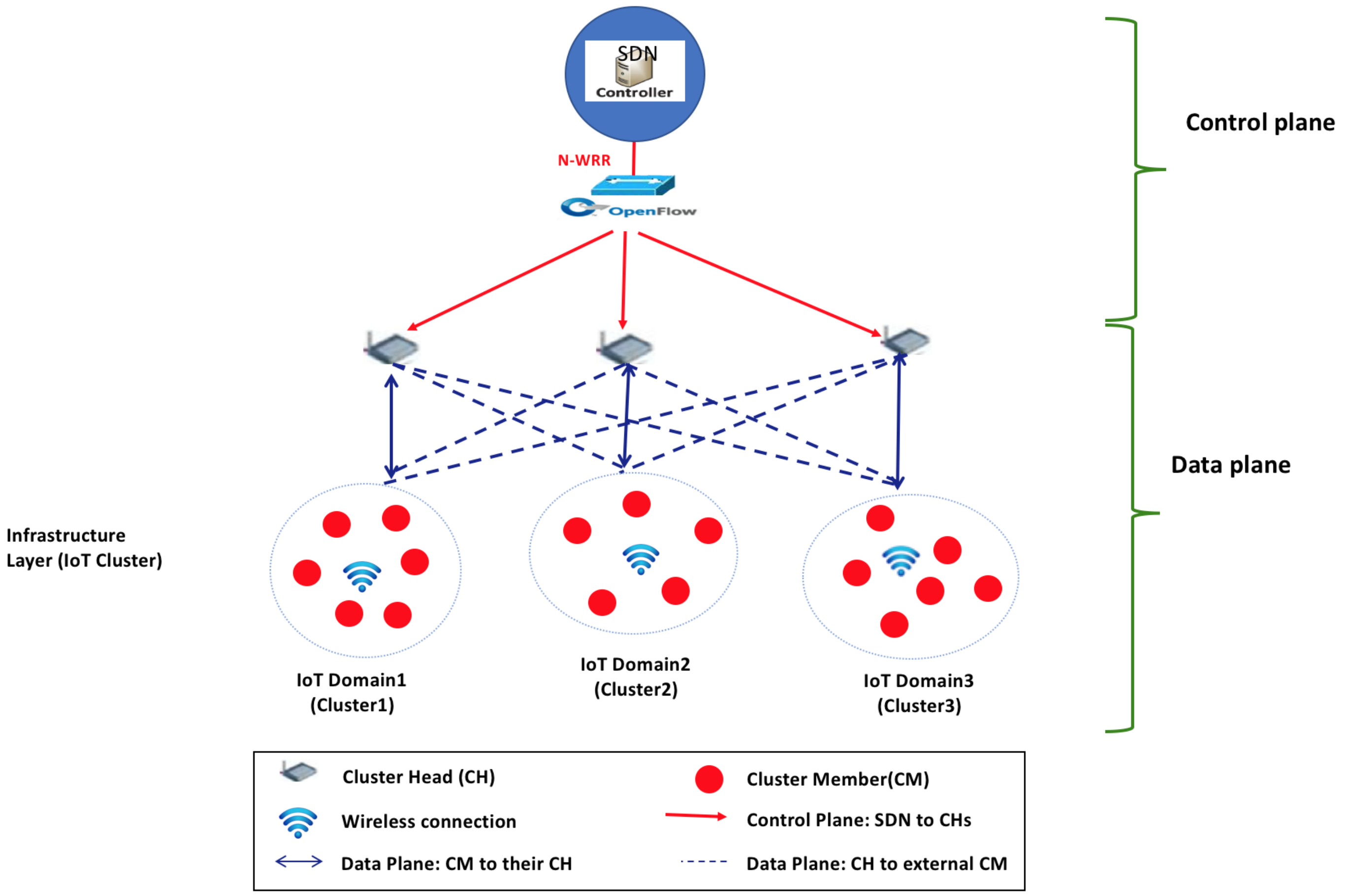

Fig. 3. Proposed load balancing system implemented in SDN under cluster structure to manage data plane layer

Algorithm 1: New-Weighted Round Robin (N-WRR)

```
N = Number of requests processed by each CH
j,k = Number of requests that a CH can add to process
iterator = keeps track of number of request still in processing for each CH
i = no of CH and iterator which is processing requests
Procedure: New Weighted Round Robin Algorithm
Begin
if (iterator [i] < CH [i]. weight)
Increment iterator [i] and Assign CH [i]
Increment N [i]
else if (iterator [i + 1] < (CH [i + 1]. weight) and (iterator [i + 2] = (CH [i + 2]. Weight
   Increment iterator [i + 1] and Assign CH [i + 1]
   Increment N [i + 1]
  else if (iterator [i + 1] = (CH [i + 1].weight) and (iterator [i + 2] < (CH [i + 2]. Weight
     Increment iterator [i + 2] and Assign CH [i + 2]
     Increment N [i + 2]
    else if (iterator [i + 1] < (CH [i + 1]. weight) and (iterator [i + 2] < (CH [i + 2]. Weight
       j = CH [i + 1]. Weight- iterator [i + 1]
       k = CH [i + 2]. Weight-iterator [i + 2]
       if j > k
        Increment iterator [i + 1] and Assign CH [i + 1]
        Increment N [i + 1]
       else
        Increment iterator [i + 2] and Assign CH [i + 2]
        Increment N [i + 2]
End
```

Algorithm 2: Weighted Round Robin (WRR)

```
N = Number of requests processed by each CH
Iterator = keeps track of number of request still in processing for each CH
i = no of CH and iterator which is processing requests
Procedure: Weighted Round Robin Algorithm
Begin
if (iterator [i] < CH [i]. weight)
Increment iterator [i] and Assign CH [i]
Increment N [i]
else if (iterator [i + 1] < (CH [i + 1] weight)
Increment iterator and Assign CH [i + 1]
Increment N [i + 1]
else (iterator [i + 2] < (CH [i + 2) weight]
Increment iterator and Assign CH [i + 2]
Increment N [i + 2]
End
```

3.3 Simulation scenario

In this section, we provide details of the implementation environment for the proposed architecture. In our simulation, we used the OpenDaylight controller [35] [36] [37] and the Mininet-Wi-Fi emulator [38] [39] to implement the SDN and several IoT domains (clusters).

The different virtual machines (SDN and Mininet-WiFi) have different IP addresses. The IoT clusters' topology was remotely connected to the OpenDaylight SDN controller. Moreover, the simulation environment consists of three clusters, specifically three IoT domains, with each cluster's CH connected to various IoT devices. Each CH has different resource capabilities. In each cluster, six IoT nodes are associated with their respective CHs. However, it's not necessarily the case that any request from the node is associated with his CH. It's possible for a request to be associated with another CH if the number of requests being processed by his CH is equal to the predefined weight.

The weight assigned to each CH determines the number of requests sent to each CH for simultaneous processing. The weights assigned to the CHs (1, 2, and 3) are 3, 2, and 1, respectively. This means that the CH with the highest weight receives a higher proportion of requests to be processed at the same time. In the event that the CH has the maximum number of requests to process at the same time and it has an additional request to process, the SDN passes the request to the other neighboring CHs. The CH with the fewest requests to process then processes the request, as shown in Algorithm 1 and described in Figure 4. This process continues until all requests are served.

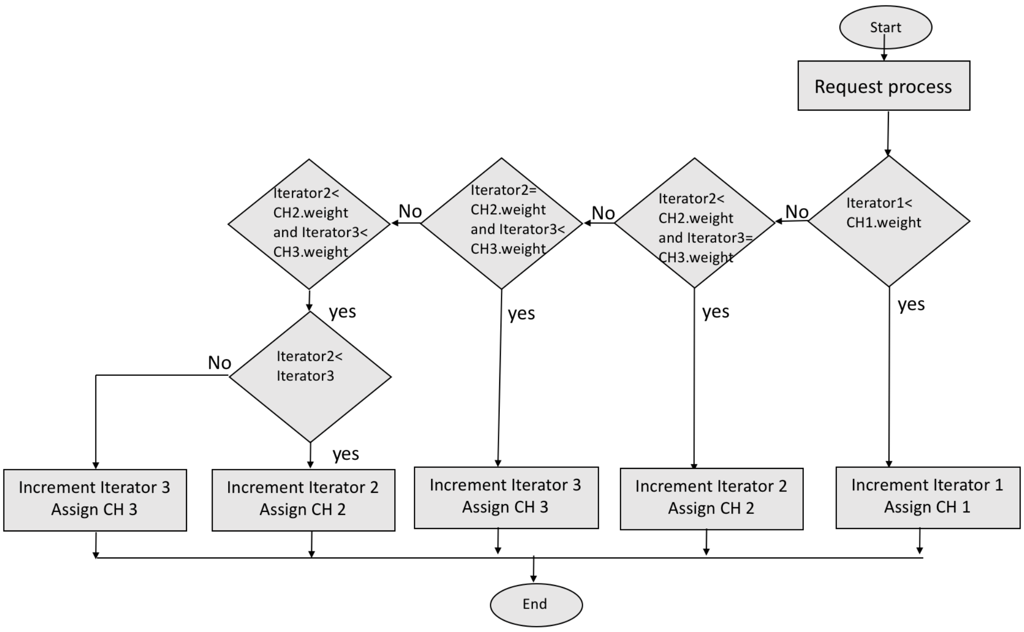

Fig. 4. Load balancing system implemented in SDN applying N-WRR with three clusters structure to process data in infrastructure layer

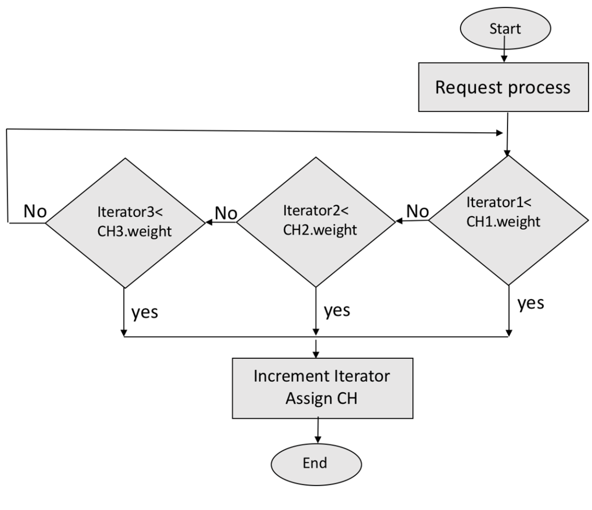

Fig. 5. Load balancing system implemented in SDN applying WRR using three clusters structure to process data in infrastructure layer

The simulations are executed on a virtual machine with a 2.7 GHz Intel Core i5 CPU and 8 GB of memory. Table 2 shows the simulation parameters. Moreover, our proposal's experience is tested in three ways. Firstly, we applied load balancing with our new algorithm, N-WRR, as described in algorithm 1, based on a multiple queue model and multi-CHs. This involves a single queue for each CH and utilizing other CHs in the event that one of the CHs has the maximum number of requests being processed, depending on the weight. The second approach involves applying the WRR described in algorithm 2. It is based on a single queuing model and multi-CHs [32]. All requests from IoT devices pass through a single queue and are then sent to CHs that collaborate to process the requests. The third one does not apply any load-balancing method. In the three methods, the metrics used in [32] include QoS parameters such as delay, bandwidth availability, Round-Trip Time (RTT), and the total number of requests processed by each CH. This allows us to assess the performance of SDN in load balancing at the data plane layer using the N-WRR algorithm 1.

The total number of requests processed by each CH is given by equation 1 [32].

$$\text{Requests by CH} = \sum_{i=1}^{CH} Ni \tag{1}$$

The total number of requests processed for all CHs is calculated by summing the total number of requests processed for each CH, as given by the equation 2. Equation 3 [32] gives the average number of requests being processed.

$$\text{Total requsts} = \sum_{i=0}^{n} Ni \tag{2}$$

$$\text{Avg requests} = \frac{\sum_{i=0}^{n} Ni}{CH} \tag{3}$$

Table 2. Simulation environment

Simulation Parameters	Parameter Values
SDN Controller	Opendaylight
Simulator	Mininet-Wifi
Number of SDN controllers	01
Number of Cluster (IoT Domain)	03
Number of IoT devices	18
MAC protocol	Mac/802.11
Testing Time	100s
Testing Tool	Iperf

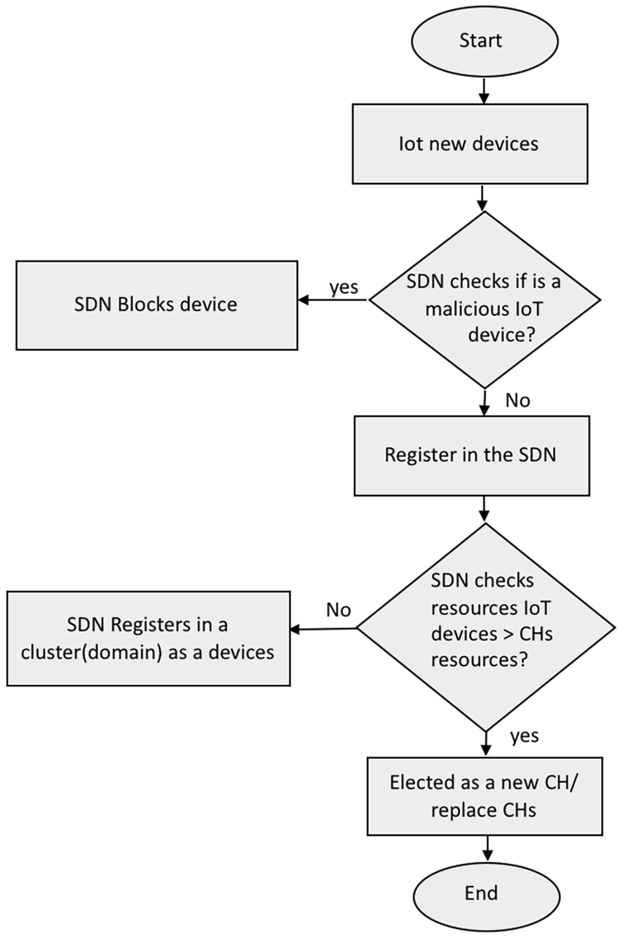

Fig. 6. Adding new IoT device and re-clustering

4 EVALUATION AND PERFORMANCE ANALYSIS

This section presents the results achieved from the simulation of the proposed architecture. The results include a comparative analysis of our load balancing approaches (N-WRR, WRR, and no load balancing method) in terms of the RTT (Figure 7), the number of requests processed for each CH (Figure 8), and the network's bandwidth and data transfer (Figure 9).

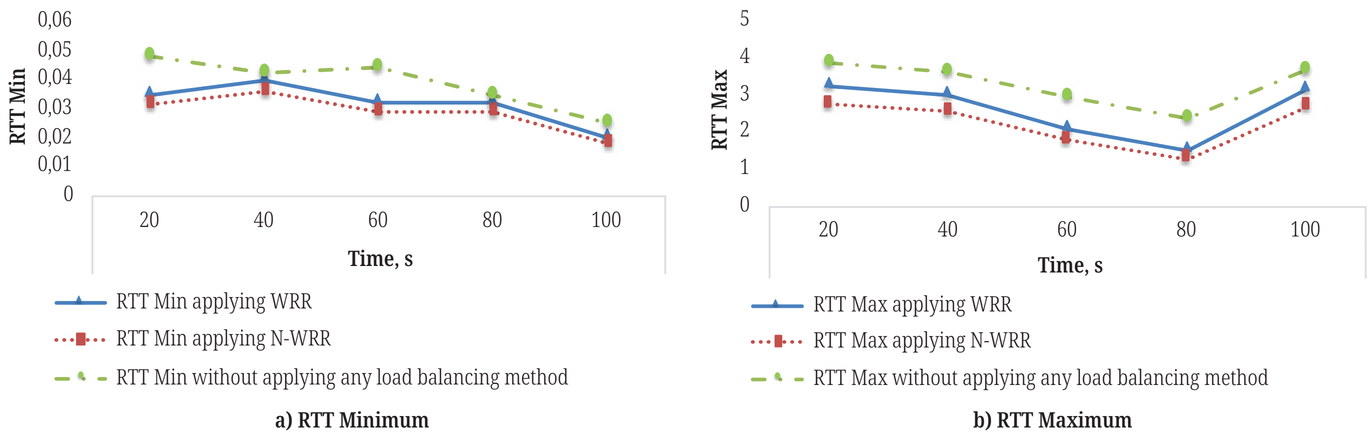

Fig. 7. Comparison of ping-time statistics between N-WRR, WRR, and without applying any load-balancing method

Figure 7 illustrates the RTT, which measures the duration for sending packets and receiving a response. The RTT Min is the shortest and minimum time it takes for a single ping. As shown in Figure 7(a), the RTT Min decreased by 10% and 35%, respectively, after applying the N-WRR compared to the WRR and without any load balancing method. While the RTT Max for a single ping is reduced by 15% and 40%, as shown in Figure 7(b).

Furthermore, throughput refers to the volume of IoT transaction requests that can be successfully transferred from the source to the destination within a network within a specific timeframe. As we know, RTT is a crucial factor affecting throughput in IoT networks; a low RTT results in higher throughput, as demonstrated in the findings presented in Figure 7. By employing the cluster structure with the N-WRR algorithm for CHs to handle IoT node requests, it contributed to reducing time overhead and processing. We conclude that our proposed algorithm can improve the throughput compared to the other two methods.

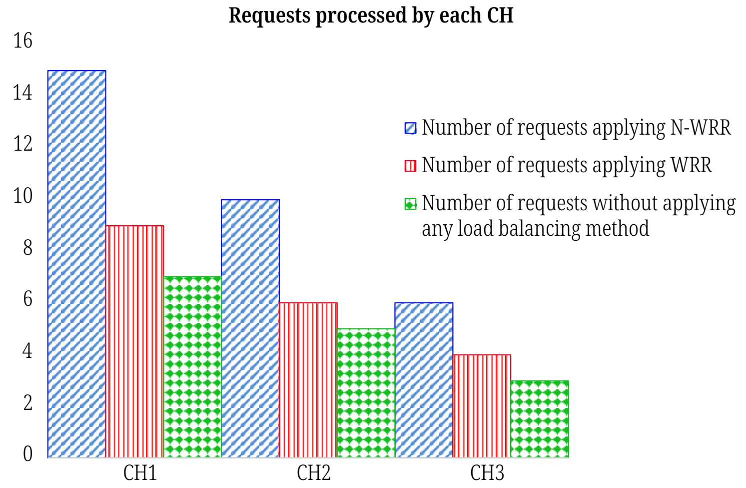

Fig. 8. Comparison of the number of requests processed for each CH using N-WRR, WRR, and without applying any load balancing method

The request processing latency in the proposed architecture is reduced by utilizing the SDN controller and implementing the N-WRR load-balancing algorithm. This results in processing more packets compared to the WRR method, as illustrated in Figure 8. This can be explained by the use of multiple queues and multiple CHs for processing in N-WRR.

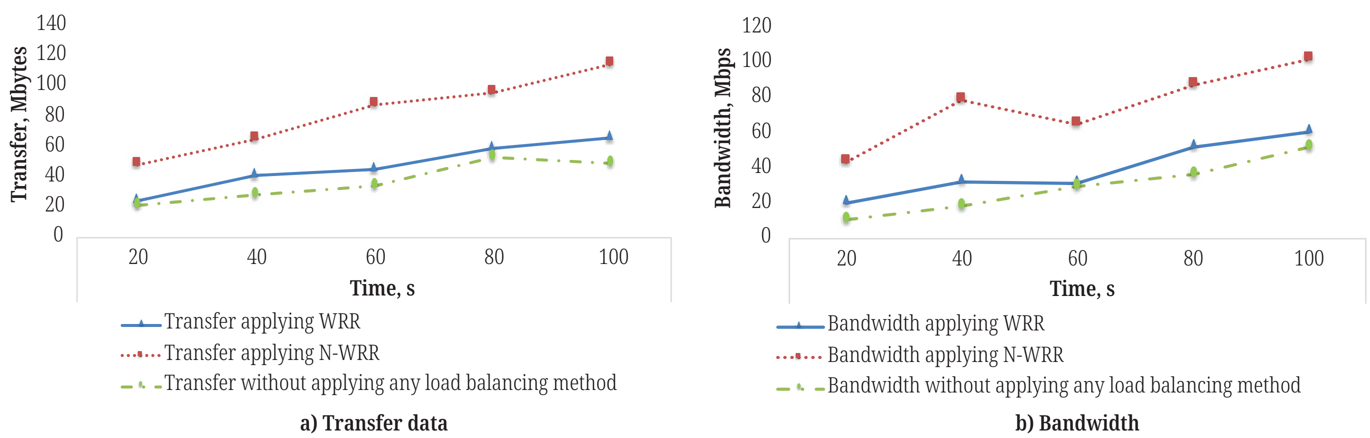

Fig. 9. Comparison transfer and bandwidth results applying N-WRR, WRR, and without applying any load-balancing method

Furthermore, to measure the bandwidth and data transfer of the network, we used the iperf tool. The results of the test are depicted in Figures 9a and 9b.

From Figure 9a, we observe that the average transferred data is doubled when applying our N-WRR compared to the other two methods. The same result is obtained for the bandwidth, as shown in Figure 9b.

5 CONCLUSIONS

In this paper, we propose a solution to ensure an efficient network and to address load-balancing challenges using various technologies such as SDN, clustering, and a new algorithm named N-WRR. The improved algorithm has been implemented in the SDN to perform load balancing in the data plane layer (infrastructure layer).

The simulation results indicate that implementing load balancing on SDN using our N-WRR algorithm approach is highly efficient compared to using the simple WRR approach on SDN or not applying any load balancing method at all.

This approach reduces the RTT, leading to higher throughput and increased data transfer and bandwidth. Furthermore, our N-WRR algorithm proposal increases the total number of processed requests.

Nevertheless, improving the mechanism for determining the weight assigned to each device to achieve an optimal result in processing requests remains the challenge of the N-WRR. Our future aim is to develop an automatic mechanism.

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