

# A Multi-Objective Routing Mechanism for Energy Management Optimization in SDN Multi-Control Architecture

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**ABSTRACT** This paper proposed and implemented an energy-aware routing multi-level and mapping problem (EARMLP) algorithm to minimize the overall power consumption in Software-Defined Networking (SDN)-based core networks. To enforce network utilization toward green policies design for Data Centers (DCs), SDN leverages protocol configurations for routing available in the infrastructure. Therefore, the proposed mechanism aimed to design an optimal routing strategy that considers system configuration and traffic demand between the data and control planes in networks. The problem is then addressed from the perspective of the policy-based EARMLP technique, which is used to carefully determine the optimal assignment between controllers and their switches to optimize network energy savings. Hence, a controller placement problem (CPP) is established to select the optimal locations and number of controllers in core networks and create an optimal mapping and resource allocation between switches and controllers. Since the formulated energy-aware routing algorithm is designed as a multi-objective NP-hardness of the problem, a heuristic approach is developed to find optimal solutions for traffic routing between inter-controllers and controller-switch in terms of energy-aware consumption strategies. Consequently, the proposed optimal routing mechanism can rearrange traffic to meet provisioning criteria by utilizing the capacity-aware design. Remarkably, the energy saved in networks by our suggested method can approach up to 70% of the energy saved in SDN-based networks compared to other methods.

**INDEX TERMS** Controller placement problem, dynamic routing, energy-aware, optimization, SDN.

## I. INTRODUCTION

Software-Defined Networking (SDN) paradigm separates control planes from data planes; it enables flexible and efficient network administration and traffic management [1]. Advanced communications technologies, such as Network Functions Virtualization (NFV), can enable Data Centers (DCs) to provide more innovative programmable energy management systems [2]. All functions and control traffic in

such a high-speed network are handled and executed by controllers and servers located in DCs [3]. The DCs of the wide-area network (WAN) located in various domains managed by multiple operators and service providers are composed of multiple network domains. Each DC has several network devices at various locations, such as SDN switches [4]. Therefore, in SDN, excessive DCs power consumption becomes an issue when the underlying network resources and connections in the network rise. It also becomes an issue when the number of nodes (switches and routers) are deployed inefficiently during excessive traffic volume, leading to high energy

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operating costs [5]. In this context, the SDN control and management layers employ routing protocol and signaling configurations available in the infrastructure to enforce and maximize network usage for green policies architecture [6]. The objective is to develop adequate techniques to reduce and conserve network energy without sacrificing performance.

Traditional routing algorithms, on the other hand, struggle to identify optimal flow pathways to decrease network power consumption [7]. They provide static routing options of flows but lack the flexibility to modify flow routes based on changing network conditions to meet the quality of service (QoS) requirements and balance link utilization [8]. In such circumstances, current research has relied on network energy strategies to achieve further energy savings solutions using an efficient flow routing technique [9], [10]. The power-aware traffic design should use fewer connections without overloaded links and prolonged flow delays. Moreover, the routing paths should be manipulated to provide multiple ways while maintaining network performance and reliability [11]. Furthermore, limiting the number of active components while accounting for control and data plane traffic is a simple and efficient technique to consolidate data network utilization and minimize power consumption [12], [13]. For instance, in over-provisioned networks, energy-aware routing approaches consolidate traffic through a group of connections and devices [14]. However, several approaches adopt an energy-aware routing technique, enabling various traffic aggregation algorithms to be used in backbone networks to decrease connection load [15], [16]. In addition, some energy-related network research relied on the deployment of efficient routing algorithms for connection monitoring and path assignment [17], [18]. Other studies have attempted to reduce the number of hops between switches and controllers, accounting only for the data plane on SDN [19], [20]. Moreover, the data plane connections should be routed through network controllers. Regardless of the relevance of resource allocation placement strategy in network efficiency, the impacts of energy cannot be overlooked [21]. Thus, we believe that there is still a potential need to quantify energy efficiency, resource utilization, and network load balancing, which are helpful in the energy-aware routing strategy.

Critical factors must be addressed to achieve high efficiency and energy savings in an SDN-based distributed controller network, multi-control architecture and optimum network performance. The quality of assigned paths, control loads, and the dynamic controller change in resource management, affect network load balancing across controllers in a rapidly expanding network density. However, several issues may arise if just hop count is evaluated in the assignment process, which does not account for link propagation delay. Propagation delay, for example, is an important factor in assignment computations in large-scale networks. On the one hand, transmitting a traffic flow across a shorter path decreases latency and increases network utilization, both of which reduce energy consumption [22]. Therefore, having optimal controller locations and numbers in the core network

help in best mapping correlation and pathways between controllers and switches and minimizing the number of required network devices, allowing for lower power usage [25]. An energy-aware routing (EAR) technique is developed in this study to implement an optimal traffic routing mechanism between network entities. The problem is addressed from policy-based multi-level mapping techniques to carefully determine the optimal assignment between controllers and their switches to optimize network energy savings [23], [24]. For this, a two-phase algorithm is adopted. The assignment and mapping problem can be modelled as a novel controller placement problem (CPP) in the first phase [25]. Then, the maximum power usage associated with directional links is included in the second phase. Therefore, the paper finds trade-offs between latency, cost, and resilience by examining i) energy consumption, ii) network link utilization, iii) path length, iv) controller locations. Accordingly, the following are the paper's significant contributions:

- A multi-objective energy-aware routing multi-level and mapping problem (EARMLP) is developed. This strategy uses a realistic dynamic traffic routing scheme and suitable resource allocations to tackle network energy conservation and reduce overall power consumption.
- The model employs a capacity and network topology awareness and traffic management technique for network flow to decrease overall energy use and overhead communication costs while meeting the constraints of control paths and controller load balancing.
- The proposed CPP Algorithm is used to perform controller positions and optimal mapping between network entities mechanisms in distributed-based SDN with multiple controllers, reducing the number of active links, hence conserving energy.

This paper aims to evaluate the different influencing variables that affect assignment, optimal mapping, and dynamic resource allocation in SDN, which results in energy savings. As a result, the algorithm performance was assessed in terms of many factors such as propagation delay, controller capacity, robustness, and optimum amount of criteria assignment. Therefore, in this study, the performance of an energy-aware approach was examined across multiple network topologies, evaluating the SDN-based network's energy consumption strategies for efficient resource utilization and green networking.

This paper is organized as follows: Section II provides a synopsis of the related works. Section III goes through the fundamentals of energy management strategies for our model design. Section IV introduces the system model, as well as the corresponding model flow and power description. Section V further covers the energy-aware problem formulation. Section VI presents the proposed solution to the energy-aware challenge. Section VII discusses the performance evaluation of the proposed model and the outcomes. Finally, the paper comes to an end with a conclusion.

## II. RELATED WORKS

The related works are divided into three categories: a) energy aware and routing methods, b) energy-aware and controller placement, c) energy aware and virtualization implementation. Following that, the works in each category are evaluated.

### A. ENERGY-AWARE AND ROUTING METHODS

In recent years, the idea of energy-efficient green networking has been a critical topic for the industry and the science sector for economic and environmental reasons [18], [26]. The most significant complementary direction of network energy-saving methods focused on entire network traffic engineering/analysis and routing optimization models with various constraints to lower power consumption [9], [17], [19], [27]. Furthermore, limiting the number of active components and traffic demand impacts network hardware energy consumption [13].

Accordingly, the study in [28] formulated a power-aware approach for SDN networks that combines dynamic routing and control plane configuration. This technique reduces the number of active nodes and connections required to dynamically handle changing traffic patterns within the network. Rather than limiting the capabilities of power-aware solutions to low-load circumstances, the research proposed power-aware method for minimizing power utilization while avoiding the reduction of higher priority traffic performance in the network.

Another work in [12] presented an energy-efficient routing traffic management algorithm that considered varying throughput demands of flows in different network topologies with defined connection capacities to minimize the number of hops. Despite its low complexity, the proposed routing method focuses on Integer Linear Problem (ILP) power-saving in SDN by examining only data plane traffic and demonstrating that data plane connections cannot be sent via controllers. In addition, when the shortest route is used, weights are assigned to links and nodes based on their states, as presented in [29]. To meet the variance conditions at a lower cost than any single path route, the proposed randomized Dijkstra-based Routing (RDBR) applied centralized routing control over random node placement. The Sub-gradient descent technique was used to determine the Lagrange multiplier after reformulating the problem as an unconstrained problem.

Traffic metrics in a network can lead to cost savings, but many other performance indicators are considered. For instance, if a link becomes overloaded and QoS cannot be maintained, a novel local routing modification method can be proposed to adjust network routers and connections before and after the overloaded path rather than the full path [17]. Routing configurations, on the other hand, are more constrained, making optimization challenges significantly more computationally complex. It is worth noting that both flow-based and shortest-path routing may use a single per-flow or several paths per destination, respectively.

In these instances, shortest-path routing allows the network administrator to adjust only a small number of link weights, one for each connection, which can be easily modified using modern management techniques. Additionally, reducing traffic flow time on controller load while preserving network stability and achieving QoS standards [30].

### B. ENERGY-AWARE AND CONTROLLER PLACEMENT

Multi controllers in the SDN control plane can provide better energy savings by distributing switches between controllers in the most energy-efficient fashion while taking load balancing across controllers into account. SDN can help to alleviate energy consumption by providing realistic routing algorithms and suitable allocations based on optimal controller placement and mapping sites [31]. Hence, several heuristic techniques based on variable measurements and near-optimal assurances have been proposed to tackle such difficulties in terms of multiple metrics and computing time.

Considering the optimum placement of controllers in the network topology, the study in [13] developed an ILP for the energy-aware approach that optimizes the number of active links shared by data and control plane traffic. The model simply takes into account links utilization and control path latency. Also, an energy-aware based on a binary integer program (BIP) was developed for CPP energy-aware utilizing a modified genetic algorithm to select locations for maximizing the network energy savings [32]. It considered both the propagation latency and the model load of controllers. However, these approaches required prior knowledge about network controllers, nodes, and applications.

Despite its fluctuation, traffic is often defined by a time-periodic profile, which allows network operators to plan ahead. As a result, network administrators must optimize network settings based on traffic projections or real-time traffic measurements. Moreover, it is essential to consider that the SDN network switches, links, and CPU cores consume considerable energy. Hence, the model in [33] outlined the technique for energy efficiency and the crucial aspects by spreading controller load over numerous CPU cores while reducing the frequency of operation. However, the algorithm was complicated, allowing for more sophisticated processes to be implemented but providing less flexibility in responding to unforeseen circumstances in SDN without traffic consideration.

Recall that an SDN-based EAR network often relies on specific structures to gather data and distribute configuration instructions, as well as robust controller placement that is dynamically managed to meet service requests and utilize network resources efficiently.

### C. ENERGY-AWARE AND VIRTUALIZATION DEPLOYMENT

Integrating virtualization into SDN is a viable approach for effectively managing available resources by leveraging centralized control to deliver scalable network operations [34]. To cope with such an issue, several key challenging trade-offs between different goals must be met, such as minimizing

**TABLE 1. The merits and drawbacks of recent works on energy-aware techniques in SDN networks.**

Ref.	Optimal placement	Model for optimal routing	Constraints	Weakness
[13]	No	Heuristic and (ILP) for routing in SDN	Links & delay of control paths & load balance	Single objective in the data plane utilization of links and the delay of control paths no control
[12]	No	ILP for minimizing the cost route and the number of active switches	Links capacity & number of hops	Single objective for low-loaded nighttime traffic active Flow switches
[28]	Yes	Heuristic and ILP routing for SDN to allocate traffic demands in real time	Active nodes & links	Used only in-band control traffic
[33]	Yes	ACPA to find number of controllers and optimal locations	Potential transmitted energy consumed by the controller	Ignored path and link utilization
[19]	No	Heuristic and ILP optimization for SDN Carrier-grade network	Link utilization & number of hop	Applied only for centralized control architecture
[29]	No	Randomized Dijkstra-based with Lagrangian Relaxation for resource utilization	Link & routing cost	Centralized control architecture and complexity
[37]	No	NLIP and modified based Dijkstra routing for SFC deployment	Active nodes & link states	Computation complexity
[32]	Yes	Heuristic and BIP for network control traffic	Propagation delay & load & links	Independent paths from switches to controllers
[15]	No	Heuristic and ILP for resource allocation and SFC placement	Power consumption of controllers & frequency of operation	Single objective function and less flexibility
[36]	No	Heuristic for SFC deployment in multi domain	Load balancing & resource allocation	Utilized only resource allocation

network latency, reducing the number of active nodes in the network, as well as cutting CPEX and OPEX costs. Additionally, pushing them into low-energy states is essential for decreasing network energy consumption [26].

Several proposals recently suggested multi-objective algorithms to address an energy-efficient multi-domain network service under integrated SDN and NFV deployment framework consideration [16], [35]. The proposed heuristic considered only resource allocation to maximize energy consumption and load balancing of multi-domain networks. Similarly, the work in [36] focused on reducing energy in a hybrid SDN/NFV by applying a mechanism to select a path based on modified Dijkstra to turn off the nodes.

Likewise, the research in [37] provided an energy-efficient and traffic-aware placement to reduce operational and network traffic costs. All network flow service chains must be controlled, and Virtual Network Functions on physical nodes with low network traffic costs must consider heterogeneous physical nodes and workload. Related work was presented in [38] for energy-saving models across multiple NFV placements. However, since the virtualization solution is limited to servers, particular challenges, such as resource partitioning and load migration issues, remain. Virtualization technology has a high migration cost since the location of service deployment significantly affects resource efficiency in terms of time and energy.

Although previous efforts have provided ongoing techniques for reducing network energy consumption, the system should consider the reference architecture, traffic demand and flows for every part involved in the traffic flow.

Table 1 lists the merits and drawbacks of the most recently published studies in different categories of CPP energy-aware techniques in SDN networks. To enhance energy efficiency in the SDN control plane, we use an innovative technique based

on optimum mapping between switches and controllers. In contrast, exchanges between data and control plane traffic can provide several energy-profile benefits, including scalable and reliable knowledge, energy conservation, and resilience. Rather than focusing on system energy, the emphasis is on optimization frameworks for distributed architecture, traffic demands, and the SDN network's energy consumption to test the efficiency of the proposed routing-aware approaches in the core network. Thus, the network can benefit from the trade-off between location and performance using our strategy.

### III. NETWORK ENERGY MANAGEMENT

Network energy management (NEM) is the task of determining the configuration and routing processes that could reduce a network's total power consumption while taking system configuration and traffic demand across network nodes into account [27]. Also, maintaining energy efficiency (EE) and resource allocation is critical, as it is one of the most important aspects of network design to alleviate environmental and economic constraints [35]. For example, sharing resources between servers, CPU memories, and storage can further resolve the energy efficiency problem in DCs [37].

When designing different configurations with power-aware network architecture to meet provisioning criteria, being mindful of resource usage can significantly increase power savings. Come with that, the service providers must strengthen their energy-saving policies in the DC, backbone network, and access network, which must be regarded as the most significant efficiency factor in their OPEX [39].

Again, SDN architecture appears to promote the energy-efficient implementation of green network policies since energy-aware solutions can be conveniently implemented in the SDN control plane [40]. Additionally, SDNs



are primarily responsible for communication and enabling the dynamic connection of devices at the physical layer. Using the network architecture depicted in Fig. 1, the programmable controller at each domain performs traffic management and regularly sets internal routing policies, such as resource allocation and energy demand, based on the entire network's knowledge [17]. However, the controller can improve the whole network power profile by specifying which devices to put into power-saving mode based on the QoS needs of data flows [41]. Otherwise, network devices route traffic follow the flow tables according to the present rules of the controller and deliver incoming packets [42]. Network traffic between the data and control planes must also be prepared and redirected through the backhaul network and the core, which frequently has the bandwidth, latency, capacity, resource, and cost-efficiency constraints [43].

Nevertheless, due to increased network activity and ongoing growth, distributed networks confront significant load balancing and energy conservation challenges. The most complicated feature of provisioning in multi-domain networks is the lack of global awareness about all domains [44]. Routing such traffic over a series of links contributes to certain connections being overloaded, affecting network infrastructure energy consumption. Such a sudden change in traffic due to unforeseen activity may result in network failure or capacity decrease, as well as data loss. Reducing energy-hungry resources in the core, such as large IP routers, can reduce overall network energy efficiency [2]. For instance, the master controllers on the management and orchestration layer, directly connected to the internet and transport traffic at the lowest layer, provide a more energy-efficient solution [13]. Many energy-centric advantages can be achieved by employing reliable information collection and QoS robustness methods while conserving network energy rather than server energy.

Implementing network redundancy policies allows the core network to manage service resources and scalability. The subset deployment of the conceptual model leads to extremely reliable networks with several redundant links and excessive bandwidth over-provisioning. However, these redundancies reduce energy efficiency when all network equipment is turned on at total capacity [45].

Although redundancies enhance network performance reliability, they also significantly increase network capacity by decreasing active elements. These are contradictory since reducing the number of active nodes in a cost-effective network increases aggregation traffic on physical connections and nodes, resulting in network latency failures. On the other hand, Link aggregation is important because it enables simple link capability improvements by implementing new controller rules [46].

#### IV. THE SYSTEM MODEL

This section develops a heuristic energy-aware routing (EARMPL) algorithm to determine the optimum routing and resource sharing in the core network while conserving

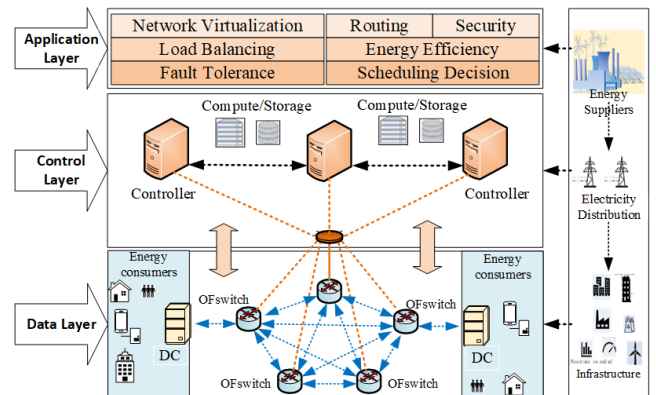


FIGURE 1. The SDN architectural framework under consideration for energy management design.

energy. The developed energy-aware solution is transferred to a multi-level placement problem (MLP) for the network's energy function cost. Since the energy-aware routing (EAR) problem is known to be NP-Hard [47], it is difficult to get rapid solutions for such large-scale topology situations because resource utilization and time complexity increase exponentially with network size. Hence, a heuristic is extensively designed to give near-optimal solutions to the SDN mentioned above power consumption problem [26]. Such heuristics for the network allow competing decision-makers to find a trade-off between objectives and solving time to deliver suitable solutions promptly. Thus, no single objective is available to assist the decision-maker in finding an approximate set of non-dominated solutions from this set. Also, no decision has to be taken before invoking the optimization by defining some constraints or weighted objective functions [48]. On the contrary, providing a feasible solution is assessed by all objectives, which take the decision afterward.

Furthermore, in the case of a set of solutions for a given combination of objectives, the only need is a function that translates components of the search space to their performance with a certain objective [49]. Therefore, the CPP can be handled efficiently by employing heuristics from the domain of multi-objective combinatorial optimization [20], [50]. The dynamic controller resource is positioned using a local network distributed mechanism to limit the number of active nodes and links while achieving QoS criteria and reducing energy consumption. Hence, finding placement performance is evaluated as an adequate trade-off for different competing objective measures and conditions crucial for an efficient operation such as position, number of switch-controller latency, and load balancing.

The subject of decision analysis is a subset of multi-criterion decision making and choosing among them is the primary focus of multi-objective optimization and multi-criterion decision making. In most instances, the position and number of SDN controllers necessary to provide a reliable and resilient network operation in advance [51]. However, optimizing server positioning and routing simultaneously can result in some incompatibility. Since lower placement costs mean fewer servers are installed, higher routing costs can

TABLE 2. The primary notations used in the model.

Notation	Description
$E$	Set of weighted edge and link
$N$	Network nodes
$i, j$	Indices set of switches and controllers, receptively
$K$	Integer represents the number of controllers
$\lambda_{ij}$	Traffic flow between $i$ and $j$
$\zeta_E$	Link capacity
$\zeta_C$	Controller capacity (kbps)
$f_r(d_i)$	Flow requested by data plane
$f_C(d_j)$	Flow traffic of control plane
$f_{ij}(G_{NF})$	Overall network flow
$f_{ij}(d)$	Amount of traffic flow between $i$ and $j$
$L_j(C)$	Controller load
$U_j$	Controller utilization
$P_{ij}^C$	Controller power utilization
$e_{ij}$	Decision for the link status
$x_{C,S}$	Decision to indicate the node state is forming ON/OFF
$Z_{jr}$	Decision for the selection of the next controller
$\rho_{e,f}$	Decision for path selection between $i$ and $j$
$r_{r,f}$	Path selection decision to route traffic to the next domain
$D_{ij}$	Distance between $i$ and $j$

result in some traffic routing through a longer path to accomplish network functions. On the other hand, lowering routing costs requires more servers, which raises placement costs. Furthermore, a computationally fast approach for energy consumption must be constrained in order to ensure low latency and high availability of server positions, resulting in increased network quality.

**A. NETWORK MODEL DESCRIPTION**

The network is given as a graph  $G = [E, N]$ ,  $N$  representing a set of all switches  $S$  and controllers  $C$  in a network, where  $(S, C) \in N$ . Table 2 shows the notations used in our model. Let  $E$  be a set of weighted links for requested traffic demands and paths among connected nodes  $N$ , where  $(i, j) \in E$ . Let  $f_{ij}(d) = \sum_{i,j \in N} \lambda_{ij}$  represents the total traffic flow between any two nodes. Each  $e_{ij} \subseteq E$  defines a set of active links or edges. Each controller has a capacity of  $\zeta_C$  representing the default processing capacity at the ideal state, and each link has a capacity of  $\zeta_E$ . The linear model also uses the following binary decision variables. An edge  $e_{ij} = \{0, 1\}$  for  $e_{ij} \in E$  is a selection restricts it restricts the links state if it can be turned OFF or ON. Each link consists of a set of paths  $p_{ef} \in e_{ij}$  that decide whether the path is chosen as a control path or a set of paths that can be used to route demands. Further,  $x_{S,C}^U \in \{0, 1\}$  this decision indicates that the node state is forming. In addition,  $r_{e,f} = \{0, 1\}$ ,  $r_{e,f} \in e_{ij}$  represents the selection of traffic demand and the collection of control path subset for routing traffic to the next domain; otherwise, it is equal to 0.

**B. THE NETWORK FLOW ROUTING SCENARIOS**

The energy-aware approach focuses on using a multi/shortest possible routing to every request that minimizes the number of controllers, the number of active connections, and the overall power consumption cost of the least possible active links [52].

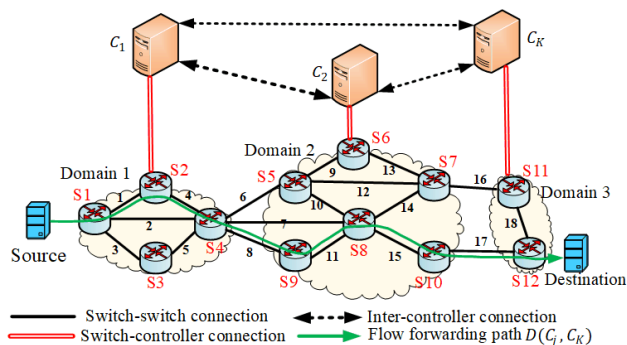


FIGURE 2. A minimum flow route from source to destination across multiple domains.

In this work, we only mention the energy consumption generated by the controller nodes and links. The controllers (servers/routers) located in service regions have varying resource capacities, such as memory, computation, and storage resources requirements consume up a lot of server power. Also, the optimum number of switches that a controller handle should represent the controller load. Thus, the best mapping ensures the effective distribution of servers over a range of optimal sites, with a given set of demands and link capacities to achieve load balancing and reduce overall power consumption.

Figure 2 shows a flow path from the source to the destination under the most utilized path. Typically, the SDN network is composed of three SDN domains. Each domain is managed by a centralized domain controller that controls all underlying network switches and forwarding devices. We assume the routing path follows the most minimum flow route with more active nodes based on the energy-efficient approach. Active connections reduce complexity by utilizing, for example,  $S1 \rightarrow S2 \rightarrow S4 \rightarrow S9 \rightarrow S8 \rightarrow S10 \rightarrow S12$  with a more significant number of sleep modes to decrease energy usage.

The model also assumes three states: firstly, the control paths between switches and their corresponding controllers can exchange network traffic demands and control messages in-band and out-of-band. Secondly, the router in the network is assumed to be a potential controller placement. Thirdly, there are limited controllers in the structure, and all routers on the network can be rerouted. There are numerous options for the routing algorithm metric. It may be budget aspects (e.g., the expense of running devices and maintenance) or a network efficiency issue (e.g., propagation delay, consumer QoS demand).

The minimum route selection and network controller's placement determine if multiple flows share the same routers, switches, and servers. If this is the case, the optimum resource distribution approach should be devised to accomplish fair resource utilization under the limits of available resources. Henceforth, load balancing and path utilization load are essential aspects that must be investigated to satisfy traffic demands and boost QoS [53].

The efficiency has also been measured from different perspectives, including total network power consumption and

the best controller position for the network flow to minimize overhead and energy costs when satisfying those constraints.

### C. DESIGN CONSIDERATION

Demand is defined by a set of flow requests, each of which is specified by a source. In addition,  $f_{ij}(G_{NF})$  represents the set of total traffic demands between any two devices and their respective destinations. Suppose the total network flow is composed of control flow  $f_c(d_j) \in C$  and data flow  $f_r(d_i) \in S$  that is given by  $f_c(d_j) \cup f_r(d_i) = f_{ij}(G_{NF})$ . Thus, the entire demands that must be routed between network nodes and their controllers is denoted by:

$$f_{ij}(G_{NF}) = \sum_{j \in C} \sum_{e \in E} f_c(d_j) + \sum_{i, j \in N} f_r(d_i). \quad (1)$$

In general, the flow cost is the fraction of flow that must not exceed the bandwidth of the link. When the flow is routing over a network segment, the link capacity may be a constant (possibly given for each link) or a cost function during network provisioning. Besides, control messages are shared using the same links as data traffic, with no additional edges. Thus, an appropriate routing decision can be made well based on sufficient information collection based on optimal control location and resource sharing. The energy-aware routing output can be evaluated in this manner. Following the hop, reduction decreases the expense of group relationships while increasing each group balance and reducing the latency of shorter connections. The network must be in optimum mapping to maximize energy usage while satisfying the traffic demands of all network interfaces related to network traffic and routing policies. Since EAR alternates between multiple paths from a source to a destination to minimize energy consumption, the cost of the route from the source to the destination is provided by the minimum flow route with the most active nodes:

$$\text{Minimize } P_{load}^{rout} = \sum_{e \in E} C_{e_{ij}^{C,S}}^U e_{ij} \quad (2)$$

Under the following constraints:

$$\sum_{C \in K} U_j^C = K. \quad (3)$$

Constraint (3) is the controller availability constraint, which ensures that the number of domains is limited to K.

$$\sum_{C \in N} \chi_{ij}^{C,S} = 1 \quad \forall S \in N. \quad (4)$$

Constraint (4) is the mapping constraint that requires the switch or VM to be assigned or located to only one controller as in

$$U_j^C \leq \sum_{C, S \in N} \chi_{ij}^{C,S}, \quad (5)$$

This constraint (5) indicates the relationship between the routing variables of the node state and the controller availability.

$$\rho_{e,f} \leq \chi_{ij}^{C,S} \quad \forall e_{ij} \in f_{ij}(d), C \in C_U^K, \quad (6)$$

Constraint (6) verifies that the communication routes between controllers and switches do not contain controllers that are not the traffic source or destination.

$$\sum_{e_{ij} \in E} \rho_{e,f} = 1 \quad \forall e_{ij} \in f_{ij}(G_{NF}), \quad (7)$$

Constraints (7) ensure that only one path  $\rho_{e,f} \in e_{ij}$  is selected to route intra-domain traffic flow  $f_{ij}(d) \in f_{ij}(G_{NF})$  between the data and control planes. Also, its need to ensure that this the paths selection is also the shortest path, given by the constraint (8):

$$\sum_{C \in N} \sum_{C \in K} \rho_{e,f} = 1 \quad \forall i, j \in f_{ij}(d), \quad (8)$$

$$\rho_{e,f} = 0, \quad (9)$$

Constraint (9) shows that a node can only be turned off after all active links have been turned off. The previous set of constraints ensures a subset of controller communications. So, each switch exclusively communicates with its controller in order to avoid rerouting extra traffic. Therefore:

$$\sum_{C, S \in N} \rho_{e,f} f_{ij}(G_{NF}) \leq \zeta_E e_{ij} \quad \forall i, j \in E \quad (10)$$

Constraint (10) is the link availability constraints, ensuring that the sum of all traffic demands of flows along each active link cannot exceed its bandwidth or link capacity. Based on the distributed network topology, the traffic rate capacity is the aggregation capacity of traffic flowing through all paths between network nodes.

$$\sum_{C, S \in N} f_{ij}(d) - \sum_{C, S \in N} f_{ji}(d) = \begin{cases} \lambda_{ij} & \text{if } C = S \\ -\lambda_{ij} & \text{if } C \neq S \\ 0 & \text{if otherwise} \end{cases} \quad (11)$$

Constraint (11) is a flow consistency constraint that states a flow restriction occurs when a traffic flow is generated at its source and then sent to be absorbed in its destination ( $\sum_{d \in D_{traffic}} f_{ij}(d) \in f_{ij}(G_{NF}) \leq 0$ ).

The total traffic entering controllers and the flows originating from requesting demand from switches or network devices are identified as traffic throughput. The energy used by the interconnections between network nodes and controllers is proportional to their load. The total capacity of the virtual nodes or in a physical device or links also identifies the power threshold level for the network, which is less or equal to this physical node or links. For instance, when a controller is installed in a multi-domain network, the server selection should be rendered with the least additional energy usage expense for each traffic implementation. If the selected server cumulative energy costs exceed the given threshold value, the deployment is re-selected to another appropriate server.

The controller then computes a route and the corresponding rules to install on nodes for each demand set in the routing table. All requests are assigned and become overloaded; the energy-saving module is enabled. Moreover, if the link is disabled, no flows can be forwarded, ensuring that each

active link's total traffic  $e_{ij} \in E$  is less than the maximum established link utilization. The flow is then transferred to the next controller via a boundary node. Therefore, constraint (12) describes the state of the connection, which ensures that only one boundary node is selected with each inter-domain data traffic demand. Constraint (13) and (14) guarantees that only one path is used to reroute all multi-hop data traffic demand to the next node of choice.

$$\sum_{C \in C_K} Z_{jr} = 1 \quad f_{ij}(d) \in f_{ij}(G_{NF}) \quad (12)$$

$$\sum_{C \in C_K} r_{e,f} = Z_{jr} \quad f_r(d_i) \in f_{ij}(d) \quad (13)$$

$$D_{ij} = \sum_{\rho_{e,f} \in E} e_{ij}. \quad (14)$$

These selected paths must respect the time limit and inter-controller delay by constraint (15) and delays between domain controllers by constraint (16).

$$\sum_{i,j \in N} \sum_{C \in C_K} T_{Average(i,j)r_{e,f}} \leq \tau_{threshold} \quad \forall C, S \in N \quad (15)$$

$$D(C_j, C_K) = \sum_{i,j \in N} \sum_{C \in C_K} D(i, j) U_j^C U_j^{C_K} \quad (16)$$

The delay  $Dl = \sum_{i,j \in N} D(i, j) f_{ij}(d)$  is the transportation latency of flows over a link. It is calculated by considering the propagation performance of all network consumer flows.

After completing this estimation, distributed controllers in various SDN domains typically exchange specific output parameters and identify the chosen next controller ( $U_j^{C_K}$ ) or next switch assignment  $Z_{jr}$  to route each inter-domain traffic request. This shared information mainly establishes reference criteria for determining the domain with the best performance and the lowest risk of failure. More network knowledge measurements should be gathered to learn about the network status.

## V. THE ENERGY-AWARE PROBLEM FORMULATION

This section adds the maximum power usage associated with directional links. However, the location and number of controllers in a network affect energy savings. The maximum number of controllers can create a combined link connecting two network entities. Since the connection comprises a set of switches, the total power used for traffic transmission on the route is increased by increasing the number of nodes linked to the available controller. Furthermore, the energy consumption of the switches is often determined by the average processing time for processed traffic in the queue buffer of the switches.

Suppose the path or switch processing activities power  $P_{ij}^N$  is often referred to as the maximum power involved with a functional link. It also refers to the path processing activities' power given by  $(\rho_{e,f} \times P_{load}^C - K \times P_C)$ , at the traffic demand defined by  $D_{traffic}$ ,  $P_C$ ,  $P_{ij}$ ,  $K$ . Let  $P_{load}^C$  allow for the establishment of a new option for configuring the controller

operating mode when keeping the effect of the switch operation in mind. Let  $P_{ij}^C$  is the sum of controller power necessary to send a flow between a source and a destination. Thus, the additional energy expended by the route ( $\rho_{e,f}$ ) when it is fully loaded, of the association, is given by:

$$P_{ij}(C) = \begin{cases} \Phi P_{ij}^N & \text{if } 0 < \rho_{e,f} \leq 1 \\ P_{ij}^C & \text{if } \rho_{e,f} = 0 \end{cases} \quad (17)$$

The model objective function is to maintain an optimum routing in the network for all the flows and compute and assign a path for each demand. This is particularly true when each node is active and each connection has the highest active controllers. As a consequence, the overall power consumption at full load specified along the network's route between source and destination is:

$$P_{Max}^{rout} = \phi(P_{ij}^C + P_{load}^{rout}). \quad (18)$$

The overall network power consumption combines two parts: the amount of constant power consumed by multiple network equipment such as the server or DC. The second term is dynamic power consumed by the entire network interfaces relevant to network traffic and routing policies.

In a practical situation, the constant is referred to as a cost coefficient including all bandwidth and storage resources provisioned by a system  $\phi = BW/L$  when  $\phi = 1$ ,  $P_{ij}^C = 0$  respectively. However, this paper focuses on dynamic power consumed by routes only on the number of effective links. Since all power systems at full load (in ideal and active operation) under the flow conservation constraints must be minimized, the optimization problem and objective function are defined as follows:

$$\text{Minimize } P_{Max}^{NW} \quad (19)$$

Subjected to constraint (3) to constraint (16) and also:

$$L_j(C) \leq \zeta_C. \quad (20)$$

Constraint (20) ensures that any controller total allocated computing resources cannot exceed the controller capacity. In addition, the total requested traffic demand for all links has to be less than the physical path capacity:

$$\sum_{j \in C} \sum_{i \in S} \lambda_{ij} f_r(d_i) \leq f_C(d_j) x_{C,S}^U \quad (21)$$

This constraint extends the node and connection capability to the traffic matrix initiated between the source and destination, including power off nodes and links, it yields

$$\sum_{i \in N} \chi_{ij}^{C,S} \leq \sum_{C,S \in N} \phi x_{C,S}^U \quad \forall P_{ij} = 0 \quad (22)$$

This last constraint (22) implies that a node should only be turned off when all event connections are turned off. It also determines if the node demand is within the network threshold of:

$$0 \leq \frac{f_{ij}(G_{NF})}{\zeta_C} \leq 1 \quad (23)$$



Constraint (23) ensures the utilization limit of each physical machine. Our computation emphasizes turning off connections and nodes despite considering that the EAR model involves turning off connections. The overall network energy-aware function helps the connections and nodes switch off to decrease energy consumption.

The calculation of network overall power consumption considers the link load as well as the physical and virtual component capacities. Further, optimally rerouting traffic and removing unused capital by putting them in low-energy states allows for significant energy savings. Consequently, the network load balancing and reliability state are attained

## VI. THE PROPOSED SOLUTION FOR ENERGY-AWARE PROBLEM

This section provides an approximation of our proposed EARMPL solution. Since the formulated problem is a multi-objective optimization, it divided into three sub-problems and solved simultaneously. First, a heuristic CPP policy approach is to reallocate the resources for the energy-aware routing algorithm subproblem, and user flow resource sharing sub-problems.

Also, the modified version is simple to implement by changing the classical  $K$  equal-shortest-path selection technique in route subproblem selection. The path length is calculated based on the number of hops between a source and edge switch pair [22]. Addressing the power awareness architecture and routing challenges within the constraints imposed by the implementation frameworks is a critical concern. The methodology seeks the best routes among network components while limiting the number of active links to save energy consumption. To start, the algorithm defines and evaluates all network connections and assignments based on Algorithm 1.

Hence, the shortest path routes and the weights of the connections can be adjusted proportionally to their physical distances and set inversely to their links ability taking demand into account. Similarly, the energy solution uses limited network links to aggregate traffic.

Toward this goal, the first stage generates an initial set of routes. The second stage obtains the optimum controller positioning based on the assignment and neighboring characterized by  $U_j^C$ ,  $\chi_{ij}^{C,S}$  and  $E$ . The controller and switch associations are stored in the traffic load matrix created by the agreeing capacity-based CPP strategy [24]. Our proposed algorithm performs the initialization step prior to processing the results to avoid looking for physical network paths when the clustering algorithm runs. Therefore, a connected graph is randomly generated with equal weight nodes and links. It is worth noting that the connection between two controllers is not pruned if one is another controller. The task is to find a control route between each forwarding device and the corresponding domain controller that has previously been saved in the traffic matrix.

As previously mentioned, the switches requested the controller use the original control plane set up as new traffic flow entries, information, and fault notifications. As a result,

### Algorithm 1 Energy-Aware Routing Multi-Level and Mapping

---

```

Input  $G, K, C_K \in U_j^K$ 
1 : Initialization
2 : Do the assignment based on CPP
3 : Instruct the traffic matrix
4 : For  $C, S \in N$  do
5 : Calculate the cost metric for all  $i, j \in E$ 
6 : Route initialization
7 :  $RouteSelection \leftarrow AllPossible\_Routes(i, j, K)$ 
8 :  $U_\rho$  subset of routes  $\forall \rho_{e,f} \in E_{ij}$  from  $s$  to every controller  $K \in C_K$ 
9 :  $Cost\_index$ 
10 : For  $e_{ij} \in AllPossibleRoute$ 
11 :  $\rho_{e,f} \leftarrow ShortestPath$  Select the path
12 : Update  $U_\rho$  do
13 :  $Cost\_inter\_controller$ 
14 : end
15 : For all path  $\rho_{e,f} \in E$   $AllPossible\_Routes$  do
16 : For all links  $e_{ij} \in E$  do
17 : Delete links and nodes that do not satisfy maximum utilization
18 :  $Exclude\_routes$ 
19 : For 1: the size of  $AllPossible\_Routes$ , do
20 : For controller_inter_capacity do
21 : If  $\zeta_C \geq U_\rho$  Max utilization
22 : Else if
23 : end for
24 : Do shortest_path_Selection
25 : If  $x_{C,S}^U \leq 1$ 
26 : Re_routing
27 : Select the node to perform routing of  $f_r(d)$  via  $\rho_{e,f}$ 
28 : For each iteration update link state
29 : For each iteration  $update\_link\_state$ 
30 : end for
31 : end if
Output Total active routs, hops, energy-saving (%)

```

---

there is an initial collection of active connections and any connection utilization before traffic flows enter the network. The method then defines a neighbor for the route chosen based on node degree order. As a result, describing how many constraints were applied can identify and decide the best switch controller associations for energy consumption and load balancing. Precisely, all network connections are mapped with the same metric, which equals the cumulative number of demands. The service region is configured so that the network components in each group are well balanced to reduce the costs across groups. This segmentation strategy ensures that the fewest resources are used, hence, lowering the overall power demand of the physical network.

In the second step of the algorithm, the set of allowable paths and routes between nodes that fulfill the control and data plane communication constraints should be identified. Any path  $\forall \rho_{e,f} \in E$  is represented by the following parameters:  $\{i, j, \zeta_E, L_{BW}, D_{ij}\}$ . In addition, the algorithm prioritizes connections of larger capacity over those of lower capacity to identify a minimum cost at a minimal number of hops. However, the selected routes (in lines 7, 8 and 9) often have the lowest cost and sufficient bandwidth to handle the control flow and adequate capacity for the specified demands to be the best/primary path for transmitting traffic. Also, the number of links is specified as active network links that must meet the required constraints for control and data plane interactions to achieve the energy-saving objective.

The route selection methodology is defined in Algorithm 2. The key is to carry out the energy-aware saving mechanism to decrease active network links and remove residual bandwidth connections that are less than the requested requirement. Our measurements identify the most minor loaded facilities (high utilization) and links as the optimum acceptable flow path between two nodes when several flow routes are available. In particular, Algorithm 2 filters out nodes and excludes connections that do not have sufficient resources to associate with each other during the next allocation step. Nodes and controllers that were not included, as specified by constraints (20) and (21), were put into a state known as sleep mode.

The shortest path routing in Algorithm 3 is a modified version based on the Dijkstra algorithm [54], which identifies the best route from one node to another in a network [11], [29], [36]. It is designed to execute in the shortest amount of time feasible without jeopardizing the quality of the result. We use our method to find a near-optimal solution with the least computational complexity since the execution time directly impacts the response time to the SDN controllers for network requirements. Based on the dynamic connection costs calculated in Step 1, the technique is then used to find the shortest or lowest-cost route (or the link costs achieved once during topology discovery). The utilized bandwidth of the route  $\zeta_E = f_{ij}(G_{NF}) - U_{\rho_{e,f}}$  serves as the evaluation parameter. Thus, the shortest route uses the least amount of power via nodes and connections. As a result, multi-path routing reduces the end-to-end latency of traffic from any network service.

The feasible disjoint paths for routing solutions must guarantee reliability and fault tolerance. Also, network design's highest permissible latency constraints limit any arbitrary network service and control traffic on these links. However, the control traffic does not pass through any other controller in the switch-controller pair, not the source or destination. When a node is disconnected from its controller, the controller sends an additional control message to the next controller informing it of the flow forwarding rule that must be implemented in one of the nodes under its control. The SDN controller regularly collects information about available network infrastructure and performs a route scan for each control flow in the network.

The controller also monitors data flows in decreasing order and then allocates capacity beginning with the data flow with the maximum capacity requirement. Creating such paths seeks to consolidate route selection and prevent the proposed heuristic efficiency from degrading and overcoming delay constraints. Accordingly, the reduced space search iteration is determined by the network topology of the energy-aware optimal controller location. The routing algorithm is accomplished when our modified shortest route method reaches the target node.

Although this model can optimize power consumption strategies in an SDN-based network, due to the NP-nature of the energy-aware routing challenge, the number of resources used and the time complexity increase exponentially as the network expands. Since Dijkstra runs with a complexity of  $O(E + N \log N)$  [36]. The complexity of the process for K-shortest path algorithm of the order is represented by  $O(eN(E + N \log N))$ , where  $N$  is the number of nodes in the network,  $E$  is the number of edges, and  $e$  is the size of the initial set of paths.

The input sizes may vary when determining an algorithm execution time. Thus, the worst-case time complexity is typically considered the most prolonged time the algorithm takes for a given size. Accordingly, in Algorithm 1, we search among potential  $N$  nodes and assess their influence on the other nodes using the assignment.

---

#### Algorithm 2 Routing Selection Algorithm

---

```

Input       $e_{ij}, x_{S,C}^U, \rho_{e,f}$ 
1 :          Initiate Weighted  $G$ 
2 :          For  $i = 1 : Node\_Target$  do
3 :              Source: Active_controller
4 :              Target: Active_controller
5 :               $tmp\_requested$  data,  $AllPossible\_Routes$ 
6 :          For  $j = 1 : size\_tmp\_rout$  do
7 :               $tmp\_rout = tmp\_rout(tmp\_rout > 0)$ 
8 :              Total_active_Routs,          Con-
              troller_capacity
9 :          For  $K = 1 : size\_tmp\_rout$  do
10 :             Check path capacity  $\zeta_E = f_{ij}(G_{NF}) -$ 
               $U_{\rho_{e,f}}$ 
11 :             If controller_capacity( $tmp\_source, target$ )-
              requested_data
12 :                 Update the rout
13 :             End if
14 :         End for
14 :     End for
Output     Total_active_Routs, Controllers_capacity

```

---

The developed EAR method based on the capacitated CPP algorithm achieves the optimal  $K$ -center controller placement [55]. Hence, the computational complexity can be calculated as  $O(NKt)$ , where ( $t$ ) is the number of iterations and refers to the number of placed controllers and assigning a switch to set the path. For controller-switch mapping

**Algorithm 3** Shortest Path Routing Selection

---

```

Input       $G = [N, E], f_r(d_i), K, \zeta_C, \zeta_E$ 
1 :      Calculate the cost to neighbor on weighted
          $G$ 
2 :      for  $1:N$  do
3 :          Find the minimum cost paths  $\rho_{e,f}$ 
4 :          for  $i : N_{NE}$  do
5 :              if Distance  $> \rho_{e,f}$ 
6 :                   $\{i, j\} = 1$  there is a link and path
                    exist
7 :                       $min_{ij} = \{\zeta_E\} \geq \sim f_{ij}(G_{NF})$ 
8 :                      else  $\{i, j\} = 0$ 
9 :                      end for
10 :         for active node
11 :             compute  $PreviousHop(i) = i;$ 
                     $NextHop(i) = i;$ 
12 :         end
13 :         Compute cost metric  $C(e_{ij})$  for all edges
                     $i, j \in E$ , path, cost
14 :         If  $i: length(path) = 0$ 
15 :             Store shortest distance  $\leftarrow tmp[distance]$ 
16 :             begins with the node that is closest to the
                    source
17 :              $[t, u] = min(tmp);$ 
18 :             for each neighbor do
19 :                 if ( $CostMatrix\ i, j + D_j < D_i$ )
20 :                      $distance(destination) = distance(source)$ 
                     $+ CostMatrix(source, destination);$ 
21 :                 Update the shortest distance when a
                    shorter path is found;
22 :             end for

```

---

subproblem, the complexity is  $O(N \log N)$ . Based on the number of nodes, links, and the shortest routing, the number of connections, and the physical network's paths adjacency matrix, scanning and listing all forms of paths can take time. Therefore, the total algorithm complexity  $O(N(E + N \log N))$ .

## VII. PERFORMANCE MODEL EVALUATION

This section conducts the simulation setup to evaluate the proposed algorithm and the results. Model simulations are run to monitor network operations with varying controllers via link cost, energy efficiency, link utilization, and path evaluation value. All simulations for the proposed algorithms were performed using MATLAB runs on a machine with an Intel Core i7 /GN 10 processor and 16 GB of RAM.

### A. MODEL SIMULATION

In the simulation, we considered the network traffic and flow generation following the structure for predefined optimum location and number of controllers achieved by our previous algorithm in [55]. We randomly generate the topologies that are similar to real-world networks selected from Zoo topology [47]. These networks are often used in the literature

to evaluate alternative controller placement techniques [32], [51]. To keep our simulation simple, we concentrate on a set of sized networks, selecting three topologies with varied sizes and configurations in order to compute all feasible routes and evaluate their power consumption.

It is known that the tested networks have different energy levels to which the switch-to-controllers apply varying control loads generated at random intervals ranging from 20 Mbps to 100 Mbps. The processing capacity of the controller is set to 7800 k packets/s as adapted from [47]. Each OpenFlow switch linked to servers is considered to have a capacity of 1 Gbps through all links.

The performance of our method is compared to the other two EAR techniques using shortest path routing algorithms: a) *Method 1*, which is the original shortest path algorithm for distance-based energy-aware routing algorithm (DBEAR) following the standard Dijkstra algorithm [54], and b) *Method 2* is constraint distance-based EAR (C\_DBEAR) with a capacity constraint [32]. The classical shortest-path selection method is often used to calculate the route length and the hops count between a source and destination edge switch pair. However, when computing the path for data flows between the source and destination nodes based on distance, this conventional method does not account for changes in link-state information. The route is established node by node using the unconstrained algorithm, which starts with the source node. At each step, it attaches a node to the route, which is the next node on the unconstrained shortest path from source to destination, assuming the starting node of the partly constructed path.

On the other hand, in method 2, the constraint shortest path picks the next active node with the shortest distance and appends the link to the route. Although the two approaches are simple and have polynomial complexity, there is no assurance that the created route can offer optimum solutions. As previously stated, our proposed model-based Dijkstra algorithm considers the weighted distance to the next hop device rather than the Euclidean distance. It considers the link cost values of assigned devices. It takes into account all aspects of data transmission, including reliability, routing, and resource utilization. However, none of the previous methods considered similar metrics and constraints.

### B. ANALYSIS AND RESULTS DISCUSSION

#### 1) ASSIGNMENT COST AND DELAY

To evaluate the effectiveness of our algorithm efficiency, the analysis considers two distinct aspects of the network: topology and load. In particular, the energy-aware routing process aims to compute routes for the specified demands and minimize the flow routing process between the number of active nodes in the network to increase utilization and reduce costs. This implies that the active connections that remain are more loaded.

The average routing cost in the network is estimated by means of the number of all path utilization for corresponding

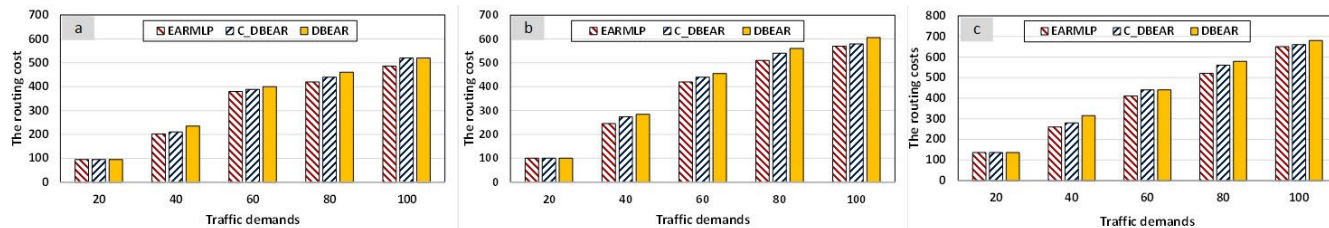


FIGURE 3. All path costs of the three algorithms for: a) the small network (25 nodes), b) the medium network (54 nodes) and c) the large network (100 nodes).

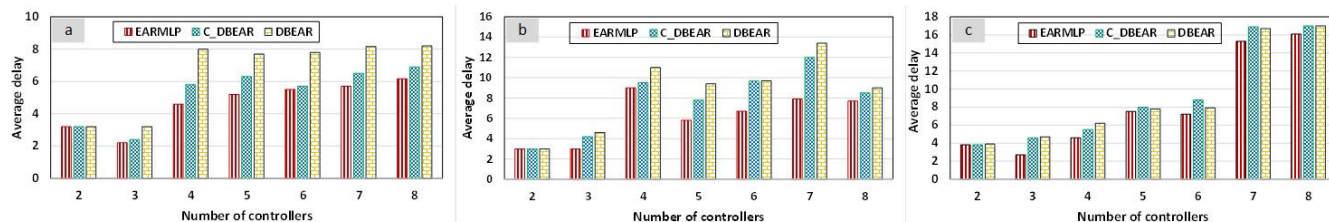


FIGURE 4. The average end-to-end network delay over the number of controllers for: a) the small-scale network (25 nodes), b) the medium-scale network (54 nodes) and c) the large-scale network (100 nodes).

traffic requests in link usage. The shortest route between the current node and the controller with the lowest power performance is returned, along with the network’s connection rate allocation. A performance comparison was made for the average cost of energy usage for three categories of networks ranging from small size network (25 nodes and 87 links), medium network (54 nodes and 181 links), to large size network (100 nodes and 460 links). Hence, the sum of the network energy saving costs is the total performance expense of the algorithm at minimum routing selection.

The routing selection method procedure prioritizes selecting the active nodes for controller positions. The three algorithms’ routing costs over traffic demands are highlighted in Figures 3a, 3b and 3c, representing small, medium, and large network sizes, respectively. At starting the traffic demands, the three algorithms EARMLP, C\_DBEAR and DBEAR search for the network paths selected to be the shortest distances between the controllers and the switches. Therefore, the routing costs for the three network sizes are nearly equal. This can be significantly observed in Figures 3a (small network size/25 nodes) and Figure 3b (medium network size/54 nodes) compared to Figure 3c (large network size/100 nodes).

On the other hand, if the network size increases, the traffic demands increase as well as the overall routing cost. So, Figure 3a reveals the routing cost is around 500 when the traffic demand is 100 in the network with 25 nodes. It can be seen; the EARMLP algorithm outperforms the other two algorithms. By reducing the number of active nodes in the network, the EARMLP is able to increase utilization and reduce costs.

According to network size, these routing costs increase at traffic demand 100 as Fig. 3b is about 600 and Fig. 3c is about 700. This implies that the power saving decreased with improved network loads and requested demand in controller

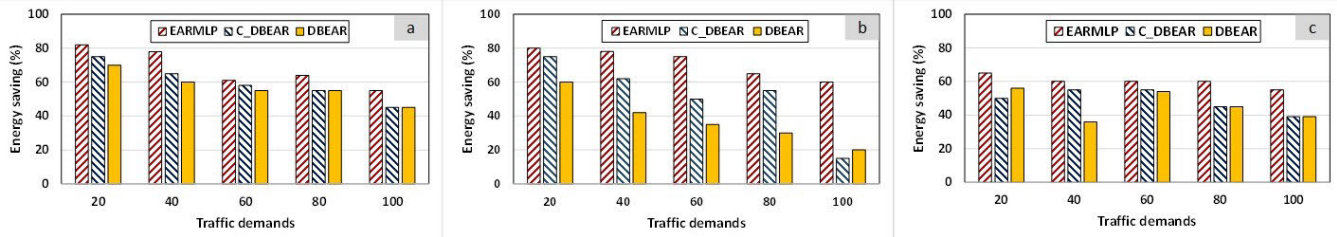
topologies. As the number of requests grows, more servers (more services and traffic) are deployed in multi-domain networks. However, these servers need more resources such as CPU and memory to instantiate the deployed services and NFs for providing reliable operation that results in significant energy consumption. However, in these figures, the EARMLP algorithm has a minimum routing cost of around 20% compared to others. Nevertheless, to examine the trade-off between delay and energy consumption, we further observed the improved delay of the control paths for energy saving. The average network routing delay determines how long the network takes on average. Therefore, the shortest paths initialize the algorithms; however, the EARMLP algorithm exhibits the least delay since our method has the fewest connections in the route, followed by C\_DBEAR and DBEAR through the three network sizes as shown in Figures 4a, 4b and 4c. So far, the average delay rises as the number of controllers grows for routing reasons, as seen for the three algorithms in Fig. 4. This is because many controllers create a longer route and processing delays while performing network tasks, resulting in longer end-to-end latencies.

To further reduce the utilized links and assigned switches, our proposed EARMLP strives to immediately select the route and connection with the lowest utilization as compared to other two energy-saving algorithms. The DBEAR algorithm only examines the number of hops and ignores other performance indicators when choosing a path. The delay tends to rise somewhat with the increase in traffic volume for all energy-saving strategies.

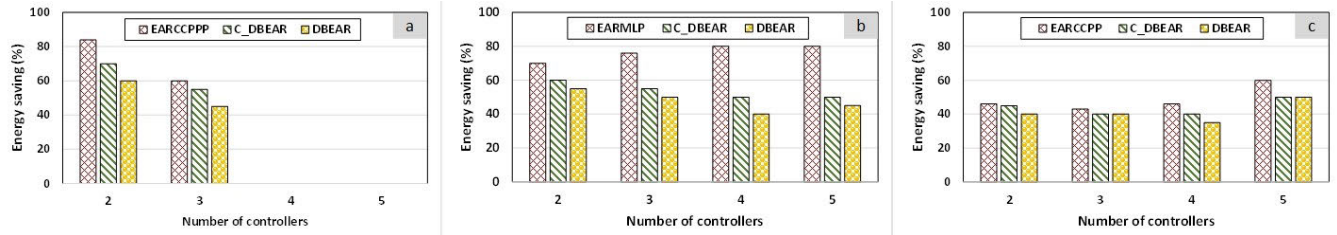
## 2) THE ENERGY SAVING

The three algorithms also indicate the effectiveness of energy-saving in network scenarios over various traffic demands. The energy-saving strategy aims to reduce the





**FIGURE 5.** Performance of minimizing the link over traffic demands for energy saving on: a) the small size network (25 nodes) b) the medium size network (54 nodes) and c) the large size network (100 nodes).



**FIGURE 6.** The impact of selecting the optimum number of controllers and energy saving for: a) the small size network (25 nodes), b) the medium size network (54 nodes), and c) the large size network (100 nodes).

active nodes while simultaneously consolidating network resource use to achieve the lowest total operating cost. Therefore, the total number of network connections that are inactive/sleep state is used to calculate the energy-saving metric ratio (%) for various placement methods on topologies. Another option is the number of inactive links divided by the total number of network links which is provided as follows:

$$\sum_{C, S \in N} P_{f,e} / \sum_{\forall e_{ij}} E. \quad (24)$$

The proposed heuristic algorithm implementation updates the deployment of controllers and turns off all servers in order to limit power use. So, if we prioritize shortest paths, slightly raised path segments are activated throughout the network. The EARMLP can effectively create shorter pathways using already active links and nodes. Specifically, when the traffic expands, it saves much more energy than the other methods. However, the node pairs with longer pathways are unable to assign their path along these randomly arranged short routes efficiently, and as a result, overall network performance decreases.

Figures 5a, 5b, and 5c depict the variation of energy savings for the three network sizes in each iteration. For instance, the energy-saving percentage in small networks 25nodes can be improved from 70% when using DBEAR to 75% when using C\_DBEAR to 80% when using EARMLP under the 20 demand request network load. That indicates the proposed routing EARMLP algorithm achieves better performance in terms of energy savings than C\_DBEAR and DBEAR algorithms. Moreover, the percentage number rises from 60% (DBEAR) to 65% (C\_DBEAR), eventually reaching up to 78% (EARMLP) with 40 proposed demand requests. Similar results can be seen in medium size in Figure 5b, which indi-

cates the EARMLP utilizes power conservation effectively in all three topologies.

On the other hand, when the network size increases, fewer pathways become more scattered, which results in more difficulty using domain controllers that have already been switched on. In comparison, our technique saves nearly 45% and 65% more on cost resources than the other two methods, C\_DBEAR and DBEAR, respectively. At low traffic loads in the three networks, the EARMLP, C\_DBEAR and DBEAR algorithms behave virtually to identify the energy savings. However, our EARMLP algorithm outperforms the others by up to 70% average energy savings as nodes and traffic increase. The energy cost disparity between algorithms continues to rise as input flow increases.

### 3) IMPACT OF NUMBER AND LOCATION OF THE CONTROLLERS IN ENERGY SAVING

To examine the trade-off between the number of controllers and energy consumption, we further observe the improved energy saving of the control paths. The optimum number of controllers for each network size is determined and set by our previous results in [55]. As predicted, energy conservation reduces as the number of demands increases since new routes occur. Furthermore, the optimum placement and number of controllers impact traffic routing, minimize link utilization, and reduce hops and routing costs. The effective energy-aware approach calculates the total energy savings for various controllers by considering all feasible options for the controller positions. The result shows that the EARMLP method consumes less energy than other algorithms C\_DBEAR and DBEAR in the three networks. Because it always provides priority to select active nodes for the placement of controller instead of OFF network devices.

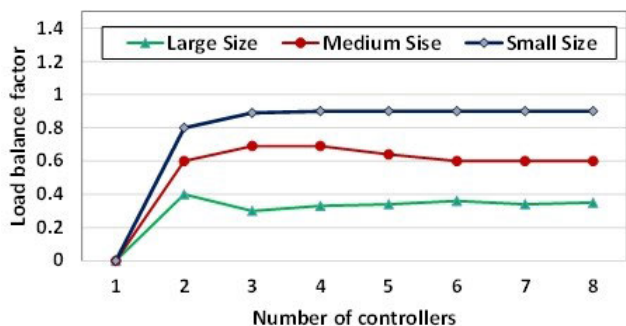


FIGURE 7. Load balancing for different network sizes using the EARMLP algorithm.

The impact of optimum number selection for the number of the controllers reduces to 2 controllers at the small size network, which is depicted in Fig. 6a. Also, this can be seen in Figure 6b, which presents the energy saving at selected 4 optimal controllers in the medium network size. As the network size increases, the best energy saving occurs at selected 5 optimal controllers in the large network size, as depicted in Fig. 6c.

#### 4) LOAD BALANCING

The load balancing factor is one of the main objectives formulated by minimizing the link utilization in a network. According to its concept, it is defined as the ratio between the amount of flow transfer and the link’s capacity. Although the C\_DBEAR algorithm and DBEAR algorithm try to save energy, they overlook the load balancing impact on multi-domain networks because they do not work in the distance and capacity of the link. Therefore, Fig. 7 shows load balancing results over the number of controllers using the proposed algorithm. The selection of routing paths that use the least number of resources significantly influences the traffic load of all network connections. When a controller knows the value of the traffic demand, it can make the best decision. However, the congestion causes packets to be dropped randomly. Traffic distribution is affected by the energy-aware routing because certain active routes are more congested than others.

To assess the influence of our method on control path propagation delay, we collected the length of each traffic demands related to control connections as well as the associated average route length in terms of hops for these traffic demands. Even while the method does not really take into account the available connection bandwidths, the link resource consumption and load balancing, Our proposed method, EARMLP, accomplishes the mentioned process in order to improve performance.

Furthermore, Fig. 8 displays the number of active hops and the relation with the number of controllers considering all potential controller locations for various sizes of the three networks.

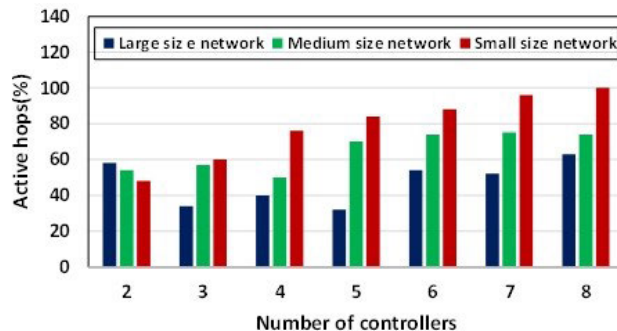


FIGURE 8. All active hops over the optimum number of controllers.

A more significant proportion of traffic is redirected across more hops as the number of controllers increases. For example, where the optimum number of controllers is 5, the hopes used are less than 40% (for large network size with 100 nodes in this case), 75% (for medium network size with 54 nodes), and 83% (for small network size with 25 nodes). This is because of the shorter path-finding mechanism of the EARMLP algorithm executed within the active nodes. A controller location is feasible, as long as the assumptions stated to avoid routing more traffic through other controllers can be preserved. Since it intends to divert flows to alternate shortest paths, the heuristic algorithm determines the location and optimum number at the initial step and route length. This is accomplished regularly by identifying the underused connections and then diverting the flows.

#### VIII. CONCLUSION

This article addresses energy awareness in distributed network architectures to achieve efficient routing and energy savings in SDN. In distributed systems, the rule of controller placement and load balancing among connections is energy savings. However, reducing route length is challenging when network elements cooperate in an SDN framework; as a result, network elements must be interoperable. Therefore, we place the controllers for a distributed control plane in this work to maximize the possibility of energy saving in SDN. Consequently, the energy-aware algorithm is intended to optimize energy usage and load balance levels. The model considered several metrics such as distributed network topology, traffic flow rerouting, the number of active links/devices, and the number of hops. A quality network management system is used to demonstrate energy savings, with different decisions for adjusting traffic loads and a limitation on the number of active devices to achieve power savings whilst maintaining adequate routing capabilities. The proposed energy-aware routing technique combines resilience and resource management to optimize network energy savings throughout the evaluation process. The model simulation results indicated that the EARMLP has advantages over other algorithms for different network sizes.

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