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RESEARCH ARTICLE

Energy-Efficient Data Center Network Infrastructure With Network Switch Refresh Model

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ABSTRACT Data centers and their underline transmissions are required to guarantee critical services in a 24/7/365 framework. The extensive energy consumption of these data centers and their transmission networks impose a threat to globally available scarce energy resources. Furthermore, addressing performance and energy requirements trade-offs is also challenging. This article has been specifically focused to assess the inside-energy-view of typical data center networks and assess how network infrastructure replacements or ''refresh'' can lead to a better energy-efficient data center network (DCN) design without compromising performance or service level requirements. Server refresh techniques are found in the literature. However, considering network infrastructure refresh to attain energy efficiency is the first of its kind. A model has been proposed in this article that works on algorithms to recommend network switch replacements. The algorithms perform parametric analysis for replacement. The analysis considers parameters impacting the performance and energy consumption of the switches. In addition to technical parameters, the proposed model has also evaluated the cost impacts of the replacement. The replacement is only recommended if it is energy efficient and performance effective and validated when replacement is also cost-effective. The proposed model has been evaluated through two replacement options, one with the same manufacturer and the other with a different manufacturer. Replacement with two different options has been proposed to evaluate the impact of various manufacturers in designing a better energy-efficient data center meeting all service level requirements and performance guarantees. The results obtained from the proposed reflect the attainment of the desired objectives.

INDEX TERMS Data center, energy efficiency, environmental impacts, network infrastructure, network refresh, device replacement policy.

I. INTRODUCTION

With the increasing demand of data centers, the importance of energy consumption control is also growing. The energy utilization of Internet has observed gigantic increase at all levels from data center to end users. However, data centers are considered as the most energy consuming sector [1]. The demand of corporate and strategic sectors to establish their private clouds has further increased the role and importance of data centers. The increase in size and quantity of data centers consequently enhanced the energy consumption proportion of IT in world's total energy utilization. The electricity demand for data centers start increasing since early 2000 and it was predicted that the incremental rate will rise at an alarming pace [2]. The energy requirements of the data centers are expected to be four times in next ten years according to the forecasts in [3]. Although, the issue of energy consumption has been undertaken by few countries and policies has been devised which limit the energy usage of global data centers to 1% to 2% of the global electricity usage [4], however, more efforts are expected and needed.

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Over-provisioning of resources is one of the key aspects of rising the energy consumption of data centers. Data centers are over-provisionally designed in order to maintain the Quality of Service (QoS). According to the research, only 10% to 50% of the computing resources has been utilized [5]. Similarly, only 5% to 25% of the network resources are utilized at a time [6]. The importance of network utilization in data center energy consumption is enhancing with the network traffic growth due to the advent of Internet of Things (IoT), 5G, and bitcoin networks [7], [8]. It has been noticed that with the increase in size and quantity of the data centers including both computation and networking, the over-provisioning rate has also increased substantially [9]. To overcome the energy consumption due to the over-provisioning of resources, numerous techniques have been proposed in the literature. There are many different approaches found in literature for energy efficiency of numerous data center components such as computation, cooling and other relevant hardware. However, very little attention has been paid towards data center network energy efficiency approach [10].

One of the emerging and successful methods to reduce the energy demands of data centers is hardware refresh [11]. The method of hardware refresh is highly recommended by the JCR Technical Report (Best Practice Guidelines for the EU Code of Conduct on Data Center Energy Efficiency) [12]. Hardware refresh is the process of replacing the existing devices with the latest devices. The purpose of replacement is to enhance the capacity and performance of the devices. Nowadays, hardware refresh is being performed to reduce the energy requirements. In some cases, energy efficiency is included in the design considerations of the replaced device. Otherwise, due to huge computational capacity, replaced device can perform large number of operations consuming the same energy which is required by existing device for performing lesser computation. Therefore, it can be said that hardware refresh result in enhanced performance with higher productivity. It also reduces the risk of failures and also prevent from hardware obsolescence. These additional benefits other than energy efficiency are not obtainable from other techniques present in literature for reducing the energy requirements of data center IT devices. Moreover, as the hardware refresh technique is devices specific, therefore, it can be applied to any type of data centers. Implementation of hardware refresh technique to computational resources that is servers has been found in literature. In [1], impacts of server refresh over environment has been discussed. The rate of server refresh from environmental sustainability point of view has been calculated. Similarly, as per assessments in [13], server refresh is also valuable in small data centers with only little investments. To the best of our knowledge, there are many data center network efficiency techniques found in literature, however, efficiency attainment through network infrastructure refresh technique has not been applied yet. The objective of this work is to make an energy efficient highly utilized data center networks (DCNs) without compromise over Service Level Agreements (SLAs). Network infrastructure refresh seems to be the most promising approach for achieving the desired objectives. In addition to that, the process of attaining performance aware energy efficient DCNs must not impact the operational cost of data center operations.

In this study, a model is presented that works on the proposed algorithms for decision making of network switch refresh. The algorithms in the developed model take data from two datasets and then perform comparisons. Three different algorithms perform three different comparisons in each of the module of a proposed model. The first module compares the parameters that are involved in power consumption measurements of the devices. Second module takes parameters that can impact the performance of the network. Third module compares devices' lifetime details and their rack space requirements related parameters. The recommended device then validated through multiple analyses including cost analysis, energy efficiency analysis and cost required for bits transferred at unit USD cost.

The rest of the paper is organized as follows. Section II discusses the previous work related to the energy efficiency of data centers attained through IT devices. Section III presents the methodology of the proposed model. In Section IV, case study of network devices exist in a real world data center is presented. Section V performs the comparative analysis of two proposed replacements. One proposed replacement contains the device of same manufacturer as of existing device. The other proposed replacement is from the dataset of different manufacturers. The comparative analysis is performed to analyze the impact of manufacturer over energy consumption. In Section VII, conclusion are drawn, limitations of the current work and future enhancements are also discussed.

II. LITERATURE REVIEW

It is a known fact that data center networks are usually highly underutilized [14]. For data center managers there can be several valid reasons for over-provisioning of data center infrastructure which include servers, switches, and routers. Need of high availability, redundancy and security are some of the reasons of over-provisioning. Therefore, targeting over-provisioning factor may not be a good solution and will affect performance and service level agreements committed by data center managers. Hence there is a need to carefully assess the energy consumption of existing devices and find alternative devices that conserve energy with similar or better performance. Hardware Refresh is a technique through which energy efficiency can be obtained without deteriorating the performance. In [15], the prospects of energy reductions in future data centers has been discussed. The authors have also mentioned about the importance of network device replacement for achieving energy efficiency. The authors in [1] has also emphasized the importance of hardware refresh for data center energy efficiency. They have discussed the environmental impacts of hardware refresh in detail by implementing a framework. They have also validated the proposed framework through the use of real data sets. In another article [13], the importance and benefits of hardware replacement is discussed. The Return of Investment (ROI) of hardware refresh is evaluated.

The advantage of hardware refresh technique over other energy efficiency techniques is that hardware refresh ensures performance enhancement in addition to energy efficiency. Network refresh increase reliability as well as security. Through the implementation of network refresh mechanism, network become efficient and it can support innovative and newer applications easily. It can be concluded that network refresh not only enhances the organization technically but also provide business boost. There are many other techniques that are employed for data center networks energy efficiency including sleep mode of network devices at low traffic, use of artificial intelligence [16], [17], [18] in data center networks. In [19], a framework has been proposed for IoT which dynamically alters the topology as per flow demands. In [20], strategy regarding dynamic overbooking of resources has been presented. Dynamic allocation has been through monitoring the network and virtual machine utilization without any knowledge of workload. The dynamic resource overbooking results in reduced SLA violations in addition to energy efficiency attainment. A framework named HeporCloud has been proposed in [21] that performs workload allocation and also migration. The resource allocation and migration of workload is performed so that energy efficiency can be attained. During the allocation of workload, the resources communicate with the framework. This communication overhead results in delayed response time of the system. Another approach of resource scheduling in data centers has been proposed in [22]. The scheduling algorithm considers the SLA for rescheduling to get optimized energy efficiency as well as optimized Customer Satisfaction Level (CSL). A QoS aware energy efficient virtual machines consolidation algorithm has also presented in [23]. The proposed algorithm enhances the throughput of the system in addition to the reduction in SLA violations, cost and response time at a very little increase in energy consumption.Resource consolidation may also be integrated with hardware refresh as the replaced device can be used in place of more than one old device due to its enhanced capability. Therefore, hardware refresh can also lead to resource consolidation and results in vast reduction in power utilization of data center. Although we have not mainly discussed resource consolidation in our work as our focus is on validation of our proposed algorithm. However, there are many works present in literature exploiting resource consolidation [24], [25], [26] which can be incorporated into hardware refresh. From literature review, it can be deduced that careful hardware refresh considering numerous factors can lead to energy efficient data centers.

III. METHODOLOGY - PROPOSED MODEL

In this section, working layout of the proposed model is presented. The proposed model works on the basis of proposed algorithm which aims to reduce the energy requirements of network device in the data center through its replacement with energy efficient networking device. The real-world data center network consists of numerous switches, routers, firewalls and other communication device. This study mainly focuses on achieving the network efficiency through switches replacement only. Switches may have different number of ports such as 12, 24 or 48 ports. The bandwidth of each switch can be evaluated through their port types. The switches in data center network are one of the most important element. Usually, three tier network switch infrastructure is used for traffic communication to end servers. However, due to inefficient and over-provisioned server resources, the utilization of the switch infrastructure is poor [27], [28]. The low utilization also leads to high power consumption of the switch infrastructure. Therefore, we have considered switches for the evaluation of the proposed algorithm. In this study, the term devices is referred to as switches only.

Let us consider an example from real-world data center switch, Cisco WS-C3560G with both 24 and 48 ports. It can be seen that both switches have exactly the same configuration except the number of ports and their corresponding power consumption. The power usage of 48 port Cisco WS-C3560G is 116% higher than the 24 port switch. Therefore, 12 Watts can be saved by replacing single Cisco WS-C3560G-48TS-S with two Cisco WS-C3560G-24TS-S switches. Here, an added advantage gained through replacement, is the single point of failure removal. Secondly, it can also be noticed that the performance will be intact as both of the switches have 10/100/1000 ports. However, it is worth noticing that replacement of single switch with two switches can cause a rack space issue.

Consider another switch Cisco WS-C2960S which is also available in both 24 and 48 ports. The power consumption of 48 port Cisco WS-C2960S-48TS-L is 21% higher than Cisco WS-C2960S-24TS-L. Therefore, replacement two Cisco WS-C2960S-24TS-L switches with single Cisco WS-C2960S-48TS-L can save 14 Watts of power. The ports in Cisco WS-C2960S-48TS-L are twice as ports in Cisco WS-C2960S-24TS-L. However, the switching capacity of both switches is same which 176 Gbps which shows that QoS cannot be intact after replacement. Moreover, the replacement of two switches with a one hardware will create single point of failure issue. However, the replacement leaves a space in the rack, so a backup switch can be added. The redundant hardware will only be powered-on, once the active switch gets un-operational.

From the discussed two cases, it can be concluded that replacement process needs thorough investigation using numerous parameters. In some cases, only few parameters are sufficient, however, it is not always the case. It can be noticed that in both cases discussed above, the parameters required for replacement varies. Therefore, the consideration of parameters must be broad. A rigorous policy is required that can handle a broader category of different configurations and parameters. The proposed model takes various performance and power related parameters for creating the appropriate replacement policy.

TABLE 1. Manufacturers and their models in the dataset.

Manufacturer	Model
Cisco	3560 Catalyst Series 3750 Catalyst Series 3850 Catalyst Series 4948 Catalyst Series SG500 Series
Juniper	EX Series QSF Series
Aruba/HPE	CX 6300 2540 Series 2530 Series

The parameters selected in the proposed model, represent energy as well as performance of the networking device. The developed model performs a comparative analysis of the proposed device with the existing device. Device replacement would be acceptable if the proposed device is energy efficient as well as giving performance enhancement. Proposed model has two layers, one is Recommendation Layer and the other is Validation Layer. Recommendation Layer recommends that replacement is feasible or not and then Validation Layer performs certain checks before final replacement. If the Recommendation Layer accept replacement but Validation Layer do not validate the replacement, hardware refresh will not be performed. The graphical representation of the model with all modules and algorithms is shown in Fig. 1. Details of the model are discussed in the following subsections.

A. RECOMMENDATION LAYER

Recommendation Layer recommends that replacement is feasible or not through the comparative analysis of selected devices from datasets of existing and proposed devices datasets. The details of datasets, parameters used for comparison and the details of modules working in the Recommendation Layer are mentioned following sub-sections.

1) DATASET

The Recommendation Layer of the proposed model comprises of two datasets. The first dataset consists of the networking devices that exist in data center whereas the other dataset consists of the devices that can become part of data center in future and can play their role in data center performance and energy efficiency. The first dataset is named as Existing Devices Dataset (EDD) and the other dataset is referred as Proposed Devices Dataset (PDD). We have limited the dataset to three manufacturers which are selected as per their presence in traditional data center. The selected manufacturers and their models which are present in the dataset can be seen in Table 1.

2) PARAMETERS USED FOR ANALYSIS

The objective of the parametric analysis is to choose the device with lower energy consumption. Therefore, power usage parameters are most important for the modeling. The included power usage parameters are:

- Power Usage of the Device.
- Power over Ethernet (PoE) - provided the device holds the PoE capability.

PoE is the ability to pass electric power through Ethernet cables. PoE increase the power consumption of the devices.

Another objective of the proposed model is to ensure that network performance will not be depreciated due to energy efficiency. Therefore, parameters that monitor the performance of the network are also considered in the model. The included performance parameters are:

- Number of Ports of the Device.
- Port Type.
- Switching Capacity - The switching capacity is the maximum amount of data that can be handled between the switch interface processor or the interface card and the data bus.
- Number of SFP Ports - provided the device holds the SFP capability.
- Type of SFP Ports.

Small Form-Factor Pluggable (SFP) is a small transceiver that can be plugged in and then connects to Fibre Channel and Gigabit Ethernet (GbE) optical fiber cables at the other end. These transceiver modules are evolved due to the requirements of high speed data transfer. SFP ports may have capacity of 1/10/40/100 Gigabits. Its updated and advanced variants are named as SFP+ and Quad Small Form-Factor Pluggable (QSFP). A Gigabit Interface Converter (GBIC) is also a similar kind of transceiver module. The small size of GBIC is termed as Mini GBIC. SFP modules are also sometimes referred to as "mini-GBIC" due to their smaller size. Few other parameters that are included in the analysis are:

- Rack Unit (RU).
- End of Life (EOL) of the Device.

3) MODULES AND ALGORITHMS

The proposed model has three modules in the replacement layer. These modules select one of the devices from EDD and compare it with one of the devices from PDD. The algorithm in each module performs the comparison of devices as per the considered parameters of the selected devices. Three separate modules are designed so that the power usage parameters and performance parameters can be compared individually. The third module is used to compare other parameters which are also important to be considered before performing any replacement within data center. The parameters which are considered in third module include Rack Space and End of Life (EOL) of the device. Each module of the model follows an algorithm. The algorithms evaluate the feasibility of the replacement. The objective of each algorithm is to compare the parameters as per the module, that is algorithm of first module works on power usage parameters, algorithm of second module works on performance parameters and the algorithm in the third module compares other selected

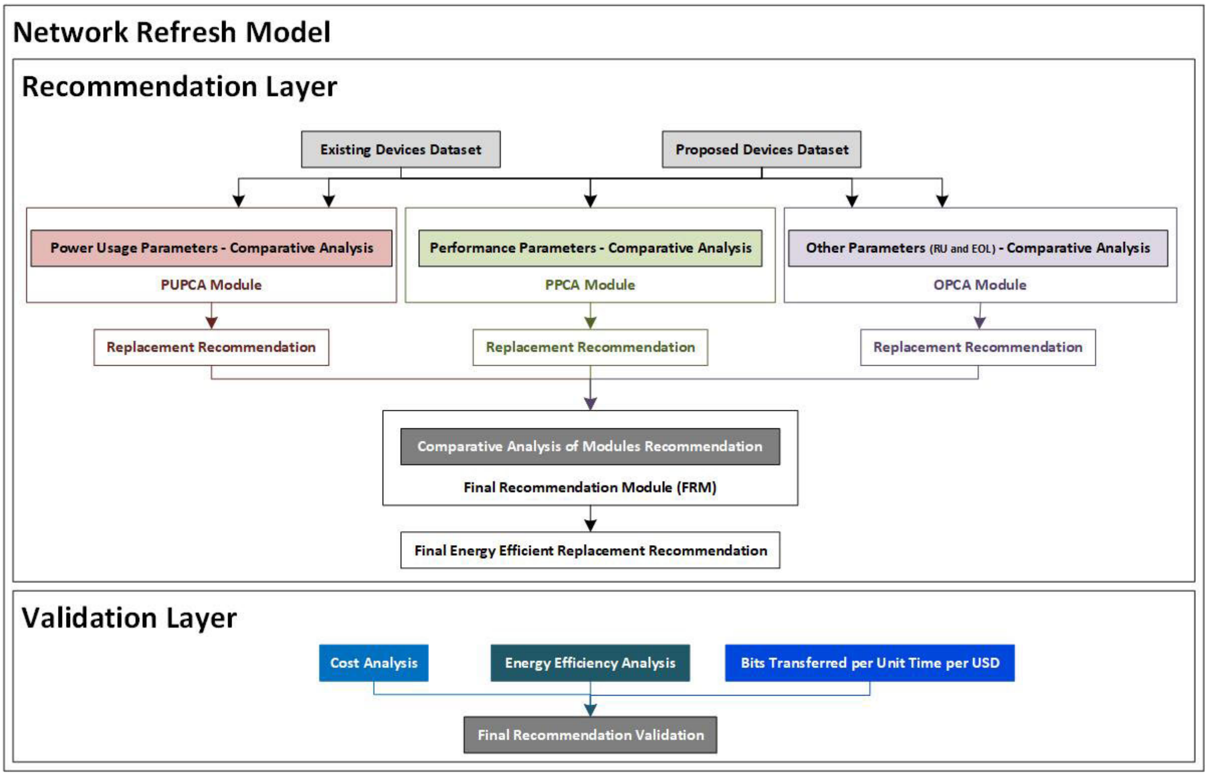

FIGURE 1. Proposed model for data center network device replacement/refresh.

TABLE 2. Acronyms used in the algorithms.

Terminology	Abbreviation
$D_P P_{PRF}$	Proposed Device Performance Parameters
$D_P P_{PU}$	Proposed Device Power Usage Parameters
$D_P P_O$	Proposed Device Other Parameters
EE	Energy Efficiency
$E_{PRF}[]$	Array of Performance Parameters of Existing Devices
$P_{PRF}[]$	Array of Performance Parameters of Proposed Devices
$E_{PU}[]$	Array of Power Parameters of Existing Devices
$P_{PU}[]$	Array of Power Parameters of Proposed Devices
$E_O[]$	Array of Other Parameters of Existing Devices
$P_O[]$	Array of Other Parameters of Proposed Devices
P_N	Number of Ports
P_T	Ports Type
P	Power Consumption in Watts
C	Switching Capacity in Gbps
SFP_N	Number of SFP Ports
SFP_T	SFP Ports Type
RU	Rack Unit
PoE	Power over Ethernet
EOL	End of Life Date of device
E in subscript	E in subscript represents parameter of Existing Device
P in subscript	P in subscript shows Proposed Device Parameter

parameters considered in the third module. The abbreviations used in the algorithms are shown in Table 2. P_N represents Number of Ethernet Ports in a hardware. The type of Ethernet port is represented by P_T. Gigabit Ethernet port is represented by GbE, Fast Ethernet by FE and GBASE-T is the Gigabit Ethernet over twisted pair. Switching capacity is represented by C, measured in Gigabits per second (Gbps). Power Consumption is represented by P, measured in Watts. Details of each module along-with their respective algorithms are described below.

Power Usage Parameters Comparative Analysis (PUPCA Module) - The first module named Power Usage Parameters Comparative Analysis (PUPCA) evaluates power usage of proposed and existing devices. The algorithm named as Algorithm 1, compares the power usage of existing device with the proposed device. In case of PoE support, PoE requirements of existing device is also compared with the PoE requirements of proposed device. The algorithm in the module recommends the switching of device only if the power consumption of suggested replacement is lower than the existing one.

Performance Parameters Comparative Analysis (PPCA Module) - Second module named Performance Parameters Comparative Analysis (PPCA) compares performance parameters of the devices. The algorithm in the module named Algorithm 2 suggests replacement only if the performance of the proposed device is higher than the existing device.

Other Parameters Comparative Analysis (OPCA Module) - The third module named Other Parameters Comparative Analysis (OPCA) uses algorithm named as Algorithm 3 that include rack space and important life and support dates of device. The rack space requirement is one of the economical factor that needs to be evaluated. RU parameter is added because the replacement of single device should not impact the data center infrastructure at rack level. The algorithm implemented in the module recommends replacement only

Algorithm 1 PUPCA Module

INPUT: Existing Devices and Proposed Devices Dataset
OUTPUT: Device Replacement Recommendation based on Power Usage Parameters

procedure Power Consumption Comparison(Array $E_{PU}[]$)
  Array $P_{PU}[]$
  var Proposed_Device = FALSE
  while $P_{PU}[]$ in Proposed_Devices[] **do**
    Select P_E *from* $E_{PU}[]$
    Select P_P *from* $P_{PU}[]$
    if $P_P < P_E$ **then**
      Select PoE_E *from* $E_{PU}[]$
      Select PoE_P *from* $P_{PU}[]$
      if PoE_E != NULL && $PoE_P < PoE_E$ **then**
        Proposed_Device = TRUE
      end if
    end if
  end while
  if Proposed_Device == TRUE **then**
    Return *Passed*
  else
    Return *Failed*
  end if
end procedure

in case of lesser or equal rack space requirements of the proposed device. Similarly, the EOL date of the proposed device must be greater than the date in which comparison has been performed or atleast, higher than the EOL date of existing device.

Final Recommendation Module - (FRM) - Final Recommendation Module (FRM) contains Algorithm 4 which is Main Procedure that calls all other algorithms. The responsibility of FRM is to take the final replacement decision according to the decisions of each module. There are four workable scenarios that impact the decision of FRM. Fig. 2 represents the final recommendation of FRM as per scenario. In Scenario I, when all three modules recommend replacement, the FRM straight forwardly recommends replacement. However, in Scenario II and III, when OPCA and PPCA modules do not recommend replacement respectively, the FRM will not recommend replacement. In Scenario IV, when PUPCA module do not recommend replacement but PPCA recommends it then FRM will evaluate the energy efficiency of both existing and proposed replacement. If the proposed device is more energy efficient as compare to the existing device, only then replacement will be recommended.

B. VALIDATION LAYER

After the recommendation given by the recommendation layer, the recommended device has to undergone validation tests which will be performed by validation layer of the proposed model. Validation layer performs three validations.

Algorithm 2 PPCA Module

INPUT: Existing Devices and Proposed Devices Dataset
OUTPUT: Device Replacement Recommendation based on Performance Parameters

procedure Performance Comparison(Array $E_{PRF}[]$)
  Array $P_{PRF}[]$
  var Proposed_Device = FALSE
  while $P_{PRF}[]$ in Proposed_Devices[] **do**
    Select $P_{N(E)}$ *from* $E_{PRF}[]$
    Select $P_{N(P)}$ *from* $P_{PRF}[]$
    if $P_{N(P)} \geq P_{N(E)}$ **then**
      Select $P_{T(E)}$ *from* $E_{PRF}[]$
      Select $P_{T(P)}$ *from* $P_{PRF}[]$
      if $P_{T(P)} \geq P_{T(E)}$ **then**
        Select C_E *from* $E_{PRF}[]$
        Select C_P *from* $P_{PRF}[]$
        if $C_P \geq C_E$ **then**
          Select $SFP_{N(E)}$ *from* $E_{PRF}[]$
          Select $SFP_{N(P)}$ *from* $P_{PRF}[]$
          if $SFP_{N(E)}$!= NULL && $SFP_{N(P)} \geq SFP_{N(E)}$ **then**
            Select $SFP_{T(E)}$ *from* $E_{PRF}[]$
            Select $SFP_{T(P)}$ *from* $P_{PRF}[]$
            if $SFP_{T(P)} \geq SFP_{T(E)}$ **then**
              Proposed_Device = TRUE
            end if
          end if
        end if
      end if
    end if
  end while
  if Proposed_Device == TRUE **then**
    Return *Passed*
  else
    Return *Failed*
  end if
end procedure

First, the variations in the cost due to replacement will be analyzed. Second validation test comprises of energy efficiency analysis. Third validation is performed by analyzing the number of bits transferred per unit of electricity cost in USD. The details of each of the analysis is shown below.

Cost Analysis - The most important validation in replacing the existing device with the recommended one is the analysis of the cost incurred to perform the recommended replacement. The first added cost in the recommended device would be the procurement cost. Additionally, the electricity cost charges will also vary according to the energy requirements of the recommended device. The formula for the cost analysis module is represented through equation (1). If the analysis result show that additional cost will have to be paid for replacement, then the recommendation will not be validated.

$$AdditionalCost/Savings = PC + [AEC_E - AEC_P] \quad (1)$$

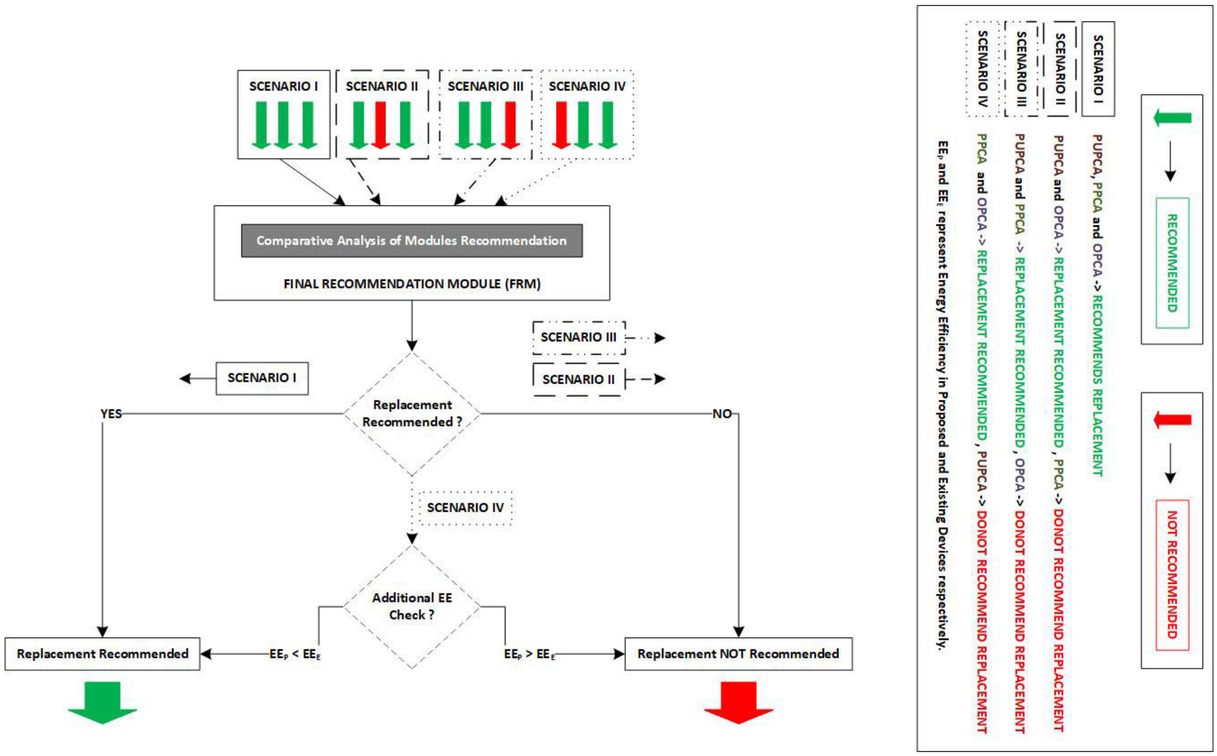

FIGURE 2. **Scenarios in replacement layer as per modules recommendations.**

Algorithm 3 OPCA Module

INPUT: Existing Devices and Proposed Devices Dataset
OUTPUT: Device Replacement Recommendation based on EOL and RU Parameters

procedure Other Parameters Comparison(*Array* E_O[])
  Array P_O[]
  var Proposed_Device = FALSE
  while P_O[] in Proposed_Devices[] **do**
    Select RU_E *from* E_O[]
    Select RU_P *from* P_O[]
    if $RU_P \leq RU_E$ **then**
      Select EOL_E *from* E_O[]
      Select EOL_P *from* P_O[]
    end if
    if $EOL_P > EOL_E \,||\, EOL_P > Current\ Date$ **then**
      Proposed_Device = TRUE
    end if
  end while
  if Proposed_Device == TRUE **then**
    Return *Passed*
  else
    Return *Failed*
  end if
end procedure

where left hand side of the equation (1) shows the cost savings or the additional cost incurred due to replacement, PC represents the Procurement Cost of recommended replacement and $AEC_E$and AEC_P show Annual Electricity Costs of existing and proposed/recommended replacement respectively.

Energy Efficiency Analysis - Energy efficiency 3analysis is mandatory as the motive of device replacement is the attainment of energy efficient data center network. Energy efficiency is calculated through the CNEE metric. In case of Scenario IV of Recommendation module, energy efficiency validation is already done for recommendation purposes. However, for other remaining scenarios, validation of energy efficiency will be performed in validation layer. The working formula for energy efficiency analysis is represented using equation (2).

$$CNEE = \frac{\text{Power Consumed by Network Device}}{\text{Effective Network Switching Capacity}} \tag{2}$$

Bits Transferred per Unit Electricity Cost - The third and the last validation is the checking of bits that has been transferred through the network at unit electricity cost. Equation (3) represents the calculation of transferred bits.

$$Bits/USD = \frac{\text{Switching Capacity}}{\text{Electricity Cost}} \tag{3}$$

In case, the cost analysis module or energy efficiency analysis module do not validate replacement recommendation and the bits transferred per unit cost module support replacement then the percentage of validation rejection and validation acceptance will be compared. If the module validating the replacement has high percentage as compare to the rejected one then the recommendation will be validated, otherwise not.

Algorithm 4 Final Recommendation Module - FRM

INPUT: Call ALL other procedures **OUTPUT:** Final Recommendation of Device Replacement

procedure Main((D_PP_{PRF}, D_PP_{PU}, D_PP_O))
  Performance Comparison (Proposed_Device)
  $D_PP_{PRF} \leftarrow$ *Proposed_Device*
  Power Consumption Comparison (Proposed_Device)
  $D_PP_{PU} \leftarrow$ *Proposed_Device*
  Other Parameters Comparison (Proposed_Device)
  $D_PP_O \leftarrow$ *Proposed_Device*
  if D_PP_{PRF} && D_PP_{PU} && $D_PP_O == Passed$ **then**
    Replace the Device
  else if $D_PP_{PU} == Failed$ **then**
    Select P_E *from* $E_{PU}[]$
    Select P_P *from* $P_{PU}[]$
    Select C_E *from* $E_{PRF}[]$
    Select C_P *from* $P_{PRF}[]$
    Compare power required for data transfer
    $EE_E = P_E/C_E$
    $EE_P = P_P/C_P$
  end if
  if $EE_P < EE_E$ **then**
    Replace the Device
  else
    Existing Device performing better
  end if
end procedure

IV. REAL-WORLD TRADITIONAL DATA CENTER CASE STUDY

Now, let us consider a real-world data center and evaluate the attainable energy efficiency by replacing its networking devices. We have considered a data center of public sector organization. The networking devices of the data center are 289 in number including routers, switches, controllers and other appliances. The total power consumption of the networking devices is 76 kW. Among these 289 networking devices, 260 devices are switches which is 90% of the total devices. These 260 devices constitute of 22 different models of switches from various manufacturers including Cisco, Juniper, Aruba/HPE, Dell, Fortinet. Among 260 switches, 188 switches belong to Cisco from which 126 switches are selected for replacement. Therefore, it can be seen that 72% of the switches are from same manufacturer. Remaining 28% comprises of 04 more manufacturers including Juniper, Aruba/HPE, Dell, Fortinet. Among these manufacturers, Aruba/HPE and Juniper have highest percentages. Hence, the selected manufacturers comprise of approximately 85% of all manufacturers. Power consumption of these switches is 71 kW. Hence, it can be noticed that major portion of the network energy consumption is originated by switches. In this study, few devices of Cisco, Juniper and Aruba/HPE are selected for evaluating the applicability of the proposed model. Power Consumption, Switching Capacity, Quantity and Annual Electricity Cost of the existing devices are shown in the Table 3. The total count of selected devices is 160 which is approximately 62% of the total number of switches present in the data center. Aggregated power consumption of the selected devices is approximately 44 kW which is 62% of the total power consumption of the switches present in the data center. The replacement of the selected devices with some other device is performed for achieving energy efficiency in network. In this study, eight different models of switches constituting three different manufacturers from the data center are considered for evaluation. Most of the existing devices, selected for analysis are from Cisco manufacturer. The other selected manufacturers include Juniper and Aruba/HPE. In each of the considered case study, two recommended replacements are mentioned. Both of the replacements follow the algorithms. In the first recommendation, the dataset has been taken of the same manufacturer as of the existing device. The second recommended replacement is taken from the dataset of the devices of other manufacturers. The comparative analysis of both replacements is carried out to determine which of the replacement is preferable.

- Device I to Device VII represents Scenario I with Device V switching capacity values at edge. Similarly, power consumption in Device VII is also at edge.
- Device VIII is representing the Scenario IV as per Fig. 2.
- Scenario II and III are not shown as they are simple rejection scenarios.

A. WORKING OF THE REPLACEMENT LAYER

The replacement details of the devices in each case study is shown in Table 4. Acronyms used in Table 4 are same as in algorithms and are summarized in Table 2. From Table 4, it can be seen that in all the replacements, some of the considered parameters are not changed. The improvement in each of the selected parameter is not mandatory. Therefore, it can be seen that the number of ports and RU of the proposed replacements are same as the existing devices in all case studies. The improvement in energy consumption and switching capacity are most important so that the replacement of device would result in energy efficiency of the network provided the RU, number and type of ports same as existing device. Table 4 shows the percentage improvement of both the parameters. Table 4 shows two different replacement recommendations for each considered device. One recommendation is from the same manufacturer as of existing device and the other from different manufacturer. From the table, comparative analysis of both replacements is also possible. Let us discuss each of the device presented in Table 4 below:

- Device I - Both switching capacity and power consumption are improved means the recommended replacements can transmit more bits in unit time in comparison to the existing device with energy conservation. However, replacement with different manufacturer shows higher energy improvement while switching capacity improvement rate is higher in replacement with same manufacturer.

TABLE 3. Existing devices in public sector real-world data center.

Device	Model	P (Watts)	C (Gbps)	CNEE (Watts/Gbps)	Qty	Annual Electricity Cost (USD)	Weighted Annual Electricity Cost (USD)
Device I	Cisco WS-C3560G-24TS-S	74	32	2.31	28	13582.46	380308.88
Device II	Cisco WS-C4948	300	96	3.12	15	55034.17	825514.05
Device III	Juniper EX2200-24P	470	56	8.39	10	86266.96	862669.6
Device IV	Cisco WS-C3560X-48P-S	715	160	4.46	2	131235.91	262471.82
Device V	Cisco WS-C3750X-48T-S	350	176	1.98	3	64206.53	192619.59
Device VI	Aruba 2530-24G (J9854A)	222.2	88	2.52	24	40761.97	978287.28
Device VII	Cisco WS-C3850-24T-S	350	92	3.80	71	64206.53	4558663.63
Device VIII	Cisco WS-C3560-24TS-S	45	8.8	5.11	7	8255.13	57785.91

TABLE 4. Existing devices and their proposed replacement options.

	Device	Model	P_N*	P_T	P (Watts)	Difference (%)	C (Gbps)	Difference (%)	SFP_N	SFP_T	RU	EOL
Device I	Existing Device	Cisco WS-C3560G-24TS-S	24	GbE	74	-	32		4	GbE	1	31-Jan-12
	Proposed Replacement (Same Manufacturer)	Cisco WS-C3650-24TD-S	24	GbE	70.1	5	88	175	4	1/10 GbE	1	31-Oct-20
	Proposed Replacement (Different Manufacturer)	Aruba 2530-24G (J9776A)	24	GbE	48	35	56	75	4	GbE	1	31-Oct-21
Device II	Existing Device	Cisco WS-C4948	48	GbE	300	-	96	-	4	GbE	1	01-Aug-12
	Proposed Replacement (Same Manufacturer)	Cisco WS-C3850-48T-S	48	GbE	127.24	58	176	83	4	1/10 GbE	1	31-Oct-19
	Proposed Replacement (Different Manufacturer)	Juniper EX2300-48T	48	GBASE-T	70	77	176	83	4 (optional)	1/10 GbE	1	NOT Declared Yet
Device III	Existing Device	Juniper EX2200-24P	24	GBASE-T	470	-	56	-	4	GbE	1	01-Feb-19
	Proposed Replacement (Same Manufacturer)	Juniper EX2300-24MP	24	GBASE-T	435	7	128	129	4	GbE	1	NOT Declared Yet
	Proposed Replacement (Different Manufacturer)	Cisco SG500X-24P	24	GBASE-T	432.9	8	128	129	4	10GbE	1	30-Apr-2023
Device IV	Existing Device	Cisco WS-C3560X-48P-S	48	GBASE-T	715	-	160	-	2 (optional)	10 GbE	1	31-Oct-16
	Proposed Replacement (Same Manufacturer)	Cisco WS-C3650-48PD-S	48	GbE	640	10	176	10	4 (optional)	1/10 GbE	1	31-Oct-20
	Proposed Replacement (Different Manufacturer)	Aruba 2540-48G (JL357A)	48	GbE	459	36	176	10	4 (fixed)	1/10 GbE	1	30-Apr-21
Device V	Existing Device	Cisco WS-C3750X-48T-S	48	GBASE-T	350	-	176	-	4 (optional)	10 GbE	1	01-May-16
	Proposed Replacement (Same Manufacturer)	Cisco WS-C3850-48T-S	48	GbE	127.24	64	176	0	4 (optional)	1/10 GbE	1	31-Oct-19
	Proposed Replacement (Different Manufacturer)	Juniper EX2300-48T	48	GBASE-T	70	80	176	0	4 (optional)	1/10 GbE	1	NOT Declared Yet
Device VI	Existing Device	Aruba 2530-24G (J9854A)	24	GbE	222.2	-	88	-	2	GbE	1	-
	Proposed Replacement (Same Manufacturer)	Aruba 6300M (JL662A)	24	GbE	81	63	448	409	4	1/10/25 GbE	1	-
	Proposed Replacement (Different Manufacturer)	Cisco WS-C3850-24P-S	24	GbE	88.32	60	92	4	4	GbE	1	31-Oct-19
Device VII	Existing Device	Cisco WS-C3850-24T-S	24	GbE	350	-	92	-	4	GbE	1	31-Oct-19
	Proposed Replacement (Same Manufacturer)	Cisco C9300-24T-E	24	GBASE-T	350	0	208	126	8	10 GbE	1	NOT Declared Yet
	Proposed Replacement (Different Manufacturer)	Aruba 6300M-24G (JL664A)	24	GBASE-T	64	82	880	856	4	1/10/25/50 GbE	1	NOT Declared Yet
Device VIII	Existing Device	Cisco WS-C3560-24TS-S	24	MbE	45	-	8.8	-	2	GbE	1	05-Jul-09
	Proposed Replacement (Same Manufacturer)	Cisco WS-C3650-24TD-S	24	GbE	70.1	(56)	88	900	4	1/10 GbE	1	31-Oct-20
	Proposed Replacement (Different Manufacturer)	Aruba 2530-24G (J9776A)	24	GbE	48	(7)	56	536	4	GbE	1	31-Oct-21

* The acronyms used in the table are defined in Table II.

- Device II - Both switching capacity and energy consumption are improved. Here, the improvement in capacity in both recommendations is same. However, replacement with different manufacturer will result in more energy conservation.
- Device III - In this case, energy conservation is small in both recommendations. Improvement in bit transfer rate is same in both replacement options.
- Device IV - In this case, the switching capacity improvement is small in both recommendations. More energy conservation can be attained when replaced with different manufacturer.
- Device V - In Device V, no improvements has been obtained in terms of switching capacity. energy conservation is high in both, however, replacement with different manufacturer is giving highly improved results.
- Device VI - The energy requirements are improved to approximately same extent in both replacement options. However, replacement with same manufacturer is giving huge increment in switching capacity whereas replacement with different manufacturer is providing negligible improvements in switching capacity.
- Device VII - In this case, no energy savings has been obtained in case of replacement with same manufacturer. Replacement with different manufacturer is giving high energy conservation. Switching capacity improvement is magnificently high in case of replacement with different manufacturer. Moreover, replacement with same

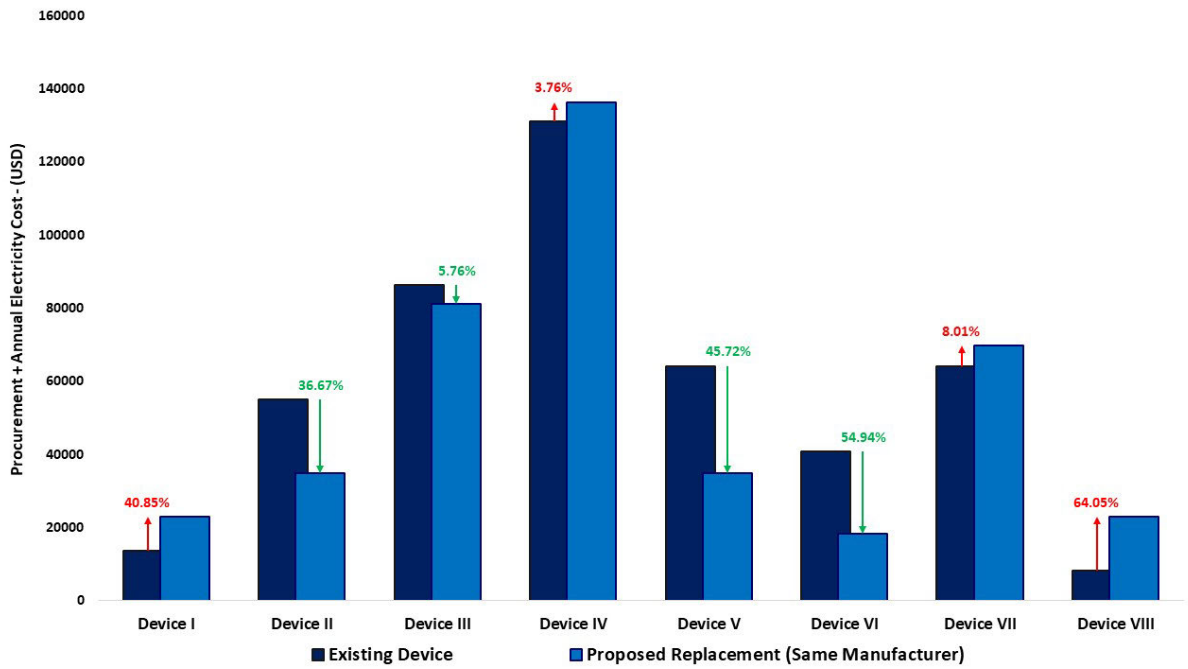

FIGURE 3. Procurement cost + annual electricity cost analysis of recommended replacement (same manufacturer).

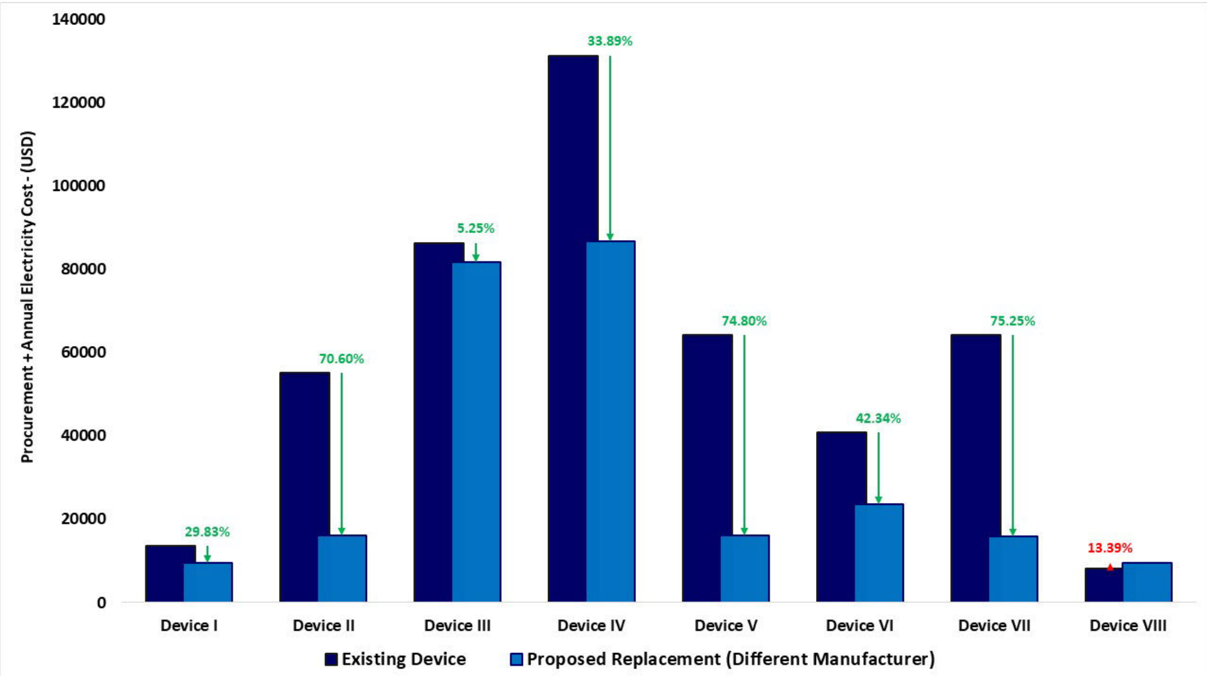

FIGURE 4. Procurement cost + annual electricity cost analysis of recommended replacement (different manufacturer).

manufacturer is also giving promising results in terms of switching capacity improvement.

- Device VIII - In this case, energy consumption will be increased in both recommendations instead of improvement. However, magnificently huge improvements in switching capacity is obtainable in both replacement options. Therefore, this case refers to Scenario IV as mentioned in Fig. 2.

B. WORKING OF THE VALIDATION LAYER

After the technical evaluation performed by the Recommendation Layer, Validation Layers inspects the recommended replacement form economical point of view. The cost analysis of the recommended replacement is performed. Fig. 3 and Fig. 4 shows the alteration in annual electricity cost due to replacement with same and different manufacturer respectively. From the figures, it can be seen that considering the replacement with the same manufacturer, the replacement will save cost in four cases whereas remaining four cases requires additional cost to be paid. However, considering the replacement of the total quantity of all the switches taken in the Case Study saves approximately 0.204 millions United States Dollar (USD). In case of replacement with different manufacturer, cost of only one device has increased as shown in Fig. 4. Therefore, in replacement with different manufacturer 4.810 millions USD can be saved. From the graphs in Fig. 3 and Fig. 4, it can be seen that overall the replacement of all considered devices will result in benefit. However, if only beneficial cases are taken into consideration, they will add more to the overall savings. In replacement with same manufacturer, replacement of four devices will contribute to cost saving whereas replacement with different manufacturer showing cost benefits in seven replacements. Therefore, considering only beneficial replacement, savings of 0.977 millions USD can be attained in case of same manufacturer and 4.818 millions USD in case of different manufacturer. It can be seen that the difference in savings while considering all replacements or considering only beneficial cases is less in different manufacturer as it has seven beneficial replacement out of eight devices.

Another validation strategy is the comparative analysis of energy efficiency in existing and replaced device. The evaluation is done through the known energy efficiency metric named Communication Network Energy Efficiency (CNEE) [29]. As we are considering performance in addition to the energy efficiency, therefore, communication metrics is more appropriate for analysis. Formal analysis of the chosen CNEE metric is performed in [30]. CNEE metric best suits the analysis as our work has details of the network devices only. CNEE is defined as the ratio of power consumed by the network device over the switching capacity of that network device as shown in equation (2). The units of the equation (2) used in [30] are Watts/bits/sec. Here, as the switching capacity of considered network devices are in Gbps, so we have considered CNEE as Watts/Gbps. In [29] and [31], CNEE is defined in Joules/bit. The minimization in the value of CNEE represents the improvements in energy efficiency.

The graph in Fig. 5 shows the change in power requirements for each Gigabit transfer before and after the device replacement. The energy efficiency attainment in each of the device is shown in the graph. From the analysis of the CNEE values, it can be observed that both parameters of the equation (2) are playing significant role in energy efficiency attainment. The little improvement in both the parameters can lead to high energy efficiency of the network. In Device I, both proposed replacements are saving 62% to 66% energy with variation in the power and switching capacity of both replacement options. In replacement with same manufacturer, power usage improvement factor is only 5%. However, 2.75 times increment in switching capacity results in approximately 66% of energy efficiency improvement. From the Fig. 5, it can be seen that in all the devices, CNEE has been improved when replaced with same manufacturer. Fig. 6 shows the improvement in CNEE when replaced with different manufacturer. From the figure, it can be noticed that in all devices, replacement with different manufacturer result in CNEE improvement. Therefore, it can be concluded that replacement is feasible in all cases with both same and different manufacturer. In addition to cost and energy efficiency improvement validation, improvement in number of bits transferred per USD cost is also validated. Switching capacity of the device is the maximum possible number of bits transferred in a unit time. The ratio of switching capacity over the USD cost required to transfer these bits are evaluated and comparative analysis of existing vs replaced device is performed. Fig. 7 and Fig. 8 are representing the comparative analysis of the bits transferred per USD of existing devices with recommended replacement with same and different manufacturer respectively.

There may be a contradiction between three validation results as can be seen in cost validation of four considered devices when replacement with same manufacturer. The cost analysis of Device I, IV, VII and VIII does not validate replacement, however other two validations accept the replacement. In such cases, we consider the aggregated result of all three validations and verify that replacement is feasible or not. Similarly, Device VIII is not validated as per cost analysis in case of replacement with different manufacturer. However, energy efficiency and bits transferred per unit cost per USD are well validated. Therefore, replacement is considered as feasible. Summary of results obtained from the case study related to the implementation of proposed model is presented in Table 5. From the table, it can be seen that replacement with same manufacturer will require a little budget but it leads to conserve two-third of the energy consumed by existing devices. The performance of the network will also be more than twice of the existing performance. Replacement with different manufacturer is seen to be highly cost effective as well as huge gain in energy conservation and performance enhancement can also be observed.

V. COMPARATIVE ANALYSIS OF DIFFERENCE BETWEEN REPLACEMENTS (SAME VS DIFFERENT MANUFACTURER)

In this study, it can be noticed that two replacements are performed for each considered device. One replacement is with the device of same manufacturer as the manufacturer of existing device whereas the other replacement is with the device from different manufacturer. Fig 9 shows the differences in the cost improvements of both proposed replacements. From the figure, it can be noticed that except Device VI, all the replacements with different manufacturer are more cost saving. The savings in Device III in both replacements are approximately same and replacement with same manufacturer is only 0.54% more than the replacement with different manufacturer. From Table 4, it can be observed that the manufacturer in case of Device VI is Aruba/HPE. The replacement in case of Device VI with the same manufacturer is 22% more beneficial as compare to the other replacement option. In other four cases, replacement with different manufacturer

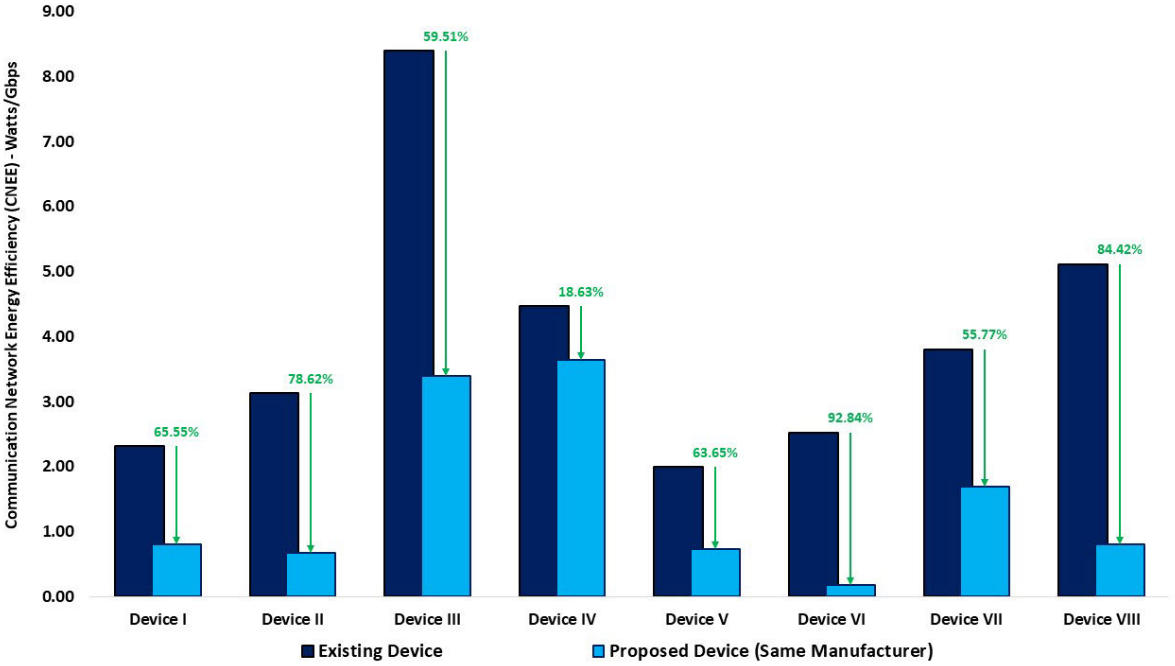

FIGURE 5. Energy efficiency analysis of recommended replacement (same manufacturer).

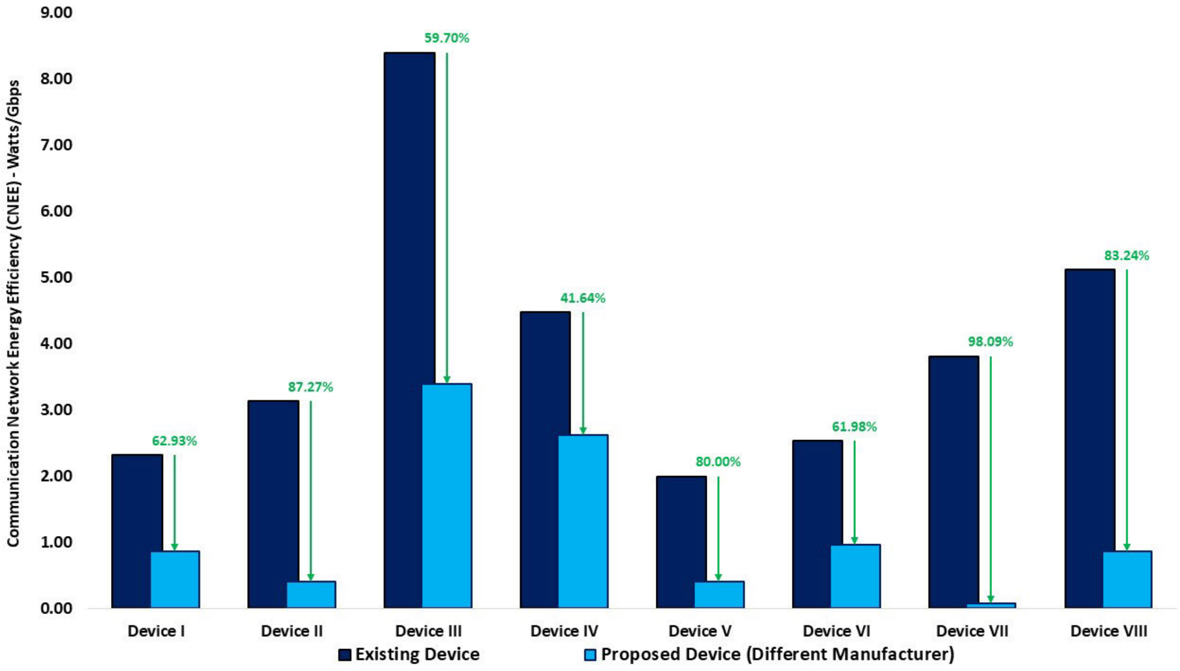

FIGURE 6. Energy efficiency analysis of recommended replacement (different manufacturer).

is better as also shown in Fig. 9. The different manufacturer in these four cases is Aruba/HPE. Therefore, it can be concluded that Aruba/HPE devices are more cost effective as compare to Cisco devices.

Similarly, comparative analysis of the energy efficiency improvement using same and different manufacturers is also performed and shown in Fig. 10. From Table 4, it can be seen that replacement with different manufacturer in Device I, power usage improvement is 35% which is huge as compare to the improvement in replacement with same manufacturer. However, the switching capacity only improved 1.75 times. Therefore, overall energy efficiency is approximately 63%

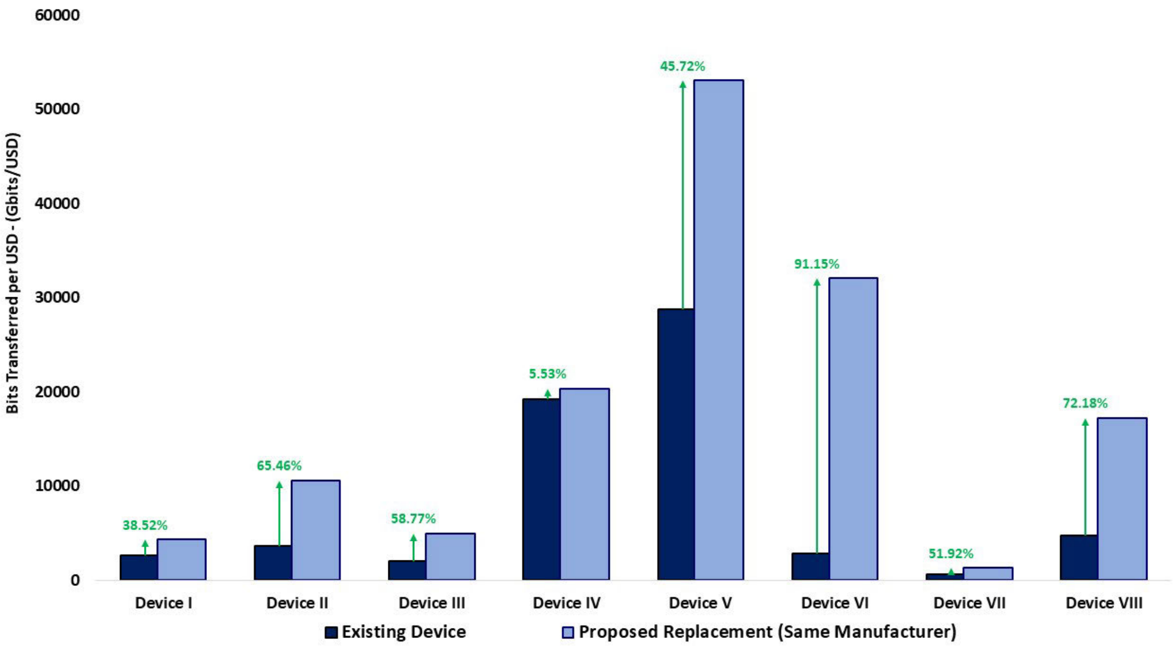

FIGURE 7. Analysis of bits transferred per USD of recommended replacement (same manufacturer).

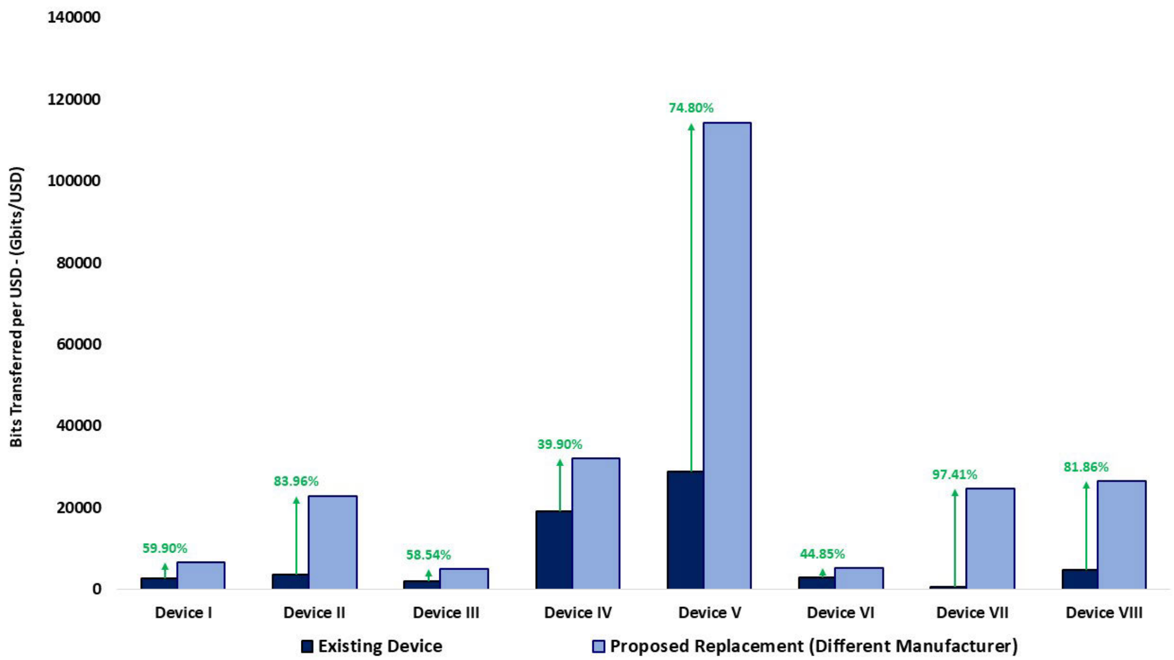

FIGURE 8. Analysis of bits transferred per USD of recommended replacement (different manufacturer).

which is comparable to energy efficiency obtained in replacement with same manufacturer. Huge improvement in energy consumption is also achievable with extensive improvement in single parameter. It can be seen in Device IV that switching capacity improvement is only 10% in both replacement options, however, 42% of the energy efficiency is attained with 36% improvement in power consumption. The other replacement option offers only 19% of energy efficiency as the improvement in power consumption is only 10%. Similar patterns can be observed in Device VIII with alteration in parameters. In Device VIII, switching capacity has been greatly enhanced in both the replacement options resulting in

TABLE 5. Summary of replacement results in both options.

	Power Saving (%)	Performance Enhancement (%)	Cost Reduction (%)	Energy Efficiency (%)	Bits/USD (%)
Same Manufacturer	15.07	203.23	(0.66)	66.35	57.35
Different Manufacturer	60.87	433	54.32	81.41	77.45

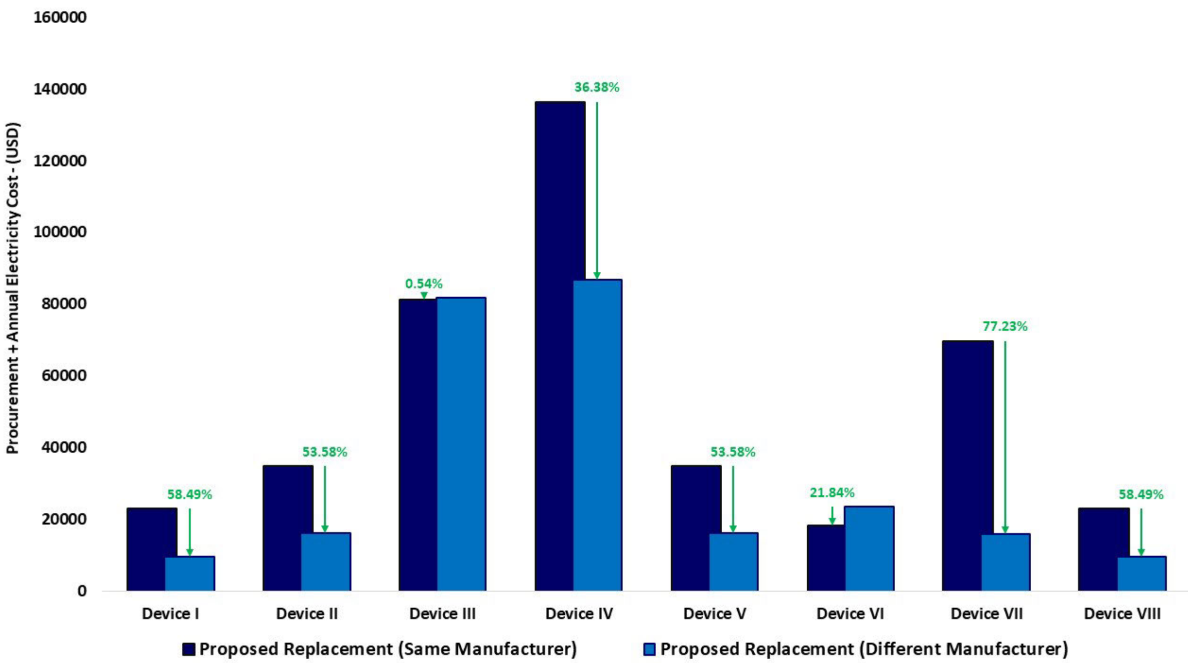

FIGURE 9. Comparative cost analysis of recommended replacement (same vs different manufacturer).

more than 80% of energy efficiency. In Device VI, the power consumption reduction is fairly same in both replacement options. However, as the replacement with same manufacturer is offering 05 times more switching capacity as compare to the switching capacity of the device of different manufacturer. Therefore, it can be seen that the replacement with same manufacturer is giving 93% energy efficiency while only 62% of the energy efficiency is obtainable with other option. Similar patterns can be observed in case of remaining devices.

Comparative analysis of third validation parameter that is number of bits transferred in unit time in unit cost has also performed between replacement with same and different manufacturer. From Fig. 11, it can be noticed that except Device VI, all the replacement with different manufacturer are more beneficial in terms of bits transferred in unit in unit cost. In Device VI, the exiting manufacturer is Aruba/HPE. The different manufacturer in four cases where different manufacturer is more beneficial as compare to same manufacturer is also Aruba/HPE.

From the comparative analysis of replacement with same and different manufacturer of all the validations show that Aruba/HPE is good option for achieving energy efficiency of data center networks with optimized performance and cost. Due to Aruba/HPE consideration as a replacement of Cisco switches, it can be observed from Table 5 that replacement with other manufacturer can give 34% more energy efficiency as compare to replacement with same manufacturer. Similarly, replacement with different manufacturer suggests 46% more power conservation in comparison to replacement with same manufacturer. Moreover, more than twice performance enhancement is also achievable when replaced with different manufacturer in contrast to replacement with same manufacturer. Replacement with different manufacturer will also perform 50% more cost reduction as compare to replacement with same manufacturer. Approximately 34% more bits at unit USD cost can be transferred if different manufacturer is chosen as replacement. Therefore, it can be concluded that change of manufacturer can greatly alter the cost, energy as well as performance statistics.

VI. COMPARATIVE ANALYSIS OF PROPOSED MODEL WITH EXISTING TECHNIQUES

The proposed network refresh model is first of its kind, therefore, no existing model is found in literature that is based on same technique. However, there are many different

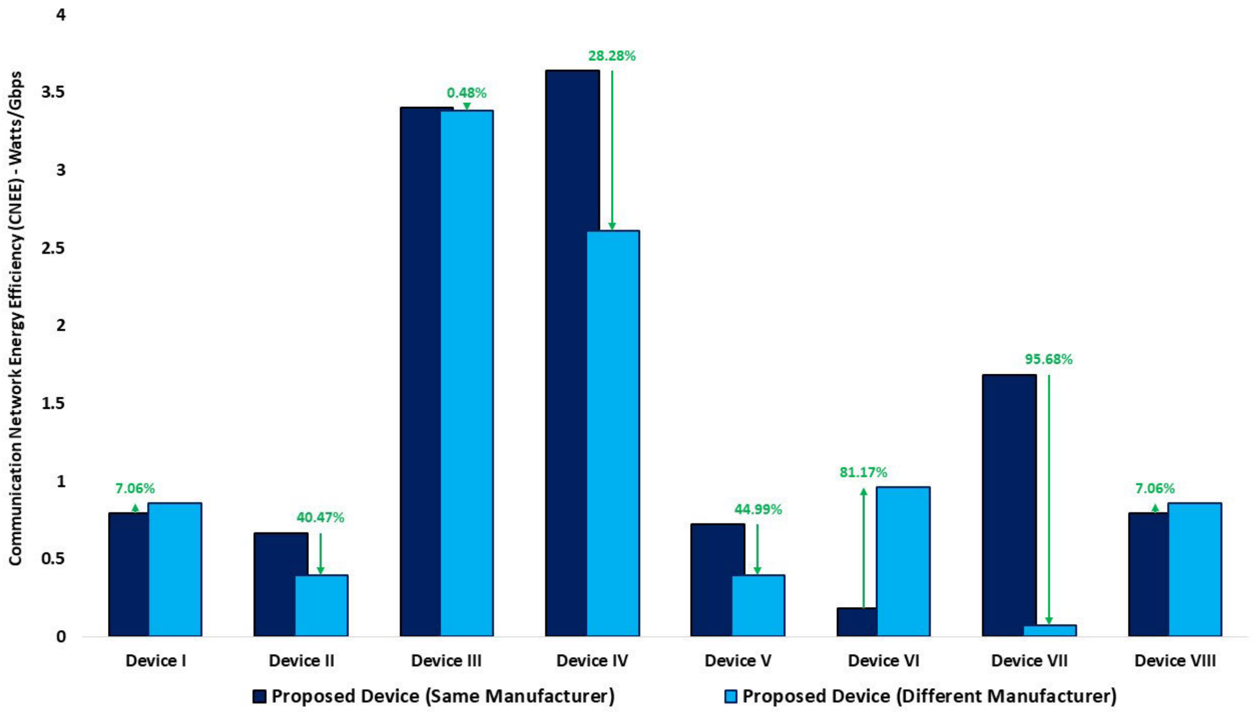

FIGURE 10. Comparative CNEE analysis of recommended replacement (same vs different manufacturer).

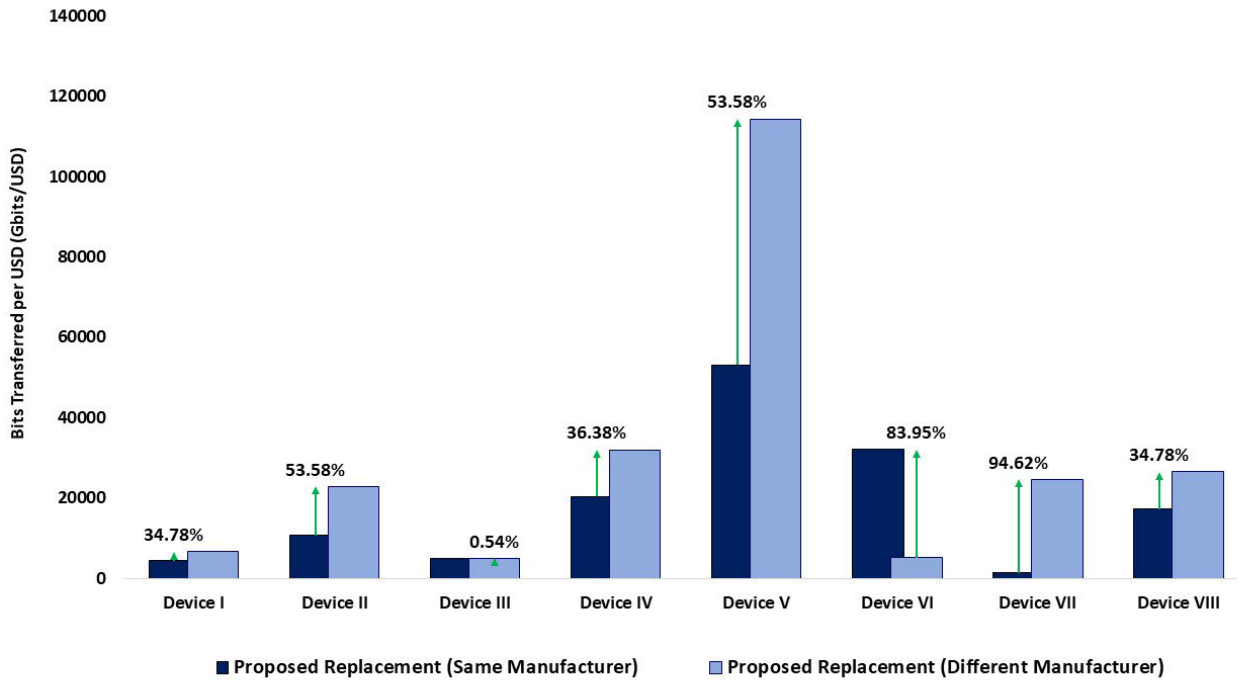

FIGURE 11. Comparative analysis of bits transferred per USD of recommended replacement (same vs different manufacturer).

network energy efficiency techniques and data center energy efficiency techniques are available in literature. A comparative analysis among existing network/data center energy efficiency techniques is presented in Table 6. From the table, it can be seen that considering both replacement options, proposed model is performing better among all existing techniques in terms of energy efficiency and power enhancement. However, little investment is required in case of replacement

TABLE 6. Comparative analysis with existing energy efficiency techniques.

Technique	Energy Efficiency (%)	Performance Enhancement (%)	Cost Reduction (%)
HeporCloud [21]	45.61	17.9	N/A
CDEERS [22]	51.1	9.6	N/A
EEQoS [23]	(3.8)	40.5	31.4
EPERCS [24]	11.9	5.5	N/A
CAPRO [25]	50	(0.67)	N/A
Proposed Model			
Same Manufacturer	66.35	203.23	(0.66)
Different Manufacturer	81.41	433	54.32

with same manufacturer. Replacement with different manufacturer is giving better results in terms of energy efficiency, performance enhancement and cost effectiveness too.

VII. CONCLUSION

In this study, we have proposed an algorithm that performs the replacement of network device to make data center energy efficient. A case study of real world data center's devices has been performed for the evaluation and validation of the algorithm. The algorithm recommends the replacement when comparative exploration of parameters show energy conservation as well as switching capacity improvement. Results also show that switch replacement can lead to attain energy efficiency without investing into huge budgets. The comparative analysis of multiple recommended replacements is also presented. The validation of the replacement is performed through cost impacts of replacement in addition to energy efficiency and performance analysis. In case of contradiction among three performed validations, the percentage that has greater value either in support or against replacement will be selected as can be seen in four devices (Device I, IV, VII and VIII) when replaced with same manufacturer and in one (Device VIII) with different manufacturer. The purpose of the multiple proposals is to emphasize that the selection of appropriate manufacturer is also very important for achieving the target of sustainable data centers. The difference in the energy reduction with the replacement of devices with the same and different manufacturer is also investigated.

VIII. LIMITATIONS AND FUTURE WORK

This work is limited to switches only. As it is noticeable from the case study that huge portion of DCNs comprises of switches only, the proposed model can cover major portion of the DCNs. However, consideration of other network equipment is planned in future. Another limitation of this study is its implementation to three manufacturers only. However, it can be seen from the analysis of various data centers, it is obvious that the major share of the switches in data centers comprise of these selected manufacturers. Moreover, consideration of few manufacturers is beneficial from economic feasibility point of view. Energy efficiency can be obtained by applying the proposed model to a portion of network. It is not always feasible to replace all switches of the data center. However, energy conservation along-with performance enhancement can be obtained by applying network refresh to few equipment only. Another limitation of the study is the limited number of parameters used for technical evaluation of replacement.

Future work includes consideration of additional devices other than switches. The effect of the type of networking devices (for example; security devices, firewall) over the energy consumption of data center network will also be carried out. Moreover, additional parameters of data center networks QoS can be included along-with switching capacity for more appropriate recommendations. Similarly, additional costing factors of replacement policy may also be included in the algorithm to achieve further refined replacement recommendations.

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