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Comparison of Software-Defined Networking based Energy-Aware Routing for Data Center Architectures

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ABSTRACT: Energy consumption has increased drastically with increase in the size of Data centers. Most of the energy consumed in a network is not completely used for network functions alone. Hence, new techniques should be adapted to use energy efficiently. Software-defined Networking is a networking architecture where the network control including routing is detached from the forwarding hardware device present in the network infrastructure and is placed as a programmable software called the SDN Controller. There are many advanced architectures for Data center network which employ multi-path routing. They try to provide better performance and high network capacity. But these routing techniques do not consider the network energy consumption. Energy-aware techniques are proposed recently which use power efficiently resulting in reduced network energy wastage and increased resource utilization. In this paper, we present our work where we have implemented an Energy-aware routing technique based on Software-defined networking for different data center architectures and the results were compared.

KEYWORDS: Software-defined Networking, Energy-aware routing, Data center architectures, routing and topology.

I. INTRODUCTION

In the past decade, size of Data centers has increased rapidly with the advent of cloud computing. This has resulted in heavy power consumption and carbon footprint. One of the statistics show 1.5% of the global electricity consumption was from data centers [1]. Due to this, there is restriction to the growth of cloud services. This is affecting the world economically and environmentally. Most of the communication in internet might happen through huge data centers in the future [2]. Hence, more energy efficient data centers have to be created.

A Data Center is cluster of large number of computing resources connected together as a network to host applications and data storage [3]. As the number of components increases, the way the network is connected becomes complex. The data center network architecture is a very important part of data center design which can be called as a communication backbone [3]. Recently this field of design is receiving research interests [4]. The traditional architecture for data centers is the tree based three-tier architecture. Many research works have been carried out to develop more efficient data center architectures like Fat-tree architecture, BCube architecture, Dcell architecture etc. Some of the major issues in these architectures are: scalability, fault tolerance, bandwidth utilization, automation of address allocation and naming etc. [3]. Some of these issues can be overcome with the use of Software-defined Networking.

Software-defined Networking (SDN) is an evolving architecture which tries to make the network easily manageable and cost effective [5]. SDN takes the networking infrastructure to the next level. SDN moves the network control to a centralized external control unit. Hence this architecture used along with the traditional data center network architectures can enhance the network structure and its functioning.

Though these architectures enhance the network's performance, they don't concentrate on the energy consumption part. All the energy consumed by resources are not effectively used for the network functions alone. Energy is wasted in all these structures leading to low utilization of the resources. To overcome this issue many Energy aware techniques are

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introduced based on flow, bandwidth, packet size, time etc. [6-11]. These Energy-aware routing techniques can be used to increase the utilization of resources.
In this paper, we present our work that involves

- Implementation of an Energy-aware routing technique called EXR into a Software-defined Networking controller and comparing the results with fair-sharing scheduling technique.
- Incorporating this Controller into different data center architectures and comparing the results.

II. RELATED WORKS

- Naeimeh et al. [6] proposed the idea of using redundancy elimination (RE) in energy-aware routing. According to this technique the RE decides which router to be used and which router to be deactivated to save energy.The results show the proposed solution saves energy efficiently.
- Al-Fares et al. [7] proposed a dynamic flow scheduling scheme, i.e., Hedera,it is used in data center networks multi rooted hierarchy. This technique helps in better utilization of the links without affecting the control of the network.
- Wilson et al. [8]presented a deadline-aware control protocol, called D3, this technique can control the transmission rate of network flows based on their deadlines. Results show that latency of mice flows can be improved efficiently. It also increases the transmission rate.
- Hong et al. [9]proposed a preemptive distributed quick flow scheduling pro- tocol, i.e., PDQ, this technique aims at minimizing the average completion time of the flows in the work within their deadline.
- Youssef et al. [10]proposed an energy-aware routing protocol that aims to improve the throughput and minimize the energy consumption. The algorithm was successful in choosing the shortest path improving the performance.

III. DATA CENTER NETWORK (DCN) ARCHITECTURES

DCN architecture is an important part of data centers [3]. This determines the performance and throughput of the data

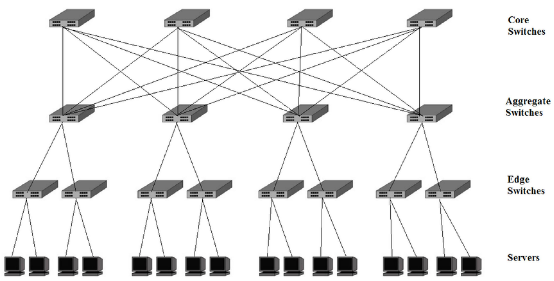

Fig 1 Three-tier Data center architecture

centers. An analysis shows that 70% of communication in a network happens within the data centers [12]. Different Data center architectures can have different objectives based on bandwidth, throughput, power consumption etc. For our study, we concentrate on fixed topologies like the traditional tree based three-tier architecture, Fat-tree architecture and the BCube architecture.

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A. THREE-TIER ARCHITECTURE

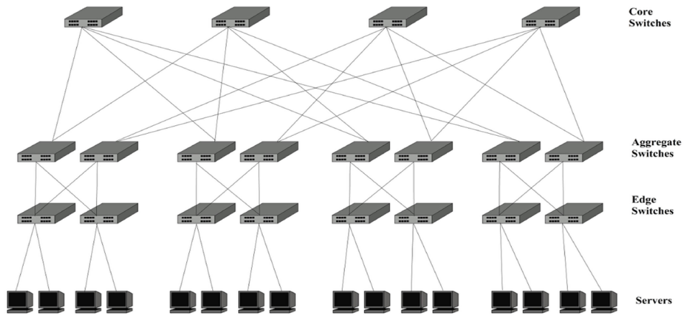

Fig 2 *Fat-tree Data center architecture*

In a Three-tier architecture as shown in the figure 1, there are three levels of switches namely core level, aggregation level and edge level. The core level is at the root of the tree followed by aggregation level and the edge level. The edge level switches are connected to the servers. All the core level switches are connected to all the aggregation level switches. No two switches are directly connected in the same level or from non-adjacent levels [4]. The higher levels have high-end switches to enable better performance and reliability. But these high-end switches are expensive. Hence, this architecture is not cost effective.

B. *FAT-TREE ARCHITECTURE*

n/2 ports of edge switches are connected to the servers. Fat-tree architecture comprises of n number of cells called pod
A Fat-tree architecture is a modified version of traditional tree topology and it has the same three levels- core, aggregate and edge [13]. Consider n is number of ports in each switch of the edge level. (n/2) switches which form the aggregation level are connected to these edge level switches. The remaining formed by the (n/2) aggregate switches, (n/2) edge switches and the servers. The core level consists of $(n/2)^2$ n-port switches. Each of these core level switches connect to the n-pods in the Fat-tree [3, 13]. The Fat-tree architecture for n = 4 is as shown in figure 2. This architecture was mainly developed to overcome the cost factor in data centers. The high-end switches present in three-tier architecture are replaced by higher number of low-end switches and all the switches in the network are of the same kind.

C. BCUBE ARCHITECTURE

BCube [14] is a recursively constructed structure. BCube consists of units called $BCube_0$. This is recursively built to create $BCube_k$ consisting of k levels. $BCube_0$ consists of an n-port switches and n servers. Every server is connected to one of the switches in higher levels. While constructing higher levels of BCube, n-extra switches are added and these switches are connected to one server in each of the lower level BCubes [15]. This architecture was specially designed to support portability. Though the deployment time is less, service time for the network is high. An example is shown in figure 3.

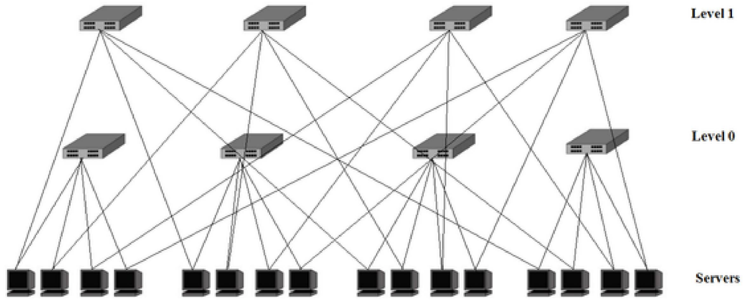

Fig 1 *BCube Data center architecture*

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III. SOFTWARE-DEFINED NETWORKING

Software-defined networking (SDN) is an evolving networking technology that gives hope to overcome the limitations of current network infrastructures. Traditionally, the data and control components reside inside the networking devices. SDN separates them and places the control into an external element called the SDN Controller. The Controller is a centralized independent unit which leads to simpler policy enforcement and network configuration and evolution [16].

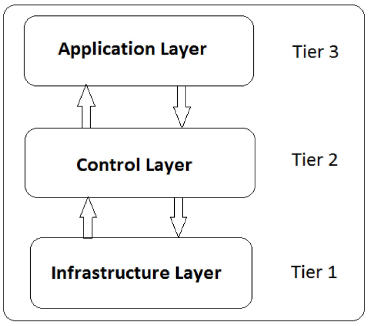

Fig 4 *SDN three-tier architecture*

SDN can logically be depicted as three tier architecture as shown in figure 4 [17].

- Infrastructure Layer (Tier-1): This layer consists of all the networking devices such as switches, routers, middle boxes etc.
- Control Layer (Tier-2): The Control layer consist of the control unit called the Software-defined networking Controller. It is also called Network operating system.
- Application Layer (Tier-3): The Application layer consists of all the network applications and services that access the network devices through the Controller.

SDN has two APIs to connect these layers. The Northbound API is the interface between the application layer and the control layer. There is no standard northbound interface. Most commonly used northbound APIs are NOSIX and SFNet. The Southbound API is the interface between the data plane and the control plane. Two of the most well-known protocols are OpenFlow and OpenvSwitchDatabase (OVSDB) [16]. The OpenFlow protocol provides information about the flow and links for the controller. Based on these features, the Energy-aware technique is implemented into the controller

Benefits of Software Defined Networking

- It separates the control and data structures.
- The network is less error prone to modifications.
- New high level policies can be implemented easily because of the controller
- The controller has global knowledge of the network.
- The network control is granular.

IV. ENERGY-AWARE ROUTING

The energy consumed by an active switch depends on two parts. The fixed part being the power consumed by hardware components like chassis, fans, switching fabrics, etc. which is constant and the dynamic part which is the power consumed by the ports in a switch which is variable. The ports can enter sleep mode when not used and when all the ports of a switch are in sleep mode, the switch can be put to sleep. This way energy consumption can be reduced [18].
In general, most of the energy-aware techniques try to reduce the number of active switches by allotting more traffic to fewer switches and letting other switches to sleep. This results in sharing of bandwidth among the flows. This kind of routing is called Fair-Sharing Routing (FSR). [19] Though this is an efficient technique, throughput is affected due to

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bandwidth sharing. Hence, we consider an energy-aware routing technique called Exclusive Routing (EXR) proposed by Li et al. [18].

EXR modifies the SDN Controller to provide exclusive routing to all the flows i.e. at a time only one flow uses the link [15]. The flows are divided into active flows and suspended flows. Whenever a new flow arrives or an active flow ends,

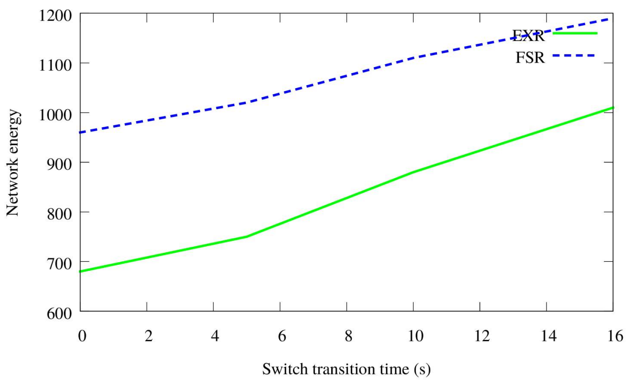

Fig 5 Network energy vs. Switch transition time for Three-tier Data center architecture

the EXR function is triggered. The switches report to the controller about the flows. The controller runs the EXR scheduling technique and updates the flow sets for every trigger. The EXR has three functions [18]:

2 Path calculation: this function is responsible for calculating the idle path for every flow that arrives.

3 Schedule Suspend: this function is responsible for allotting the path to the flows depending on priority.

4 Select Preemption: this function determines which path to preempt depending on priority.

This technique allots the link only to one flow at a time hence there is no fight for bandwidth among the flows. When a port is not in use, the port is put into sleep mode. When all the ports are idle, the switch is put into sleep mode. This way resource utilization is increased.

V. SIMULATION EXPERIMENT

A. SIMULATION TOOL

We have used Ns-3 simulation tool to implement all the concepts. The Ns-3 simulator is a discrete-event based network simulation tool. It supports OpenFlow protocol which is necessary to implement the concept of Software-defined networking. It supports the simulation of all the data center networks we have considered. We have used OpenvSwitch instead of the normal switches. OpenvSwitch is especially for OpenFlow protocol. Ns-3 provides in-built controllers and as well supports external controllers. Ns-3 provides a GUI tool called netanim for the animation. GNUplot is used for plotting all the graphs.

B. SIMULATION RESULTS

All the three architectures are implemented along with the SDN controller and the Energy-aware routing technique. The following graphs show the results on different parameters for all the three architectures.

Figures 5 shows the comparison of EXR and FSR for network energy consumed against switch transition time in Three-tier architecture.

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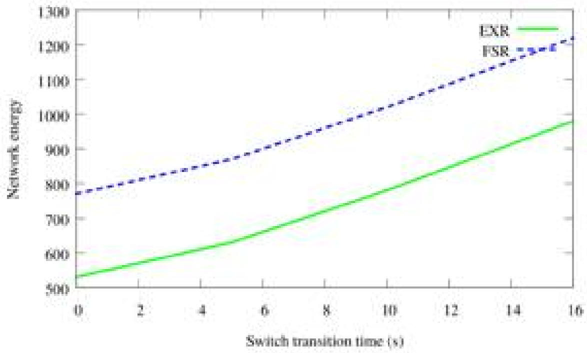

Fig 6 Network energy vs. Switch transition time for Fat-tree Data center architecture

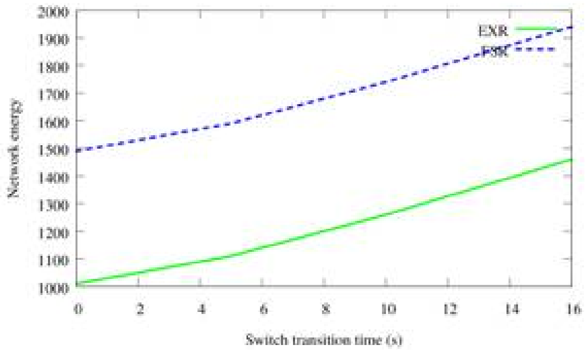

Fig 7 Network energy vs. Switch transition time for BCube Data center architecture

Similarly, Fig 6 and Fig 7 show the results for Fat-tree and BCube respectively. It is clearly seen that FSR consumes more network energy compared to EXR. For BCube architecture the difference between FSR and EXR is considerably high compared to Three-tier and Fat-tree architecture.

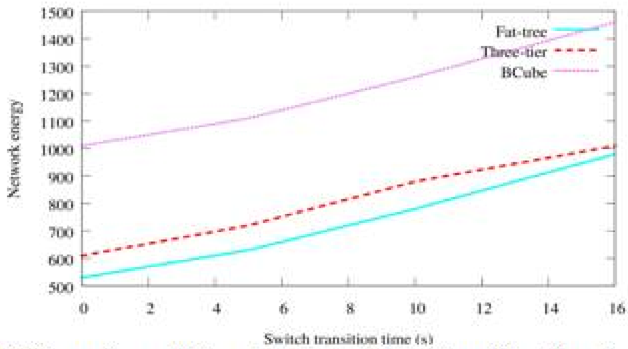

Fig 8 Comparison of Network energy vs. Switch transition time for Data center architectures

Figure 8 shows the comparison of the network energy consumed against the switch transition time for all the three architectures. From the graph it is evident that Fat-tree architecture consumes less energy compared to BCube and Three-tier.

Figures 9, shows the comparison of EXR and FSR for network energy consumed against the flow arrival rate in Three-tier architecture.

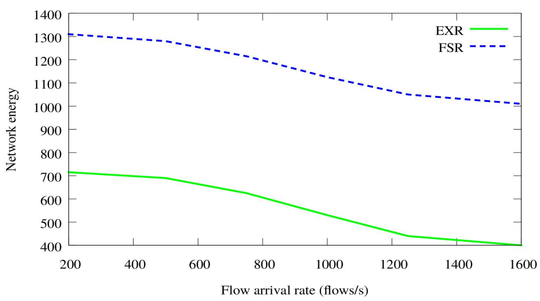

***Fig 9** Network energy vs. Flow arrival rate for Three-tier Data center architecture*

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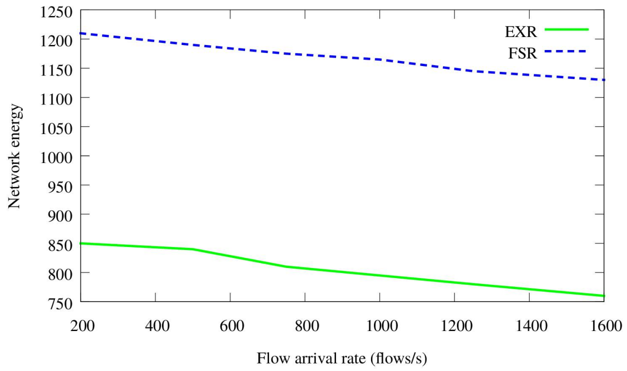

Fig 10 Network energy vs. Flow arrival rate time for BCube Data center architecture

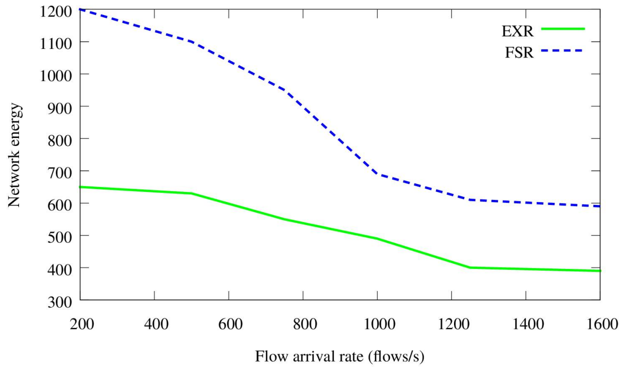

Fig 11 Network energy vs. Flow arrival rate for Fat-tree Data center architecture

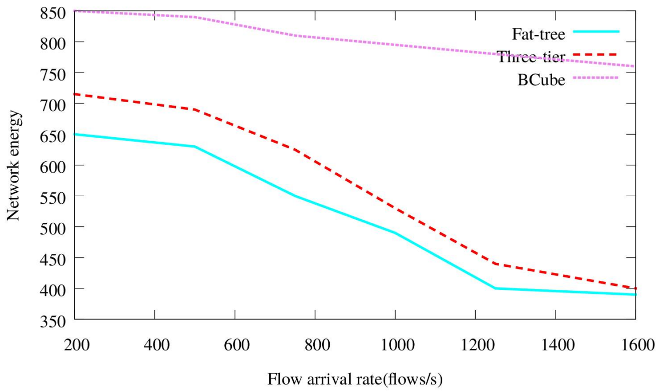

Fig 12 Comparison of Network energy vs. Flow arrival rate for Data center architectures

Similarly, Fig 10 and Fig 11 show the results for Fat-tree and BCube respectively. From these three graphs we can infer that FSR consumes more energy compared to EXR. As the flow rate increases, the network energy is reducing because the resource utilization value is increasing due to more number of active ports. Hence, when all the resources are utilized to their fullest, the power wastage can be reduced. Even in the case of flow arrival rate, for BCube architecture the network energy difference between FSR and EXR is considerably high compared to Three-tier and Fat-tree architecture. gure 12 shows the comparison of the network energy consumed in all the three architectures against the flow arrival rate. From the graph it is seen that Fat-tree architecture consumes less energy compared to BCube and Three-tier.

VI. CONCLUSION

Software-defined networking can solve most of the issues related to network control in the traditional networking. Data centers can incorporate SDN to improve their performance. Energy-aware routing based on SDN reduces the energy consumption considerably because when the switches are put to sleep mode, the energy usage related to hardware is eliminated. From the results, we can conclude that Fat-tree architecture consumes less energy compared to Three-tier

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and BCube. Research can be carried out to find more efficient Energy-aware routing techniques that can bring about green revolution in large data centers.

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