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Research paper

Green SDN: Trends of Energy Conservation in Software Defined Network

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Abstract

Because of the exponential growth of the data in the Internet, storing and computing the data become a challenging issue. Therefore the data center networks are used to provide the infrastructure for storing and computing the data. Most of the network devices present in the data center network is comparatively idle for most of the time and resulting in a waste of energy. To overcome it, the Software Defined Network is proposed which allows the administrators to manage the network devices using a centralized controller and enables programmable network devices. It optimizes the utilization of network resources efficiently and results in significant amount of energy saving. There are several approaches proposed for optimizing the energy in the Software Defined Network which takes a network towards green energy and lower carbon print. This paper presents a survey on energy conservation techniques used in the software defined networks which makes the networks more capable and productive. We also provide a brief comparison of possible energy conservation techniques and guidelines for future research.

Keywords: *Dynamic resource allocation, Energy conservation, Green SDN, Power management, Software defined network, Traffic engineering.*

1. Introduction

As usage of Internet has been incrementing day by day in recent years, there should be a better coordination among the network devices connected with internet because of their distributed network control. For example, today's the network devices such as switches and routers maintain a table locally which helps them in forwarding the data traffic to other network devices. The routing protocols like spanning-tree, OSPF and BGP distributed over the network follow the same rules/polices as defined by the protocol standard to take the traffic-forwarding decisions. Therefore these traditional networking protocols limit with flexibility, little room for creativity and difficulty to implement the coordinated strategy among the network devices. Hence Software Defined Networks(SDN) is proposed to control the network devices by running the software on centralized controller [4]. SDN provides more flexibility by adding new rules/policies to the network devices dynamically in the form of network applications and allows network engineers to implement flexible forwarding policies in the switches and routers. Since traffic in the network is not uniform always, some of the network devices such in the SDN are idle and consumes some energy [9]. Therefore it is necessary to have global view on network to control the power states of the network devices in SDN effectively.

Therefore in this paper, we present a survey on energy conservation in the SDN and rest of the paper is organized as follows. In section 2, the overview of SDN is presented and in section 3, the importance of energy conservation in SDN is given. In Section 4, various energy conservation techniques proposed for SDN are described and the comparison is provided. Section 5 discusses about the challenges of SDN in ICT and 5G and finally we conclude the survey in the section 6.

2. Overview of SDN Architecture

The idea behind the SDN has been evolving since 1990s by introducing programmable network such as OPENSIG, Active Networking and DCAN which propose the techniques that enable the control of network interfaces, switches and management layer respectively [5][15]. Many techniques similar to SDN have been proposed in 2000s. NetConf is an example for SDN like technique that can be used to install, change and delete the configuration of the network devices based on the requirements. The general architecture of SDN consists of three layers: Infrastructure layer, control layer and application layer. The infrastructure layer is also called as data plane which includes all the forwarding elements of the network and it is responsible for forwarding/monitoring the data. The control layer is also called as control plane which manages the various operations like routing as per the user's requirement and network requirements. It provides a platform for software controller which communicates with the various forwarding elements of the network in the data plane. The application layer receives global view and abstracted view of the network and uses this information to set the rules/polices/guidelines to control plane. It also contains network applications that introduce the security, manageability, traffic-control etc. There are two interfaces known as northbound interface and southbound interface which is set between application-control layer and control-infrastructure layer respectively. Through these interfaces, the rules/policies are informed to the adjacent layers.

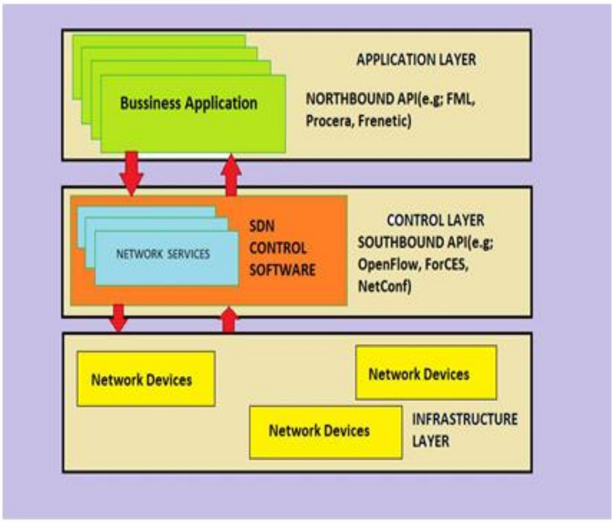

Fig. 1: A three-layer software-defined networking (SDN) architecture

3. Importance of Energy Conservation

The information and communication technology (ICT) undergoes a phenomenal growth from 1G to 5G leading to rise in energy consumption as shown in Fig 2. It results in increasing of carbon dioxide levels in the atmosphere which has 5% share in global carbon dioxide and this percentage rises in fast pace due to increasing number of network devices like servers routers and switches[7]. For a switch, the shielding of a port brings out 1-2 watt of energy savings and switching from empty load to full load results 8% increase in energy consumption. Therefore controlling of network devices becomes a urgent need in ICT which is possible by means of SDN. If the network is completely controlled by the SDN controller, then 50% of energy is saved as compared with traditional network. If the network is partially controlled by the SDN controller i.e. partially deployed SDN, then 40% of energy is saved when there is 60% of SDN nodes in the network.

Fig. 2: Level of carbon dioxide with varying technologies

4. Energy Conservation Techniques

Many techniques have been proposed in the past which could be used to save the energy in software defined network. In this paper, we classify the energy conservation techniques into the following categories:

1. Based on controlling the behavior of switch
2. Based on dynamic resource allocation
3. Based on power management
4. Based on traffic engineering

1) Based on controlling the behavior of switch: The links in the internet is not fully utilized most of the time. For example, only 30-40% of the links in backbone networks of internet service provides is utilized always. But it consumes about 95% of the power compared to 100% link utilization. In order to avoid the unnecessary power consumption, the switches and links is made into off state based on the link utilization. An OpenFlow protocol is used to control the switches and links in SDN. It controls the openflow switch and the traffic in the link by adding, deleting and modifying the flow entries in the flow table. It also helps the openflow switch to have a secure channel with opeflow controller. When a switch in the SDN is turned on or a link in the SDN is made from idle to full utilization, additionally 8% of power is consumed. Therefore it is necessary to have fast restoration of traffic in a switch and link quickly.

Fast restoration of traffic in a link is achieved by a centralized controller using openflow protocol. But due to its dependency on a centralized controller, it is difficult to achieve the restoration in large networks. So a very specified and simple topology with low load can be used during which some of the links can be turned off [14]. The problem in switching off the unutilized link subject to controller load, average node-to-controller propagation delay and maximum number of nodes attached with controller within latency bound. K-Critical algorithm [2] is used to find the minimum number of controllers that satisfies delay, latency and route convergence. In [12], control logic is proposed which moves to one or more centralized controller in order to minimize propagation delay between switches and controllers resulting in energy savings of up to 55% during off peak times.

2) Based on dynamic resource allocation: Data center network (DCN) is a infrastructure with fully clustered equipments, storage, network devices etc. which are used for online applications and computations. There are about 33 million physical servers deployed inside data centers around the world [20]. The statistic report given in [10] shows that data centers use 1.5% of world-wide usage of electricity and the power consumption of network devices inside a data center is about 10-20% of overall consumption [10]. The majority of network devices in data centers are relatively idle resulting in a waste of energy [17]. Further it is a big challenge to manage the network traffic, links and bandwidth efficiently among the network devices in data centers. The issue of network resource management in DCN is solved by SDN because it provides programmable control plane and data plane with help of SDN switches and SDN controller. Generally The SDN controller communicates with DCN via its northbound APIs for interactive network management in a centralized way [15].

The author of [17] proposes an energy saving algorithm for data centers. The energy conservation is achieved through preprocessing the traffic SDN and centralized management of network devices. The traffic processing module of the algorithm deals with network traffic based on current network load collected from the controller and use minimum number of network devices to meet the current demand. The device control module of the algorithm shuts down the idle devices to achieve better energy efficiency. In [10], a multi path routing called Exclusive Routing (EXR) is proposed which provides the flexibility to administers to define the priorities of flow based on the size of flow, flow deadline etc. It results in effectively saving network energy compared with fair sharing routing. Even there are many energy-aware algorithms for SDN, flow scheduling, aggregation of data traffic by choosing the routing paths flexibly and fairly sharing the link bandwidth are still a challenging issues in SDN.

The computation plays an increasingly important role in the future generation of computer and communication network. The computation of resource in SDN, C-RAN (Cloud-Radio Access Network) and MCC (Mobile Cloud Computing) are provided as a cloud pool consisting of computing node, CPU, storage and network switch etc. These resources are controlled in a centralized manner with help of virtualization so that the resources are made into dynamically configurable, scalable, sharable and re-allocable on demand [19].

3) Based on power management: The overall energy saving of a network depends on the extent to which the power management techniques are successful in implementing the sleep mode and rate adaptation of the link based on the utilization [3][11]. The author of [3] defines two states: Performance state and Sleep state. The performance state helps to save power when the routers are active whereas sleep state helps to save power when routers are idle. The performance state changes the rate of links and their associated interfaces dynamically which save the energy. The rate of individual links is adjusted dynamically based on the utilization and queuing delay of the link. The sleep state makes the network devices and associated interfaces off quickly when they are idle. It makes the network interfaces to sleep during short idle periods also. Entering into a low power state, high link data rate inherently consume more energy for the network interfaces [6].

In [11], the authors investigate the power management solution based on increasing the sleeping mode or operating at reduced rate. They argue that both methods save much of energy expenditure of the network and there is a potential for energy saving with the hardware support. A new power manager module (PM) and a clock controller (CC) are proposed for openflow switch in [18]. PM defines three modes: idle mode, working mode and sleep mode. CC is used to control the frequency of the openflow switches. At working mode and idle mode, the CC maintains the operating frequency at 125 MHz whereas the frequency is reduced to 0 MHz at sleep mode. The operation of openflow switch is controlled through the power manager register block which is responsible for communicating with registers to read and write the threshold values such Max queue length, Max packet number, idle timeout, Wait timeout which are configured by software. By dynamically adjusting the threshold value based on the availability of resources, sustainable energy conservation in OpenFlow switch is achieved.

4) Based on traffic engineering: Even there are many techniques used to improve the power saving, the SDN is not fully leverages especially in large scale multi-controller DCNs. To provide the solution for this problem, a mechanism name E3MC is proposed in which a fine-grained routing and dynamic control mapping are used for energy optimizations for both forwarding and control plane of SDN. It saves 50% of network energy at an acceptable level of computation cost [22]. The energy aware approach of SDN makes use of traffic engineering to optimize the overall power consumption. An energy-aware traffic engineering approach is proposed in [8] to optimize the energy consumption in SDN. The idea behind the traffic engineering used in the model is to find the minimum number of links that can be used to satisfy a given traffic demand. It determines the optimal distribution of switches required between controllers in terms of energy efficiency and load balance between controllers. In addition, the solution takes into account of link utilization and the delay in control paths. Further, a heuristic algorithm is also provided to reduce the time complexity of proposed energy-aware approach in the large scale topologies. Authors of [20] investigate the problem of energy aware traffic engineering in hybrid SDN/IP network. In the hybrid network, a single controller controls all the SDN-enabled switches in the network and the remaining network nodes are IP routers running hop-by-hop routing using a standard routing protocol. In an IP network, the routing protocol called OSPF is the most commonly used intra-domain internet routing protocol. A weight is assigned to each link and traffic flows are routed along the shortest paths computed using these weights. IP network energy can be minimized by determining an optimal set of link weights. The set of OSPF link weights and the traffic flow routing are jointly optimized to achieve the energy efficiency.

5. Discussion

In order to meet the demands of an exponential increase of capacity, improved data rate and quality of the service of the next-generation networks, there is a need to adopt energy-efficient architectures by considering all the influencing network parameters. A green communication is an urgent need [1][13]. The ICT and 5G need energy aware techniques for various network devices connected with internet in order to achieve green communication. There are many many challenges while implanting the energy conservation techniques. There are many energy conservation techniques in the literature among which switch on/off the network devices based on the utilization is very simple technique but incurs more complexity while implementing in partially deployed SDN. This because it is a NP hard challenge as we have to compromise for delay caused to up the devices and throughput performance. Although switch off the underused network devices results in better energy conservation, sudden increase of traffic and unavailability of network devices leads to congestion and loss of packets in the network, Hence the network devices in down condition should be made available immediately. Queue management is the one of the techniques used to minimize the congestion and loss of packet. But tradeoff between uptime of network devices and queue management needs the investigations. It is also necessary to improve the stability of routing algorithm in the network while applying the on/off of network devices. An important issue in SDN is that placement of controller in the network has a direct influence in the energy conservation which can be solved by setting a proper topologies.

With the dramatic increase of users in the internet and their demand of quicker access to the internet, 5G technology is introduced which results in prodigious rise in energy consumption. The rise in the energy consumption due to 5G technology leads to rapid increasing carbon dioxide levels in the atmosphere as shown in Fig 2. The estimated number of devices connected with internet is 50 billion by 2020 and further 100 billion by 2030 and requires 1000 times escalated data rates. As a result, energy efficient communication becomes a mandatory in future which is possible by integration of 5G and SDN. Since the 5G is characterized by heterogeneity, an advanced techniques/algorithm need to be employed for resource allocation, traffic control, rate allocation, spectrum management and security. Further there are many vendors in the network industry so that it is necessary to maintain the interoperability of network components. In today’s industry there should be some standards for intercommunication of network devices. SDN can support independent network elements as the users can dynamically control the network through applications.

Table 1: Analysis of Energy Saving Protocols

Ref. No.	Protocol Name	Utilized Controller	Emulation/ Simulation	Technique/ Method Used	Energy Efficiency Level High>=80% Medium: 50-60% Low: <50%	Issues that may arise	Target Environment
14.	Multilayer Traffic Engineering	NOX	Emulab	Based on controlling the behavior of switch.	High	A large flow table leads to increase in cost. May slightly curb forwarding performance.	Data Centers
2.	Maximum Link Utilization	Any Controller	Custom Made	Based on controlling the behavior of switch.	Medium	Binary Integer Programis computationally intractable for largescale networks.	Fixed Networks, Data Centers.
10.	Exclusive Routing (EXR)OpenFlowExtension	Any Controller	Custom Made	Based on dynamic resource allocation	High	Prioritizing of networks is needed and that is a very complex task.	Data Centers
15.	5G HetNet Management	Any Controller	Custom Made	Based on dynamic resource allocation	Medium	5G networks are characterized by their heterogeneity. Effective technologies need to be employed for spectrum management, traffic control, resource allocation, density management and security.	Mobile Networks
19.	Computation Diversity	SDN Controller	Custom Made	Based on dynamic resource allocation	Medium	Allocation and utilization of computation resources efficiently and effectively in networks and communications can be complex.	Mobile Networks, Data Centers.
11.	Power Management (sleeping and rate-adaptation)	SDN Controller	Custom Made	Based on power management	High	For better results low frequency should be maintained to operate dynamic voltage scaling.	Data Centers, Fixed Networks.
18.	NetFPGA	Any Controller	Custom Made	Based on power management	Low	Although the NetFPGA resources are not very expensive but power saving scale is low.	Data Centers, Fixed Networks.
22.	Energy Efficiency via the Elastic Multi-Controller	Any Controller	MATLAB	Based on traffic engineering	Medium	In Fat-Tree and BCube power saving can show inconsistency.	Data Centers, Fixed Networks.
21.	Hybrid Energy-Aware Traffic Engineering	Any Controller	NS2	Based on traffic engineering	Medium	In real work partiallt SDN deployment can be very complex.	Data Centers, Fixed Networks.

6. Conclusion

This paper focuses on the concept of SDN and the different types of technique used for energy conservation in SDN. The techniques includes turning a network devices on/off, link rate adaptation, openflow protocol, re-routing the traffic flow, dynamic resource allocation, sleep mode, multi-path routing, selection switches and controller, load balancing among the links, minimizing the propagation delay, fast restoration of traffic etc. Among these techniques, on/off of network devices provides better energy saving than the other techniques for data center and fixed networks. We present the challenge of 5G to the environment with respect to energy consumption.

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