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ISO 9001:2008

Study Paper on
Software Defined Networking (SDN) as a tool for energy efficiency approaches in Information and communication technology (ICT) networks

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Abstract
Energy consumption of Information Communication Technologies (ICT) is showing drastically increasing trend, mainly on account of new application based on Internet and Internet of Things (IoT). This is a cause of concern for environment and sustainability. Several methods have been deployed for introducing energy efficiency in ICT networks, namely re-engineering, dynamic adaptation and Sleeping/standby modes. In this paper we discuss the concept of an emerging technology, namely, Software Defined Network (SDN) in which standardized networking protocol is replaced with centralized control. This architecture of SDN offers several advantages over the conventional methods such as centralized management, low capex, flexibility & scalability and network function virtualization. With these advantages, SDN can be considered as an emerging technique for energy efficiency provided it is able to overcome the challenge of standardization of the technology which can lead to interoperability among the diverse networks in which it can be utilized. Effort of world standardization bodies such as ETSI, ITU, ONF and IETF etc is necessary for its widespread deployment.

Content

1. INTRODUCTION

Energy consumption of equipments being used in Information and Communications Technologies (ICT) is increasing at a rapid pace[1]. New applications based on Internet and Internet of Things (IoT) with the increasing demand of video and cloud services, smart phones and tablets is increasing the traffic across networks. This is leading to the present trend of increasing ICT energy consumption. For example, it has been projected[2] that Internet traffic will increase up to 85 times by 2017 compared to 2010. Similarly, people using Internet are expected to increase from 2.3 billion to 3.6 billion by 2017 as compared to 2010.

According to GWATT, the total energy consumption for ICT during 2013 was 109 GW which represents 6% of the world electricity consumption. Accordingly, network energy bills of telecom operators represent more than 10 percent of their operational expenses. Majority of this consumption (69 GW) was on infrastructure equipment such as access network (21.2 GW), service core and data centres (37.1 GW) and other networks (1.6 GW). Remaining major chunk was on devices (39 GW) which included consumption on Personal Computers (36.9 GW), Smart phones and mobile phones (0.6 GW each), and printers and tablets (1.1 GW).

Such huge consumption of energy by ICT equipments is a cause for concern that warrants the attention of technocrats and IT managers for improving the energy efficiency of IT equipments. Several methods of bringing about energy efficiency in IT equipments have evolved over the years, specifically with the objective of reducing carbon foot prints from use of ICT. Some of the approaches that have been adopted recently are described in the next section.

2. APPROACHES TO ENERGY SAVING IN ICT NETWORKS

In the past few years, energy cost and electrical requirement of telecom companies and internet service providers has been continuously increasing. So, the concept of energy efficient networking has become very much popular. Thus, to increase the energy efficiency of network, hardware improvement and mechanism that can exploit the network-specific features has to be integrated.

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[1] Gelenbe, E., & Caseau, Y. (2015). The impact of information technology on energy consumption and carbon emissions. Ubiquity, 2015(June), 1.

[2] Bell Labs has developed an interactive application to highlight the current energy consumption of our ICT networks and of the Internet. The application — called the Global 'What if' Analyzer of NeTwork Energy ConsumpTion, or G.W.A.T.T. — and available at the website www.gwatt.net, forecasts trends in energy consumption and efficiency based on different traffic growth and technology evolution scenarios.

There are three basic approaches to low energy networking which are depicted in Figure 1 and described in details as follows:
(i) Re-engineering;
(ii) Dynamic adaptation;
(iii) Sleeping/standby.

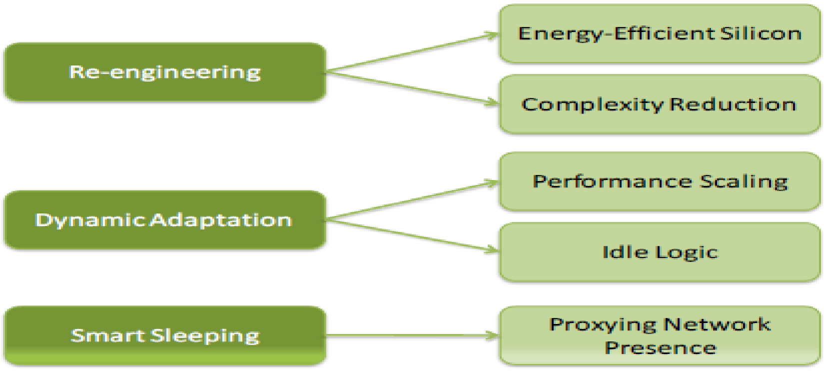


Figure 1: Approaches for the energy efficiency

(i) Re-engineering: This is related to use of more efficient silicon technologies and reducing the complexity inside the network equipment. For example Complementary Metal Oxide Semiconductor (CMOS) is one of the energy efficient technology (e.g., ASICs, FPGAs, network/packet processors, etc.) and memory technologies (e.g., Ternary Content-Addressable Memory (TCAM)) for packet processing engines. In contrast to conventational technologies such as Bipolar Junction Transistor (BJT) which consumes power of the order of milli-watt (mw), CMOS consumes power of the order of microwatt.

(ii) Dynamic adaptation: This can be performed by using two power-aware capabilities, namely, performance scaling and idle logic. Performance scaling is achieved by reducing the applied voltage at CMOS and by changing the clock frequency. For instance, the power consumption of CMOS based silicon can be approximately characterized as follows:
$P=CV^2f$ …………………………………… (1)

where P is the Power consumption, C the capacitance of CMOS, and V is the operating voltage and f is the frequency.

On the other hand, idle logic allows reducing power consumption by rapidly turning off sub-components when no activities are performed, and by re-waking them up when the system receives new activities.

(iii) Sleeping/standby: Sleeping/standby approaches are used to smartly and selectively keep unused network/devices to low standby modes, and to wake them up only if necessary. However, since today‘s networks and related services and applications are designed to be continuously and always available, standby modes have to be explicitly supported with special proxy techniques which will be able to maintain the network connectivity of sleeping components as shown in Figure 2. The main objective of such proxy, e.g., network connection proxy (NCP), is to respond to routine network traffic as the device sleeps, and to wake the device when and only when it is truly necessary.

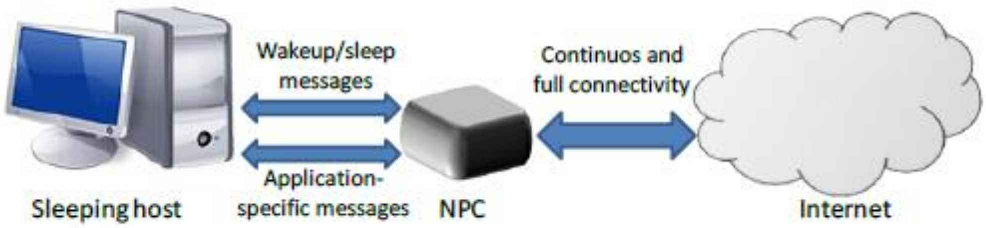


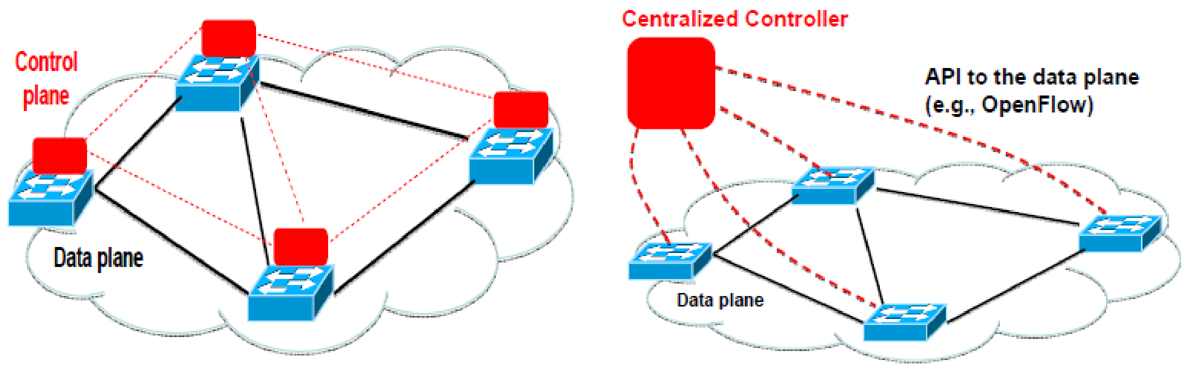
Figure 2: Example of network connection proxy

A new emerging technique that has immense potential for energy conservation for IT equipments is Software Defined Network (SDN) in which standardized networking protocols is replaced with centralized control. This technique provides several benefits that are described in Section 4.

3.0 Architecture of SDN

In traditional network, network devices such as router and switches acts as black box with application implemented on them. Moreover, data plane and control plane are integrated in each device (Fig.3a). However, SDN is a new technology in which control of network devices is detached and placed centrally that is it separates the control plane from data plane (Fig.3b). It also provides the flexibility to develop and test new protocol in real networks as controller is placed centrally.

This enables the intelligence of the device to be split from the packet-forwarding engine and controlled centrally, while data transport is distributed.



(a) Traditional network

(b) SDN network

Figure 3: Comparison of traditional and SDN network

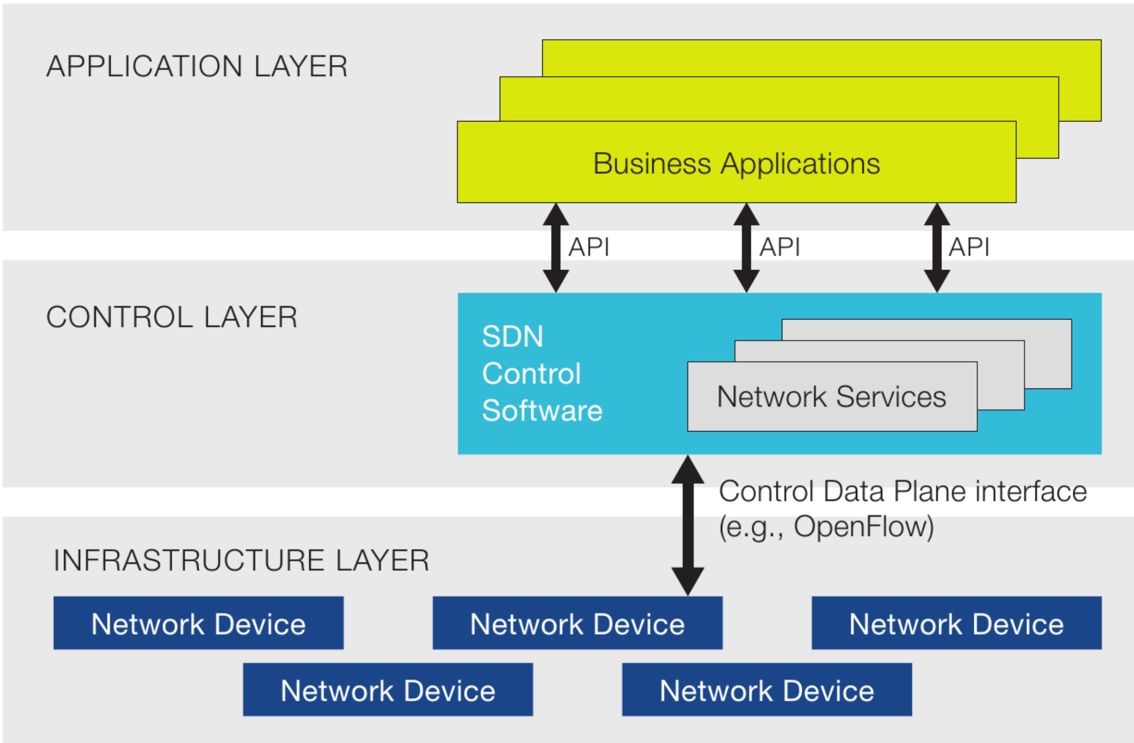


Figure 4: Software Defined Networking (SDN) structure
(Source: https://www.sdxcentral.com)

SDN architectures generally have three components, namely SDN applications, SDN controller and SDN Networking Devices which are described as follows:

SDN Applications: SDN Applications are programs that communicate behaviours and needed resources with the SDN Controller via application programming interface (APIs). It can also build an abstracted view of the network by collecting information from the controller for decision making purposes. These applications include energy efficient networking, security monitoring, access control for operation, management of the network, analytics, or business applications used to run large data centres.

SDN Controller: The SDN Controller is a logical entity that receives instructions or requirements from the SDN Application layer and relays them to the networking components. The controller also extracts information about the network from the hardware devices and communicates back to the SDN Applications with an abstract view of the network, including statistics and events about what is happening.

SDN Networking Devices: The SDN networking devices control the forwarding and data processing capabilities for the network. This includes forwarding and processing of the data path.

4.0 BENEFITS OF SDN

SDN offers several advantages over traditional network. Some of the key benefits are:

Energy management: Energy optimization can be applied at various components of the SDN architecture or SDN itself can be used as a means of energy saving. Energy saving in SDN can be addressed algorithmically or through hardware-based improvements.

Directly Programmable: Network directly programmable because the control functions are decoupled from forwarding functions which enables the network to be programmatically configured by proprietary or open source automation tools.

Network Functions Virtualization (NFV): NFV and SDN are two closely related, independent, complementary and mutually beneficial technologies. SDN function involves separation of control and data; centralisation of control and programmability of network whereas NFV deals with transfers of network functions from dedicated appliances to generic servers. Network Functions Virtualisation is able to support SDN by providing the infrastructure upon which the SDN software can be run.

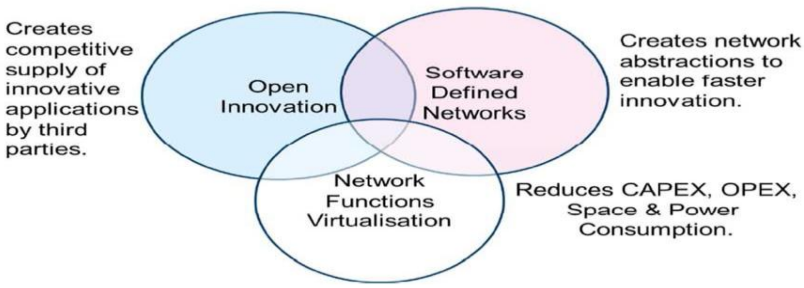


Figure 5: Network Functions Virtualisation Relationship with SDN (Source: ETSI)

Centralized Management: Network intelligence is logically centralized in SDN controller software that maintains a global view of the network, which appears to applications and policy engines as single, logical switches.

Reduce Capex: SDN potentially limits the need to purchase purpose-built, ASIC-based networking hardware as new application can easily be installed at the top of controller in application layer.

Reduce Opex: SDN enables algorithmic control of the network elements such as hardware or software switches / routers that are increasingly programmable, making it easier to design, deploy, manage, and scale networks.

Agility and Flexibility: Software Defined Networking helps organizations rapidly deploy new applications, services, and infrastructure to quickly meet changing business goals and objectives.

Enable Innovation: New type of services, application and business model can be created directly in application layer without disturbing other parts.

Network management and resource utilization: By decoupling the control and data plane it provides flexibility to the system and resources can be utilised according to the requirement by programming the control plane.

Bandwidth: SDN can utilise the available bandwidth efficiently by allocating to the required user dynamically.

5.0 METHODS OF ENERGY EFFICIENCY IN SDN

Energy optimization can be applied at different components of the SDN. The hardware-based solutions are applied on the forwarding switches and Software-based solutions are applied on the controller.

Energy efficiency methods in SDN can be divided into four categories-

(i) Traffic aware,
(ii) Compacting TCAM,
(iii) Rule placement, and
(iv) End host aware

(i)Traffic Aware Solutions
With traffic aware energy efficiency approaches, energy consumption can be reduced by turning off some forwarding switches during low traffic load, or putting CPUs or ports at sleep mode. The solutions in this group have the potential to significantly improve energy efficiency in SDN. Elastic tree is a power manager, which dynamically adjusts the set of active network elements –links and switches to satisfy changing traffic loads. It consists of three logical modules- optimizer, router and power control as shown in Figure 6.

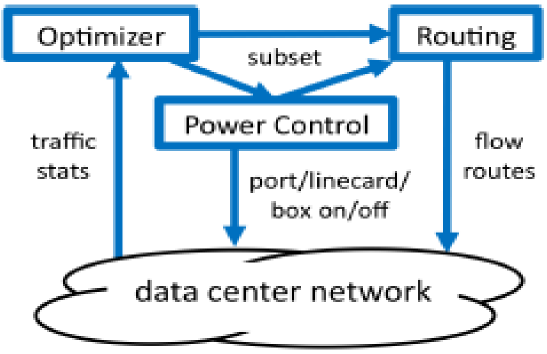


Figure 6: System Diagram

The role of the optimizer is to find the minimum power network subset which satisfies current traffic conditions. Its inputs are the topology, traffic matrix, a power model for each switch, and the desired fault tolerance properties (spare switches and spare capacity). The optimizer outputs a set of active components to both the power control and routing modules. Power control toggles the power states of ports and entire switches, while routing chooses paths for all flows, then pushes routes into the network.

There are three different methods for computing minimum power network subset: Formal model, Greedy bin-packing, Topology-aware heuristic. Each method achieves different trade off between scalability and optimality.

The formal model formulates the power saving problem by specifying objective function and constraints. The objective function minimizes the sum of the total number of switches turned on and the number of links. The advantage of the formal model is that it guarantees a solution within some configurable optimum; however, it only scales up to 1000 hosts.

The greedy bin-packing optimizer evaluates possible flow paths from left to right. The flow is assigned to first path with sufficient capacity. The optimizer improves the scalability of the formal model.

The topology-aware heuristic optimizer splits the flow and finds the link subset easily. It is computationally efficient, since it takes advantage of a fat tree structure and takes only port counters to compute link subset. This approach uses IP to formalize the optimization problem. The drawback is degradation of performance because of turning on and turning off components.
It uses Correlation-aware Power Optimization (CARPO) algorithm. CARPO takes three steps, Correlation Analysis, Traffic Consolidation and Link Rate Adaptation to optimize the power consumption. In the first step, CARPO takes the data rates of the traffic flows as input and analyzes the correlation relationship between different traffic flows. In the second step, based on the

correlation coefficients from the previous analysis, CARPO uses the 90-percentile data rate of each link in the previous period to consolidate the traffics under the link capacity constraint. After the consolidation, unused switches and ports are turned off for power savings. In the last step, CARPO adapts the data rate of each active link to the demand of the consolidated traffic flows on that link, such that more power savings can be achieved.

(ii) Compacting TCAM Solutions

SDN offers several benefits over the present network in terms of providing flexibility but it comes with a cost at the switching devices. For example SDN redefines flows to be identified by a 15 field (unlike in IP where it is defined by 2-5 field depending on the layer they belong to). This mandates each flow entry in TCAM table to be 356 bits (15 fields) which is 7 times more than that of an L2 switching device (conventional IP switch). This implies that the bit-length of flow entries stored in TCAM will now be 7 times more than that of an L2 switch. These impacts SDN switches in several ways. Firstly, it requires higher sized TCAM for storing the same number of flows that an L2 switch can hold. Secondary, this can quickly fill up the flow tables and lead to flow table explosion. Recent studies have established that the flow arrival to the SDN switches can be of the order of 72,000 flows/sec. Thirdly, the number of operations which have been mostly the lookup operations, will now be converted into the insert operations as there will be more misses in TCAM table. The combined affect all these results in higher power dissipation and longer access latency, many times more compared to existing TCAM in high performance switches.

Flow Identifiers (Flow-ID) are used as replacement for the flow entries. The switches store only the Flow-ID’s in the table rather than storing the entire 15 field per flow entry. These Flow-IDs are pushed on to the headers with the help of SDN. All operations in the TCAM are performed on this shorter Flow-ID and the energy can be saved proportional to the number of bits reduced. This concept of flow-ID is very similar to that of Multiprotocol Label Switching (MPLS). MPLS is a type of data-carrying technique for high-performance telecommunications networks that directs data from one network node to the next based on short path labels rather than long network addresses. This avoids complex lookups in a routing table.

Compacting Flow Entries using Flow-ID

The flow entries in a table classify incoming packets into different flows. Once a flow entry is identified, subsequent packets belonging to the flow need not match the entire flow entry. The size of the entry can be now compacted and replaced with a shorter ID for classification. Hence we introduce the notion of "Flow-ID". Flow-ID is a numeric identifier used to identify the flows uniquely. In the switch flow table, the flow entry can be reduced to the size of the 'Flow-ID' and associated actions. All routings are performed based on the Flow-ID's. SDN's programming capability is leveraged to take advantage of the Flow-ID. Packets are identified to belong to a flow based on the Flow-ID and actions corresponding to the flow are applied on the packets. This requires that the headers of the packet carry the Flow-ID information to be able for the switches to identify the flow to which the packet belongs. Switches perform lookup operation based on the Flow-ID rather than full sized flow extracted from the header. Fig. 3 shows the SDN architecture consisting of the controller, Open Flow switches and host machines.

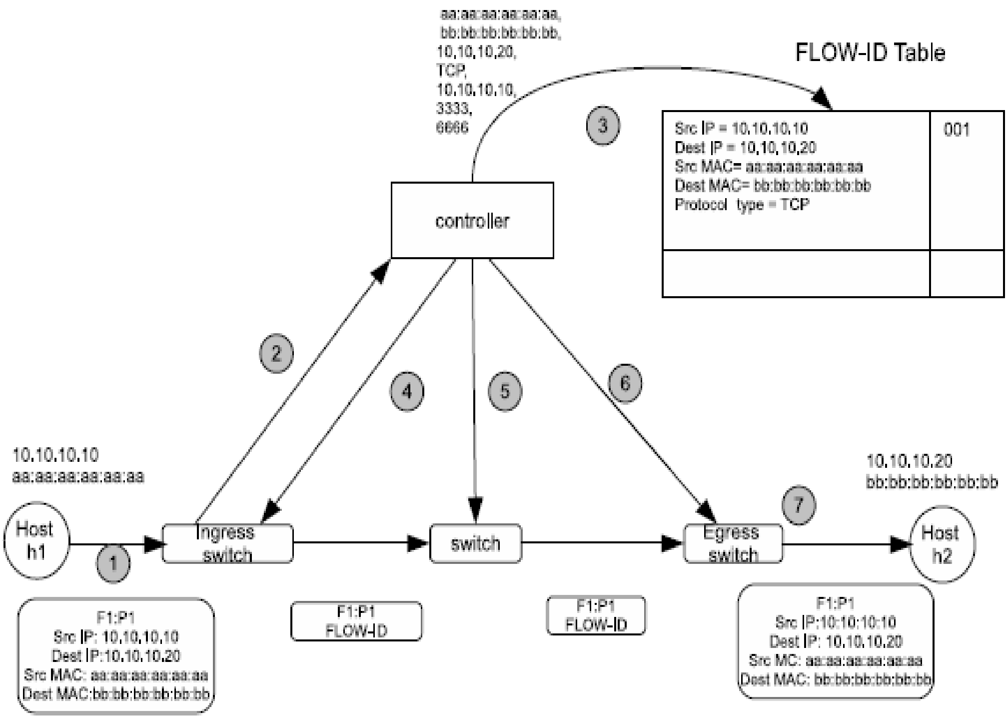


Figure 6: System overview showing Flow-ID creation, utilization through different steps

Step 1: In OpenFlow the first packet of a new flow arriving at an interface of a switch as shown in figure 6.

Step 2: Packet is forwarded to the controller.

Step 3: The controller generates a *Flow- ID* for the flow and stores it in its local reference table as illustrated in figure 6.

Step 4: The controller responds back to the switch with an OpenFlow action message consisting of the actions to be performed on the packets of the flow.

In our work, we augment the 'action' part of the rule with a Boolean 'COMPACT' flag. If the flag is clear, the switch performs the standard actions on the packets. For instance, the flag is set to be clear if the destination address is connected to the same switch. Otherwise (COMPACT flag set), the switch utilizes the Flow-ID and performs operations on the packets corresponding to the Flow-ID and output it to specific port as given in the action part.
Compact operation consists inserting the Flow-ID into the header of the packet. Leaving aside the 'preamble' and 'start of delimiter' fields in the Ethernet Frame, the Flow-ID is stored in 2 bytes of the frame. The 'preamble' and the 'start of delimiters' are used by the link layers for purpose of determining frame boundaries and are left intact. In OpenFlow enabled switches, the 'PUSH' allows addition of bits of data to specified segments of the packet. We use the 'PUSH' tag of the OpenFlow architecture to add a new header on to the packet containing just the 'Flow-ID'. The original header and packet payload is encapsulated within this header.

Step 5: The controller sends a flow insert operation to all the switches along the path of the packet. This flow entry consists of a "Flow-ID" and associated actions to it. When a packet arrives at the intermediate switches, the 'Flow-ID' is extracted from the header and is matched against the entries in the flow table (proactively installed by the controller on the switches). These switches do not perform any COMPACT operations and do not require any additional hardware. They perform the normal operations of an OpenFlow switch except that they extract the Flow-ID's from the header and search for a matching entry in the lookup tables.

Step 6: For the egress switches, the controller sends a flow insert operation that contains the "Flow-ID" and actions to remove the 'Flow-ID' from the header of the packets.
Step 7: The header that was in the original packet without the Flow-ID is forwarded to the output port to deliver to the end hosts.

Table 1: Power dissipation comparison for TCAM operations: L2, OpenFlow and Compact TCAM[3]

No. of entries = 100,000			
Operations	**L2 Sw. (60 bit) (in nJ)**	**OpenFlow Sw. (356 bit) (in nJ)**	**Using Compact TCAM (16 bit) (in nJ)**
Write/Insert	195167	792677	56614
Search/Lookup	447065	1807142	131685

[3] https://pdfs.semanticscholar.org/e512/a2b248c5178fb7a7a9d528883624e2a56fff.pdf

(iii) Rule Placement Solutions

The energy efficiency techniques for rule placement solutions start by formalizing the energy cost model and the constraints associated, then applies heuristic technique to find optimum energy saving strategy. Forwarding rules are generated and pushed to the forwarding switches by the controller. The controller generates rules and pushes them to the forwarding switches. Placing the rules to respective switches distributed across the network and optimizing given an objective function under the constrains is NP-hard problem. The objective function in our particular case is minimizing energy where as the constrains are the number of switches, flow table capacity, link capacity, and number of ports per switch.

(iv) End Host Aware Solutions

Server virtualization enables the working of multiple virtual machines simultaneously on a single physical server, thus decreasing electricity consumption and wasting heat as compared to running underutilized physical servers. Hence, instead of operating many servers at low utilization, virtualization technique combines the processing power onto fewer servers that operate at a higher total utilization.

6. CHALLENGES

As SDN is very promising field as it offers many advantages over traditional network like directly programmable, centralized control, flexibility etc, as described in Section 4 above. But, at the same time methods of energy efficiency in SDN has many challenges. Some of the key challenges are as follows:

- **Standards**: Currently many organization (ETSI, ONF, IETF, ITU) are working on SDN but complete standards of SDN has not been developed so far which is a big obstacle in deployment of the SDN
- **Quality of service:** In traffic aware solutions, turning the network components on and off based on network load helps in reducing energy consumption. But turning the network component on and off dynamically affect the components and quality of service (QoS).
- **Scalability and flexibility:** The traffic aware model needs to be scalable in the case of high traffic load (As it is scalable only up to 1000 hosts).
- **Cost:** Forwarding switches use TCAM, which is highly expensive and have high power consumption. Similarly in compacting TCAM solutions, information stored in TCAM cannot be further compressed after a certain threshold.
- **Fuzzy nature of network environment:** Since the problem of optimization of energy efficiency is NP-hard (i.e. for which convergence to a solution is not always possible), utilizing heuristic techniques is

inevitable. But the limitation of such heuristic techniques is that they do not give the exact solution in a given time. In case of network where environment is dynamic i.e. data is changing continuously problem becomes very challenging.

7. WAY FORWARD

Currently many organizations (e.g. ETSI, ONF, IETF, and ITU) are working in the area of developing standards so that it could be deployed at the earliest. But, it would not be easy to deploy SDN with existing base of networks supporting critical installation and business. The transition to SDN therefore requires simultaneous support of SDN and existing network. Further development is required to achieve a hybrid infrastructure in which traditional, SDN-enabled, and hybrid network can operate. Such interoperability requires the support of an appropriate protocol that both introduces the requirements for SDN communication interfaces and provides backward compatibility with existing IP routing and multiprotocol label switching (MPLS) control plane technologies.

ITU-2013-2016 study period kicked-off with marked emphasis on SDN in response to the directive issued by World Telecommunication Standardization Assembly (WTSA)-12. ITU-T Study Group 11 (Signalling requirements, protocols and test specifications) is tasked with developing signalling requirements and protocols for SDN, and this work aligns with the functional requirements and architectures developed by Study Group13(Future networks).
ITU has already give some recommendation on SDN for example **ITU-T Y.3300** describes requirement and architecture of SDN including the definitions, objectives, high-level capabilities, requirements, and the high-level architecture of SDN, **ITU-T Y.3320**, describes requirements for using formal specification and verification techniques in SDN, **ITU-T Y.3321** Requirements and capability framework for NICE (Network Intelligence Capability Enhancement) implementation making usage of software defined networking technologies (S-NICE).

8.0 CONCLUSIONS

Introduction of SDN as a technique for energy efficiency has been discussed in detail in the paper. This technology complements the existing methods of energy efficiency often used in networks, namely re-engineering, dynamic adaptation and Sleeping/standby modes. SDN offers several advantages over the conventional modes of energy efficiency such as centralized management, low capex, flexibility & scalability and network function virtualization. Due to these advantages, SDN can be considered as an emerging technique for energy efficiency provided it is able to overcome the challenge of standardization of the technology which can lead to interoperability among the diverse networks in which it can be utilized. Effort of world standardization bodies such as ETSI, ITU, ONF and IETF etc is necessary for its widespread deployment.

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APPENDIX: IMPORTANT TERMS USED IN THE PAPER

About European Telecommunications Standards Institute (ETSI): ETSI produces globally-applicable standards for Information and Communications Technologies (ICT), including fixed, mobile, radio, converged, aeronautical, broadcast and internet technologies. ETSI is an independent, not-for-profit association whose more than 700 member companies and organizations, drawn from 62 countries across 5 continents worldwide, determine its work programme and participate directly in its work.

About Open Network Foundation (ONF): Launched in 2011 by Deutsche Telekom, Facebook, Google, Microsoft, Verizon, and Yahoo!, the Open Networking Foundation (ONF) is a growing non profit organization with more than 140 members whose mission is to accelerate the adoption of open SDN. ONF promotes open SDN and OpenFlow technologies and standards while fostering a vibrant market of products, services, applications, customers, and users.

About Internet Engineering Task Force (IETF): The Internet Engineering Task Force (IETF) is a large open international community of network designers, operators, vendors, and researchers concerned with the evolution of the Internet architecture and the smooth operation of the Internet. It is open to any interested individual. The actual technical work of the IETF is done in its working groups, which are organized by topic into several areas (e.g., routing, transport, security, etc.).

About International Telecommunication Union (ITU): ITU is a specialized agency of the United Nations (UN) and is responsible for issues that concern information and communication technologies. ITU coordinates the shared global use of the radio spectrum, promotes international cooperation in assigning satellite orbits, works to improve telecommunication infrastructure in the developing world, and assists in the development and coordination of worldwide technical standards. The ITU is active in areas including broadband Internet, latest-generation wireless technologies, aeronautical and maritime navigation, radio astronomy, satellite-based meteorology, convergence in fixed-mobile phone, Internet access, data, voice, TV broadcasting, and next-generation networks.

WTSA (Telecommunication Standardization Assembly)-12: The World Telecommunication Standardization Assembly is held every four years and defines the next period of study for ITU-T. WTSA-12 took place 20-29 November 2012 in Dubai, United Arab Emirates.

Heuristic techniques: In computer science, artificial intelligence, and mathematical optimization, a heuristic is a technique designed for solving a problem more quickly when classic methods are too slow, or for finding an approximate solution when classic methods fail to find any exact solution. This is achieved by trading optimality, completeness, accuracy, or precision for speed.

NP Hard: NP-hardness (non-deterministic polynomial-time hard), in computational complexity theory, is a class of problems that are, informally, "at least as hard as the hardest problems in NP". More precisely, a problem H is NP-hard when every problem L in NP can be reduced in polynomial time to H, that is given a solution for L we can verify it is a solution for H in polynomial time.

NFV (Network Function Virtualization): NFV deals with transfers of network functions from dedicated appliances to generic servers.

CMOS (Complementary Metal Oxide Semiconductor): It is a technology for constructing integrated circuits.

ASIC (Application Specific Integrated Circuit): It is an integrated circuit (IC) customized for a particular use, rather than intended for general-purpose use.

FPGA (Field Programmable Gate Array): A field-programmable gate array (FPGA) is an integrated circuit designed to be configured by a customer or a designer after manufacturing – hence "field-programmable". The FPGA configuration is generally specified using a hardware description language (HDL). FPGAs contain an array of programmable logic blocks, and a hierarchy of reconfigurable interconnects that allow the blocks to be "wired together", like many logic gates that can be inter-wired in different configurations. Logic blocks can be configured to perform complex combinational functions, or merely simple logic gates like AND and XOR. In most FPGAs, logic blocks also include memory elements, which may be simple flip-flops or more complete blocks of memory.

TCAM (Ternary Content-Addressable Memory)
Content-addressable memory (CAM) is a special type of computer memory used in certain very-high-speed searching applications. It is also known as associative memory, associative storage, or associative array. It compares input search data (tag) against a table of stored data, and returns the address of matching data. Binary CAM is the simplest type of CAM which uses data search words consisting entirely of 1s and 0s. Ternary CAM (TCAM) allows a third matching state of "X" or "don't care" for one or more bits in the stored data

word, thus adding flexibility to the search. For example, a ternary CAM might have a stored word of "10XX0" which will match any of the four search words "10000", "10010", "10100", or "10110".