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Electricity Cost Aware Virtual Machine Placement Schemes in Distributed Cloud

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Abstract— In recent times, energy efficiency has become an important criterion considered by information and communication technology (ICT) infrastructure providers. This is largely motivated by economic and environmental reasons. By leveraging on technological advancements, it is possible to accomplish desired energy efficiency improvements in the ICT industry. This paper leverages on the virtualization concept (behind the success of cloud computing) and time of usage concept (enabled by smart grid technology) to reduce non-renewable power consumption and total electricity cost of cloud and network infrastructure providers. A mixed integer linear programming (MILP) model was developed to study the impact of varying electricity prices across time zones on the placement of virtual machine (VM) clusters in distributed clouds connected via internet protocol over wavelength division multiplexing (IP over WDM) core network. Results showed that VM clusters are placed at nodes with the cheapest electricity for the three VM cluster placement schemes considered. These results are achieved at the expense of increased non-renewable power consumption and electricity cost in the IP over WDM core network.

Keywords— Cloud Computing, Energy Efficiency, IP over WDM, Smart grid, Time of Usage

1 INTRODUCTION

Over the years, advancement in the information and communication technology (ICT) industry has played pivotal roles in reducing the environmental impact and energy consumption in several economic sectors through data processing, transport and storage services offered. However, the ICT industry is estimated to be responsible for over 2% of total carbon dioxide (CO2) emissions (Peoples, et al., 2013). It is also widely reported that telecommunication networks and datacenters are the largest consumers of electricity among other ICTs (Erol-Kantarci and Mouftah, 2015) (The EINS Consortium, 2013). Therefore, research focused on improving energy efficiency of datacenters and telecommunication networks is expected to make significant contributions in attaining desired energy efficient ICTs. By leveraging on features of novel ICT solutions and services such as cloud computing and smart grids, it is possible to achieve significant reductions in environmental impact and operation cost of the ICT industry.

Cloud computing is a major evolution in information and communication technology. It enables access to computing resources such as computing power, storage and network as utilities. This is achieved by delivering on-demand computing resources via the internet on a pay per use business model. Virtualization of computing, storage and networking physical resources in datacentres is the backbone of cloud computing services. Virtualization abstracts the physical resources and makes multiple access possible through flexible creation, management and release of logical entities of the physical resources. Virtualization is made possible by hypervisors which serves as an abstraction layer controlling the operation of created logical entities called virtual machines (VMs) (Bilal, et al., 2014). In a distributed cloud computing architecture, high speed communication networks are needed to transport high bandwidth demanding data within and between datacentres and between datacentre and service demanding users. An optical networking technology is a commonly deployed network infrastructure used to meet demands in the cloud computing era. This is not unrelated to features such as high speed and large bandwidth that characterises optical networking technologies (Zhang, et al., 2010).

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Modernization of generation, transmission and distribution of electricity with advanced sensing, communication and control technologies is responsible for smart grid revolution in power utilities infrastructure and architecture. These integrated technologies that are being adopted in smart grids are leading to new concepts such as time of usage (ToU), real-time pricing, distributed generation and demand management in the power sector (Erol-Kantarci and Mouftah, 2015). ICTs are critical to the feasibility of the smart grids. Likewise, the novel concepts brought about by smart grid open opportunities for the design of a more energy efficient, eco-friendly and affordable ICT industry. This paper leverages on the novel smart grid concept of ToU in the placement of virtualized computing resources in distributed clouds over the optical core network.

Energy efficiency in optical networks was extensively surveyed by Zhang, et al. (2010), where the authors highlighted standardization efforts and relevant researches in energy consumption reduction in optical access, metro and core network technologies. Shen and Tucker (2009) investigated energy efficiency in an internet protocol over wavelength division multiplexing (IP over WDM) core network via formulation of mixed integer linear programming (MILP) models and heuristics. Results obtained showed that a lightpath bypass in the optical layer is both more energy efficient and cost efficient because it reduces the number of IP router port required compared to non-bypass approach. A hybrid IP over WDM network architecture was proposed by Dong, El-Gorashi, and Elmirghani (2011). In the hybrid architecture, power supply is mixed, composing of non-renewable energy and renewable energy sources. The authors extended Shen and Tucker's (2009) research by formulating a linear programming model and heuristics that minimizes non-renewable energy consumption. The authors showed that the number and location of nodes with access to renewable energy directly affect the consumption of non-renewable energy and CO2 emissions.

Shen, Lui, and Bose (2014) developed a "Follow the Sun, Follow the Wind" strategy that reconfigures lightpath virtual topology in an IP over WDM network every day (at midnight). Daily reconfiguration was adopted in order to ensure minimum consumption of non-renewable energy based on daily weather forecast and available renewable energy at each node. The smart grid ToU concept was exploited to minimize the electricity bill of an IP over WDM core network provider in a paper by Cavdar, Yayımlı, and Wosinska (2011). This is achieved by leveraging varying electricity prices across time-zones, given that a core network span a large geographical area falling in different time zones. Lawey, El-Gorashi, and Elmirghani (2014) investigated energy efficient placement of virtual machines over the core network among other topics. MILP models were formulated to optimize the placement of VM under migration, replication and slicing VM placement schemes while minimizing power consumption in both cloud datacenters and core network. The slicing scheme proved to be the most energy efficient VM placement scheme, because total distributed datacenter power consumption is maintained and significant power consumption savings were made in the core network.

In addition to exploring ways to achieve a more energy efficient and greener internet, researchers have also investigated ways to concurrently ensure energy efficiency in the internet backbone and in datacenters hosting cloud computing services. Research effort in this area are motivated by strong dependence of cloud computing services on internet infrastructure and the combined volume of energy consumed by the both datacenters and network infrastructure as mentioned earlier. Dong, El-Gorashi, and Elmirghani (2011) optimized the location of data centers in IP over WDM network while minimizing power consumption. Effects of IP over WDM routing techniques (lightpath bypass or non-bypass), network topology and number of datacenters were investigated. The authors also studied the impact on energy savings as result of data replication scheme. Furthermore, Dong, El-Gorashi, and Elmirghani (2011) considered the impact of utilizing renewable energy resources and power losses on the optimal location of datacenters while minimizing network non-renewable power consumption. This is a somewhat application of the smart grid distributed generation concept. The impact of ToU-awareness on the operational expenditure and energy efficiency of core network and datacenters was studied by Kantarci and Mouftah (2012) via the formulation of MILP model. Their model leverages on varying electricity prices in different locations to minimize the operational expenditure of both core network and datacenters providers at the cost of increased propagation delay.

This paper extends the research work by Lawey, El-Gorashi, and Elmirghani (2014) in the following way; the impact of hourly variances in the cost of electricity is considered in addition to cloud and core network non-renewable energy consumption considered by Lawey, El-Gorashi, and Elmirghani (2014) and the total cost of electricity consumed by both cloud datacenters and the core network is concurrently minimized while placing VM clusters in distributed datacenters.

The remainder of this paper is organized as follows. Section 2 introduces a mixed integerlinear programming model that minimizes consumption of non-renewable energy consumption and total electricity cost under three different VM cluster placement schemes. Section 3 discusses and analyzes the results obtained when the model is simulated at three critical hours of the day. Section 4 concludes the paper and discusses future works.

2 MILP MODEL

Migration, replication and slicing placement schemes are considered in this paper as done by Lawey, El-Gorashi, and Elmirghani (2014). The migration scheme permits the existence of just a single copy of a VM cluster across all nodes of the distributed cloud. Under the replication scheme, a VM cluster can be replicated across all possible distributed cloud nodes in the network topology. The workload of a VM cluster replica is equal to the workload of the replicated VM cluster. The slicing scheme allows division of a VM cluster into small VM clusters with lower workload called slices. The total workload of a VM cluster is maintained across all nodes of the distributed cloud i.e. the summation of the workload of all slices of a given VM cluster is equal to the workload of that VM cluster before slicing occurs. Parameters and variable of the model are defined in Table 1.

Table 1: Parameters and Variables of the Model

Parameters			
N	Set of IP over WDM nodes	$Drate$	Download rate per user
Nm_i	Set of neighbors of node i	$Pmax$	Maximum power consumption of a server
m & n	Index the optical layer nodes in the physical topology	$Wmax$	Maximum normalized workload of a server
i & j	Index the IP layer nodes connected by virtual link	$SPPW$	Server power per normalized workload, $SPPW = Pmax/Wmax$
s & d	Index source and destination nodes of traffic demand in the IP layer	WLv	Total normalized workload of VM Cluster v
S	Distance between two neighboring EDFAs	D_{dv}	Traffic from VM v to node d, $D_{dv} = \sum_{i \in U_d : i \in U_v} Drate$
W	Number of wavelength channels carried on each fibre	M	A large number
B	Capacity of each wavelength in Gb/s	$MinW$	Minimum allowed normalized workload per VM Cluster for slicing scheme
Pr	Average power consumed by a router port	PUE_c	Power usage effectiveness of clouds
Pt	Average power consumed by each transponder	$SWPC$	Cloud switch power consumption
Pe	Average power consumed by each EDFA	SWC	Cloud switch capacity
Prg	Average power consumed by each regenerator	$SWPPB$	Cloud switch power per bit, $SWPPB = SWPC/SWC$
PO	Average power consumed by each optical switch	RPC	Cloud router power consumption
D_{mn}	Distance between nodes m and n	RC	Cloud router capacity
A_{mn}	Number of EDFA on a fiber link $A_{mn} = \left[\frac{D_{mn}}{S-1}\right] + 2$	$RPPB$	Cloud router energy per bit, $RPPB = RPC/RC$
RG_{mn}	$RG_{mn} = 1$ if there is a regenerator along the link between nodes m and n, otherwise $RG_{mn} = 0$	Red	Switching redundancy
PUE_n	Power usage effectiveness of IP over WDM network	α	Unitless factor
VM	Set of virtual machine clusters	β	Unitless factor
U_v	Set of users requesting for virtual machine cluster v	γ	Factor measure in /Cent
NVM	Number of virtual machine clusters	γ	Factor measure in /Cent
C_{ij}	Number of wavelength channels on the virtual link (i,j) with access to non-renewable power	L^{sd}	Traffic from cloud s to users in node d. $L^{sd} = \sum_{v \in VM} L^{sdv}$
L_{ij}^{sd}	Traffic demand from source node s to node d that traverses virtual link(i,j)	$Delta_{sv}$	$Delta_{sv} = 1$ if cloud s hosts copy of VM Cluster v, otherwise $Delta_{sv} = 0$
ω_{mn}^{ij}	Number of wavelength channels of virtual link (i,j) that traverse physical link (m,n)	$TNNRP$	Total network non-renewable power consumption
ω_{mn}	Number of wavelength channels on physical link (m,n) with access to non-renewable power	$CNRP_s$	Cloud s non-renewable power consumption
f_{mn}	Number of fibres on physical link (m,n)	PSN_s	Number of processing servers in cloud s
Ag_i	Number of ports use for data traffic aggregation in node i with access to non-renewable power	$TCNRP$	Total cloud non-renewable power consumption. $TCNRP = \sum_{s \in N} CNRP_s$
L^{sdv}	Traffic demand from VM Cluster v in cloud node s to node d	WL_{sv}	Normalized workload of the slice of VM Cluster v in node s
Cup_s	Cloud s upload capacity	CW_s	Total normalized workload of Cloud s

Non-renewable power consumed by the cloud in node s ($CNRP_s$) comprises of power consumed by servers and the local area network of the datacentre at that node.

a. The total non-renewable power consumed by servers are calculated as follows:

$$PUE_c \cdot CW_s \cdot SPPB \quad (1)$$

b. The total power non-renewable power consumed by clouds local area network is calculated as follows:

$$PUE_c \cdot Cup_s \cdot (SWPPB \cdot Red + RPPB) \quad (2)$$

$$CNRP_s = PUE_c \cdot CW_s \cdot SPPB + PUE_c \cdot Cup_s \cdot (SWPPB \cdot Red + RPPB) \quad (3)$$

The objective of the model comprises of the following:

1. Network non-renewable power consumption at node s ($NNRP_s$) comprises of non-renewable power consumption of all component of the IP over WDM network in that node. It is calculated as follows:

$$NNRP_m = PUE_N \cdot (Pr \cdot Ag_i + \sum_{n \in N_m: n \neq m} Pr \cdot \omega_{mn} + \sum_{n \in N_m} Pt \cdot \omega_{mn} + \sum_{n \in N_m} Pe \cdot A_{mn} \cdot f_{mn} + PO + \sum_{n \in N_m} Prg \cdot \omega_{mn} \cdot RG_{mn}) \quad (4)$$

$$TNNRP = \sum_{m \in N} NNRP_m \quad (5)$$

2. Total cloud non-renewable power consumption ($TCNRP$)

$$TCNRP = \sum_{s \in N} CNRP_s \quad (6)$$

3. Total electricity cost of non-renewable power consumed by both the network and the cloud. It is calculated as follow:

$$BILL = \sum_{s \in N} Price_s \cdot (NNRP_s + CNRP_s) \quad (7)$$

The model is defined as follows:

Objective:

Minimize $\alpha \cdot TNNRP + \beta \cdot TCNRP + \gamma \cdot BILL$ (8)

Subject to:

$$\sum_{j \in N: i \neq j} L_{ij}^{sd} - \sum_{j \in N: i \neq j} L_{ji}^{sd} = \begin{cases} L^{sd} & i = s \\ -L^{sd} & i = d \\ 0 & otherwise \end{cases} \quad \forall s,d,i \in N: s \neq d \quad (9)$$

$$\sum_{s \in N} \sum_{d \in N: s \neq d} L_{ij}^{sd} \leq C_{ij} \cdot B \quad \forall i,j \in N: i \neq j \quad (10)$$

$$\sum_{n \in N_m} \omega_{mn}^{ij} - \sum_{n \in N_m} \omega_{nm}^{ij} = \begin{cases} C_{ij} & m = i \\ -C_{ij} & m = j \\ 0 & otherwise \end{cases} \quad \forall i,j,m \in N: i \neq j \quad (11)$$

$$\sum_{i \in N} \sum_{j \in N: i \neq j} \omega_{mn}^{ij} \leq W \cdot f_{mn} \quad \forall m \in N, n \in N_m: m \neq n \quad (12)$$

$$\sum_{i \in N} \sum_{j \in N: i \neq j} \omega_{mn}^{ij} = \omega_{mn} \quad \forall m \in N, n \in N_m: m \neq n \quad (13)$$

$$Ag_i = \frac{1}{B} \cdot \sum_{d \in N: i \neq d} L^{id} \quad \forall d \in N \quad (14)$$

$$L_{sd} = \sum_{v \in VM} L_{sdv} \quad \forall s,d \in N \quad (15)$$

$$\sum_{s \in N} L_{sdv} = D_{dv} \quad \forall d \in N, \ \forall v \in VM \quad (16)$$

$$Cup_S = \sum_{d \in N} L_{sd} \quad (17)$$

$$M \cdot \sum_{d \in N} L_{sdv} \geq Delta_{sv} \quad \forall s \in N, \ \forall v \in VM \quad (18)$$

$$\sum_{d \in N} L_{sdv} \leq M \cdot Delta_{sv} \quad \forall s \in N, \ \forall v \in VM \quad (19)$$

$$\sum_{v \in VM} Delta_{sv} \geq Cloud_s \quad \forall s \in N \quad (20)$$

$$\sum_{v \in VM} Delta_{sv} \leq M \cdot Cloud_s \quad \forall s \in N \quad (21)$$

$$CW_s = \sum_{v \in VM} Delta_{sv} \cdot WL_v \quad \forall s \in N \quad (22)$$

$$\sum_{s \in N} Delta_{sv} = 1 \quad \forall v \in VM \quad (23)$$

$$\sum_{s \in N} WL_{sv} = WL_v \quad \forall v \in VM \quad (24)$$

$$WL_{sv} \geq MinW \cdot Delta_{sv} \ \forall s \in N, \forall v \in VM \quad (25)$$

$$WL_{sv} \leq M \cdot Delta_{sv} \ \forall s \in N, \forall v \in VM \quad (26)$$

$$CW_s = \sum_{v \in VM} WL_{sv} \quad \forall s \in N \quad (27)$$

Equation 8 is the objective of the model i.e. to minimize the total non-renewable power consumed by the IP over WDM core network and distributed clouds and electricity bill of the both network and cloud infrastructure providers. Equation 9 is the flow conservation constraint in the IP layer. It ensures that the total outgoing traffic is equal to the total incoming traffic at all nodes except for the source and destination nodes. Equation 10 ensures that the capacity of the virtual link in the IP layer is not exceeded as a result of traffic demand flows traversing the virtual link, it is the capacity constraint of virtual links in the network. Equation 11 is the flow conservation constraint in the optical layer. It ensures that total number of outgoing wavelengths in a virtual link is equal to the total number of incoming wavelengths except for the source and destination nodes of the virtual link.

Equations 12 and 13 represent the capacity constraints of physical links. Equation 12 ensures that the physical link's fibre capacity is not exceeded by the total number of wavelength channels in virtual links traversing it. Equation 13 ensure that total number of wavelengths channels in virtual links traversing a physical link is the same as the total number of wavelengths in that physical link. Equation 14 estimates the total number of aggregation router ports used for data traffic aggregation at each node. Equation 15 estimates the traffic L_{sd} from VM cluster v in cloud s to all users requesting for the VM cluster in destination node d. L_{sd} is used in Equations 9 and 14.

Equation 16 ensures that users requests in all nodes are satisfied by the VM clusters placed in the network. Equation 17 estimates the upload capacity of each cloud based on the traffic sent from the cloud to all destination nodes d. Equations 18 and 19 replicate VM cluster v to cloud s if cloud s is selected to serve requests for v where M is a large enough number, with units of Gb/s, to ensure that $Delta_{sv} = 1$ when $\sum_{d \in N} L_{sdv}$ is greater than zero. Equations 20 and 21 builds a cloud in location s if the location is selected to host one or more VM clusters where M is a large enough unit less number to ensure that $Cloud_s = 1$ when $\sum_{v \in VM} Delta_{sv}$ is greater than zero. Equation 22 estimates the total normalised workload of each cloud by summing normalized workloads of all VM clusters in a cloud. Equation 23 ensures only one copy of each VM cluster exist in the distributed cloud, which is used to model the migration scheme.

Equation 24 – 27 are used to model VM slicing placement scheme. Equation 24 ensures that the summation of the normalized workloads of all slices of a VM cluster is equal to the normalized workload of that VM cluster before slicing. Equations 25 and 26 ensure that the locations of the slices of a VM cluster are consistent with those selected in equations 18 and 19 and they also ensure that the slices normalised workload does not drop below the minimum allowed normalised workload per slice where M is large enough number, with units of % to ensure that $Delta_{sv}$ = 1 when W_{sv} is greater than zero. Equation 27 estimates the workload of each cloud by summing the workload of the slices of the different VM clusters hosted in the cloud.

3 Simulation and Results

The 14 nodes, 21 links NSFNET network in Fig.1 is used to evaluate non-renewable power consumption and electricity bill of the distributed cloud architecture connected by an IP over WDM core network. User requests for VMs in a cluster are generated uniformly via uniform distribution of users between the assumed 10 VM clusters. Each VM cluster has 50 VMs in it. Users are also uniformly distributed to nodes in the NSFNET network in order to generate service demands from a node to a VM Cluster. Total user population varies throughout the day as shown in Fig. 2, with a minimum of 200,000 users at 06:00 and a maximum of 1,200,000 users at 22:00. Average download rate per user of 5 Mbps is adopted from the paper by Lawey, El-Gorashi, and Elmirghani (2014). Each VM cluster is randomly assigned a workload in a range between 10% and 100%.

The price of electricity varies throughout the day, hours within a day are categorised into 3 tiers in a similar manner as in the paper by Dong, El-Gorashi, and Elmirghani (2013). Ranges of hours that fall within a tier and the corresponding prices of electricity at these hours at each node of the NSFNET are shown in Table 2. Electricity price distribution is adopted from the paper by Dong, El-Gorashi, and Elmirghani, (2013) with slight modification in each tier's hourly range. Minimum pricing of electricity occurs within the hours of Tier 1, maximum electricity pricing occurs in hours within Tier 2 while electricity pricing at hours within Tier 3 is between two extremes pricing at Tier 1 and Tier 2. For comprehensive analysis of the effect of ToU pricing on the placement of VM clusters in the distributed cloud given the objective in Equation 8, the model above is simulated at 06:00, 18:00 and 22:00 hours of the day corresponding to Tier 1, Tier 2 and Tier 3 respectively.

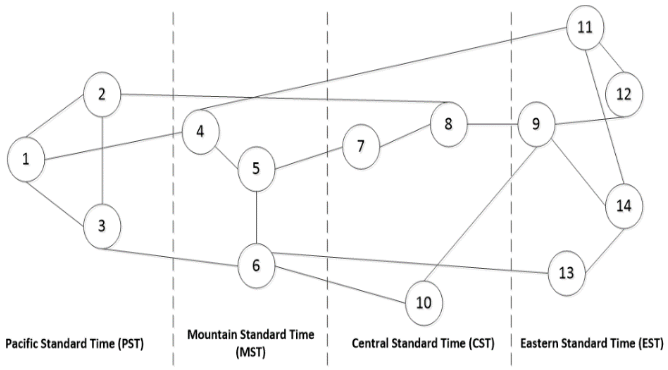


Fig. 1: NSFNET network with time zones

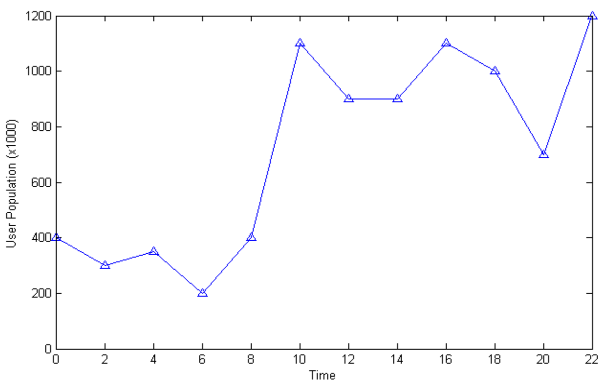


Fig. 2: User population at different times of the day

The MILP model is solved using AMPL/CPLEX software on 64-bit computer with an Intel Core i3, 2.10 GHz processor and 8 GB memory. An optimization scenario where the minimization of only operational cost (represented by electricity bill in the core network and datacenter) achieved by setting ($\alpha = 0, \beta = 0$ and $\gamma = 1$) is compared to the work by Lawey, El-Gorashi, and Elmirghani (2014) which is subsequently referred to as ($\alpha = 1, \beta = 1$ and $\gamma = 0$) setting. For consistence, the average total normalised workload of each VM cluster is fixed for all simulations. Fig. 3 illustrates the assignment of total normalised workload assigned to all VM clusters. The input parameter for the model are given in Table 3.

A. Results Under (α=0, β=0 and γ=1) Setting

Under the (α=0, β=0 and γ=1) setting, the minimization of network and cloud non-renewable power consumption in the model's objective is removed, leaving the minimization of total electricity cost as the sole objective. However, the estimation of total electricity cost is expected to also implicitly minimize both network and cloud non-renewable power consumption. The model is simulated at 06:00 (Tier 1), 18:00 (Tier 2) and 22:00 (Tier 3) to study the effect of ToU pricing policy on the placement of VM clusters in distributed clouds over an IP over WDM network.

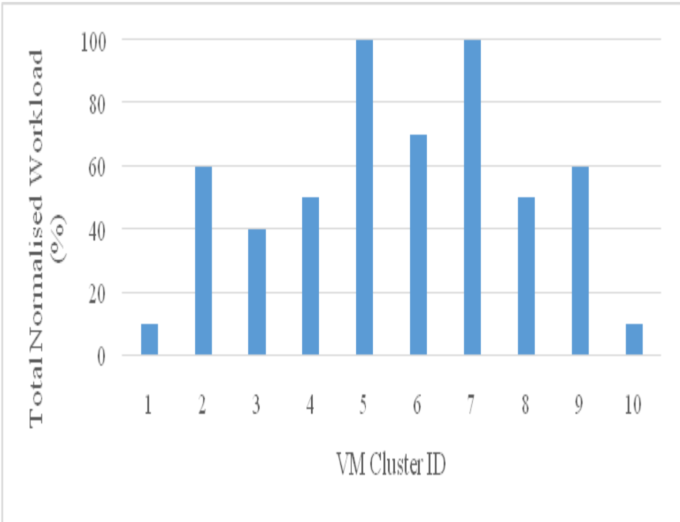


Fig. 3: Total normalized workload distribution based on VM clusters ID

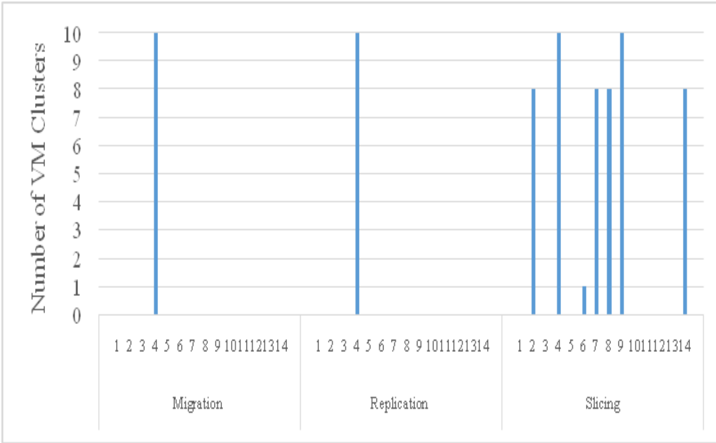
Table 2: Electricity price (in Cent/KWh) distribution at different nodes of the NSFNET at hours of the day

Time / Node	Tier 1 (22:01-6:00)	Tier 2 (6:01 – 18:59)	Tier 3 (18:01-22:00)
1	6.5	22.8	13
2	3.8	13.3	7.6
3	6.5	22.8	13
4	3.5	12.2	7
5	4.6	16	9.2
6	4.9	17	9.7
7	3.8	13.2	7.6
8	3.9	13.4	7.7
9	3.9	13.5	7.7
10	4.7	16.4	9.4
11	8.2	28.8	16.5
12	7.4	25.7	14.7
13	5.3	18.6	10.6
14	4.4	15.2	8.7

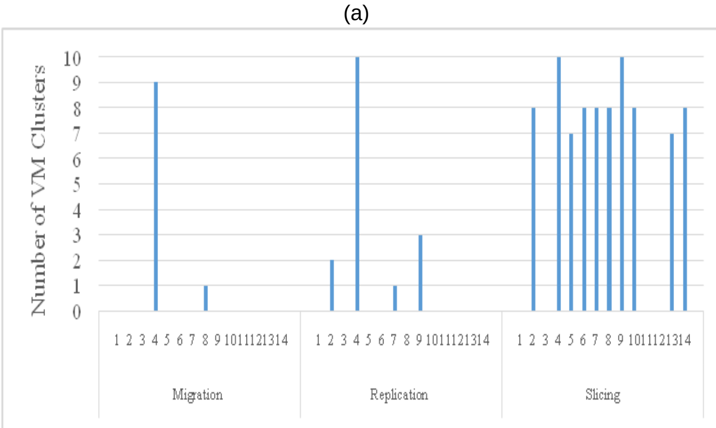
Table 3: Input parameter for LP model

Description	Value
40 Gb/s router port power consumption (*Pr*)	825 W (GreenTouch, 2015)
40 Gb/s transponder power consumption (*Pt*)	167 W, Reach 2500 km (Van Heddeghem, et al., 2013)
40 Gb/s regenerator power consumption (*Prg*)	334 W, Reach 2500 km (Van Heddeghem, et al., 2013)
EDFA power consumption (*Pe*)	55 W (Van Heddeghem, et al., 2012)
Optical switch power consumption (*PO*)	85 W (Glimmerglass Cyber Solutions, 2014)
Number of wavelengths in a fibre (*W*)	16
Bit rate of each wavelength (*B*)	40 Gb/s
Span distance between EDFAs (*S*)	80 km
User download rate	5 Mb/s
Switching redundancy (*Red*)	2
Cloud switch power consumption (*SwPC*)	3.8 KW
Cloud switch capacity (*SWC*)	320 Gb/s
Cloud router power consumption (*RPC*)	5.1 KW
Power usage effectiveness of the cloud (PUE_c)	2.5
Power usage effectiveness of the network (PUE_n)	1.5
Cloud router capacity	660 Gb/s
Number of VM Clusters	10 (50 VMs per Cluster i.e. 500 VM total)
Cluster maximum power consumption (*Pmax*)	15 KW (300 W per VM)
Cluster maximum normalized workload (*Wmax*), At 100% workload, each VM in the cluster requires 100% of server CPU processing capacity, therefore 100% VM cluster workload is equivalent to 5000% server workload.	100%
Server power per normalized workload, $SPPW = \frac{Pmax}{Wmax}$	150 W per 1% VM cluster normalized workload
VM Cluster *v* average total normalized workload (WL_v)	RAND {10, 20, 30, 40, 50, 60, 70, 80, 90, 100} %
Minimum allowed normalized workload per VM cluster (*MinW*)	5%

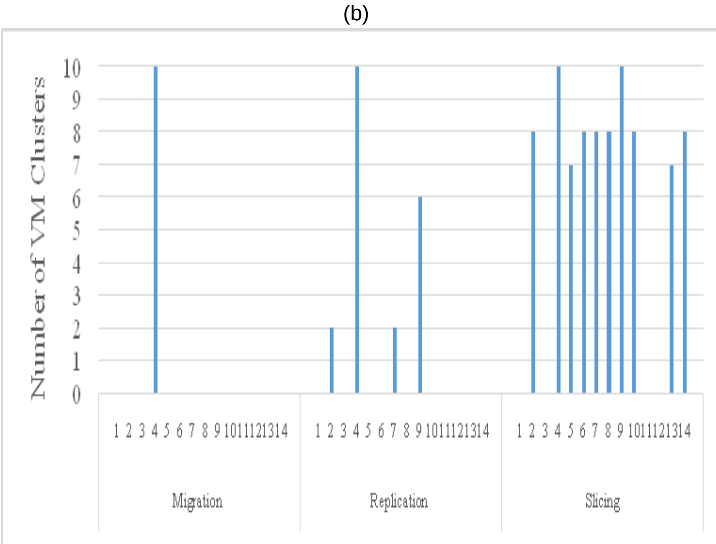
Under the migration and replication schemes at 06:00 when user demand is at its minimum, the location of the single cloud created is changed to node 4 as compared to node 6 obtained under (α=1, β=1 and γ=0) setting, see Fig.4a. This is because electricity cost is lowest at node 4 and also because cloud power consumption is the dominant factor which therefore determines the optimal result. From Table 4, it can be seen that the total cloud power consumption under the migration and replication schemes remains unchanged. However, there is 11.1% increase in total network non-renewable power consumption under both schemesin order to achieve 23.1% decrease in total electricity cost compared to results obtained under (α=1, β=1 and γ=0) setting. Under the slicing scheme at 06:00, slices of VM clusters are also hosted in nodes with low electricity cost to reduce operational expenditure (OPEX) in datacenters at the expense of 102.3% increase in network non-renewable power consumption compare to results at the same time under (α=1, β=1 and γ=0) setting.



(a)



(b)



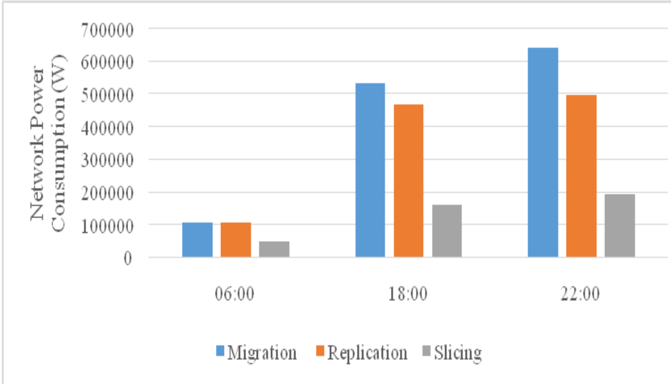
(c)

Fig. 4: (a) VM clusters placement under setting ($\alpha = 0, \beta = 0$ *and* $\gamma = 1$) at 06:00; (b) VM clusters placement under setting ($\alpha = 0, \beta = 0$ *and* $\gamma = 1$) at 18:00; (c) VM clusters placement under setting ($\alpha = 0, \beta = 0$ *and* $\gamma = 1$) at 22:00;

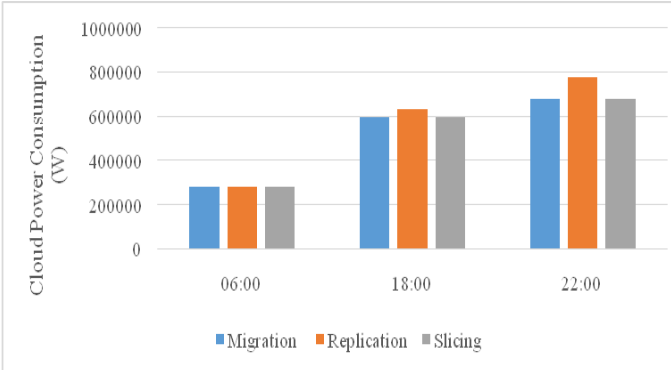
Furthermore, Fig. 4a shows that the number of slices of VM clusters created and the location where these slices are hosted is determined by the prices of electricity at nodes in the network topology. The slice scheme under (α=0, β=0 and γ=1) setting achieves 20.7% decrease in electricity cost compared to the slicing scheme under (α=1, β=1 and γ=0) setting at the same time. Despite the increase in network non-renewable power consumption under the slicing scheme when electricity cost minimization is the objective, the slicing scheme remains cheaper and is more energy efficient than the migration and replication schemes as shown in Figures 5a and 5b. This is because there is much less network non-renewable power consumption under the slice scheme compared to migration and replication schemes.

The trends under (α=0, β=0 and γ=1) setting at 18:00 when user demand is high are similar to those reported in at 06:00. Under the migration scheme at 18:00, VM clusters are hosted at nodes (nodes 4 and 8) with cheap electricity cost as shown in Fig. 4b. While nine (9) VM clusters are hosted in node 4 (with the cheapest electricity cost), only one VM cluster with light average total workload is hosted at node 8. Distribution of VM clusters between the datacenters at these two nodes leads to11% increase in total network non-renewable power consumption and 19% savings in total electricity cost compared to results under (α=1, β=1 and γ=0) setting while total cloud non-renewable power consumption remains at the same level as given in Table 4. The replication scheme ensures that in addition to the single cloud in node 4, only replicas of VM clusters with light workloads are made in order to limit the increase oftotal cloud non-renewable power consumption. The model further ensures electricity cost is minimized by placing replicas only in nodes (nodes 2, 7 and 9) with cheap electricity cost as shown in Fig. 4b. Reduction in the number of replicas and their conservative distribution compared to results obtained under (α=1, β=1 and γ=0) setting at the same led to 8.1% increase in network non-renewable power consumption and 20.8% decrease in total electricity cost. The flexibility of the slicing scheme reported by Lawey, El-Gorashi, and Elmirghani (2014) under (α=1, β=1 and γ=0) setting at 18:00 is curtailed by the need to cut OPEX. Therefore, rather than making maximum slices of each VM cluster that the slicing constraints permits and placing them at datacenters located at all nodes in the network topology, the model avoids nodes 1, 3, 11, and 12 in order to minimize OPEX as shown in Fig. 4b. About 15% decrease in OPEX is achieved at the expense of 36.6% increase in network non-renewable power consumption as shown in Table 4.

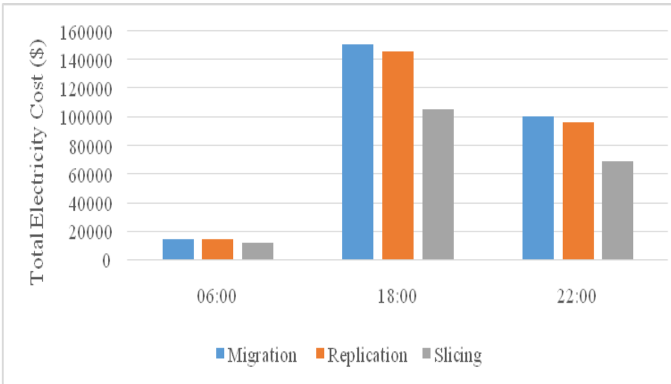
At 22:00 when user demand is at its peak, the migration scheme under (α=0, β=0 and γ=1) setting returns to single cloud in node 4 as shown in Fig.4c. In a similar trend to those reported at 6:00 and 18:00 under migration scheme, 18.3% savings is made in total electricity cost (OPEX) compared to cost under (α=1, β=1 and γ=0) setting. This savings is at the expense of 11% increase in total network non-renewable power consumption. The replication and slicing schemes at 22:00 under (α=0, β=0 and γ=1) setting follows the trends reported at 18:00, where replicas and slices of VM clusters are hosted at nodes with cheap electricity in order to minimize total electricity cost (OPEX). However, 4.2% increase in network non-renewable power consumption is obtained under replication scheme at 22:00 when results under (α=0, β=0 and γ=1) setting and (α=1, β=1 and γ=0) setting are compared. This is because cheap electricity at some nodes encouraged the creation and placement of more replicas in these nodes.



(a)



(b)



(c)

Fig. 5: (a) Network non-renewable power consumption under setting $(\alpha = 0, \beta = 0 \; and \; \gamma = 1)$; (b) Cloud non-renewable power consumption under setting $(\alpha = 0, \beta = 0 \; and \; \gamma = 1)$; (c) Total electricity cost under setting $(\alpha = 0, \beta = 0 \; and \; \gamma = 1)$.

Results in Table 4 shows that 20.2% decrease and 16.0% decrease in total electricity cost are recorded under replication and slicing placement schemes under (α=0, β=0 and γ=1) setting at 22:00 when compared with the results under (α=1, β=1 and γ=0) setting. Results obtained under (α=0, β=0 and γ=1) setting shows that increase in network non-renewable power consumption which also leads to an increase in the OPEX of network infrastructure provider is inevitable if the objective of minimizing total electricity cost and non-renewable power consumption is to be achieved. The disparity between the cloud infrastructure power consumption and that of the network infrastructure is responsible for this trend. Thus leaving little room for optimization asides ensuring that the cloud infrastructure be sited in locations with cheap electricity cost. Results under (α=0, β=0 and γ=1) setting also shows that changes in prices between different tiers illustrated in Table 2 has little or no effect on the placement of VM clusters in the distributed cloud architecture, network and cloud non-renewable power consumption. The linear relationship between ToU prices of the three tiers across the nodes of the network topology explains this phenomenon. Non-linear variation of electricity cost between tiers of the ToU pricing policy is expected to yield more interesting results.

Table 4. Percentage increase in network power consumption, cloud power consumption and total electricity cost between (α=1, β=1 and γ=0) setting and (α=0, β=0 and γ=1) setting

Percentage (%) Increase	Network Power Consumption			Cloud Power Consumption			Total Electricity Cost		
	06:00	18:00	22:00	06:00	18:00	22:00	06:00	18:00	22:00
Migration	11.1	11.0	11.0	0.0	0.0	0.0	-23.1	-19.0	-18.3
Replication	11.1	8.1	-4.2	0.0	1.8	10.7	-23.1	-20.8	-20.2
Slicing	102.3	36.6	36.7	0.0	0.0	0.0	-20.7	-15.2	-16.0

4 Conclusion and Future Work

This paper studies the impact of smart grid concept of ToU on the placement of VM clusters in distributed clouds under three different placement schemes. AMILP model was developed with an objective to minimize non-renewable power consumption of IP over WDM core network and distributed clouds and total electricity cost of network and datacenter infrastructure provider. Two different scenarios were considered, one where minimization of total electricity cost is the objective of the model and another where only the minimization of non-renewable power consumption is the objective. The results showed that OPEX minimization forces the placement of VM clusters at nodes with cheap electricity cost at the expense of increased network non-renewable power. This trend under various VM cluster placement schemes and different user demand value is attributed to dominance of VM clusters power consumption over that of the core network. Compared to the migration and replication schemes, the slicing scheme is the most energy efficient and cost efficiency scheme. However, compared to the scenario where the objective is to minimize total non-renewable power, the least savings in total electricity cost was obtained under the slicing scheme. To mitigate challenges of increased non-renewable power consumption and OPEX in the core network as result total OPEX minimization the introduction of solar power sources for the core network is proposed in future works. Non-linear variations of electricity cost between tiers of the ToU can also be explored in future works.

References

Bilal, K., Malik, S. U., Khan, S. U., & Zomaya, A. Y. (2014). Trends and Challenges in Cloud Datacenters. *IEEE Cloud Computing, 1*(1), 10-20.

Cavdar, C., Yayımlı, A., & Wosinska, L. (2011). How to Cut the Electric Bill in Optical WDM Networks with Time-zones and Time-of-use Prices. *37th European Conference and Exhibition on Optical Communication*, (pp. 1-3). Geneva.

Dong, X., El-Gorashi, T. E., & Elmirghani, J. M. (2013). Joint Optimization of Power, Electricity Cost and Delay in IP over WDM networks. *IEEE International Conference on Communication*. Budapest.

Dong, X., El-Gorashi, T., & Elmirghani, J. (2011). Green IP Over WDM Networks With Data Centers. *Journal of Lightwave Technology*, 29(12), 1861-1880 .

Dong, X., El-Gorashi, T., & Elmirghani, J. (2011). IP Over WDM Networks Employing Renewable Energy Sources. *Journal of Lightwave Technology*, 29(1), 3-14.

Erol-Kantarci, M., & Mouftah, H. T. (2015). Energy-Efficient Information and Communication Infrastructures in the Smart Grid: A Survey on Interactions and Open Issues. *IEEE COMMUNICATION SURVEYS & TUTORIALS*, 7(1), 179-197.

Glimmerglass Cyber Solutions. (2014). *Intelligent Optical System 500*. (Glimmerglass Cyber Solutions) Retrieved August 10, 2015, from http://www.glimmerglass.com/products/intelligent-optical-systems/intelligent-optical-system-500/

GreenTouch. (2015, August 15). *Reducing the Net Energy Consumption in Communications Networks by up to 98% by 2020*. Retrieved August 26, 2015, from http://www.greentouch.org/uploads/documents/White%20paper%20on%20Green%20Meter%20Final%20Results%20August%202015%20Revision%20-%20vFINAL.pdf

Kantarci, B., & Mouftah, H. T. (2012). The Impact of Time of Use (ToU)-Awareness in Energy and Opex Performance of a Cloud Backbone. *Globecom 2012 - Symposium on Selected Areas in Communications*.

Lawey, A., El-Gorashi, T., & Elmirghani, J. (2014, April). Distributed Energy Efficient Clouds over Core Networks. *Journal of Lightwave Technology*, 32(7), 1261-1281.

Peoples, C., Parr, G., McClean, S., & Morrow, P. (2013). Green Networks and Communications. In *Handbook of Green Information and Communication Systems* (pp. 127-148). OXFORD: Academic Press (Elsevier).

Shen, G., & Tucker, R. S. (2009). Energy-Minimized Design for IP Over WDM Networks. *IEEE/OSA Journal of Optical Communications and Networking*, 1(1), 176-186.

Shen, G., Lui, Y., & Bose, S. K. (2014). "Follow the Sun, Follow the Wind" Lightpath Vitrtual Topology Reconfiguration in IP Over WDM Network. *Journal of Lightwave Technology*, 32(11), 2094-2104.

The EINS Consortium. (2013). *Deliverable 8.1. Overview of ICT energy consumption*.

Van Heddeghem, W., Idzikowski, F., Musumeci, F., Pattavinac, A., Lannoo, B., Colle, D., & Pickavet, M. (2013). A Power Consumption Sensitivity Analysis of Circuit-Switched Versus Packet-Switched Backbone Networks. *IEEE Online Conference on Green Communications (GreenCom)*. Piscataway.

Van Heddeghem, W., Idzikowski, F., Vereecken, W., Colle, D., Pickavet, M., & Demeester, P. (2012). Power consumption modeling in optical multilayer networks. *Photonic Network Communications* , 24(2), 86-102.

Zhang , Y., Chowdhury, P., Tornatore, M., & Mukherjee, B. (2010). Energy Efficiency in Telecom Optical Networks. *IEEE Communications Surveys & Tutorials*, 12(4), 441-458.