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Renewable Energy in Distributed Energy Efficient Content Delivery Clouds

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***Abstract*—In this paper, we develop a Mixed Integer Linear Programming (MILP) model to study the impact of renewable energy availability, represented by wind farms, on the location of clouds and the content replication schemes of cloud content over IP/WDM networks. In our analysis, we assume that renewable energy is only available to power clouds while the IP/WDM network is powered by non-renewable energy. Our results show that popularity based replication in clouds is the most energy efficient content replication scheme when the clouds are powered only by non-renewable energy sources or when renewable energy availability is limited. With abundant renewable energy, a cloud with a full copy of the content can be built at each node. However, the model should achieve a trade-off between the transmission power losses to deliver renewable energy from wind farms to clouds and the non-renewable power consumption of the IP/WDM network. We discuss this trade-off and show how to optimize the transmission power losses of renewable energy while minimizing the non-renewable network power consumption.**

***Index Terms*—Cloud computing, popularity, content delivery, IP/WDM, energy consumption, renewable energy**

I. INTRODUCTION

Cloud computing with its several descendant technologies (XaaS: everything as a service) expands the reach of its ancestor research oriented grid computing powerful resource management to serve a larger pool of consumers through a business model where users are charged for the offered service [1]. Virtualization [2] lies at the heart of the cloud model, where requested resources are created, managed and removed flexibly over the existing physical machines such as servers, storage and networks. This opens the doors toward resource consolidation that cut the cost for the cloud provider and eventually, the cloud consumer. However, cloud computing elastic management and economic advantages come at the cost of increased concerns regarding their privacy [3], availability [4] and power consumption [5]. The cloud computing paradigm has benefited from the work done on datacenters energy efficiency [5]. However, the success of the cloud model relies heavily on the network that connects the clouds to their users. This means that the expected popularity of the cloud services will result in increased network traffic, hence, network power consumption, especially if we consider the total path that information will traverse from clouds storage through its servers, LAN, core, aggregation and access network up to users' devices. For instance, the authors in [6] have shown that transporting data in public and sometimes private clouds might be less energy efficient compared to performing the tasks in traditional desktops at the user end.

Designing future energy efficient clouds, therefore, requires the co-optimization of both external network and internal clouds resources. The lack of understanding of this interplay between the two domains of resources might cause eventual loss of power.

In [7], [8] we introduced a framework for designing energy efficient cloud content delivery over non-bypass IP/WDM core networks. We developed a Mixed Integer Linear Programming (MILP) model to optimize network related factors including the location of the cloud in the network and whether it should be centralized or distributed, and cloud capability factors including the number of servers, switches, routers and amount of storage required at each cloud location. We compared the different delivery approaches and concluded that distributing the cloud into many mini clouds in the network based on content popularity (OPR: Optimal Popularity based Replication approach) yields 40% total (network plus cloud) saving in power consumption compared to power un-aware centralized content delivery. OPR dynamically converges to a single cloud for content of larger size at low demand periods while it fully replicates content at all clouds for content of smaller size at high demand periods.

A number of papers have considered means to exploit the renewable energy in cloud datacenters [9]. In [10] the authors studied reducing the CO_2 emission of backbone IP over WDM networks powered by renewable energy sources. The work in [10] is extended in [11] to investigate the problem of whether to locate datacenters next to renewable energy or to transmit renewable energy to datacenters. In [12] the authors introduced renewable energy aware virtual machine migration heuristics. The authors in [13] developed two algorithms to route connections supporting cloud computing services so the CO_2 emissions of the network are reduced.

In this work, we extend our cloud content delivery model developed in [7], [8] to study the impact of renewable energy availability on the optimization of cloud locations, internal capability and content replication patterns. In our analysis, renewable energy is only available to clouds while the IP/WDM network is powered by non-renewable energy. We have chosen wind farms as the source of renewable energy as they are very promising in terms of production capacity and the price per megawatt hour compared to non-renewable energy [14]. The decision of a cloud provider to migrate/replicate its content near to renewable energy sources is governed by the trade-off between the non-renewable power savings achieved by powering the cloud using renewable energy and the power consumption of the network through which users requests traverse to the new cloud location. The aim of this study is to investigate this trade-off taking into account the power losses in electrical power transmission lines delivering renewable energy from wind farms to clouds as well as investigating the associated optimal content replication pattern. A summary of this work was presented orally in [15], however [15] does not include a written paper and this is the first written version of our work.

The remainder of this paper is organized as follows. Section II introduces our extended MILP model. In Section III we introduce and discuss the results of different approaches to optimize the use of wind farms renewable energy to power content delivery clouds. Finally, Section IV concludes the paper.

II. RENEWABLE POWERED CONTENT DELIVERY CLOUD MODEL

In the energy efficient content delivery cloud model developed in [7], [8] the model selects, based on users requests, the optimal number and location of clouds as well as the capability of each cloud so that the total power consumption is minimized. The model also decides how to replicate content in the cloud so that the minimum power is consumed in delivering content.

In this section we extend the model in [7], [8] to consider the availability of renewable energy sources to power the cloud. We assume the following:

- The IP/WDM network is powered by non-renewable energy.
- Wind farm power is available to power clouds. However, to maintain service availability in case of limited wind farm power, clouds also have access to non-renewable energy sources.
- There is no restriction on the number of wind farms powering a given cloud.
- Only a fraction, ρ, of the wind farm power is available to power the clouds.
- The electric power transmission loss (PL_{ws}) to deliver power from wind farms to clouds is assumed to be 15% per 1000 km.
- The popularity of the different objects of the content follows a Zipf distribution, representative of the popularity distribution of several cloud content types such as YouTube and others [16] where the popularity of an object of rank *i* is given as follows:

  $$P(i) = \varphi / i$$

  where $P(i)$ is the relative popularity of object of rank *i* and φ is:

  $$\varphi = \left(\sum_{i=1}^{N} \frac{1}{i} \right)^{-1}$$

We divide the content in our model into equally sized popularity groups. A popularity group contains objects of similar popularity.

The original model is introduced in [7], [8] and we re-introduce the relevant parts here for completeness and extend the model to consider the availability of renewable energy. We define the following sets, variables and parameters:

Sets:

N	Set of IP/WDM nodes.
Nm_i	Set of neighbors of node *i*.
U_d	Set of users in node *d*.
PG	Set of popularity groups, $\{1\ldots PGN\}$.

Parameters:

Prp	Router port power consumption.
Pt	Transponder power consumption.
Pe	EDFA power consumption.
PO_i	Optical switch *i* power consumption.
Pre	Regenerators power consumption.
RG_{mn}	$RG_{mn} = 1$ if there is a regenrator along the link between (*m,n*), otherwise $RG_{mn} = 0$.
W	Number of wavelengths per fiber.
B	Wavelength bit rate.
S	Span distance between EDFAs.
D_{mn}	Distance between node pair (*m,n*).
A_{mn}	Number of EDFAs between node pair (*m,n*).
PUE_n	IP/WDM network power usage effectiveness.
M	A large enough number.
PGN	Number of popularity groups.
PUE_c	Cloud power usage effectiveness.
S_PC	Storage power consumption.
S_C	Storage capacity in GB.
Red	Storage and switching redundancy.
S_PPGB	Storage power consumption per GB, $S\_PPGB = S\_PC/S\_C$.
S_Utl	Storage Utilization.
PGS_p	Popularity group storage size, $PGS_p = (S\_C/PGN) \cdot S\_Utl$.
CS_C	Content server capacity.
CS_EPB	Content server energy per bit.
Sw_PC	Cloud switch power consumption.
Sw_C	Cloud switch capacity.
Sw_EPB	Cloud switch energy per bit, $Sw\_EPB = Sw\_PC/Sw\_C$.
R_PC	Cloud router power consumption.
R_C	Cloud router capacity.
R_EPB	Cloud router energy per bit, $R\_EPB = R\_PC/ R\_C$.
$Drate$	Average user download rate.
P_p	Popularity of object *p* (Zipf distribution).
ND_d	Node *d* total traffic demand, $ND_d = \sum_{i \in U_d} Drate$.
D_{Pd}	Popularity group *p* traffic to node *d*, $D_{pd} = ND_d \cdot P_p$.
PL_{ws}	Fraction of electric power lost due to transmission power losses between wind farm *w* and the cloud in node *s*.
WP_w	The maximum output power of wind farm *w*.
ρ	The fraction of wind farms power available to clouds.

Variables

C_{ij}	Number of wavelengths in the virtual link (*i,j*).
L_{ij}^{sd}	Traffic flow between node pair (*s,d*) traversing virtual link (*i,j*).

W_{mn}^{ij}	Number of wavelength channels in the virtual link (*i,j*) traversing physical link (*m,n*).
W_{mn}	Total number of wavelengths in the physical link (*m,n*).
F_{mn}	Total number of fibers in the physical link (*m,n*).
Q_i	Number of aggregation ports in router *i*.
δ_{sdp}	$\delta_{sdp}=1$ if popularity group *p* is placed in node *s* to serve users in node *d*, otherwise $\delta_{sdp}=0$.
LP_{sdp}	Traffic generated due to placing popularity group *p* in node *s* to serve users in node *d*.
L_{sd}	Traffic from cloud *s* to users in node *d*.
Cup_s	Cloud *s* upload capacity.
δ_{sp}	$\delta_{sp}=1$ if cloud *s* stores a copy of popularity group *p*, $\delta_{sp}=0$ otherwise.
$Cloud_s$	$Cloud_s=1$ if a cloud is built in node *s*, $Cloud_s=0$ otherwise.
$StrC_s$	Cloud *s* storage capacity.
Δ_{ws}	The amount of renewable power of wind farm *w* assigned to power the cloud in node *s*.
$TNNRP$	Total network non-renewable power consumption.
$CNRP_s$	Cloud *s* non-renewable power consumption.
$TCNRP$	Total clouds non-renewable power consumption. $TCNRP=\sum_s CNRP_s$
CRP_s	Cloud *s* renewable power consumption.
$TCPC_s$	Cloud *s* total power consumption.
$TPLOSS$	Total transmission power losses

Three elements are to be minimized in our model:

a. IP/WDM network non-renewable power consumption.

b. Clouds non-renewable power consumption.

c. Transmission power losses between wind farms and clouds.

Under the non-bypass approach, the total network non-renewable power consumption ($TNNRP$) is composed of [17], [11]:

1) The power consumption of router ports:

$$PUE_n\cdot\sum_{i\in N} Prp\cdot Q_i+Prp\cdot\sum_{m\in N}\sum_{n\in Nm_m} W_{mn}$$

2) The power consumption of transponders:

$$PUE_n\sum_{m\in N}\sum_{n\in Nm_m} Pt\cdot W_{mn}$$

3) The power consumption of EDFAs:

$$PUE_n\cdot\sum_{m\in N}\sum_{n\in Nm_m} Pe\cdot A_{mn}\cdot F_{mn}$$

4) The power consumption of optical switches:

$$PUE_n\cdot\sum_{i\in N} PO_i$$

5) The power consumption of regenerators

$$PUE_n\cdot\sum_{m\in N}\sum_{n\in Nm_m}\text{Pre}\cdot RG_{mn}\cdot W_{mn}$$

Total clouds power consumption ($\sum_s TCPC_s$) is composed of:

1) The power consumption of content servers:

$$PUE_c\cdot\sum_{s\in N} Cup_s\cdot CS\_EPB$$

2) The power consumpton of switches and routers:

$$PUE_c\cdot\sum_{s\in N} Cup_s\cdot(Sw\_EPB\cdot Red+R\_EPB)$$

3) The power consumption of storage

$$PUE_c\cdot\sum_{s\in N} StrC_s\cdot S\_PPGB\cdot Red$$

The total transmission losses ($TPLOSS$) is calculated as follows:

$$\sum_{w\in WF}\sum_{s\in N}\Delta_{ws}\cdot PL_{ws}$$

The model is defined as follows:

Objective: Minimize

$$\alpha\cdot TNNRP+\beta\cdot TCNRP+\gamma\cdot TPLOSS \tag{1}$$

Subject to:

$$\sum_{j\in N:i\neq j} L_{ij}^{sd}-\sum_{j\in N:i\neq j} L_{ji}^{sd}=\begin{cases}L_{sd} & if\, i=s\\ -L_{sd} & if\, i=d\\ 0 & otherwise\end{cases}$$
$$\forall s,d,i\in N:\ s\neq d \tag{2}$$

$$\sum_{s\in N}\sum_{d\in N:s\neq d} L_{ij}^{sd}\le C_{ij}\cdot B$$
$$\forall i,j\in N:\ i\neq j \tag{3}$$

$$\sum_{n\in Nm_m} W_{mn}^{ij}-\sum_{n\in Nm_m} W_{nm}^{ij}=\begin{cases}C_{ij} & if\, m=i\\ -C_{ij} & if\, m=j\\ 0 & otherwise\end{cases}$$
$$\forall i,j,m\in N:\ i\neq j \tag{4}$$

$$\sum_{i\in N}\sum_{j\in N:i\neq j} W_{mn}^{ij}\le W\cdot F_{mn}$$
$$\forall m\in N\ \ \forall n\in Nm_m \tag{5}$$

$$\sum_{i\in N}\sum_{j\in N:i\neq j} W_{mn}^{ij}=W_{mn}$$
$$\forall m\in N\ \ \forall n\in Nm_m \tag{6}$$

$$Q_i=\ 1/B\cdot\sum_{d\in N:i\neq d} L_{id}$$
$$\forall i\in N \tag{7}$$

$$LP_{sdp}=\delta_{sdp}\cdot D_{Pd}$$
$$\forall d\in N\ \ \forall p\in PG \tag{8}$$

$$\sum_{s\in N} LP_{sdp}=D_{Pd}$$
$$\forall d\in N\ \ \forall p\in PG \tag{9}$$

$$L_{sd}=\sum_{p\in PG} LP_{sdp}$$
$$\forall s,d\in N \tag{10}$$

$$Cup_s = \sum_{d \in N} L_{sd}$$

$$\forall s \in N \qquad (11)$$

$$\sum_{d \in N} \delta_{sdp} \geq \delta_{sp}$$

$$\forall s \in N \ \ \forall p \in PG \qquad (12)$$

$$\sum_{d \in N} \delta_{sdp} \leq M \cdot \delta_{sp}$$

$$\forall s \in N \ \ \forall p \in PG \qquad (13)$$

$$\sum_{p \in PG} \delta_{sp} \geq Cloud_s$$

$$\forall s \in N \qquad (14)$$

$$\sum_{p \in PG} \delta_{sp} \leq M \cdot Cloud_s$$

$$\forall s \in N \qquad (15)$$

$$StrC_s = \sum_{p \in PG} \delta_{sp} \cdot PGS_p$$

$$\forall s \in N \qquad (16)$$

$$TCPC_s = CNRP_s + CRP_s$$

$$\forall s \in N \qquad (17)$$

$$CRP_s = \sum_{w \in WF} \Delta_{ws} \cdot (1 - PL_{ws})$$

$$\forall s \in N \qquad (18)$$

$$\sum_{s \in N} \Delta_{ws} \leq WP_w \cdot \rho$$

$$\forall w \in WF \qquad (19)$$

Equation (1) gives the model objective which is to minimize the IP/WDM network non-renewable power consumption, the cloud non-renewable power consumption and transmission power losses subject to weights α, β, and γ, respectively where the values of the weights are decided by the relevant approach as will be discussed in Section III.

Constraint (2) is the flow conservation constraint for the IP layer. It ensures that the total incoming traffic is equal to the total outgoing traffic for all nodes except for the source and destination nodes.

Constraint (3) ensures that the traffic traversing a virtual link does not exceed its capacity.

Constraint (4) represents the flow conservation for the optical layer. It ensures that the 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.

Constraints (5) and (6) represent the physical link capacity constraints. Constraint (5) ensures that the number of wavelength channels in virtual links traversing a physical link does not exceed the capacity of fibres in the physical link. Constraint (6) ensures that the number of wavelength channels in virtual links traversing a physical link is equal to the number of wavelengths in that physical link.

Constraint (7) calculates the number of aggregation ports for each router.

Constraint (8) calculates the traffic generated in the IP/WDM network due to requesting popularity group *p* that is placed in node *s* by users located in node *d.*

Constraints (9) ensures that each popularity group request is served from a single cloud only.

Constraint (10) calculates the traffic from the cloud in node *s* and users in node *d,* to be used in constraints (2) and (7).

Constraint (11) calculates each cloud upload capacity based on total traffic sent from the cloud.

Constrains (12) and (13) ensure that popularity group *p* is replicated to cloud *s* if cloud *s* is serving requests for this popularity group.

Constrains (14) and (15) build a cloud in location *s* if that location is chosen to store at least one popularity group or more.

Constraint (16) calculates the storage capacity needed in each cloud based on the number of replicated popularity groups.

Constraint (17) dictates the combination of renewable and non-renewable energy sources that will power a cloud *s.*

Constaint (18) calculates the renewable power delivered to each cloud from the different wind farms subject to transmission losses.

Constaint (19) ensures that for each wind farm the total renewable energy allocated to power clouds does not exceed the total renewable energy available to power the clouds.

III. RESULTS

The NSFNET network, depicted in Fig.1 is considered as an example network to evaluate the power consumption of the cloud content delivery service over non-bypass IP/WDM networks with wind farms located at nodes 4, 6 and 8, which are current US wind farm locations [11].

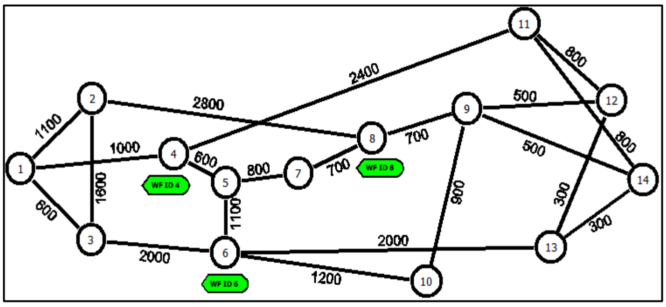

Fig.1 The NSFNET network with wind farms locations

In our evaluation, users are uniformly distributed among the NSFNET nodes and the total number of users in the network is 1,200k, estimated based on the data in [11]. The maximum output power of the three wind farms 4, 6 and 8 is 300, 700, and 400 MW [11], respectively.

Table I gives the input parameters of the model. Note that the 5Mbps average download rate is based on the results of a survey conducted in the US in 2011 [19].

TABLE I
INPUT DATA FOR THE MODEL

Power consumption of 40Gbps router port (Prp)	440W[18]
Power consumption of transponder (Pt)	148W[18]
Power consumption of an optical switch $(PO_i)\ \forall\, i \in N$	85W[18]
Power consumption of EDFA (Pe)	52W[18]
Power consumption of regenerators (Pre)	222W[18]
Transponder / Regenerators reach at 40 Gbps	2500 km[18]
Number of wavelengths in a fiber (W)	32
Bit rate of each wavelenght (B)	40Gbps
Span distance between EDFAs (S)	80km
Average client download rate $(Drate)$	5Mbps[19]
Content Server Capacity (CS_C)	1.8Gbps[20]
Content Server energy per bit (CS_EPB)	211.1W/Gbps[20]
Storage power consumption (S_PC)	4.9kW[6]
Storage capacity (S_C)	75.6×5TB[6]
Storage utilization (S_Utl)	50%
Storage and switching redundancy (Red)	2
Cloud switch power consumption (Sw_PC)	3.8kW[6]
Cloud switch capacity (Sw_C)	320Gbps[6]
Cloud router power consumption (R_PC)	5.1kW[6]
Cloud router capacity (R_C)	660Gbps[6]
Cloud power usage effectiveness (PUE_c)	2.5[8]
IP/WDM power usage effectiveness (PUE_n)	1.5[8]
Number of popularity groups (PGN)	50
Fraction of wind farms power available to clouds (ρ)	0, 0.001, 0.005

We divide the cloud content into 50 popularity groups which is a reasonable compromise between granularity and MILP model execution time. The MILP model is solved using the 64 bit AMPL/CPLEX software on an Intel Core i5, 2.4 GHz PC with 4 GB memory.

We study three approaches to optimize the use of wind farms renewable energy to power content delivery clouds:

1) Approach 1: α=1, β=1 and γ=1

This approach considers equally minimizing the three elements of equation (1). Fig.2 shows the clouds power consumption for different values of ρ. At ρ=0, all the power supplied is non-renewable and the model decides to replicate content into all the 14 possible locations according to the content popularity (OPR) where the majority of content is kept and served from the cloud in node 6 (Fig.3, blue bars) as this location has the lowest number of hops to other nodes, hence, lowest network power consumption. At ρ=0.001 the model decides to keep the distribution of content almost the same as the case with ρ=0 (Fig.3, red bars). In this case only clouds located at nodes with wind farms are powered by renewable energy as this results in the lowest transmission power losses and therefore efficiently utilizes the limited renewable energy available. At ρ=0.005, the amount of renewable energy is sufficient to power clouds at all nodes without the need for non-renewable energy. However, to reduce the transmission losses, the model limits the number clouds to 3 clouds each with a full copy of the content. (Fig.3, green bars).

Note that at ρ=0.005, cloud 8 (i.e. the cloud built at node 8) has the highest power consumption (Fig.2) in spite of the fact that all clouds have the same storage capacity (Fig.3, green bars). This is because cloud 8 serves more users than the other two clouds as it is closer, in terms of minimum hop and/or minimum distance, to more nodes.

This approach minimizes the transmission power losses by limiting number of built clouds. However, this comes at the cost of increasing the network power consumption by 33% compared to ρ=0. The next approach investigates compromising transmission losses for more power saving at the network side.

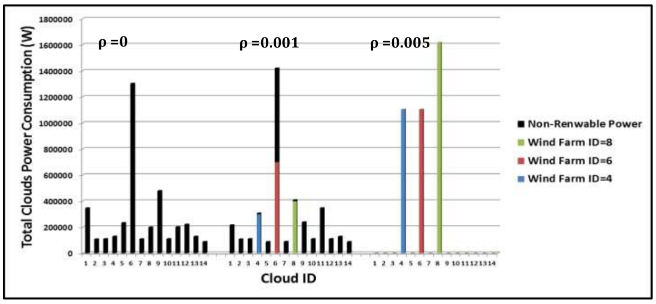

Fig.2 Clouds power consumption (Approach 1)

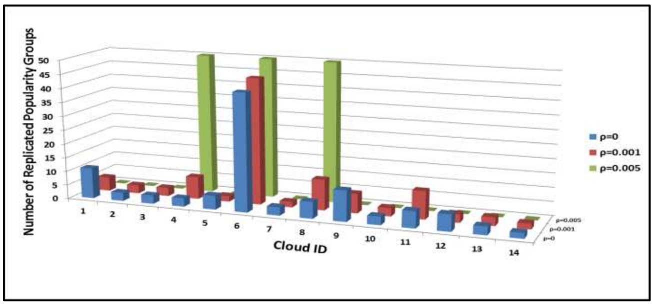

Fig.3 Number of popularity groups (Approach 1)

2) Approach 2: α=1, β=1 and γ=0

By setting γ=0, the model minimizes the network and cloud non-renewable power consumption without explicitly considering transmission losses in the objective function. The results of this approach are shown in Fig.4 and Fig.5. Note that the replication scheme has not changed at ρ=0 and ρ=0.001 compared to Approach 1, resulting in similar total power consumption. This is because although transmission losses are not considered explicitly in the objective, constraint (18) will ensure that transmission losses are minimized to efficiently utilize the limited renewable energy available. With enough renewable energy (ρ=0.005), the model decides to fully replicate content in all the 14 nodes (Fig.5, green bars). This configuration yields the minimum network power consumption as users requests are served from local clouds; therefore, only optical switches will be needed, resulting in only 1,785W of network power consumption. However, note that clouds 4 and 6 are not powered by their nearby wind farms 4 and 8, respectively. This is because enough renewable energy is available to power clouds at all nodes from any of the wind farms and as the transmission losses are not taken into account in the objective function, 1.5 MW of renewable power is lost in transmitting the renewable power from wind farms to clouds which is drastically higher than the non-renewable power saved at the IP/WDM network side (210kW). In the next approach we investigate the minimum transmission losses required to maintain the minimum network power consumption.

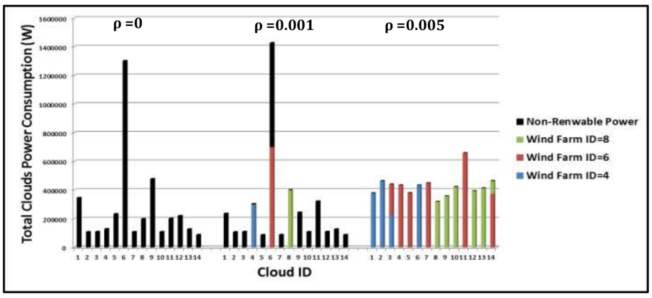

Fig.4 Clouds power consumption (Approach 2)

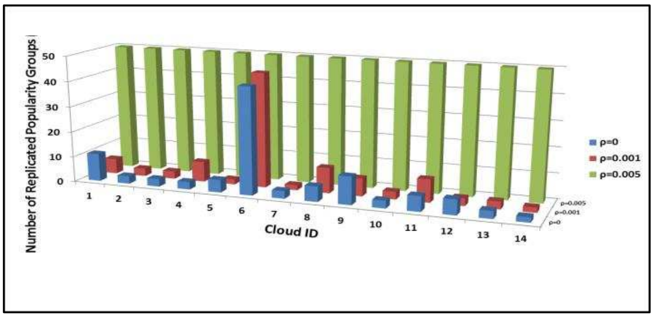

Fig.5 Number of popularity groups (Approach 2)

3) Approach 3: α=100, β=1 and γ=1

In this approach, the network power consumption is given a higher weight in the objective function than the cloud non-renewable power consumption and the transmission losses. The results of this approach are shown in Fig.6. In all cases, clouds with fully replicated content are created at all nodes to keep the network power consumption to its minimum. At ρ=0.001, as the amount of renewable energy available to power the clouds is not enough to power full replication at each cloud, wind farms power is mainly assigned to local clouds and other clouds are powered by non-renewable energy. The full replication at clouds powered totally or partially by non-renewable energy increases, increasing the total non-renewable power consumption by 25% compared to Approaches 1 and 2.

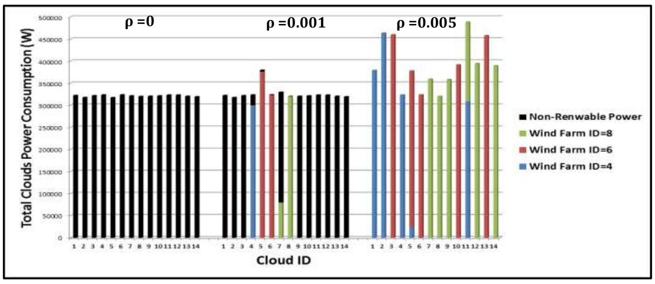

Fig.6 Clouds power consumption (Approach 3)

At ρ=0.005, the model manages to achieve the minimum network power consumption while saving 35% of transmission power compared to Approach 2. However, this is still larger than the power saved in the IP/WDM network side as 4.73W of renewable power have to be lost in transmission to save 1W of non-renewable power at the IP/WDM network.

Therefore, if total power consumption is the only metric to compare these different approaches, Approach 1 will be the apprprorate solution as it yields the minimum transmission losses. However, if the aim is to reduce CO_2 emition, which is a product of non-renewable energy generation, Approach 1 can be implemented when there is a limited amount of renewable energy while Approach 3 is implemented where sufficient renewable power is available.

IV. CONCLUSIONS

This paper has studied the impact of renewable energy availability, represented by wind farms, on cloud locations optimization and content replication schemes of content delivery clouds over non-bypass IP/WDM networks. We have developed a model to achieve a trade-off between the non-renewable power savings gained by powering the cloud by renewable energy and the power consumption of the network through which users requests traverse to the new cloud location taking into account the power losses in electrical transmission lines delivering renewable energy from wind farms to clouds. We have optimized the use of renewable energy under different scenarios. We have shown that building mini clouds in different network locations based on content popularity is the most energy efficient approaches when clouds are powered by non-renewable sources or when renewable energy is restricted. However, a trade-off between transmission losses and non-renewable power consumption in the IP/WDM network exists when there is enough renewable energy to power all the clouds. With typical transmission losses, network and cloud power consumption, building clouds in proximity of wind farms reduces transmission losses; however it is at the cost of consuming more non-renewable power at the network side. On the other hand, if the transmission losses are not considered but the renewable energy available is distance dependent, then building a cloud in each node results in saving network power consumption if enough renewable energy is available. However, if the network power consumption is the only driving force, then creating clouds with full content is the optimal configuration regardless of the availability of renewable energy.

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