Renewable Energy in Core and Data Centre Networks

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Outline

- Energy efficient core networks and renewable energy

- Renewable energy sources in IP over WDM networks with data centres

Outline

→ Energy efficient core networks and renewable energy

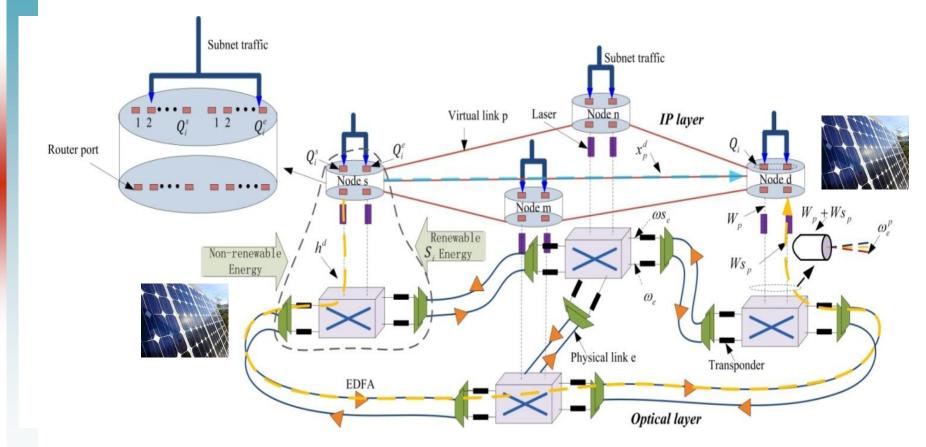• Renewable energy sources in IP over WDM networks with data centres

Outline

- Objectives

- "Hybrid-power" IP over WDM network architecture

- LP Model for Renewable Energy IP over WDM Network

- Heuristic Approach

- Scenario

- Results

Objectives

- We focus on reducing the CO_2 emission of backbone IP over WDM networks.

- A LP optimization model is developed for "hybrid-power" IP over WDM networks where the power supply is mixed, composed of non-renewable energy and renewable energy.

- A new heuristic is set up to minimize the non-renewable energy consumption (REO-hop).

- Issues addressed include
  - how to use renewable energy more effectively,
  - how to reduce the non-renewable energy consumption,
  - how to select the location of nodes that use renewable energy,
  - load dependent energy consumption of hardware.

LP Model for Renewable Energy IP over WDM Network

- The total non-renewable power consumption of the network is composed of:

  1. The non-renewable power consumption of IP ports without access to renewable energy:

  $$\sum_{i \in N} PR \cdot \left(Q_i^e + \sum_{p \in P} \delta_{ip} \cdot W_p \right)$$

  2. The non-renewable power consumption of IP ports that have access to renewable energy:

  $$\sum_{i \in N} PRS \cdot \left(Q_i^s + \sum_{p \in P} \delta_{ip} \cdot Ws_p \right)$$

  3. The non-renewable power consumption of transponders that have access to renewable energy and that of the transponders without access to renewable energy:

  $$\sum_{e \in E} \left(PT \cdot \omega_e + PTS \cdot \omega s_e \right)$$

LP Model for Renewable Energy IP over WDM Network

5. The non-renewable power consumption of optical switches that have access to renewable energy :

$$\sum_{i \in N} \left(PO_i \cdot (1 - y_i) + POS_i \cdot y_i \right)$$

6. The non-renewable power consumption of multiplexers and demultiplexers that have access to renewable energy:

$$\sum_{i \in N} \left(PMD \cdot DMe_i + PMDS \cdot DMs_i \right)$$

7. The non-renewable power consumption of EDFAs:

$$\sum_{e \in E} PE \cdot E_e \cdot f_e$$

LP Model for Renewable Energy IP over WDM Network

- Objective: minimize

$$\sum_{i \in N} PR \cdot \left(Q_i^e + \sum_{p \in P} \delta_{ip} \cdot W_p \right) + \sum_{e \in E} PE \cdot E_e \cdot f_e + \sum_{i \in N} PRS \cdot \left(Q_i^s + \sum_{p \in P} \delta_{ip} \cdot Ws_p \right) + \sum_{e \in E} \left(PT \cdot \omega_e + PTS \cdot \omega s_e \right)$$

$$+ \sum_{i \in N} \left(PO_i \cdot (1 - y_i) + POS_i \cdot y_i \right) + \sum_{i \in N} \left(PMD \cdot DMe_i + PMDS \cdot DMs_i \right)$$

- Subject to:

$$\sum_{p \in P} x_p^d = h^d \quad \forall \, d \in D$$

Flow conservation: Virtual paths

$$\sum_{e \in E} \delta_{ep} \cdot \omega_e^p = W_p + Ws_p \quad \forall \, p \in P$$

Flow conservation: Physical links

$$\sum_{d \in D} x_p^d \leq \left(W_p + Ws_p \right) \cdot B \quad \forall \, p \in P$$

Link capacity: Virtual paths

$$\sum_{p \in P} \left(\delta_{ip} \cdot W_p + \delta_{ip} \cdot Ws_p \right) + Q_i \leq \nabla^i \quad \forall \, i \in N$$

Limit on the number of router ports

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LP Model for Renewable Energy IP over WDM Network

$$PR^s \cdot \left(Q_i^s + \sum_{p \in P} \delta_{ip} \cdot Ws_p \right) + \sum_{e \in E} PT^s \cdot \omega s_e \cdot \delta_{ie}$$
$$+ PMD^s \cdot DMs_i + PO_i^s \cdot y_i \leq S_i$$
$$\forall \, i \in N,$$

Output power
of the renewable energy source

$$\sum_{p \in P} \omega_e^p \leq W \cdot f_e \quad \forall \, e \in E$$

$$\sum_{p \in P} \omega_e^p = \omega_e + \omega s_e \quad \forall \, e \in E$$

Number of wavelength channels
in each physical link

$$Q_i^e + Q_i^s = Q_i \quad \forall \, i \in N$$

Number of data aggregation
ports

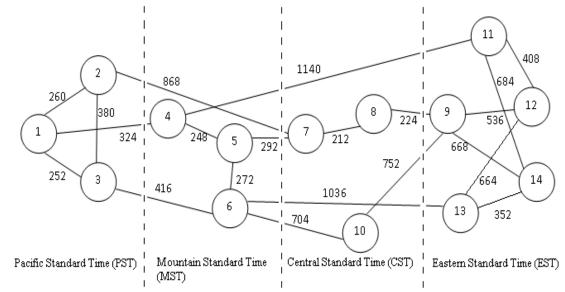$$DMe_i + DMs_i = DM_i, \quad \forall \, i \in N$$

Limit on the total number of
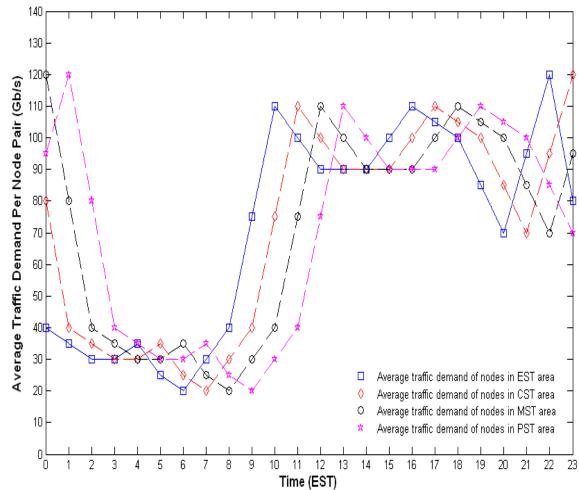de/multiplexers in each node

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Heuristic Approach

- Multi-hop bypass heuristic based on shortest-path routing will only minimize the total energy consumption not taking into account whether this energy comes from renewable or non-renewable sources.

- To minimize the utilization of non-renewable energy, we propose a new heuristic where the traffic flows are allowed to traverse as many nodes as possible that use renewable energy.

- To maintain QoS, only the two shortest-path routes are considered.

- Due to the changing traffic pattern and the fact that the output power of renewable energy sources varies during different times of the day, the routing paths are dynamic.

- The new heuristic is known as Renewable Energy Optimization hop (REO-hop).

Scenario

- The performance of the REO-hop heuristic is evaluated through simulations on the NSFNET network.

- Solar energy is used as the renewable energy source.

- As the NFSNET network covers the US, nodes will experience different levels of solar energy and traffic demands at any given point in time.

  - There are four time zones, Eastern Standard Time (EST), Central Standard Time (CST), Mountain Standard Time (MST) and Pacific Standard Time (PST). We use EST as the reference time.
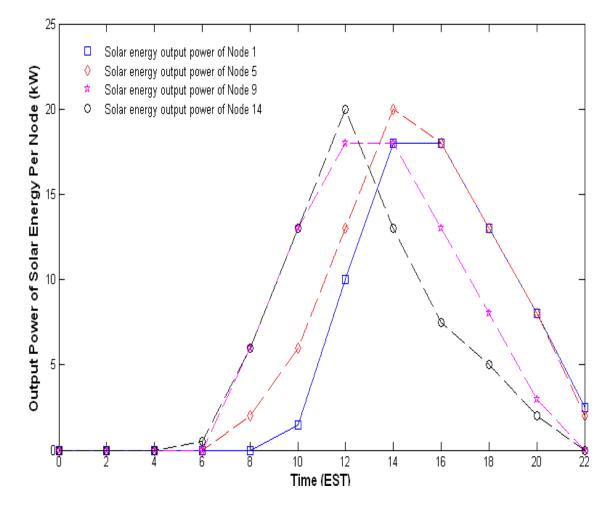
Traffic demand

- The average traffic demand between each node pair ranges from 20 Gb/s to 120 Gb/s; random with a uniform distribution and no lower than 10 Gb/s.

- Note that time zones dictate habits and therefore network utilization and traffic demands

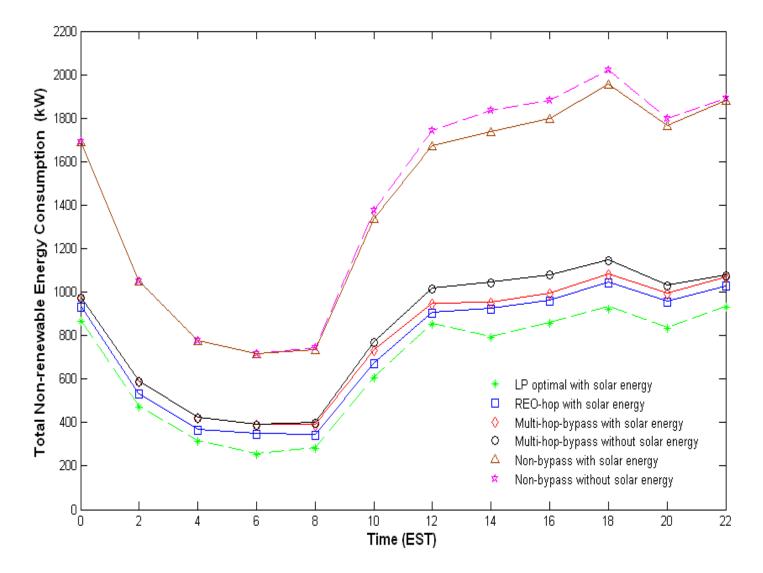13

Solar energy available at different nodes

- The geographical location of nodes dictates the sunset and sunrise time, and therefore the solar energy generated in each node.
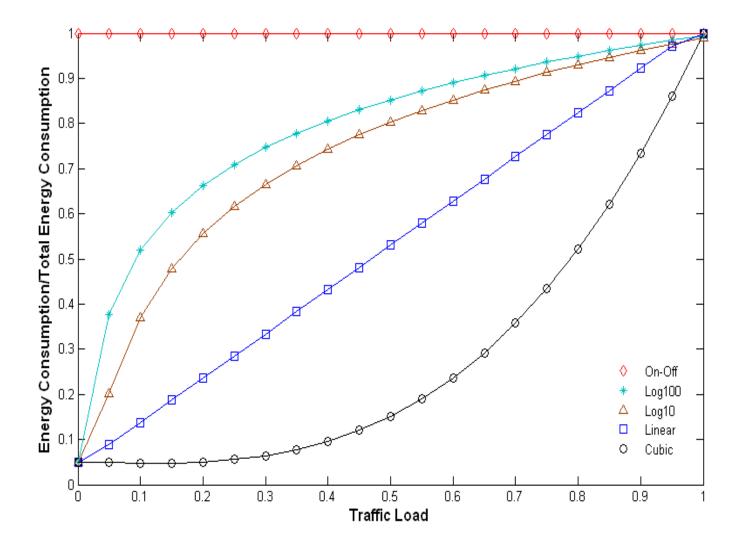
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Network parameters

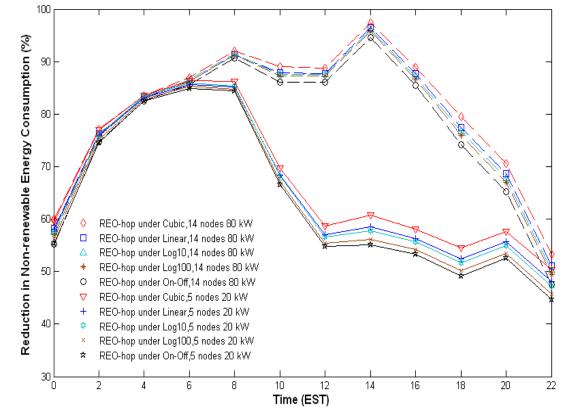|	
Distance between two neighboring EDFAs	80 (km)
Number of wavelength in a fiber (W)	16
Capacity of each wavelength (B)	40 (Gb/s)
Non-renewable energy consumption of a router port (PR)	1000 (W)
Renewable energy consumption of a router port (PR^s)	1000 (W)
Non-renewable energy consumption of an optical switch in node i (PO_i).	85 (W)
Renewable energy consumption of an optical switch in node i (PO_i^s).	85 (W)
Non-renewable energy consumption of an optical switch that has access to renewable energy in node i (POS_i)	0 (W)
Non-renewable energy consumption of a router port that has access to renewable energy (PRS)	0 (W)
Non-renewable energy consumption of a multiplexer or a demultiplexer (PMD).	16 (W)
Renewable energy consumption of a multiplexer or a demultiplexer (PMD^s).	16 (W)
Non-renewable energy consumption of a multiplexer or a demultiplexer that has access to renewable energy ($PMDS$).	0 (W)
Non-renewable energy consumption of a transponder (PT)	73 (W)
Renewable energy consumption of a transponder (PT^s)	73 (W)
Non-renewable energy consumption of a transponder that has access to renewable energy (PTS)	0 (W)
Non-renewable energy consumption of an EDFA (PE)	8 (W)

Non-renewable Energy Consumption of the Network

Hardware energy consumption profiles vs traffic

Energy saving under ALR with the REO-hop Heuristic

- With only 20 kW renewable in 5 nodes the energy saving compared to the non-bypass case without solar energy is approximately 85% (maximum) and 65% (average).

- Note that the 85% and 65% savings are almost real energy savings since the renewable energy is low here and has limited effect.

- When all nodes use 80 kW renewable energy, the energy saving is approximately 97% (maximum) and 78% (average).
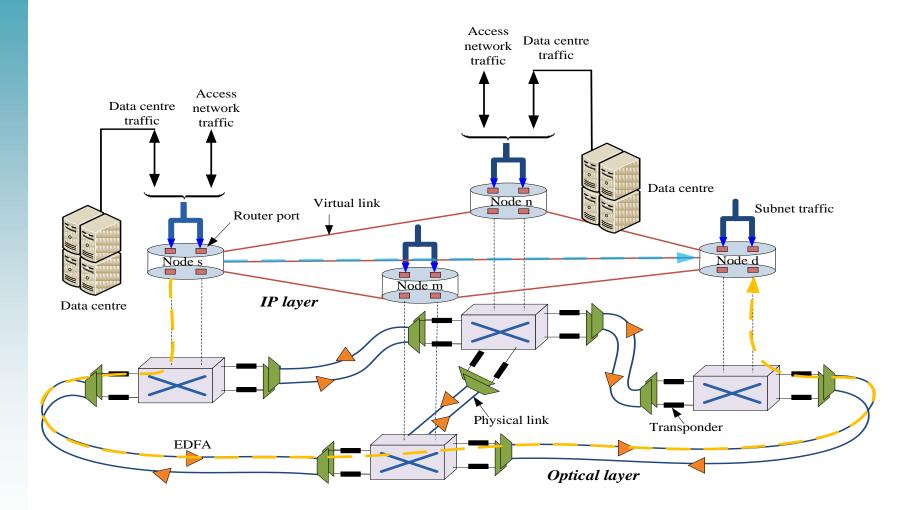
Outline

- Energy efficient IP over WDM networks and renewable energy

➔ Renewable energy sources in IP over WDM networks with data centres

Objectives

- We evaluate the merits of transporting bits to where renewable energy is (wind farms), instead of transporting renewable energy to where data centres are.

- We consider the impact of the electrical power transmission losses, network topology, routing, traffic.

- A LP model is set up to optimize the location of data centres by minimizing the network non-renewable energy consumption taking into account the utilization of the renewable energy resources and the losses.
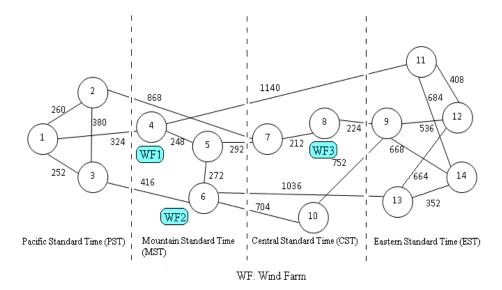
Data Centres in an IP over WDM Network

Renewable Energy in IP over WDM Networks with Data Centres

- We compare moving bits to where renewable energy is (wind farms) to transporting renewable energy to data centres.

- We study the impact of the power losses associated with transporting electrical power to data centres on the optimal data centres locations.

- We also study the impact of the other networking factors including network topology, routing, and traffic.

- We assume that solar energy is employed to partly power regular nodes (20kW).

- We assume that data centres are powered by energy generated from wind farms.

- The first LP model is extended to support the objective of minimizing the non-renewable energy consumption of data centres by optimizing the locations of data centres in the IP over WDM network assuming the lightpath bypass approach but taking into account renewable energy sources and the transmission losses.

Wind farms in NSFNET and transmission power losses

- The NSFNET network is considered to identify the optimal location of data centres using the LP model.

- We have selected only 3 wind farms based on their location and maximum output power to power the data centres in the network: 1) WF1: Cedar Creek Wind Farm, 2) WF2: Capricorn Ridge Wind Farm, 3) WF3: Twin Groves Wind Farm in blue. The maximum output power of the three wind farms is 300MW, 700 MW and 400 MW, respectively.

- We assume the transmission power loss is 15% per 1000km and the percentage of the power of wind farms allocated to data centres is assumed to be 0.3%.

WF: Wind Farm

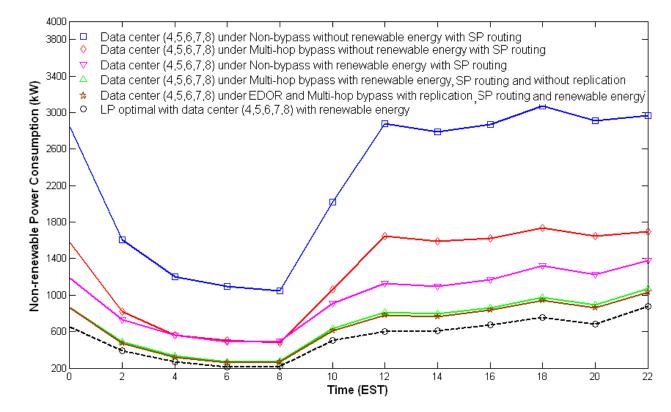# Data centre, computing, cooling and lighting power usage

- The cooling & lighting power consumption of a typical data centre is 150-200W/ft^2. Assuming a 3500ft^2 data centre, the total power consumed in a typical data centre for cooling is 700kW and the computing power consumption in a data centre is assumed to be 300kW which is typical for this data centre size.

- The power allocated by a wind farm to a data centre is known and is assumed here to be 1.4MW. This corresponds to a power usage efficiency (PUE) of 2 which is typical for a data centre.

- The renewable energy available to a data centre is a function of the transmission losses and these are location dependent. Furthermore the network topology, traffic, components' power consumption also play an important role in determining the optimum data centre location.

- Therefore the LP model here takes into account the previous trade-offs as well as the trade-offs introduced by the losses associated with the transmission of renewable energy to the data centre locations.

Renewable Energy in the IP over WDM Network with Data Centres

LP, Simulation and Results

- We run the LP model with five data centres ($Ndc=5$) under the previous assumptions.

- The optimal locations of data centres obtained from the LP model are as follows (4, 5, 6, 7, 8) where data centres 4 and 5 are powered by WF1, data centre 6 and 7 are powered by WF2, and data centre 8 is powered by WF3.

- The LP model results are such that all the data centres are located in the centre of the network.

- It can be observed that the optimum data centres locations are next to or near wind farms.

Wind farms power at data centres, solar at other nodes

- Compared to non-bypass heuristic
  - Multi-hop bypass + SP routing without renewable energy 46%.
  - Non-bypass with renewable energy 58%.
  - Multi-hop bypass + renewable energy 77% obtained from the LP network design and 71% obtained from the Multi-hop bypass + SP.
  - Introducing the replication scheme increases the average saving to 73% (Multi-hop bypass + SP).

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Summary

- Proposed the use of renewable energy in IP over WDM networks to reduce the CO_2 emission.

- An LP optimization model has been developed and an efficient heuristic, REO-hop, has been proposed to optimize the use of renewable energy in the IP over WDM architecture.

- REO-hop heuristic has reduced the non-renewable energy consumption by 49%~71% while maintaining QoS.

- An LP optimization model has been developed to optimize the selection of nodes that use renewable energy.

- The results show that moving the data centres closer to renewable energy sources maximizes the utilization of renewable energy sources and consequently reduces CO2 emissions.

- By combining the multi-hop bypass heuristic with renewable energy and the replication scheme power consumption savings up to 73% have been achieved.