Green Network and Data Centre Virtualization

NANTES DIGITAL WEEK 12>21 SEPT 2014

Leonard Nonde, Taisir El-Gorashi and Jaafar M. H. Elmirghani

School of Electronic and Electrical Engineering

University of Leeds, UK

j.m.h.elmirghani@leeds.ac.uk

EPSRC Pioneering research and skills

Global Uncertainties Security for all in a Changing World

UNIVERSITY OF LEEDS

Outline

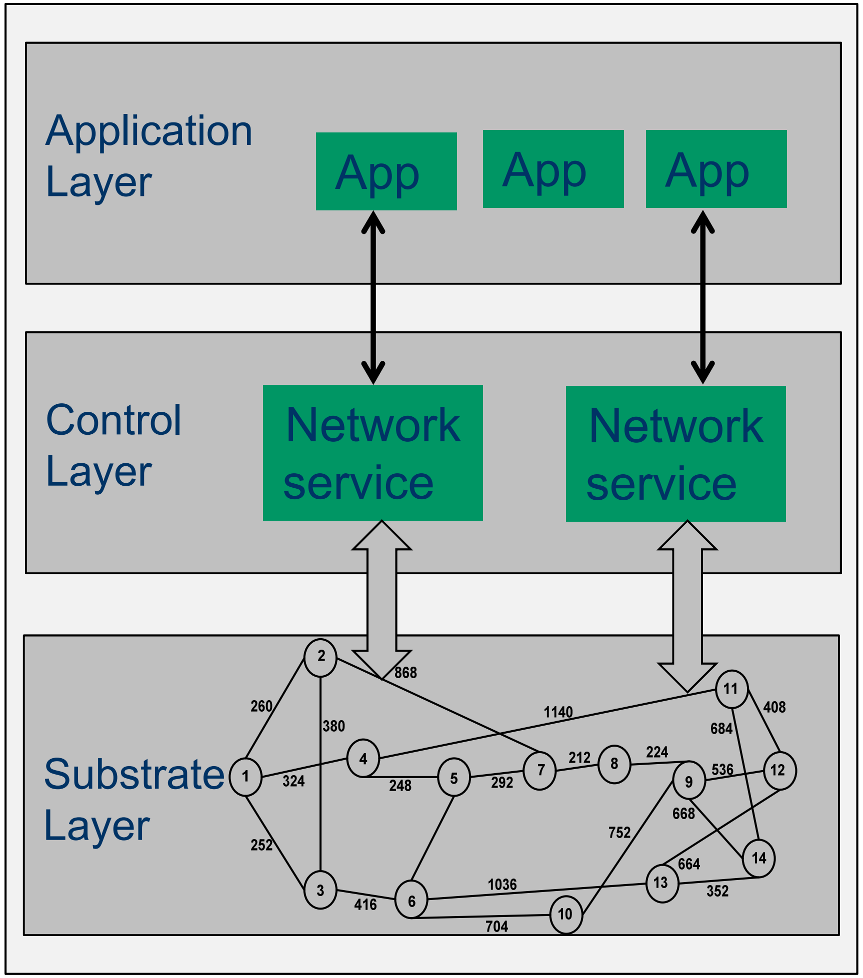
- Software-Defined Networks and Virtualization
- EEVNE in IP over WDM Networks
  - MILP Model
  - Real Time Energy Optimized Virtual Network Embedding (REOViNE) Heuristic
- Performance Evaluation
  - Energy Inefficient Data Centre Power Profile
  - Embedding of VNRs under Non Uniform Load Distribution
  - Energy Efficient Data Centre Power Profile
  - Location and Delay Constraints
- EEVNE in IP over WDM Networks with Optimal Data Centre Locations
- EEVNE in O-OFDM Cloud Network
- Summary

Outline

- ➔ Software-Defined Networks and Virtualization
- EEVNE in IP over WDM Networks
  - MILP Model
  - Real Time Energy Optimized Virtual Network Embedding (REOViNE) Heuristic
- Performance Evaluation
  - Energy Inefficient Data Centre Power Profile
  - Embedding of VNRs under Non Uniform Load Distribution
  - Energy Efficient Data Centre Power Profile
  - Location and Delay Constraints
- EEVNE in IP over WDM Networks with Optimal Data Centre Locations
- EEVNE in O-OFDM Cloud Network
- Summary

Software Defined Networks (SDN)

- In Software defined networking (SDN) network control is decoupled from forwarding (physical infrastructure) allowing:
  - Centralization of control
  - Direct programmability of devices
  - Flow based control
  - Vendor neutrality
- A range of network services can be supported on the substrate network driven by the applications.



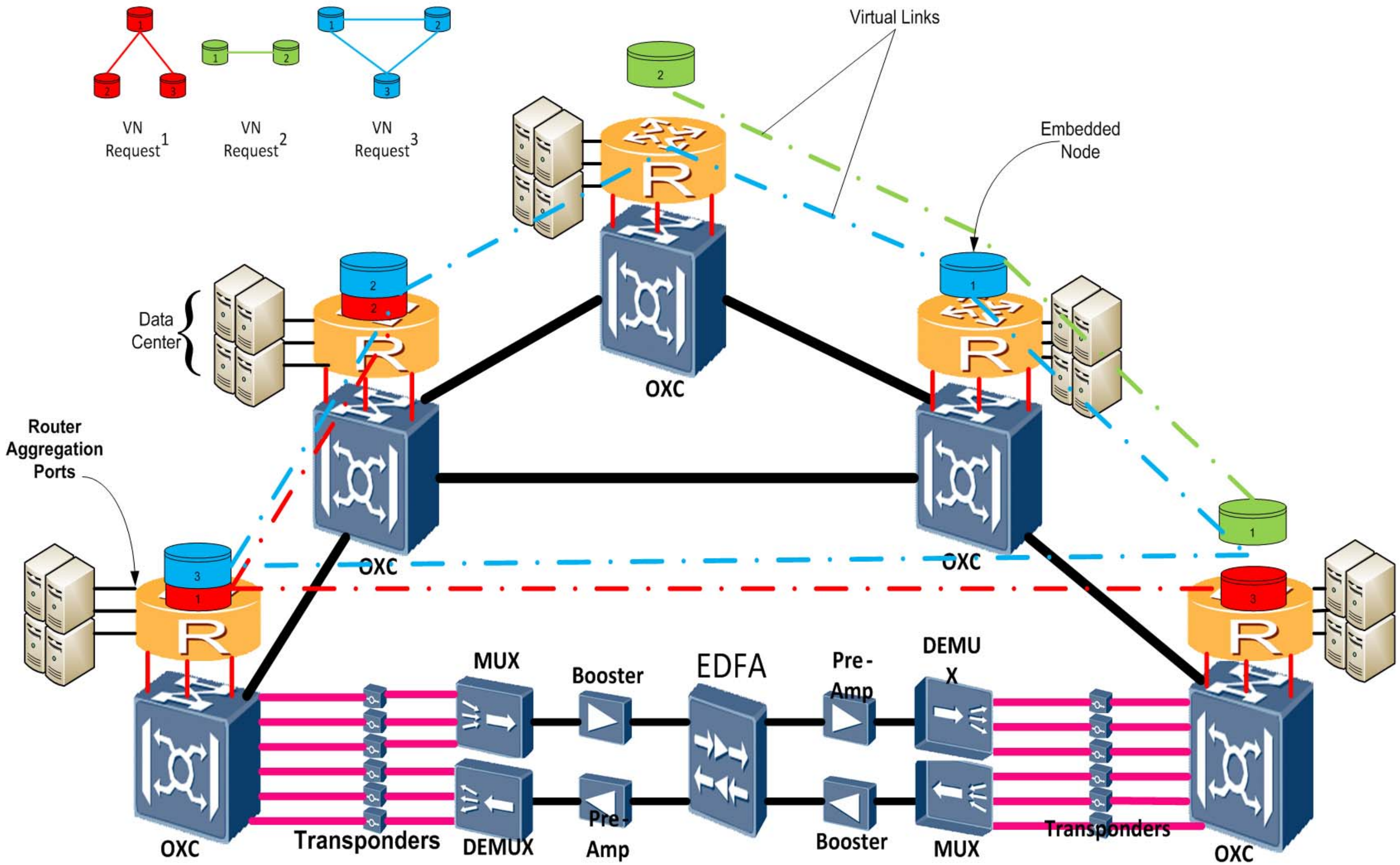
Energy Minimization with SDN

- SDN can provide dynamic and elastic network adptation to changing traffic, application, and user demands
- It can help avoid network resources overprovisioning by dynamically scaling provisioned resources.
- This can lead to efficient resource utilization and energy saving.

Outline

- Software-Defined Networks and Virtualization
- ➔ EEVNE in IP over WDM Networks
    - MILP Model
    - Real Time Energy Optimized Virtual Network Embedding (REOViNE) Heuristic
- Performance Evaluation
    - Energy Inefficient Data Centre Power Profile
    - Embedding of VNRs under Non Uniform Load Distribution
    - Energy Efficient Data Centre Power Profile
    - Location and Delay Constraints
- EEVNE in IP over WDM Networks with Optimal Data Centre Locations
- EEVNE in O-OFDM Cloud Network
- Summary

Network Virtualization



- Solution to the current ossifying forces of the Internet
- Allows the existence of several heterogeneous networks in one physical network
- Enabler of Energy Savings through resource consolidation

Total Power Consumption

Network Power Consumption

Power consumption of router ports:

$$\sum_{m \in N} PR \cdot \left(Q_m + \sum_{n \in N_m} W_{m,n} \right)$$

Power Consumption of transponders:

$$\sum_{m \in N} \sum_{n \in N_m} PT \cdot W_{m,n}$$

Power Consumption EDFAs:

$$\sum_{m \in N} \sum_{n \in N_m} PE \cdot EA_{m,n} \cdot F_{m,n} \cdot \lambda_{m,n}$$

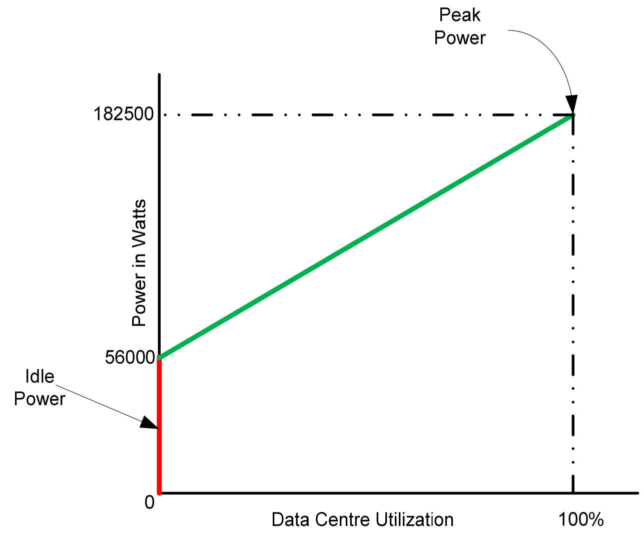
Power Consumption of Optical Switches:

$$\sum_{m \in N} PO_m$$

Power Consumption of multi/demux :

$$\sum_{m \in N} PMD \cdot DM_m$$

Energy Inefficient Data Centre Power Profile



$$PD_b^{v,s} = \begin{cases} P_{idle} + \mu \cdot CPU_b^{v,s} & if\ the\ data\ centre\ at\ b\ is\ ON \\ 0, & otherwise \end{cases}$$

The power consumption of data centers is given as:

$$\sum_{b \in N: DO_b = 0} \sum_{v \in V} \sum_{s \in R} CPU_b^{v,s} \cdot \delta_b^{v,s} \cdot \mu + K_b \cdot P_{idle}$$

MILP Model for EEVNE

Objective: Minimize

$$\sum_{m\in N} PR\cdot\left(Q_m+\sum_{n\in N_m} W_{m,n}\right)+\sum_{m\in N}\sum_{n\in N_m} PT\cdot W_{m,n}+\sum_{m\in N}\sum_{n\in N_m} PE\cdot EA_{m,n}\cdot F_{m,n}\cdot\lambda_{m,n}$$
$$+\sum_{m\in N} PO_m+\sum_{m\in N} PMD\cdot DM_m+\sum_{b\in N:DO_b=0}\sum_{v\in V}\sum_{s\in R} CPU_b^{v,s}\cdot\delta_b^{v,s}\cdot\mu+K_b P_{idle}$$

Subject to (Including):

Node Embedding

$$\sum_{v\in V}\sum_{s\in R} CPU_b^{v,s}\cdot\delta_b^{v,s}\le CPU_b \qquad \forall b\in N$$

$$\sum_{b\in N}\delta_b^{v,s}=1 \qquad \forall v\in V,\qquad s\in R$$

$$\sum_{b\in N}\sum_{s\in R} CPU_b^{v,s}\cdot\delta_b^{v,s}=\Psi^v\sum_{b\in N}\sum_{s\in R} CPU_b^{v,s} \qquad \forall v\in V$$

Link Embedding

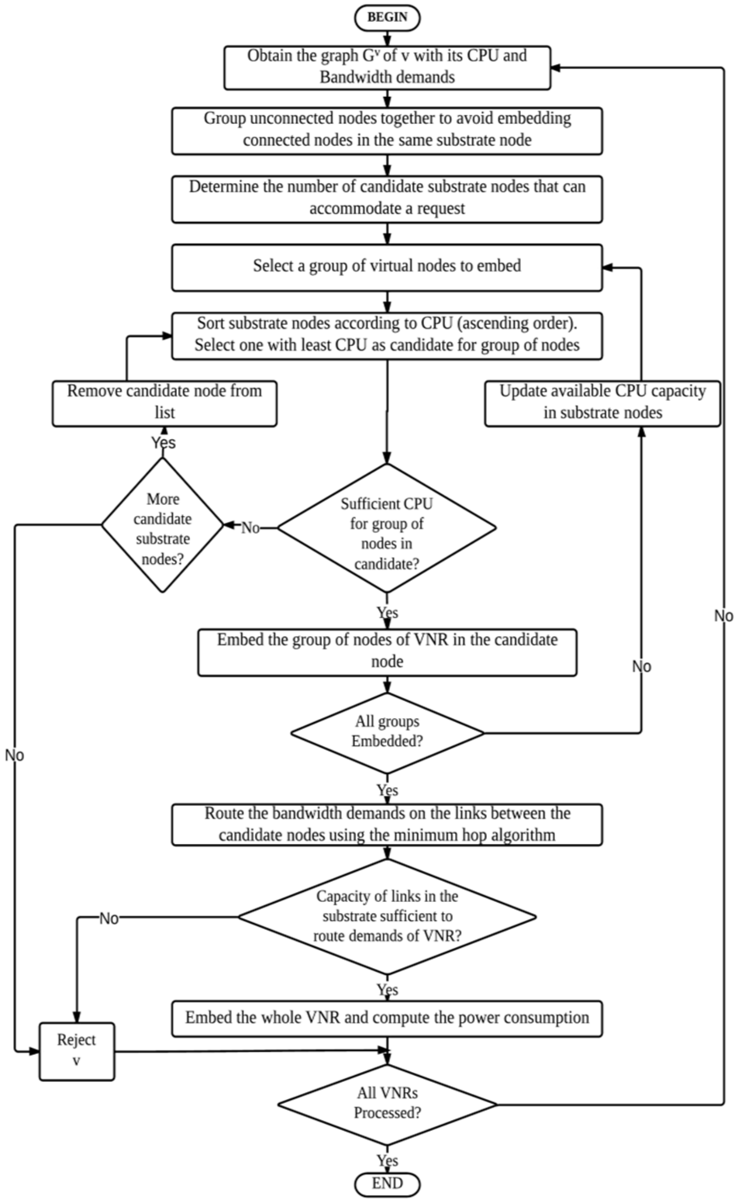
$$\delta_b^{v,s}+\delta_e^{v,d}=\omega_{e,b}^{v,d,s}+2\cdot\rho_{b,e}^{v,s,d}$$
$$\forall\, v\in V\;\; b,e,s,d\in N: b\ne e, s\ne d$$

$$\sum_{b\in N}\sum_{e\in N:b\ne e}\sum_{s\in R}\sum_{d\in R:s\ne d} \mathrm{H}^{v,s,d}\cdot\rho_{b,e}^{v,s,d}=\Phi^v\sum_{s\in R}\sum_{d\in R:s\ne d}\mathrm{H}^{v,s,d}$$
$$\forall v\in V$$

$$\Phi^v=\Psi^v \qquad \forall v\in V$$

$$\sum_{v\in V}\sum_{s\in N}\sum_{d\in N:s\ne d}\mathrm{H}^{v,s,d}\cdot\rho_{b,e}^{v,s,d}=L_{b,e}\forall b,e\in N: b\ne e$$

Real Time Energy Optimized Virtual Network Embedding (REOViNE) Heuristic



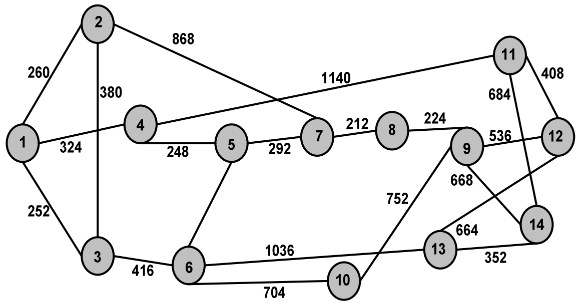
Outline

- Software-Defined Networks and Virtualization
- EEVNE in IP over WDM Networks
  - MILP Model
  - REOViNE Heuristic

➔ Performance Evaluation
  - Energy inefficient data centre power profile
  - Embedding of VNRs under Non Uniform Load Distribution
  - Energy efficient data centre power profile
  - Delay and location constraints
- EEVNE in IP over WDM Networks with Optimal Data Centre Location
- EEVNE in O-OFDM Cloud Network
- Summary

Performance Evaluation

- Each node hosts a small data centre with 500 Servers.
- The number of nodes in a single virtual network request is uniformly distributed between 2 and 6.
- The CPU demand of nodes in the virtual network request is uniformly distributed between 2% and 10% of the total CPU resources in the data centre.
- The BW on the links of the virtual network request is also uniformly distributed between 10Gbps and 130Gbps.



Substrate Network (NSFNET)

The CostVNE Model Objective [1]

$$minimize \sum_{m \in N} \sum_{n \in N_m} W_{m,n}$$

The VNE-EA Objective [2]

$$minimize \sum_{m \in N: NO_m = 0} \sigma_m + \sum_{m \in N} \sum_{n \in N_m: LO_{m,n}=0} \beta_{m,n}$$

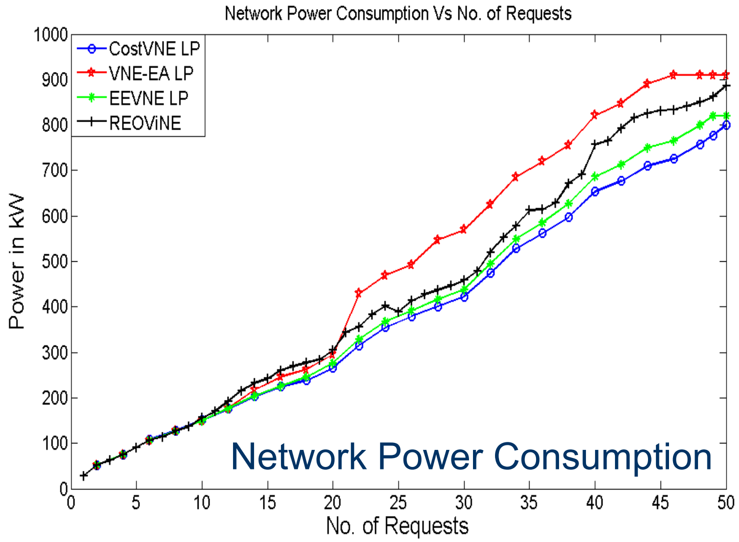
where σ_m and $\beta_{m,n}$ are binary variable to indicate the active nodes and links, respectively in the substrate network

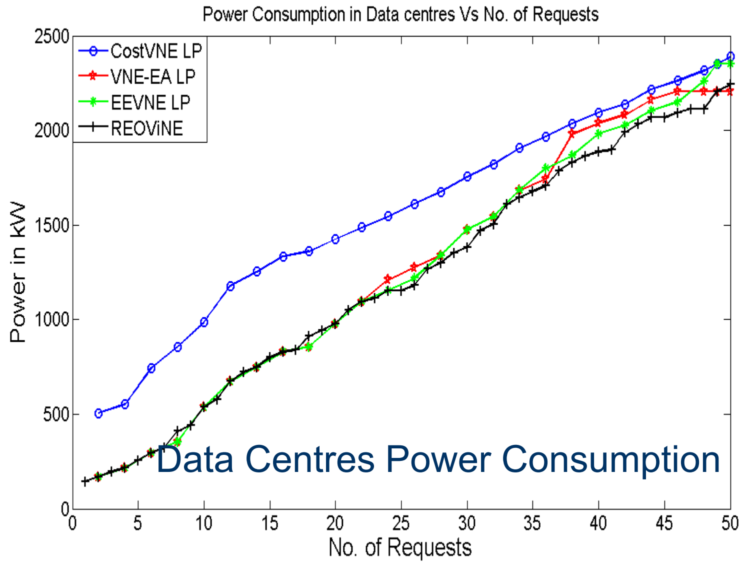
Input Parameters

Distance between two neighboring EDFAs	80 (km)
Number of wavelengths in a fiber (W)	32
Number of Fibers per link ($F_{m,n}$)	1
Capacity of each wavelength	40 (Gbps)
Power consumption of a transponder (PT)	73 (W)
Power consumption of a single router port (PR)	1000(W)
Power consumption of an EDFA (PE)	8 (W)
Power consumption of an optical switch (PO)	85 (W)
Power consumption of a multi/demultiplexer (PMD)	16 (W)
Dell Server full load power consumption	365 (W)
Dell Server idle power consumption	112 (W)
Data Centre idle power consumption (500 servers)	56000 (W)

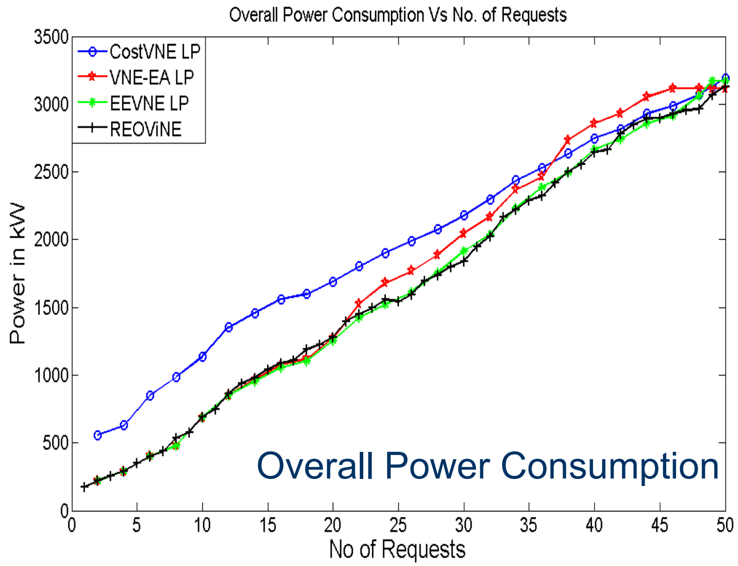
[1] Houidi, I., et al., *Virtual network provisioning across multiple substrate networks*. Comput. Netw., 2011. **55**(4): p. 1011-1023.
[2] Botero, J.F., et al., *Energy Efficient Virtual Network Embedding*. Communications Letters, IEEE, 2012. **16**(5): p. 756-759.

Energy Inefficient Data Centre

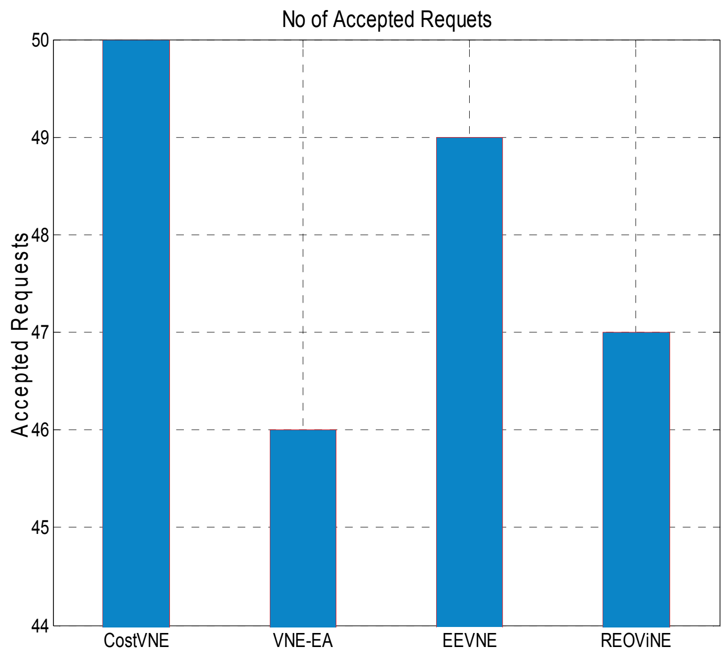


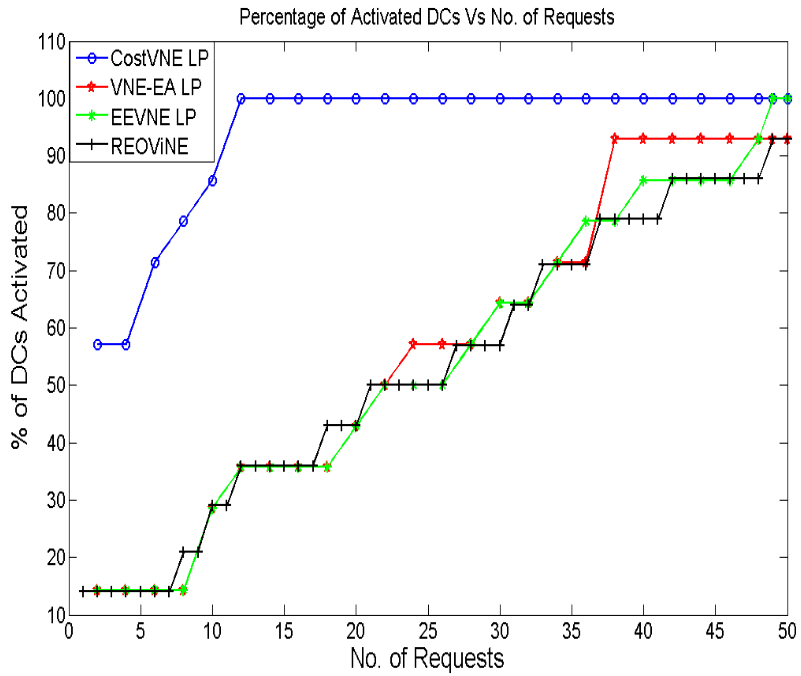


- The EEVNE model saves 60% (Maximum) of the overall power consumption compared to the CostVNE model (20% Average).
- The EEVNE model saves 9% (Maximum) of the overall power consumption compared to the VNE-EA (3% Average).
- The REOViNE heuristic approaches the EE-VNE model in terms of the network power consumption.



Energy Inefficient Data Centre



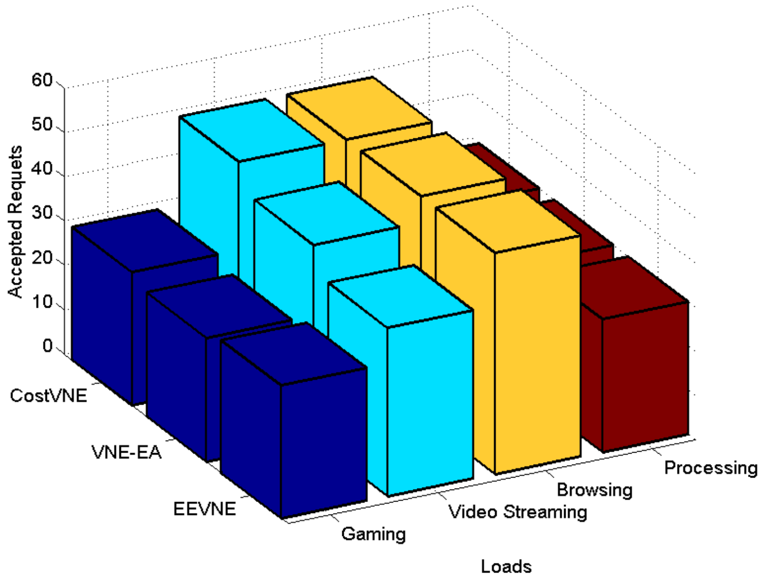


- The CostVNE model accepts all the requests because it uses the wavelengths efficiently.
- The worst performer in this case is the VNE-EA Model.

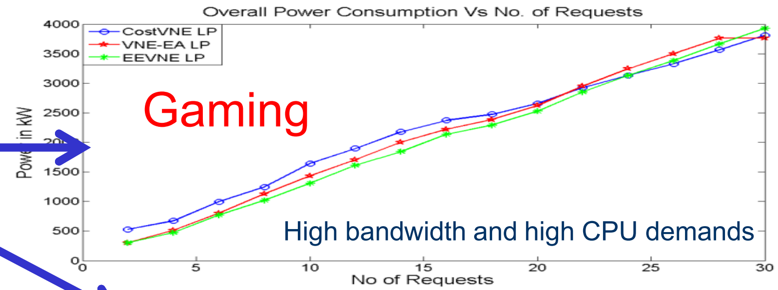
- Cost model activates more data centres at Low Loads than the EEVNE, VNE-EA model and EOVNE heuristic.
- The VNE-EA model activates more DCs as the load increases in the Network.

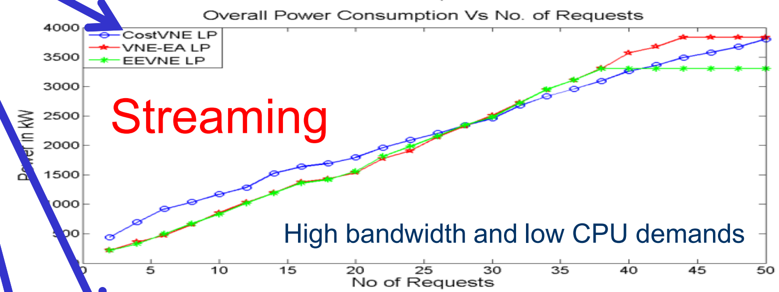
Embedding of VNRs of Non Uniform Load Distribution

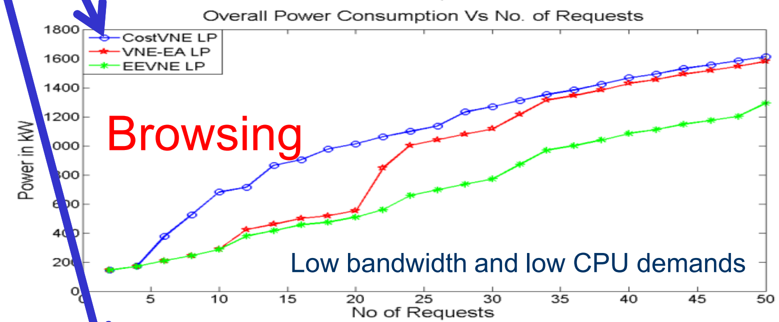
Load	Distribution
High bandwidth and high CPU demands (Load 1) Gaming	CPU (9% to 10% of data center capacity) Bandwidth demand (100Gb/s to 130Gb/s)
High bandwidth and low CPU demands (Load 2) Streaming	CPU (2% to 3% of data center capacity) Bandwidth demand (100Gb/s to 130Gb/s)
Low bandwidth and low CPU demands (Load 3) Browsing	CPU (2% to 3% of data center capacity) Bandwidth demand (10Gb/s to 15Gb/s)
Low bandwidth high CPU demands (Load 4) Processing	CPU (9% to 10% of data center capacity) Bandwidth demand (10Gb/s to 15Gb/s)

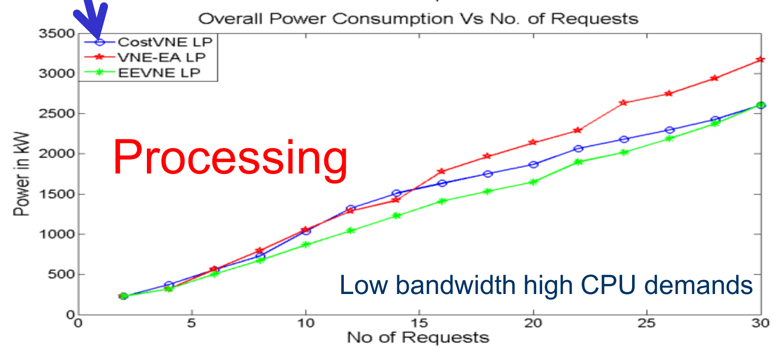


Number of Accepted Requests







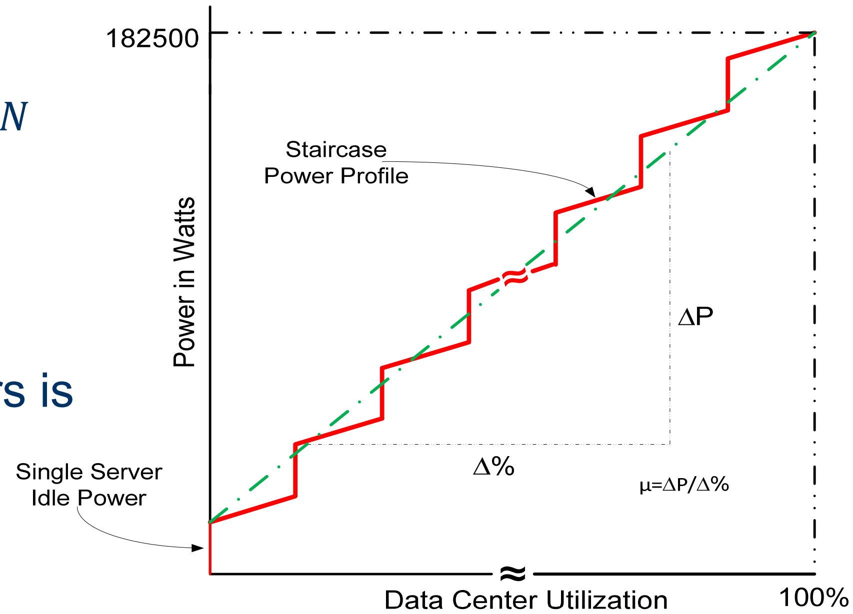


Energy Efficient Data Center

$$PD_b^{v,s} = \begin{cases} \mu \cdot CPU_b^{v,s} & \text{if the data centre is ON} \\ 0, & \text{otherwise} \end{cases}$$

The power consumption of data centers is given as:

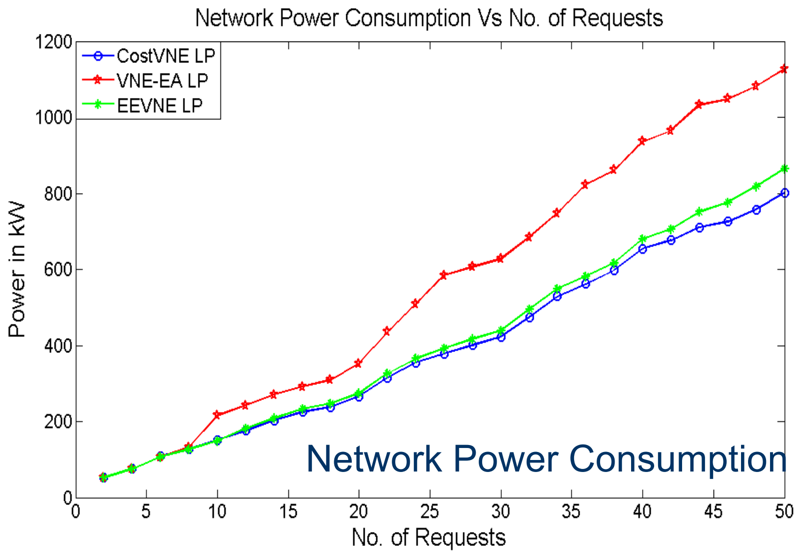
$$\sum_{b \in N} \sum_{v \in V} \sum_{s \in R} CPU_b^{v,s} \cdot \delta_b^{v,s} \cdot \mu$$

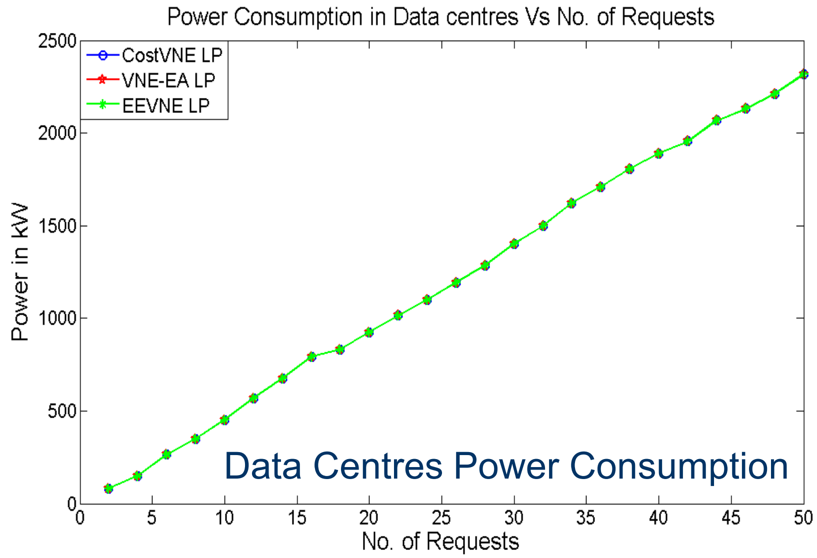


Energy Efficient (EE) Data Centre Power Profile

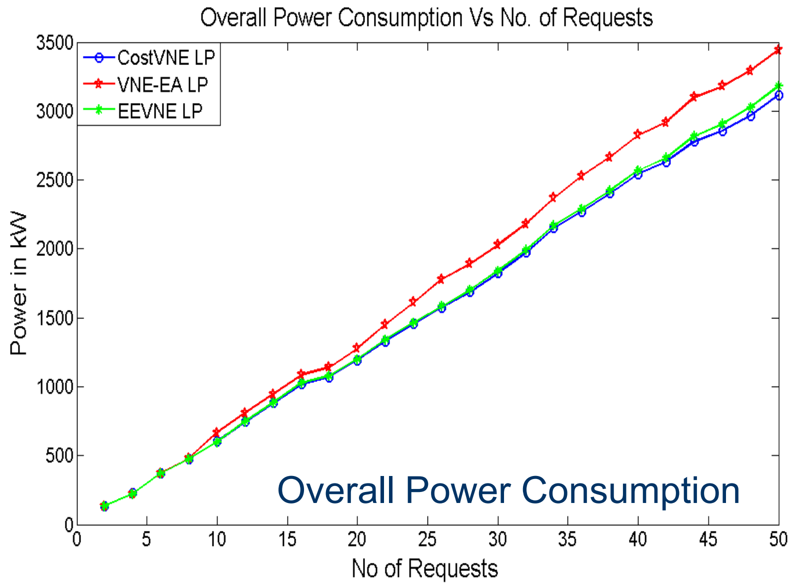
- Only the servers needed to serve a given workload are activated.

Energy Efficient Data Centre





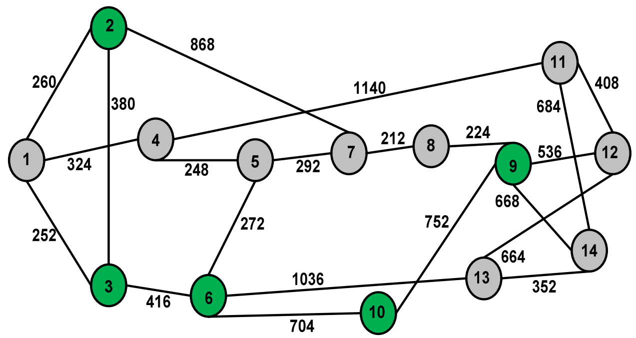
- Power savings only occur in the network making the CostVNE the most energy efficient.



EEVNE with Location and Delay Constraints

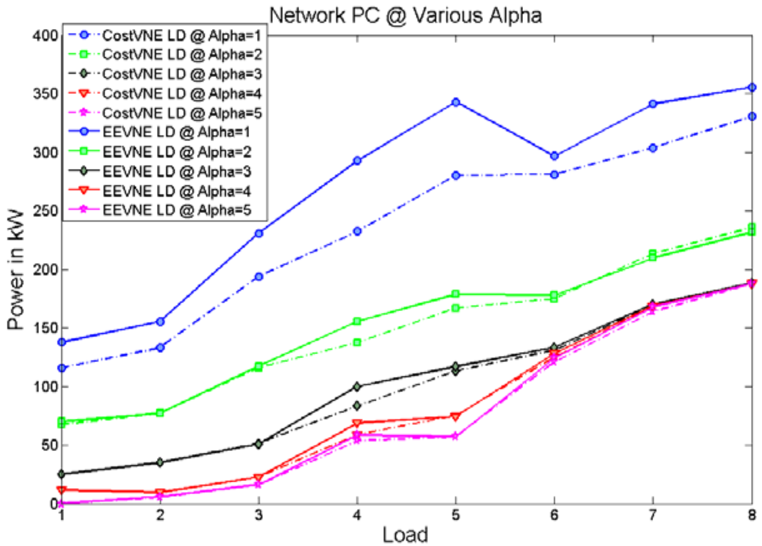
- VNR are star topologies with the master node in the center and protection or load balancing nodes connected to it.
- The number of master nodes located in a substrate node is proportional to its population.
- We consider a scenario where we embed 15 virtual network requests and evaluate the power consumption versus an increasing load of CPU and bandwidth.
- Node consolidation factor (α) is a measure of how many nodes of a VNR can be embedded in the same substrate node.
- A maximum propagation delay of 7.5ms is allowed.

Load	CPU Percentage Workload Distribution	Link Bandwidth Distribution
1	1% - 5%	10Gbps – 40Gbps
2	3% - 7%	20Gbps – 50Gbps
3	5% - 9%	30Gbps – 60Gbps
4	7% - 11%	40Gbps – 70Gbps
5	9% - 13%	50Gbps – 80Gbps
6	11% - 15%	60Gbps – 90Gbps
7	13% - 17%	70Gbps – 100Gbps
8	14% - 19%	80Gbps – 110Gbps

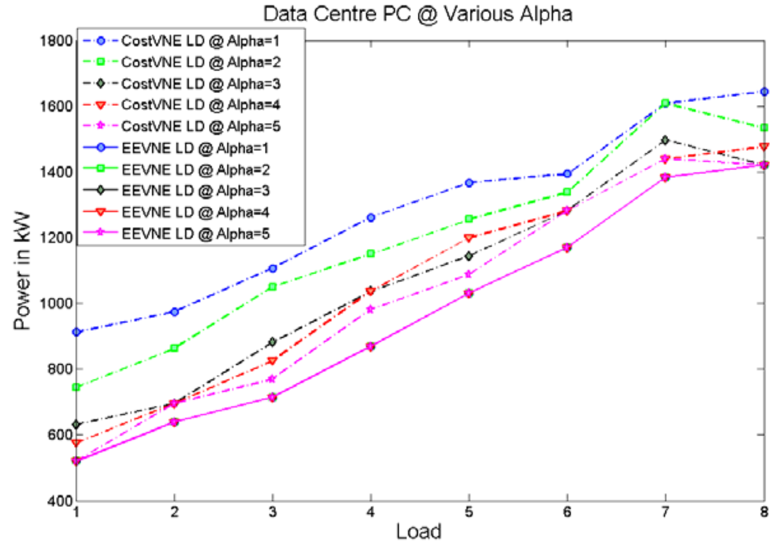


Master Node Locations

EEVNE with Location and Delay Constraints

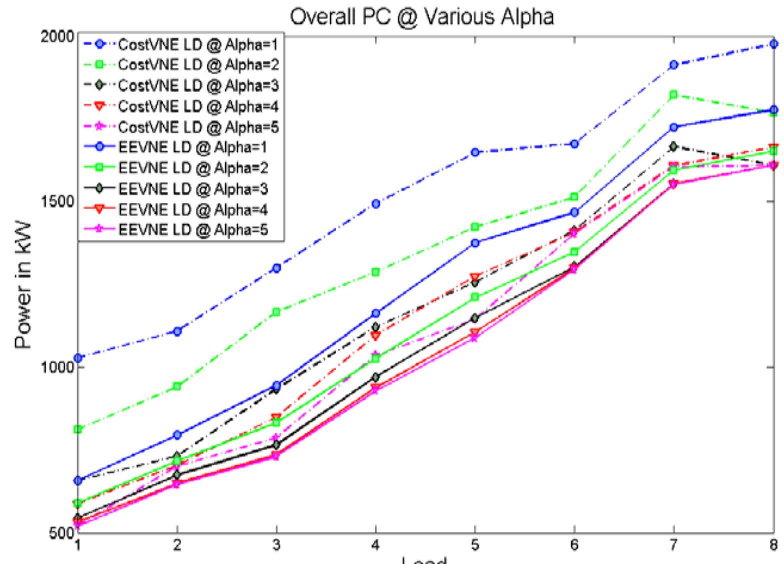


Network Power Consumption



Data Centres Power Consumption

- EEVNE saves 18% over CostVNE at α=1 and 5% at α=5.
- For the EEVNE the transition from α=1 to α=2 saves 10% subsequent increases in α have smaller savings.



Overall Power Consumption

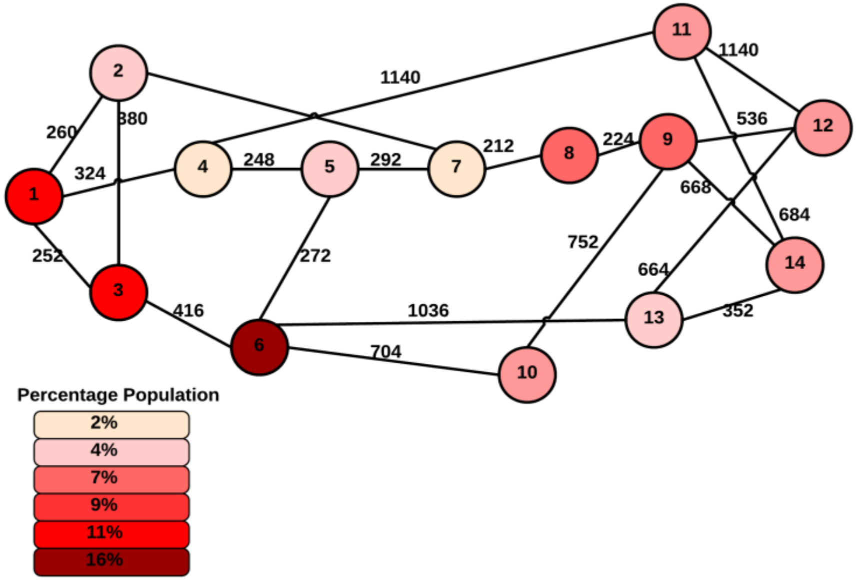
Outline

- Software-Defined Networks and Virtualization
- EEVNE in IP over WDM Networks
  - MILP Model
  - REOViNE Heuristic
- Performance and Evaluation
  - Energy inefficient data centre power profile
  - Embedding of VNRs under Non Uniform Load Distribution
  - Energy efficient data centre power profile
  - Delay and location constraints

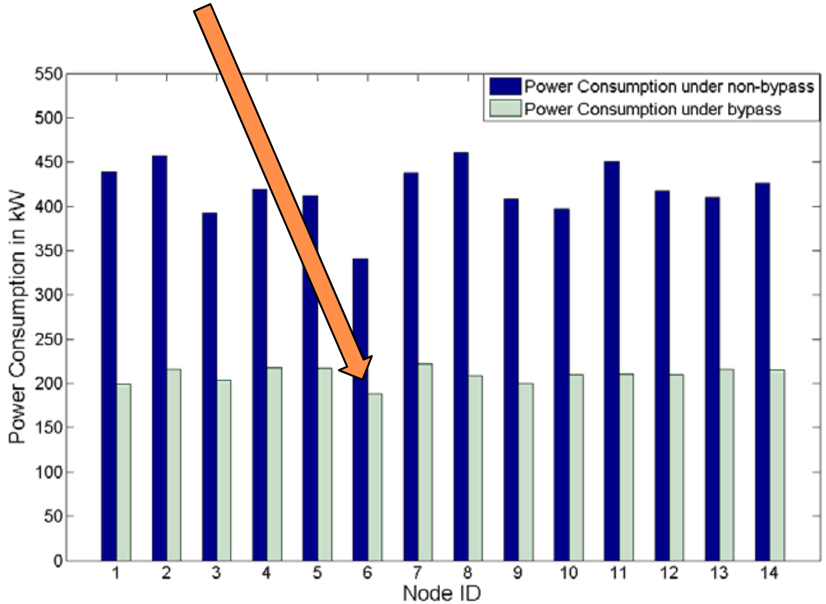
➔ EEVNE in IP over WDM Networks with Optimal Data Centre Location

- EEVNE in O-OFDM Cloud Network
- Summary

EEVNE with Optimal Data Centre Location

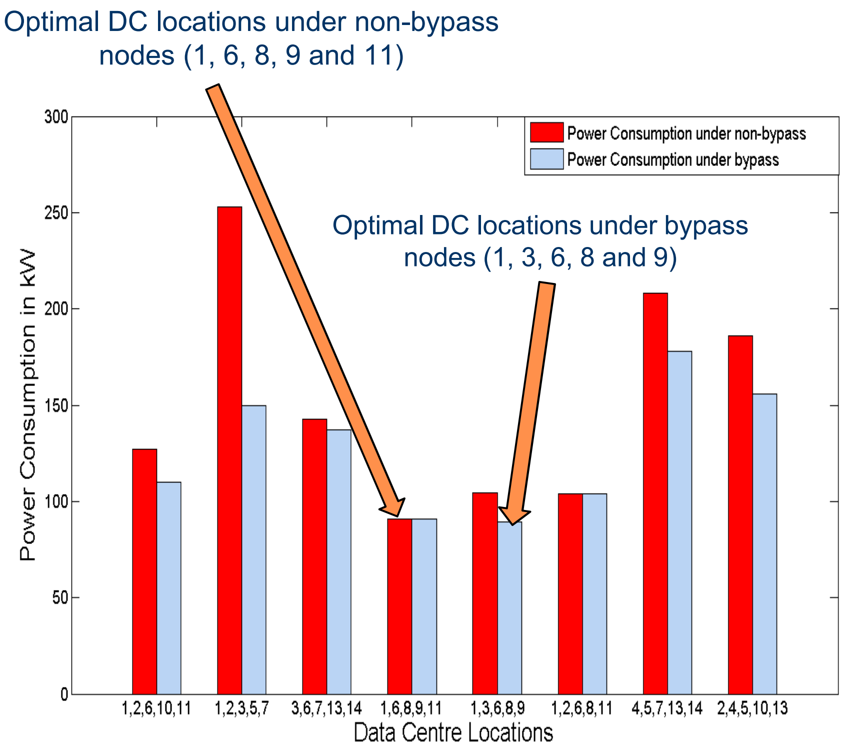


Node 6, Optimal single DC location



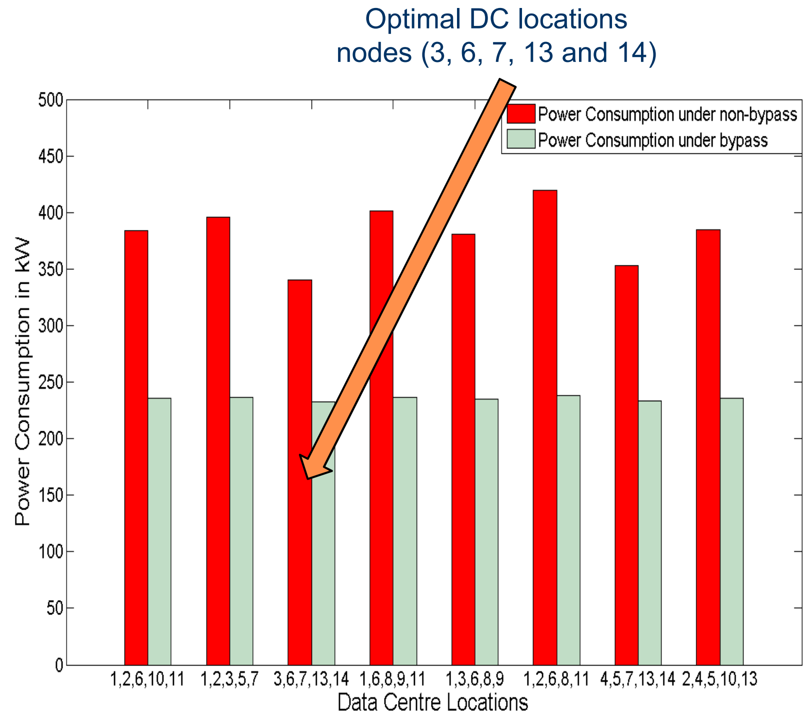
- 45 Clients distributed over all the 14 nodes based on population.
- With a single DC: 26% and 15% power saving for non-bypass and bypass approaches, respectively compared to the worst possible location.

EEVNE with Optimal Data Centre Location



Five DCs Optimal Locations at α=5

- 43% and 55% power saving for non-bypass and bypass approaches, respectively compared to the worst possible locations.

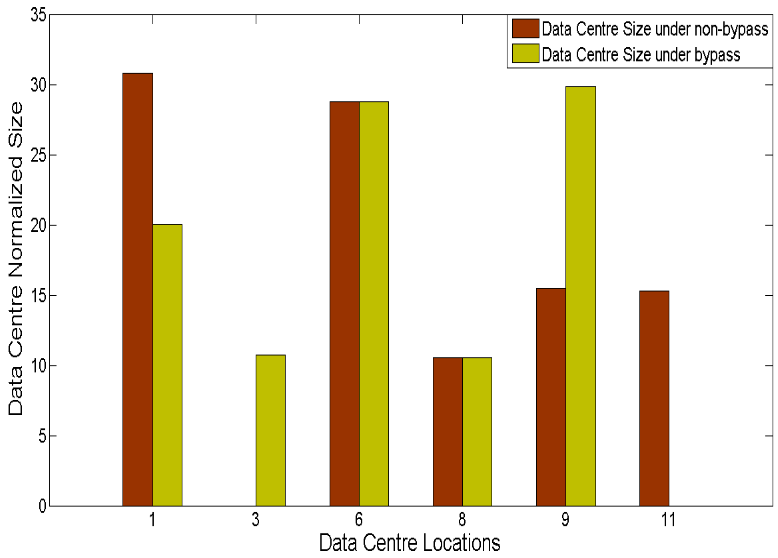


Five DCs Optimal Locations at α=1

- 19% power savings under the non bypass approach.
- Under bypass at α=1, the power consumption is the same regardless of the location of the data centres.

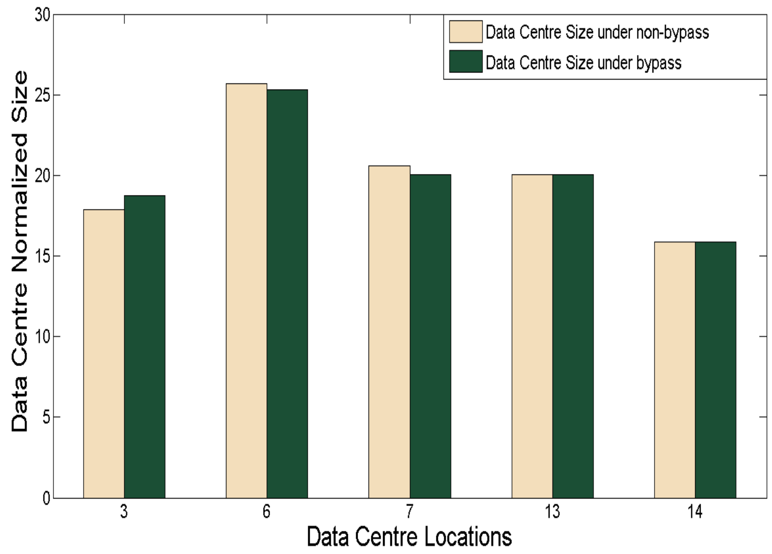
EEVNE with Optimal Data Centre Location

DC Size at α=5



- DCs 1 and 6 have highest concentration of VMs under non-bypass
- DCs 6 and 9 have highest concentration of VMs under bypass

DC Size at α=1



- DC 6 has highest concentration of VMs under both non-bypass and bypass
- Even distribution of VMs across all DCs

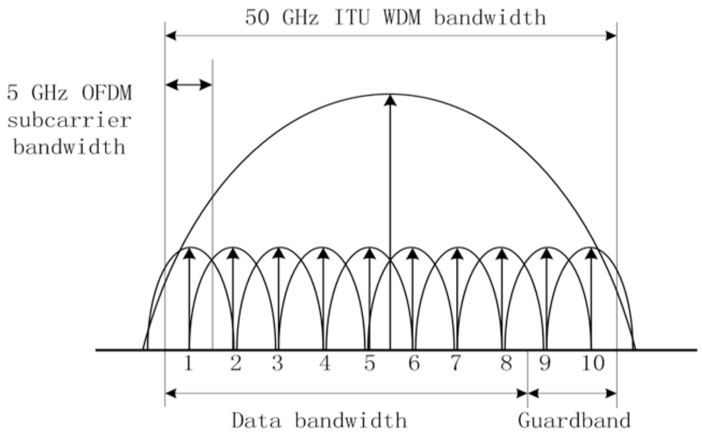
Outline

- Software-Defined Networks and Virtualization
- EEVNE in IP over WDM Networks
  - MILP Model
  - REOViNE Heuristic
- Performance and Evaluation
  - Energy inefficient data centre power profile
  - Embedding of VNRs under Non Uniform Load Distribution
  - Energy efficient data centre power profile
  - Delay and location constraints
- EEVNE in IP over WDM Networks with Optimal Data Centre Location

➔ EEVNE in O-OFDM Cloud Network

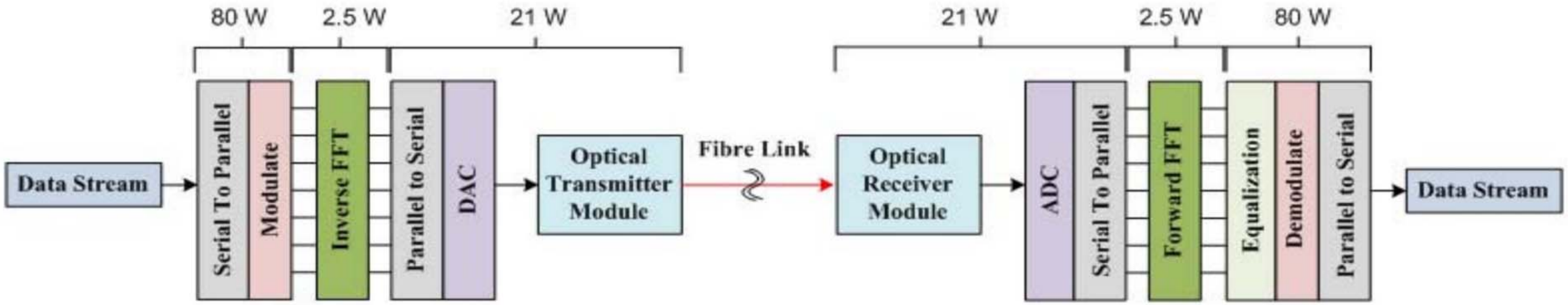
- Summary

VNE in Optical OFDM Networks



Spectrum utilization of WDM networks and optical OFDM based networks

- *The maximum line rate for an OFDM transponder* LR_{max} *is:* ***5(GHz)x3(Bits/Hz)x8=120Gb/s***.



Block diagram of a typical optical OFDM communication system

VNE in Optical OFDM Networks

Power consumption of O-OFDM transponders:

$$\sum_{b\in N}\sum_{e\in N: b\neq e}\left(\sum_{m\in N}\sum_{n\in N_m} x_{m,n}^{b,e}\left(ALR\left(\frac{\sum_{q\in Q} SC_{m,n,q}^{b,e}\cdot M_q}{LR_{max}}\right)\cdot TP_{max}\right)\right)$$

Where $ALR()$ is the ALR power profile function

Objective: Minimize power consumption

$$\sum_{b\in N}\sum_{v\in V}\sum_{s\in R} CPU_b^{v,s}\cdot\delta_b^{v,s}\cdot\mu+\sum_{b\in N}\sum_{e\in N: b\neq e} PR\cdot L_{b,e}$$
$$+\sum_{b\in N}\sum_{e\in N: b\neq e}\left(\sum_{m\in N}\sum_{n\in N_m} x_{m,n}^{b,e}\left(ALR\left(\frac{\sum_{q\in Q} SC_{m,n,q}^{b,e}\cdot M_q}{LR_{max}}\right)\cdot TP_{max}\right)\right)+\sum_{m\in N}\sum_{n\in N_m} PE\cdot EA_{m,n}\cdot F_{m,n}$$

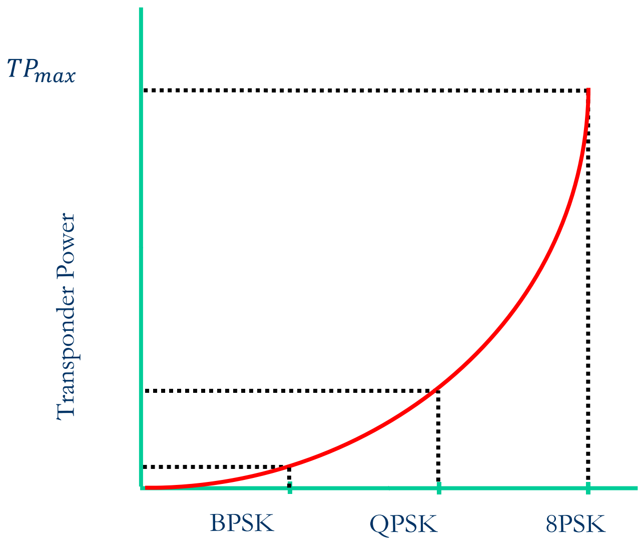
Objective: Minimize spectrum utilization

$$\sum_{b\in N}\sum_{e\in N: b\neq e}\sum_{q\in Q} SC_{n,m,q}^{b,e}\qquad \forall m\in N, n\in N_m$$

Performance Evaluation

Power Consumption of Network Devices

Power consumption of a 100Gb/s WDM transponder	135 (W)
Power consumption of an OFDM transponder at maximum line rate LR_{max}	200 (W)
Power consumption per Gb/s of an IP router port	25W/Gb/s
Power consumption of an EDFA	8 (W)

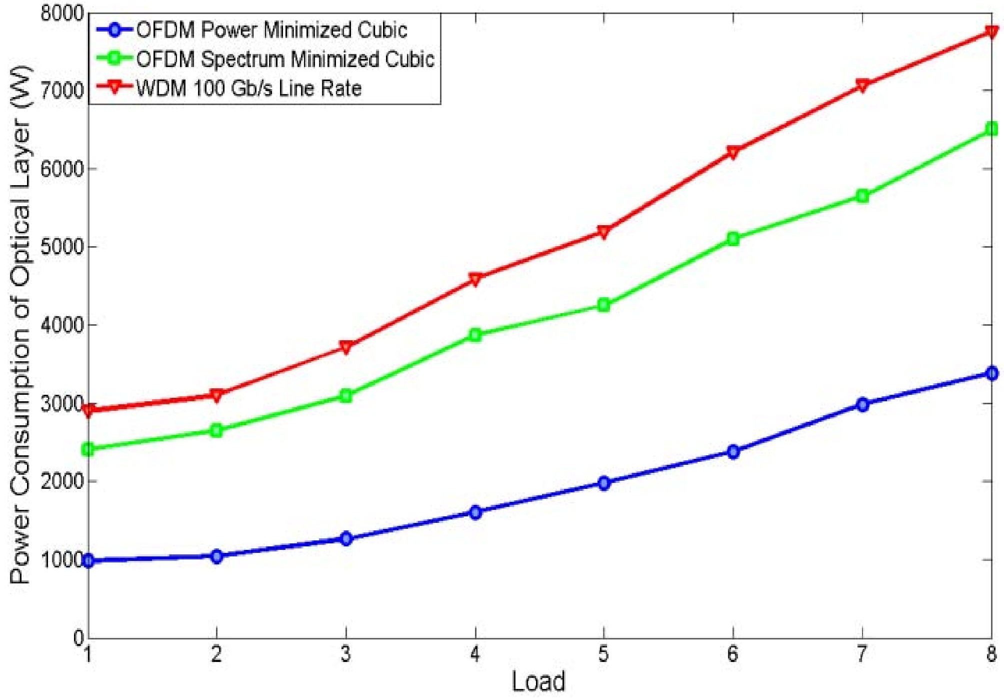


Cubic Power Profile of an O-OFDM Transponder

Load Distribution

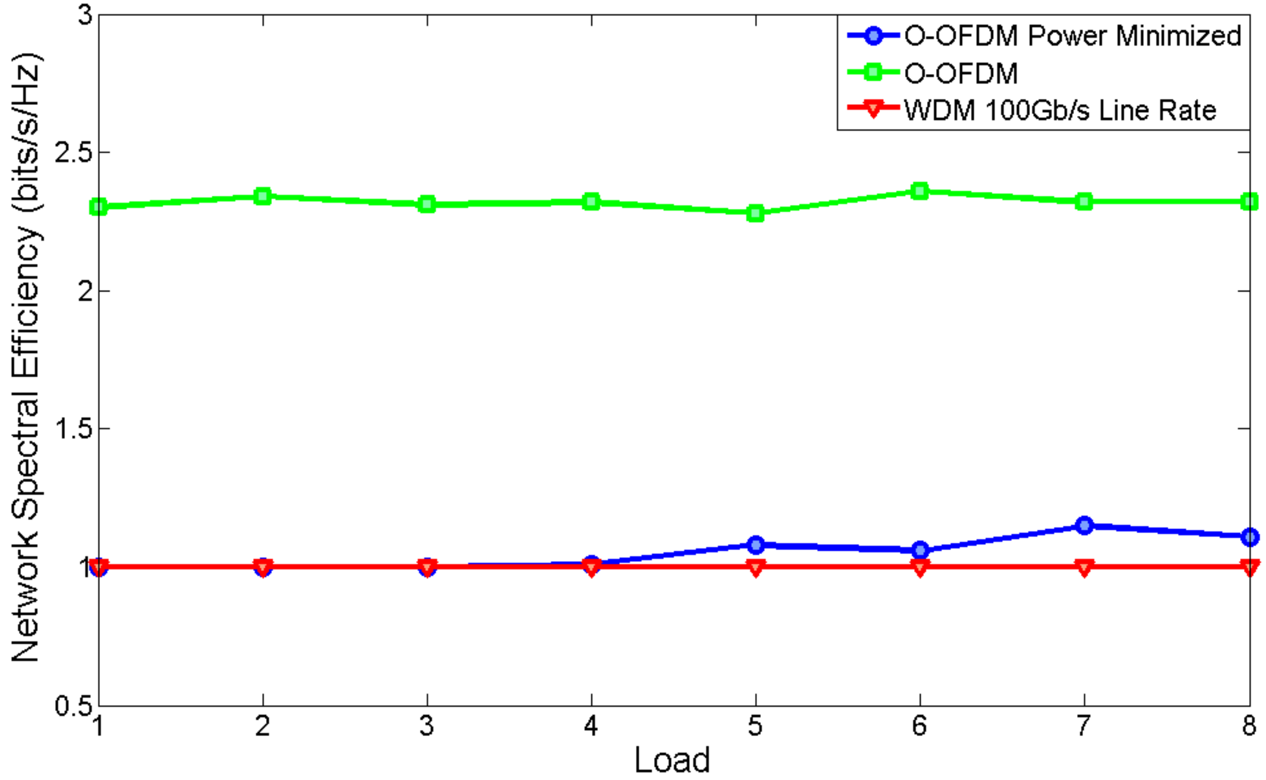
Load	CPU Cores Distribution	Link Bandwidth Distribution
1	1 - 5	10Gb/s – 40Gb/s
2	3 - 7	20Gb/s – 50Gb/s
3	5 - 9	30Gb/s – 60Gb/s
4	7 - 11	40Gb/s – 70Gb/s
5	9 - 13	50Gb/s – 80Gb/s
6	11 - 15	60Gb/s – 90Gb/s
7	13 - 17	70Gb/s – 100Gb/s
8	14 - 19	80Gb/s – 110Gb/s

The Optical Layer Power Consumption



- VNE of power and spectrum minimized IP over O-OFDM based networks has saved 63% and 17%, respectively of the optical layer power consumption compared to VNE in IP over WDM networks .

Spectral Efficiency



- The power minimized O-OFDM based network trades optical spectrum for energy efficiency.

Outline

- Software-Defined Networks and Virtualization
- EEVNE in IP over WDM Networks
  - MILP Model
  - REOViNE Heuristic
- Performance and Evaluation
  - Energy inefficient data centre power profile
  - Embedding of VNRs under Non Uniform Load Distribution
  - Energy efficient data centre power profile
  - Delay and location constraints
- EEVNE in IP over WDM Networks with Optimal Data Centre Location
- EEVNE in O-OFDM Cloud Network

➔ Summary

Summary

- We have studied energy efficient virtual network embedding in IP over WDM networks and developed a MILP model (EE-VNE) and a heuristic (REOViNE).
- Comparing our model to the bandwidth Cost model (CostVNE), a maximum power saving of 60% (average 20%) is achieved.
- Our model has also improved the energy efficiency compared to the VNE-EA model as a result of its ability to consolidate the use of data centres while optimizing the use of wavelengths.
- Under the energy efficient data centre power profile, savings only occur in the network causing our EE-VNE to minimize the use of network bandwidth.

Summary

- Allowing node consolidation by removing geographical redundancy constraints significantly reduces the power compared to embedding with full geographical redundancy.
- The selection of a location to host a data centre is governed by two factors: the average hop count to other nodes and the client population of the candidate node and its neighbours.
- Compared to VNE in conventional IP over WDM networks, VNE over power and spectrum minimized IP over O-OFDM networks has outperformed the VNE in a 100 Gb/s IP over WDM network with average power savings in the optical layer of 63% and 17%, respectively.

Related Publications

1. Nonde, L., El-Gorashi, T.E.H. and Elmirghani, J.M.H., "Energy Efficient Virtual Network Embedding for Cloud Networks," submitted for publication.
2. Nonde, L., El-Gorashi, T.E.H. and Elmirghani, J.M.H., "Green Virtual Network Embedding in optical OFDM cloud networks," *Proc IEEE 16th International Conference on Transparent Optical Networks* (*ICTON 2014*), Graz, Austria, July 6-10, 2014.
3. Lawey, A., El-Gorashi, T.E.H. and Elmirghani, J.M.H., "Distributed Energy Efficient Clouds over Core Networks," *IEEE/OSA J. of Lightwave Tech.*, vol. 32, No. 7, pp. 1261 - 1281, 2014.
4. Dong, X., El-Gorashi, T.E.H. and Elmirghani, J.M.H., "Green Optical OFDM Networks," *IET Optoelectronics*, vol. 8, No. 3, pp. 137 – 148, 2014.
5. Osman, N. I., El-Gorashi, T.E.H., Krug, L. and Elmirghani, "Energy-Efficient Future High-Definition TV," *IEEE/OSA J. of Light. Tech.*, vol. 32, No. 13, pp. 2364 – 2381, 2014.
6. Lawey, A., El-Gorashi, T.E.H. and Elmirghani, J.M.H., "BitTorrent Content Distribution in Optical Networks," *IEEE/OSA J. of Light. Tech.*, vol. 32, No. 21, pp. 3607 – 3623, 2014.
7. Dong, X., El-Gorashi, T.E.H. and Elmirghani, J.M.H., "IP Over WDM Networks Employing Renewable Energy Sources," *IEEE/OSA Journal of Lightwave Technology*, vol. 27, No. 1, pp. 3-14, 2011.
8. Dong, X., El-Gorashi, T.E.H. and Elmirghani, J.M.H., "Green IP over WDM Networks with Data Centres," *IEEE/OSA Journal of Lightwave Technology*, vol. 27, 2011.
9. Dong, X., El-Gorashi, T.E.H. and Elmirghani, J.M.H., "On the Energy Efficiency of Physical Topology Design for IP over WDM Networks," *IEEE/OSA Journal of Lightwave Technology*, vol. 28, 2012.
10. Dong, X., El-Gorashi, T.E.H. and Elmirghani, J.M.H., "Use of renewable energy in an IP over WDM network with data centres," *IET Optoelectronics*, vol. 6, No. 4, pp. 155-164, 2012.