IP-Over-WDM Cross Layer Design for Optical Networking

Nivethitha.V
II M.E Communication systems
Dr. Mahalingam college of Engineering and Technology, Pollachi

K.Ajikumar
Assistant Professor
Dr. Mahalingam college of Engineering and Technology, Pollachi

ABSTRACT
This disquisition presents a energy consumption in a network which is a important physical factor against this everlasting increase in network traffic. Since current equipment in network consumes energy inefficiently due to poor energy load proportionality we have modeled a packet optical transport networks. By employing integer linear programming (ILP), we model and optimize the energy consumption of IP/WDM (IP/WDM) networks with traffic-grooming cross layer designs. Also our study shows the energy savings in IP/WDM network. In addition to that for energy proportionality of network equipment different network schemes are required.

Keywords
Cross-layer design, optical networks, minimal energy control network.

1. INTRODUCTION
Due to the enormous increase in the Internet traffic, the energy consumption of the network has became most complicated issue in the energy aware solution. Increase in the network traffic brings a critical issues of the energy consumption problem as well as network capacity problem. In this IP-over-WDM network cross layer approach transports feedback dynamically via the layer boundaries to enable the compensation for e.g. overload, latency or other mismatch of requirements and resources by any control input to another layer but that layer directly affected by the detected deficiency. Its core idea is to maintain the functionalities associated to the original layers but to allow coordination, interaction and joint optimization of protocols crossing different layers. The cross-layer approach to system design derives from enabling interaction among protocols operating at different layers of the protocol stack in order to provide improvement in terms of some performance metric. Here fiber used for links so that it provides far greater bandwidth than copper and has standardized performance up to 10 Gbps and so on. Traffic grooming technique is an important technique to save energy consumption of networks because it maximally utilizes a WDM optical layer that consumes relatively small energy.

Traffic grooming is the process of grouping many small telecommunications flows into larger units, which can be processed as single entities. Effective grooming requires consideration of the topology of the network and the different routes in use. Grooming is a term used to describe optimization of capacity utilization in transport systems by means of cross-connections of conversions between different transport systems or layers within the same system.

The internet protocol (IP) layer is for packet processing which consumes large amount of energy [3].WDM optical layer switches a large amount of traffic by a switching process. By traffic grooming in IP/WDM network, the majority of packets in the traffic bypass IP layer function by offloading traffic to the WDM optical layer.

Here IP-over-WDM cross-layer optimization is for energy-efficient network dimensioning models. Increasing energy proportionality of network is the ultimate requirement to save energy consumption of networks has been showed. We also show that different network dimensioning approaches are required for network equipment with different energy proportionalities. In order for applications with large networks, we employ a disjoint shortest-path scheme for efficient traffic grooming dimensioning, which reduces the computation cost by orders of magnitude. In addition, we show the comparison of energy consumption and network investment cost between hop-by-hop routing and traffic grooming network models under different energy proportionality conditions.

For clear interpretation, the network model design descriptions are given in section 2. Section3 is followed by ILP Formulations and the simulations and results are followed in section 4 and 5.

2. NETWORK MODEL DESIGN DESCRIPTION
The packet optical transport network model has been modeled as shown in the Fig. 1. The network consists of IP and optical layers. An IP layer consists of routers and IP-layer-to-optical-layer interfaces. An optical layer consists of WDM cross connectors, wavelength converters, and EDFAs. IP layer node is connected with other nodes and an optical-layer node is physically connected to its neighbor nodes. In the IP layer network traffic is processed packet by packet electrically, and the optical layer transports network traffic in appropriate WDM wavelength channels by circuit switching.

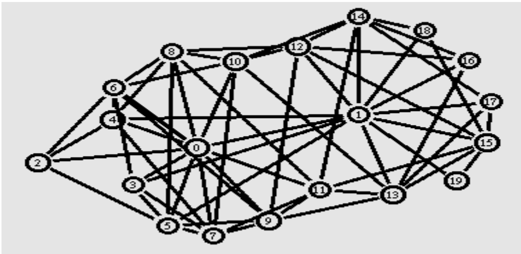


Fig.1. Schematic illustration of packet optical Transport network

2.1 Design of IP Layer

The main role of an IP layer is transferring traffic from a source node to a destination node. A line card of an IP layer switches packets in the traffic, where packet processing is conducted at each port of a line card, requiring a large amount of energy in order to switch traffic. Hence, optimizing the energy consumption in an IP network critically depends on the energy-load function of an IP router line card.

2.2 Design of Optical Layers

Two types of optical layer designs has been considered depending on wavelength conversion capability. Optical nodes with wavelength conversion can convert the wavelength of an incoming signal to another wavelength channel. However, this is not available in all optical nodes. An optical node without wavelength conversion relies on the IP layer to provide wavelength conversion to resolve wavelength contention in the process of traffic grooming.

2.3Energy Consumption Model

Here the static traffic case for network dimensioning against a maximum traffic demand. Energy consumption of network E_{net} is denoted as:

$$E_{net} = \sum_{e \in \left\{ \begin{smallmatrix} network \\ elements \end{smallmatrix} \right\}} P^e(t^e) \ , 0 \leq t^e \leq 1.$$

Where, e labels each network element, and P^e and t^e denote energy consumption of and traffic load at element, respectively. A total energy consumption of a network is the summation of energy consumptions of all network elements. The energy consumption of a network element increases as traffic load increases. For energy consumption of a network element requires two terms: load independent power term for idle-state power consumption of element and load-dependent power term of element determined by a product of varying power portion $(P_M^e - P_I^e)$ and normalized traffic load on the element t^e.The energy consumption for a given traffic load is expressed as:

$$P^e(t^e) = P_I^e + (P_M^e - P_I^e)\ t^e, 0 \leq \ t^e \leq 1.$$

An ideal network element value is zero for P_I^e and a very small value for$(P_M^e - P_I^e)$. Here, the EPI of an element is defined by

$$EPI^e \equiv (P_M^e - P_I^e) / \ P_M^e$$

In general, the current network equipment is inefficient so that it consumes relatively large amount of fixed energy even in an idle state.

3. ILP FORMULATIONS

ILP formulations for IP/WDM cross-layer optimization with hop-by-hop routing (HHR) and traffic grooming network models has been developed. Here traffic grooming is considered with and without wavelength conversion (TGWC) [15] and TG [13], respectively). The network is represented as graph G(N,L) , where N and L are the sets of nodes and links in the network, respectively. The set of node pairs is Z=$\{(i.j) | i,j \ \in N, i \neq j\}$. Assume that the set of links consists of unidirectional links (fibers) and each unidirectional link capacity is defined with the number of wavelength $w \in W$and capacity of each wavelength C_w .

Parameters and variables used

L_s^+ Set of links going out from node s

L_s^- Set of links coming in to node s

t^{sd} Normalized traffic demand of flow (s, d)

t_l^{sd} Normalized traffic of flow (s, d)on link

t_{ij}^{sd} Normalized traffic of flow (s, d)in light path(i, j)

b^{ij} Number of wavelength channels in light path(i, j)

b_l^{ij} Number of wavelength channels assigned to light path (i, j)on link$l$.

b_l Total number of wavelength channels on link l

c_w^p c_w^p is 1 if light path uses wavelength channel ; 0, otherwise

x_l^p x_l^p is 1 if light path is on link ; 0, otherwise.

P_V^{IP} Traffic-dependent power consumption of one pair of input and output IP router port.

P_F^{IP} Fixed power consumption of one pair of input and output IP router ports.

P_{WC} Power consumption of one pair of WCs

The main aim of the network models is to minimize network energy consumption.

Objective functions and constraints for HHR and traffic grooming network models are expressed as follows as:

- Hop-by-hop routing.
- Traffic grooming with wavelength conversion.
- Traffic grooming without wavelength conversion.

3.1 Hop-by-hop Routing

The network is modeled as though it flows between source and destination pairs with point-to-point optical links. No light paths are used. The source node aggregates traffic to a flow from access routers which are attached to the source node and transfers the flow through an IP router port of the source node. Intermediate nodes of a flow receive and send the flow to their next hop nodes, and finally the flow arrives at the destination node. The output wavelength of an IP router port is independent from the input wavelength. The objective function and constraints for ILP formulation are as follows:

Objective function

Minimize energy consumption of HHR network

$$\min \sum_{l\in L}(P_F^{IP}\, b_l \;+\; P_V^{IP} \sum_{(s,d)\in Z} t_l^{sd}) \qquad (3)$$

Constraints

$$\sum_{l\in L_s^+} t_l^{sd} = t^{sd},\ \sum_{l\in L_s^-} t_l^{sd} = 0\ (s,d)\in Z \qquad (4)$$

$$\sum_{l\in L_d^+} t_l^{sd} = t^{sd},\ \sum_{l\in L_d^-} t_l^{sd} = 0\ (s,d)\in Z \qquad (5)$$

$$\sum_{l\in L_n^+} t_l^{sd} - \sum_{l\in L_n^-} t_l^{sd} = 0\ \boldsymbol{n}\in \boldsymbol{N}\backslash\{\boldsymbol{s},\boldsymbol{d}\}(s,d)\in Z \ (6)$$

$$\sum_{(s,d)\in z} t_l^{sd} \le b_l \le \sum_{(s,d)\in z} t_l^{sd} + 1, \quad l\in L \qquad (7)$$

$$b_l \le W_{max}\,,\ l\in L \qquad (8)$$

Here, L_k^+ (L_k^-) is the set of unidirectional links outgoing from (incoming to) node k.

Equations (4)–(6) are constraints of traffic routing.

Equation (4) ensures that the source node of a flow sends its traffic and receives no traffic of the flow.

Equation (5) ensures the destination node of a flow to receive its traffic and not to send its traffic to other nodes.

Equation (6) describes that intermediate nodes of a flow receive the traffic of the flow and transfer the same amount of traffic to their next hops.

Equation (7) ensures that an enough number of wavelength channels are allocated to each links.

Equation (8) constraints that the total amount of traffic should not exceed the wavelength channel capacity limit of each link.

3.2 Traffic Grooming with Wavelength Conversion

Here light paths consisting of connected multiple links for virtual topologies. A light path is a sequence of unidirectional links which use different wavelengths. Optical nodes have wavelength conversion capability so that input wavelength channels of a node can be converted into different output wavelength channels. Light path is used to connect each IP routing hop. Flows that can share a light path are groomed at every IP hop. An intermediate node in the middle of the light path, which is capable of optical path switching, switches the traffic to its next intermediate node. The traffic proceeds in the optical domain until it is received by the end node of the light path that terminates the light path traffic. This node re-inserts the traffic to another light path through an IP layer of the node. Finally the traffic arrives at the destination node. Objective functions and constraints can be formulated as follows:

Objective function

Minimize energy consumption of TGWC network:

$$\min \sum_{(i,j)\in Z} (P_F^{IP} b^{ij}\ P_V^{IP} \sum_{(s,d)\in z} t_{ij}^{sd})$$

$$+ P_{WC} \sum_{l\in L}\sum_{(i,j)\in Z} b_l^{jij} \qquad (9)$$

Constraints

$$\sum_{j\in N, j\neq s} t_{ij}^{sd} = t^{sd}, \sum_{j\in N, j\neq s} t_{ij}^{sd} = 0, (s,d)\in Z \qquad (10)$$

$$\sum_{j\in N, j\neq d} t_{jd}^{sd} = t^{sd},\ \sum_{j\in N, j\neq d} t_{dj}^{sd} = 0, (s,d)\in Z \quad (11)$$

$$\sum_{j\in N, j\neq i} t_{ij}^{sd} - \sum_{j\in N, j\neq s} t_{ji}^{sd} = 0, i\in N\{s,d\}, (s,d)\in Z \qquad (12)$$

$$\sum_{(s,d)\in Z} t_{ij}^{sd} \le b^{ij} \le \sum_{(s,d)\in Z} t_{ij}^{sd} + 1, (i,j)\in Z \ (13)$$

$$\sum_{l\in L_i^+} b_l^{ij} = b^{ij}, \sum_{l\in L_i^-} b_l^{ij} = 0 (i,j)\in Z \qquad (14)$$

$$\sum_{l\in L_j^+} b_l^{ij} = b^{ij}, \sum_{l\in L_j^-} b_l^{ij} = 0 (i,j)\in Z \qquad (15)$$

$$\sum_{l\in L_n^+} b_l^{ij} - \sum_{l\in L_n^-} b_l^{ij} = 0, n\epsilon N\backslash\{i.j\}, (i.j)\in Z \ (16)$$

$$\sum_{(i,j)\in Z} b_l^{ij} = b_l\,, b_l \le W_{max}\,, l\in L \qquad (17)$$

Equations (10)–(12) are constraints of traffic routing.
Equation (13) ensures that enough channels are allocated to each light path.

Equations (14)–(16) are constraints of light path routing that ensures channels of the light path being connected from the start node to the end node of the light path consisting of links.

Equation (17) limits the number of wavelength channels in a link.

3.3 Traffic Grooming without Wavelength Conversion

Here a light path uses only a *single wavelength*. Each flow uses virtual links of light paths to send its traffic. An optical layer has no wavelength channel conversion capability. Therefore, wavelength conversion as well as traffic routing occurs in the IP layer. So ILP formulation for TG network requires more complex constraints that replaces of TGWC formulation. These constraints have to include light path wavelength assignment, continuity, and availability in a link [15], and the corresponding enumeration spaces span with $O|N|^4, O|N|^3$ and $O|N|^2$, respectively. The overall search space is reduced to $O(|N|^3 log|N|)$. The objective function and its corresponding constraint are formulated as:

Objective function

Minimize energy consumption of TG network:

$$\min \sum_{(i,j)\in Z}(P_F^{IP} b^{ij} + \quad P_V^{IP} \sum_{(s,d)\in z} t_{ij}^{sd}) \qquad (18)$$

Constraints

$$\sum_{w\in W} \sum_{p\in Pij} \quad c_w^p = b^{ij} \qquad (19)$$

$$\sum_{p\in P} \quad c_w^p x_l^p \le 1\,, \mathrm{w}\in \mathrm{W}, \mathrm{l}\in \mathrm{L} \qquad (20)$$

Here, P is the set of all light paths which connects node pairs in graph $G(N,L)$ and P_{ij} denotes the set of disjoint paths between node pairs i and j , hence $P_{ij} \in P$.

Light path channels are assigned to paths by (19).

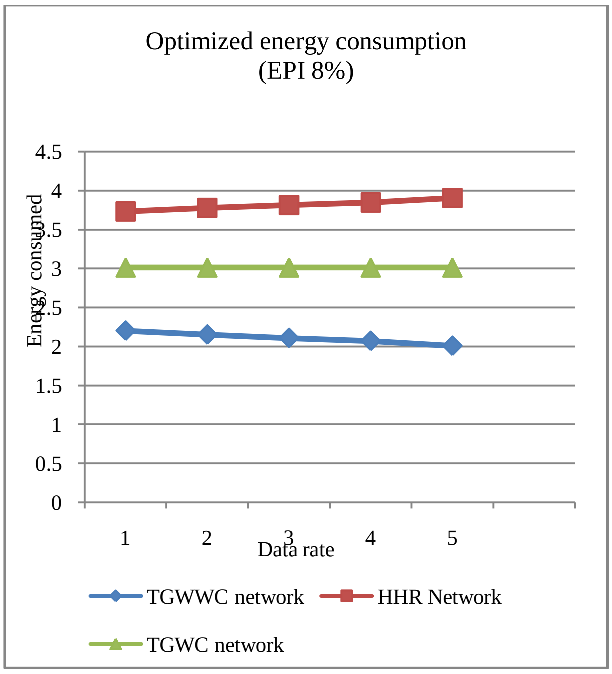
Equation (20) ensures wavelength availability in a link.

4. SIMULATIONS

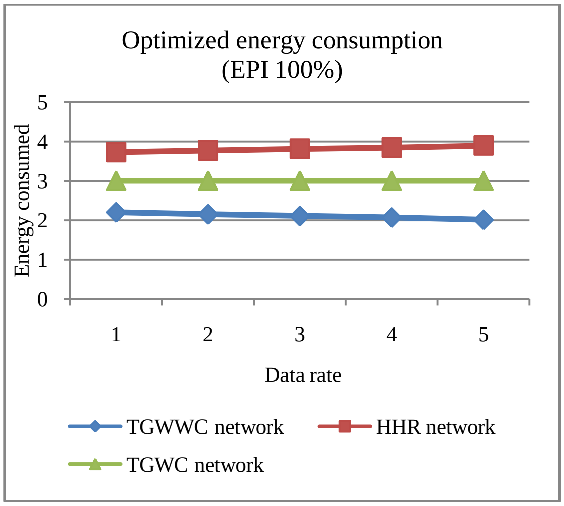
In this section, simulation is conducted to verify the energy consumption of the network. Network Simulator-2(NS2) is used for the purpose of the simulation. For network topology as per NSFNET model 14 nodes and 22 links are used. Here the links are considered as fiber and each fiber is considered to support up to 30 wavelengths. Each wavelength has the capacity of 40Gbps.Traffic of each node pair is assumed to have uniform random distribution of range of $0 \leq t \leq 1.5$, where t is a traffic load which is normalized to 40Gbps. 't'varies depending on the maximum traffic demand. For an accurate analysis of EPI effect we have with practical EPI(8%) and ideal EPI(100%).Simulation is undergone with two cases:

4.1 Objective Functions of Energy Minimization

Energy consumptions of HHR and TGWWC networks increase as the maximum traffic demands of each node pair increase. The energy consumption of the TGWC network is lower than that of the HHR network because the TGWWC network uses optical bypass technique more efficiently.

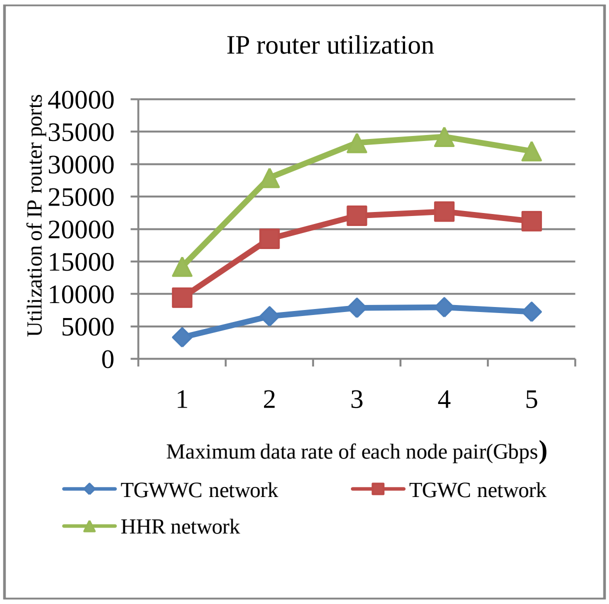


Energy savings with 100% EPI with respect to 8% EPI manifests for all kind of networks especially when the traffic demand is low.



If the traffic demand increases, energy savings of both networks reduces.

IP router port is an important factor to calculate the network equipment cost. The number of used IP router ports of HHR and TGWWC networks increase when traffic demand increases. The number of used IP router ports of the HHR network is always higher than that of TGWWC networks because of optical bypass.



4.2 Objective Functions for Traffic Minimization

For traffic minimization, the objective function is that minimizing switching processes of an IP Layer in HHR and TG network.

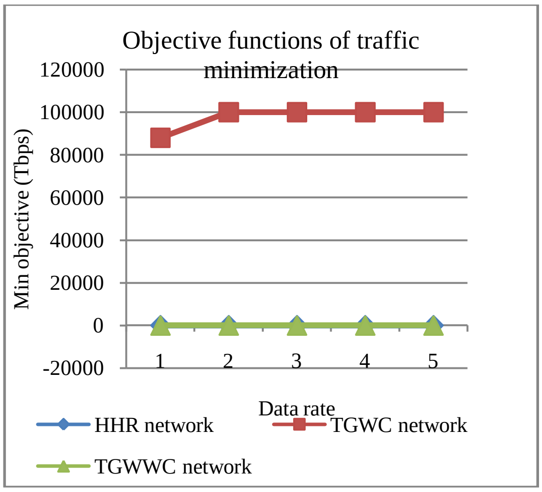
HHR network

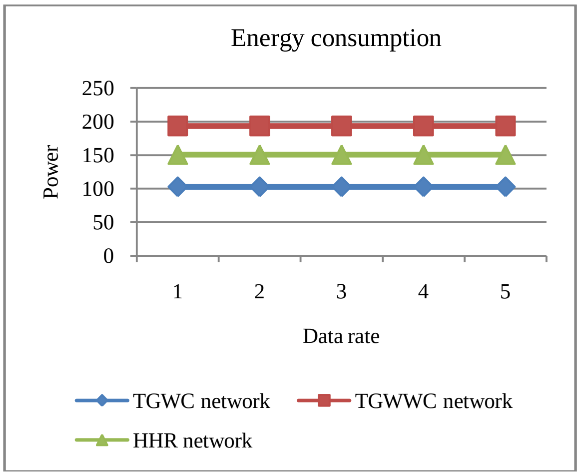
$$\min \sum_{(s,d)\in Z} \sum_{l\in Z} t_l^{sd} \quad (21)$$

TG network

$$\min \sum_{(s,d)\in Z} \sum_{(i,j)\in Z} t_{ij}^{sd} \quad (22)$$

The optimized traffic by traffic grooming network is always lower than the HHR network.





The energy consumption is directly proportional to traffic; the energy optimization of networks becomes nearly the same as traffic optimization.

5. RESULTS

Thus with the cross layer optimization model energy aware IP\WDM network has been analysed and simulated. Simulation is done with ILP optimization models with energy and traffic minimization objectives of networks. The effects of energy proportionality on network dimensioning under different objectives also have been analyzed. In future the energy efficiency also can be calculated.

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