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Table Driven Hybrid Energy-aware and SLA-based Routing Mechanism over Optical Networks

Yashar Fazili, Alireza Nafarieh*, William Robertson

Dalhousie University, Internetworking program, 1360 Barrington Street,
Halifax, Nova Scotia
Canada, B3J 2X4

Abstract

This paper introduces an improvement for Hybrid Energy Aware and SLA Based (EASB) routing mechanism enabled for GMPLS networks. The performance of EASB is enhanced significantly by consulting a routing table populated in advance, instead of route calculation for each connection request. The table is “looked up” to determine the route that has the minimum hybrid cost for the given source-destination pair of the connection request. As a result a node with lower compute capability can be used to server the equal amount of connection requests while maintaining emission and resource efficiency.

Keywords: *Co_2 emission rate; Energy-aware algorithms; GMPLS networks; Green routing algorithms; Optical Networks;*

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1. Introduction

Growing need for communication in the world is resulting in rapid growing of data and communication networks and more energy to operate these networks [1]. Connecting smaller and bigger networks using backbones that mostly run on fiber optics is posing a challenge in actively controlling and reducing the energy and emission caused by operation of these optical networks [1]. Traditional routing mechanisms such as the one introduced in [2] are not aware of energy and emission information and result in huge emissions. Using green source of energy can reduce the amount

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*Alireza Nafarieh. Tel.:+1-902-494-2057 Email: ali.nafarieh@dal.ca

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of emission however there are two basic problem with this types of energy; one being the limited availability and the second is that the information and method on how to systematically and automatically use nodes and links that are powered by green energy in transporting data without human interaction, which is the motivation behind design and testing green aware routing mechanisms.

The green power plants using green sources of energy such as wind and sun produce less emission compared to those using non-green sources, such as oil and coal. However, type of the energy sources may change over time since the sources of green energy such as sun and wind are available on a limited bases. As a result, the types of energy powering each section of the network may change randomly. Green aware routing mechanisms require to have access to information regarding the source of energy in different sections of network on a regular basis for decision making on using green nodes and links in directing data flows. To calculate the emission rate of network, energy sources of each node and link in the network must be known. According to work in [3] and [4] this information is provided by Smart Grid. The information provided by smart grid is then transmitted to the entire network using Link State Advertisements (LSAs), so every node in the link-state enabled routing area can have the same view of network emission topology, or the type of energy source available to power up each segment of network [3], [4]. This work is organized as follows: Section 2 details the related work and defines the framework of the paper. In Section 3, the new Table Driven Hybrid Energy-Aware and SLA Based Routing Mechanisms (T-EASB) is proposed. The simulation environment and the performance analysis of the network are discussed in Section 4. Section 5 draws the conclusion followed by the list of references.

2. Related Work

2.1. Hybrid Energy Aware and SLA Based Routing Mechanism (EASB)

The work in this paper is the continuation of the previous work detailed in [1]. EASB is aware of source of energy hence it can use energy information in decision making, to choose a route for a connection request that first of all meets the requested SLA parameters (such as availability for route) and has a lower emission rate (when multiple routes are available). EASB uses K shortest path method to calculate k most available routes between a given source and destination. The length of each calculated route is then combined with the corresponding logarithmic value of sum of Co_2 emission rates (Emission Factors, EF) of links of route, using a balancing factor to come up with a hybrid cost. The route with the lowest hybrid cost that meets the SLA parameters, serves the connection request. Equation (1) shows the method of calculation of hybrid cost (HCost) of a route between source (S) and destination (D) for EASB, which is exactly the same for T-EASB:

$$Hcost_{(S,D)} = \alpha \times \lambda_{(S,D)} + (1-\alpha) \times \log(EF_{(S,D)}) \tag{1}$$

Where α=0.35 based on work in [1], is the balancing factor used to combine two different metrics. $\lambda_{(S,D)}$ Is the length of the route in hop counts and $EF_{(S,D)}$is the Co_2 emission of the entire route. This operation is very processor intensive since dijkstra is ran k times for each request. After serving the request the results are simply “Trashed” and could not be used even with similar requests (request with same source and destination).

2.2. Parameters for Optical links

The work in [5] has proposed energy values for nodes and inline amplifiers of optical link used in the simulation part of this paper. The algorithm suggested in [5] has showed that it is possible to improve the energy efficiency of the optical network by minimizing the number of working optical amplifiers in the network. In this paper the unused fibre optics are placed in off/standby state. EASB and T-EASB keep the links with higher emission rates in standby state and the optical link of “hop” is turned on only when the resources (lambdas or wavelengths) of green links are exhausted.

2.3. Energy TLVs and Emission Calculation

Work in [3] and [4] have proposed set of new link-state advertisements that would carry energy related information across the link-state routing area. These information combined with the actual amount of energy consumed by each optical link and node of the network can provide the exact amount of emission. For example a link powered up by 0.5 kW feed, using coal (880 gCo_2/kWh in [6]) as a source of energy and uptime of 10 hours would emit 4400g Co_2 or simply 440 g/h Co_2 as emission rate or EF. Emission rate is used in this work as a parameter for decision making. In this paper it is assumed that amount of load does not change amount of energy usage of any node by a significant amount and the energy usage of each link is independent of amount of traffic being transferred.

3. Table Driven Hybrid Energy-aware SLA-Based (EASB) Routing Mechanism

With T-EASB method based on ideas in [7] and approach in [2], a routing table "R" is populated first and then is used to fetch the stack of k routes between source-destination pair of the connection request. This saves the control plane from running the dijkstra or k shortest path for every single connection request. First, an "n by n" table R presented in Fig. 1 is created for a network of n nodes. Each element or cell of table denoted by r_{sd} (routes from source to destination) will store a stack of k most available routes between node s and node d such as work illustrated in [2]. Since TE tunnels are bidirectional [8] in GMPLS networks, return path is also needed for connection request however, destination node can use the same "reversed" route to create the returning route, and there is no need to calculate the return route from destination to source. This means that only half (upper triangle) of the routing table must be calculated and the return paths (below main diagonal) are the transpose of "reversed routes in all stacks" of top part as seen in Fig. 1. In other words (n)*(n-1)/2 k shortest paths operations must be executed. While populating each r_{sd}, the hybrid cost using equation (1) is also calculated and saved in a separate table of $Hcost_{sd}$. Each route in the stack of r_{sd} is marked as "accessible" denoted by r_{sd_access}, which means that route is available to use. Then the transpose of the table for returning routes with is added to the table. After this step the control plane is ready to serve the requests. It is also important to note that this table must be recreated in case of emission topology changes, since the emission values are different. This method is highly efficient if the total number of connection requests in every topology change interval (e.g. 6 hours) is more than total number of calculated routes of upper triangle part of routing table. This concept has been tested in the simulation part.

When a connection request is received, the stack of routes between the source-destination of the connection request is fetched from the table. Control plane finds the route with minimum hybrid cost in the stack that meets the SLA (availability) requirements of the connection request. Control plane then tries to assign the resource (lambdas) of the chosen route. If the assignment is successful, the request is served and the dynamic resource table that keeps track of number of available to assign wavelengths or lambdas of each link is updated. If the assignment is not successful (tunnel could not be signalled), the route is marked as "inaccessible" in the stack and next route with the lowest hybrid cost that meets the SLA requirements is found in stack and the process of resource assignment is repeated. If no route is "accessible" the connection request is rejected. When a tunnel is terminated, the resources of the route are returned to the pool of resources, and, if no topology change has been occurred the routes is flagged as accessible in the stack of routes. Algorithm 1 shows the pseudo code of process of populating table. Fig. 2 shows the flowchart of how connection requests are handled.

Algorithm 1 : Creation and Population of table R

```
FOR (s=1: n)
    FOR ( d=i+1: n )
        √ $r_{sd}$ ε R = k_shortestpath(s,d);
        FOR (i=1:k)
            $Hcost_{sdi}$ = Calculate the hybrid cost for $r_{sdi}$ using (1) ; $r_{sdi\_access}$=true;
            $r_{dsi}$ = Reversed ($r_{sdi}$); $Hcost_{dsi} = Hcost_{sdi}$ ; $r_{dsi\_access}$=true;
        END
    END
END
```

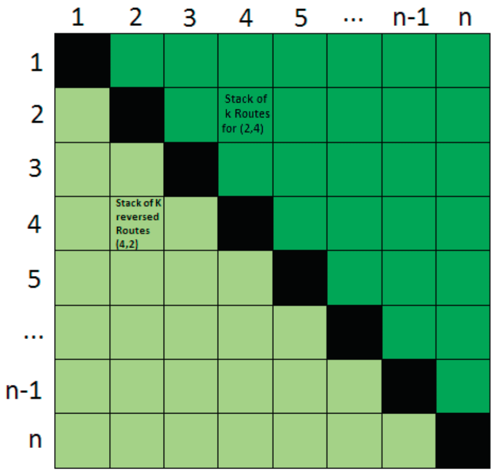

Fig. 1.n by n routing table R

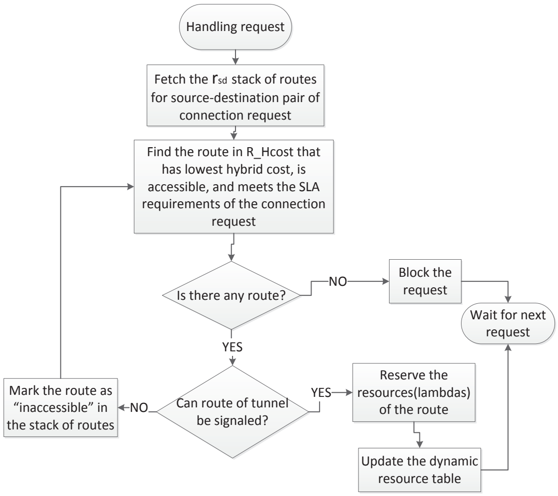

Fig. 2. Handling a connection request

4. Performance Analysis

4.1 Simulation Environment

The simulation network topology is the NSFnet network presented in Fig. 3. There are 14 nodes and 21 bidirectional links. Each link has 128 available wavelengths. The numbers on the links in Fig. 3 represent node distances in km. The First Fit method for wavelength assignment in [9] is used without the continuity constraint. Each inline amplifier is placed at every 80 km of optical links. Any random type of energy sources can power nodes and links in the network and this information is disseminated through the network using the method proposed in [3] and [4]. To deal with dynamic routing requests, it is assumed the routing and signalling information is propagated using OSPF-TE [10] and (RSVP-TE) [11]. The holding time of the connections follows an exponential distribution with the mean value of μ=6 hours. The offered load [12] is defined as the mean arrival rate multiplied by mean connection duration. The emission factor for each energy source powering nodes and optical links of the network has been adopted form the greenhouse gas emissions values provided in work [6]. Traffic of each optical link is composed of different wavelengths and one wavelength for each connection request.

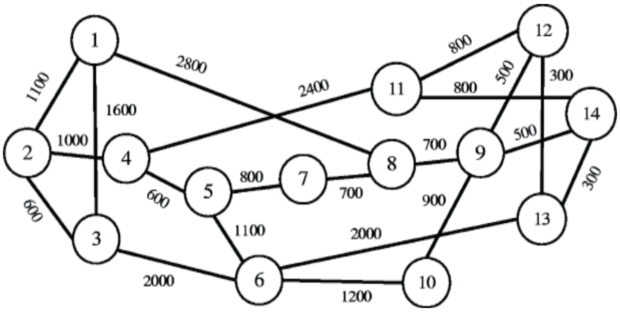

Fig. 3. NSFnet topology

4.2. Simulation Parameters

This section defines the important parameters for comparison. Two type of simulations are performed in this section. For first simulation, the total time to process a given number of successful connection requests is calculated to show the significance of T-EASB method in reducing the processing time. The total processing time for T-EASB is defined as the time to populate the routing table, added to the total time required to process or assign a route for all connection requests in a given time e.g. one emission topology change interval of 6 hours. In this test a range of 100 to 1000 connection requests are tested for 6 hours. In this case table is populated once and given number of requests e.g. 600 in 6 hours are processed accordingly. Total time for processing connection requests in EASB is simply the sum of time needed for each k shortest path operation, for each connection request. The second simulation is performed to compare the average route length to determine resource efficiency, total Co_2 generated and average Co_2 generated per unit resource to determine the greenness of EASB, T-EASB and SLA based routing mechanism (SB) in [6]. A Poisson process with mean arrival rate of 100 requests per hour is considered for the arrival process of connection requests in the second part of the simulation. The connection blocking rate or the ratio of blocked connections to total connections resulted the same for EASB and T-EASB (about 7%) and was not graphed.

4.3. Simulation Results

This section details the results of simulation for total time needed to process equal number of connection requests, followed by results of simulation for resource and emission efficiency.

With T-EASB after populating the routing table R for each scenario (100 to 1000 connection requests), the requests are processed and since memory access is very fast, there is only an insignificant time difference of 0.1 units of time between processing 100 and 1000 connection requests as seen in Fig. 4. Results of Fig. 4 only show the cumulative time required to process the entire number of given connection requests e.g. 500 and does not include the time needed to populate the table R. Fig. 5 shows the total time for processing the number of connection requests. For T-EASB this time includes constant table population time and cumulative time required to process all connection requests of each scenario (100 to 1000 connection requests). With increasing number of connection requests the total time for EASB is increased linearly as oppose to T-EASB, with almost constant and less than one time unit. The reason for almost constant timing behaviour of T-EASB is that the table population takes a certain and constant amount of time to finish for all scenarios of 100 to 1000 connection requests per 6 hours and is independent of number of connections to process which is then added by cumulative time need to process the total connection requests, which is in order of one tenth of the unit time. As shown in Fig. 5 EASB needs about 500% more time to process 1000 connection requests compared to total time of T-EASB (including time to populate table and process all 1000 connection requests). This figure shows that a control plane running T-EASB can have up to 500% more throughput with the same hardware as oppose to a network running EASB.

Simulation for other parameters has been performed with two emission topology change intervals of 6 and 12 hours. Fig. 6 and Fig. 7 show the average route length or lambda per connection for EASB, T-EASB and SB in 6 hours and 12 hours topology change interval respectively. These graphs demonstrate almost the same average route length for EASB and T-EASB. This means that although routing decision has not been performed on real-time bases for T-EASB, This routing mechanism is as resource efficient as EASB and is even resource efficient than SB. SB assigns the most available routes (regardless of their length) to all connections, resulting in increasing the route length. This problem is avoided in process of EASB and T-EASB since path selection is based on hybrid cost (which is composed of length and emission of the route) and not the best available route. Results of fig. 8 and 9 show that amount of Co_2 emission per unit resource or lambda. Emission of connection has been reduced by around 15-20% by using EASB and T-EASB as routing mechanism. These graphs also signify that T-EASB is as green as EASB in both 6 hour and 12 hour emission topology change intervals. Fig. 10 and Fig. 11 show the results of simulation for total Co_2 emission. In these graphs total Co_2 production has been reduced by almost 20% by using T-EASB and EASB. Again these graphs show similar results for T-EASB and EASB signifying that T-EASB is as green as EASB in terms of emission.

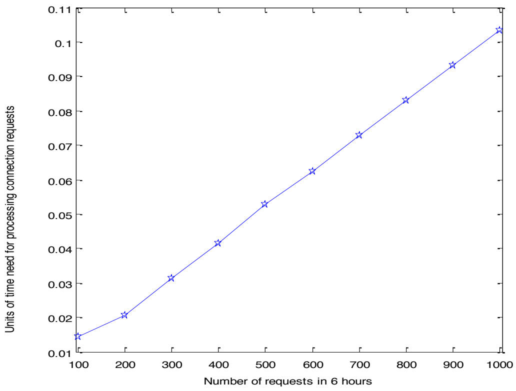

Fig. 4. Units of time to process a range of 100 to 1000 connection requests in 6 hours, after populating the table R in T-EASB

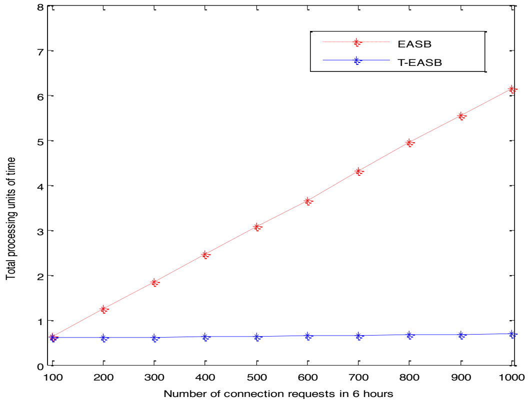

Fig. 5. Total units of time required to process 100 to 1000 connection requests per 6 hours including time required to populate the table R in T-EASB for each scenario

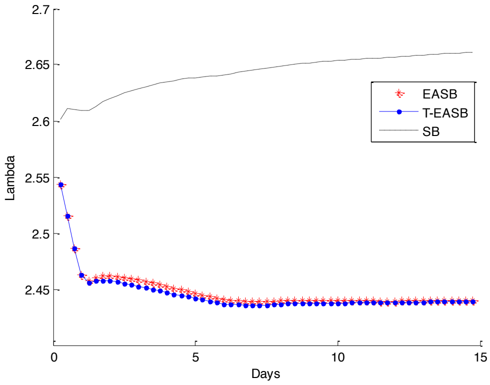

Fig. 6. Average assigned wavelength per connection in 6 hours

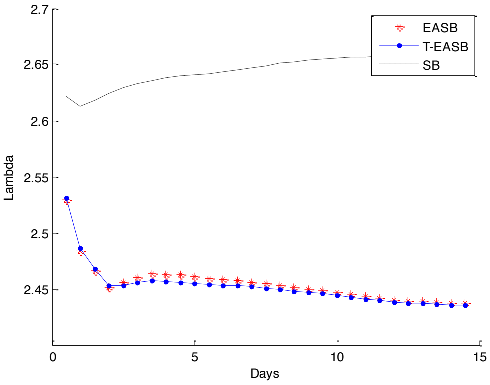

Fig. 7. Average assigned wavelength per connection in 12 hours

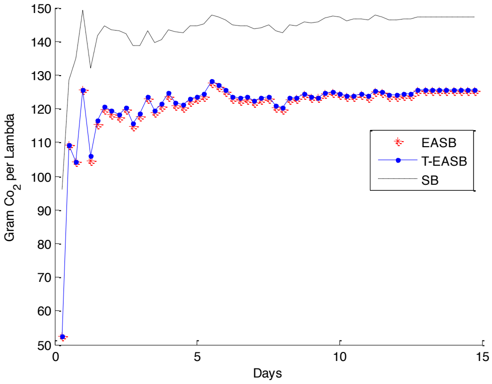

Fig. 8. Co_2 emission per lambda in 6 hours

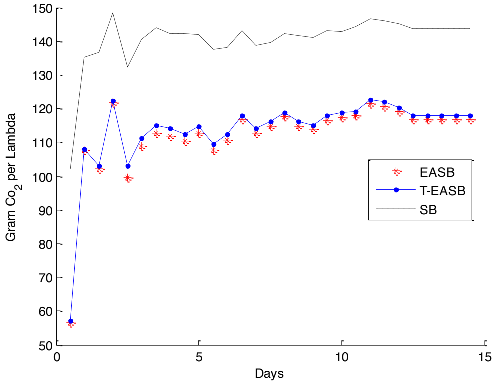

Fig. 9. Co_2 emission per lambda in 12 hours

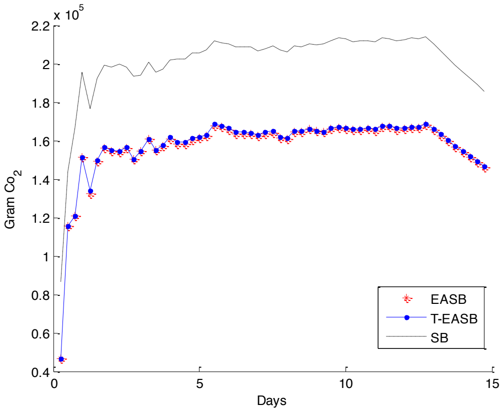

Fig. 10. Total Co2 produced every day in 6 hours

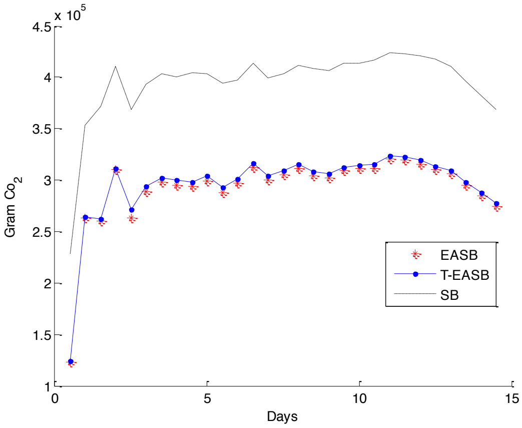

Fig. 11. Total Co_2 produced every day in 12 hours

5. Conclusion

T-EASB used the pre-calculated routes between each source-destination pair of connection request to avoid performing k shortest path for every connection request. T-EASB also remained as resource efficient as EASB with almost the same average route length.

Emission of the optical networks can be reduced by using Table driven Emission aware and SLA based routing mechanism (T-EASB) at the same rate of EASB but with significantly less “route calculation time” which can be interpreted as a method to increase the throughput of control plane of optical networks such as GMPLS.

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