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Adaptive Green Routing Mechanism over Optical Networks

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Abstract

This paper is an extension to the previous work that introduced the hybrid energy-aware and service level agreement (SLA) based routing mechanism over optical networks. This paper introduces an adaptive SLA-based routing approach to lower the Co_2 emission rate while it provides the most available routes between any pair of source and destination. The paper benefits from the hybrid path cost function presented in the previous work in which Co_2 emission rate, path length, and path availability are taken into account as the route selection process criteria. The mechanism proposed in this paper re-routes established optical paths using an adaptive green routing algorithm after the nodes in the network are informed of any changes on the emission factors of the links. As a result of employing the new energy-aware routing algorithm together with the novel path cost function, paths with the minimum Co_2 emission and less assigned network resources will be selected. The algorithm presented in this paper keeps Co_2 emission at the lowest level with maintaining an adaptive re-routing mechanism over the duration of connections while service level agreement requirements are still met.

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Keywords: Co_2 emission rate; Energy-aware algorithms; Green routing algorithms; re-rouitng algorithms; Optical Networks

1. Introduction

The Internet is growing rapidly and consequently the backbone networks such as GMPLS with optical data plane will consume more power and produce more emission [1]. In order to reduce the greenhouse gas emissions such as Co_2, emission aware routing mechanisms are required in networks.

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Although the goal of green networks is to reduce the amount of emission of networks, it is crucial to meet the current standards of networks such as optimized resource provisioning and satisfied SLA requirements. This paper introduces a significant improvement to the previous work [2] by employing an adaptive approach to the emission aware and SLA based (EASB) routing mechanism.

2. Related Work

Before introducing the adaptive emission aware and SLA based routing mechanism, it is beneficial to review the previous work in [2], introducing hybrid emission aware routing mechanism (EASB). The EASB routing mechanism takes advantage of the emission topology database which is dynamically updated and refreshed by Opaque link state advertisements (LSAs) [3], [4]. The information provided by this topology database, named as emission factors (EF) in this paper, is used to calculate the amount of emission of routes between any source and destination pair (*S,D*). The routing mechanism firstly calculates a set of *k* shortest paths using the algorithm presented in [5] between source and destination pairs (*S,D*). The cost of links are modified using the link availability values introduced in [6] based on (1), where a_{ij} is the availability of each point to point link in the route between any source destination pair.

$$C_{(S,D)} = \sum_{(i,j)\in Route} -\ln(a_{ij}) \tag{1}$$

The length (hop count) of the most available routes in (1) is then combined with their corresponding emission factor (EF) to calculate the hybrid cost (H_{cost}) used by decision making nodes in the routing algorithm. Equation (2) shows the calculation of emission factor (EF), where $link\_Co2$ is the amount of the Co_2 emission of each point to point link forming the path between source and destination pair (*S,D*).

$$EF_{(S,D)} = \sum_{(i,j)\in Route} link\_Co2_{(i,j)} \tag{2}$$

The hybrid cost is then calculated using (3) employing balancing factor α similar to the method introduced in [7], where λ is the length of the route. The value of α is set to 0.35 as discussed in [2].

$$H_{cost_{(S,D)}} = \alpha \times \lambda_{(S,D)} + (1-\alpha) \times \log(EF_{(S,D)}) \tag{3}$$

The route with the lowest hybrid cost that satisfies the SLA or availability requirements of connection requests is selected among the *k* most available routes between any source and destination pair (*S,D*). The EASB routing mechanism [2] reduces the amount of emission but still does not apply the emission topology changes to previously established tunnels. This results in less emission efficiency of the EASB mechanism. This paper introduces the adaptive EASB (A-EASB) with ability to reroute and optimize previously established tunnels with new emission factors to lower the amount of Co_2 emissions.

Authors in [3] and [4] have shown that it would be possible to reduce the emission in trade-off with an increase in the path length and the blocking rate and a decrease in SLA satisfaction rate. Increasing the path length consumes more resources, assigned wavelengths, which is translated into more average cost for ISPs. The higher blocking rate also means less SLA satisfaction rate and less revenue for ISPs since the network can accommodate fewer customers' connection requests. The previous work [2] has addressed these issues by introducing the EASB routing mechanism. However, the mechanism proposed in [2] is not capable of rerouting and optimizing previously established tunnels.

When the topology or the source of the energy, powering up each segment of GMPLS networks, is changed, proper Opaque LSAs introduced in [4], [6], and [8] are propagated within the network to update the emission topology database of the network. New connection requests are then served with fresh information in either approach of energy efficient (EE) presented in [3] or EASB presented in [2].

The work in [9] has proposed power and energy values for nodes and inline amplifiers of optical links. These values are considered as reference in the simulation part of this paper. The algorithm suggested in [9] has showed that it is possible to improve the energy efficiency of optical networks by minimizing the number of working optical amplifiers in the network. However, it does not propose any dynamic provisioning of already established connections.

3. A-EASB Routing Mechanism

To enable rerouting for optimizing the emission level in EASB, adaptive EASB, named as A-EASB in this paper, is introduced. The flowchart of the proposed mechanism is shown in Figure 1. When the emission topology is changed, the A-EASB applied on the control plane in GMPLS networks [10] checks all previously established tunnels in an attempt to find a new route with less hybrid cost for each established tunnel to reduce the emission level. In this paper the A-EASB mechanism is compared to energy aware routing algorithm introduced in [11], named as A-EE in this paper.

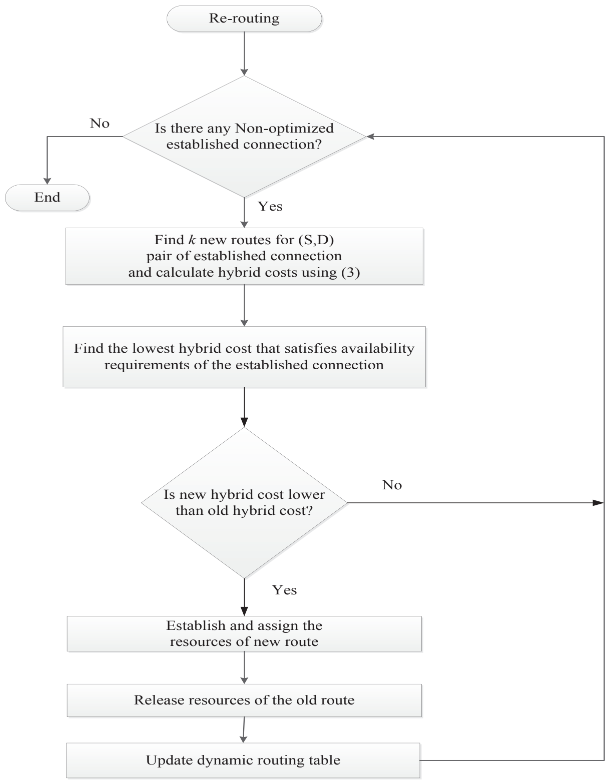

Figure 1 Flowchart of the adaptive EASB

4. Performance Analysis

4.1. Simulation Environment

The simulation network is the NSFNet network presented in Figure 2. Each link has 64 available wavelengths. The numbers on each link of Figure 2 represent the node distances in km. The first fit (FF) method evaluated in [12] is used for wavelength assignment and is used without the continuity constraint.

Each inline amplifier is placed every 80 km in optical links. Any random type of energy sources introduced in [13] can power links in the network and this information is disseminated through the network using the method proposed in [4] and [6]. The emission topology and power change interval is assumed to range from 6 to 24 hours. The arrival process of connection requests follows Poisson process with mean arrival rate of 6 minutes. The holding time of the connections follows an exponential distribution with the mean value of 12 hours. For the first part of the simulation, it is assumed that the power change interval is every 6 hours and does not change. The graphs in Figure 3 to Figure 7 belong to this part of the simulation. However, to show how the rerouting mechanism behaves for longer power change intervals, the power change interval ranges from 6 to 24 hours in the second part of the simulation. Figure 8 to Figure 12 belong to the second part of the simulation.

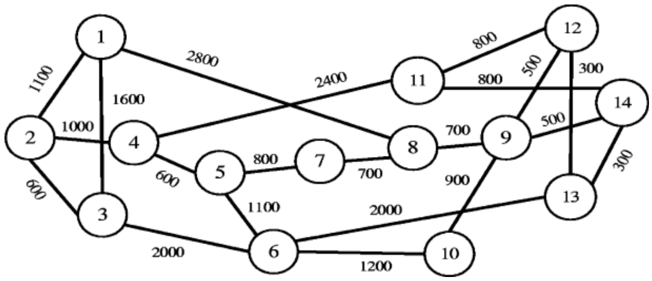

Figure 2 NSFNet network topology

4.2. Simulation Results

In this section, average of Co_2 emitted per resource assigned (lambda) is evaluated for A-EE and A-EASB. This section also details the results of path length analysis with lambda per connection graphs. The other parameter described and graphed in this section is average SLA satisfaction rate, which is the ratio of the number of established connections that meet the requested availability of connection request to the total number of established connections. This section also confirms 0.35 as the appropriate value for α in (3) to calculate H_{cost} for A-EASB.

Figure 3 graphs the result of analysis for average amount of Co_2 emission per wavelength or resource assigned. This figure shows about 15% emission reduction per lambda for EASB using A-EASB. This shows that the adaptive mechanism reduced the emission by re-optimizing the emission of established tunnels. As expected, EE has also emission reduction around 30% per lambda. Figure 4 shows the SLA satisfaction rate of the established tunnels. Since EASB and A-EASB are aware of the route availabilities, they always assign (if available) a tunnel with lowest hybrid cost to a connection request that meets the requested availability of the connection request. Figure 4 shows that adaptive approach does not change the satisfaction rate of EASB but reduces the SLA satisfaction of EE by 1%, which is initially 12% less than A-EASB. This is because the new tunnel replacing the older tunnel might not meet the availability or SLA requirements of the connection request. Figure 5 shows results of simulation for average route length analysis. This figure shows the same average route length or lambda numbers for connection request in A-EASB and 10% reduction for EE; however A-EASB is about 30% more lambda efficient and assigns shorter tunnels to connection requests compared to A-EE. Figure 6 shows the average route length using different values for balancing factor alpha and Figure 7 graphs the average value of emission per wavelength assigned for different values of balancing factor alpha. These figures confirm αvalue of 0.35 to be used with equation 3 to calculate the hybrid cost for A-EASB. In these graphs A-EASB with α of 0.35 produces 25% less emission per lambda at only 11% increase in average lambda assigned per connection compared to α value of .1.

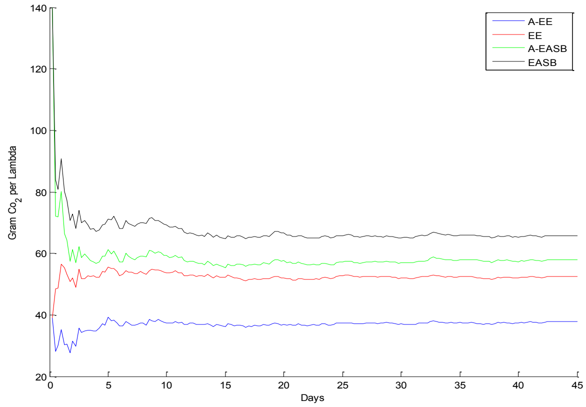

Figure 3 Amount of Co2 emission per wavelength per connection

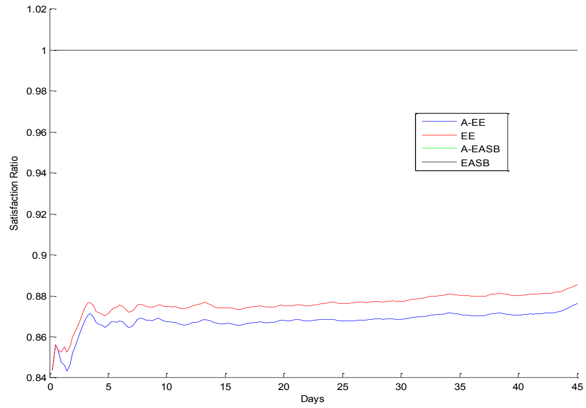

Figure 4 SLA satisfaction rate

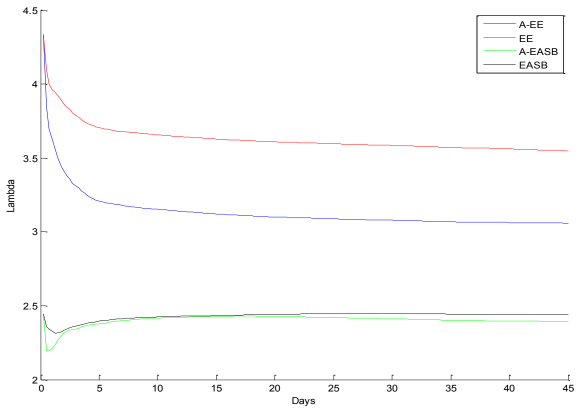

Figure 5 Average lambda per

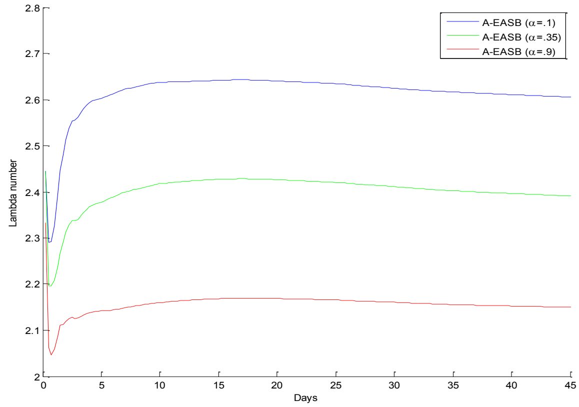

Figure 6 Average lambda per connection for different α values

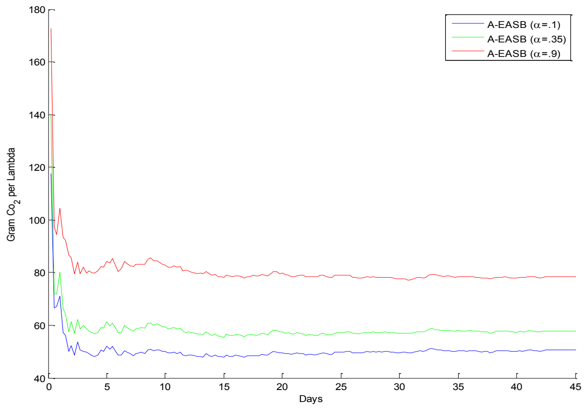

Figure 7 Emission per lambda for different α values

Figure 8 to 12 belong to the second part of simulation with 6 to 24 hour time interval between emission topology changes. In these graphs name of each mechanism is followed by a number such as 6, 12 or 24 that describes the power change interval value. For example A-EASB-6 shows the results of analysis for A-EASB when power change interval is 6 hours. Figure 8 shows the total number of assigned lambdas per 6, 12 and 24 hours. This figure shows almost the same average number of total number of lambdas assigned every 6, 12 and 24 hours for EASB, as seen before in Figure 5. Figure 9 shows results of average emission per lambda for 6 to 24 hour analysis. This figure shows that rerouting decreases the amount of emission per lambda by 10 to 15% in all scenarios of 6, 12 and 24 hours power or emission topology change interval. The value of emission is higher with 6 hours power change interval as 6 hours is less than average duration of tunnels and more tunnels can stay in more inefficient state. Figure 10 for SLA satisfaction for 6 to 24 hours shows that rerouting does not decrease the SLA satisfaction of the EASB as EASB and A-EASB have 100% SLA satisfaction versus average of 87% SLA satisfaction for EE and A-EE. Figure 11 shows the ratio of total emission produced every 6, 12 and 24 hours over corresponding total lambdas assigned. This graph shows that rerouting could successfully reduce the emission of EASB by about 15% and emission of EE by close to 30% in all scenarios. This figure also shows that rerouting is more effective at 6 hours power change interval. Figure 12 combines the information showing the difference of 30% in total number of assigned lambdas per 6, 12 and 24 hours. This shows that A-EASB is more resource efficient than A-EE.

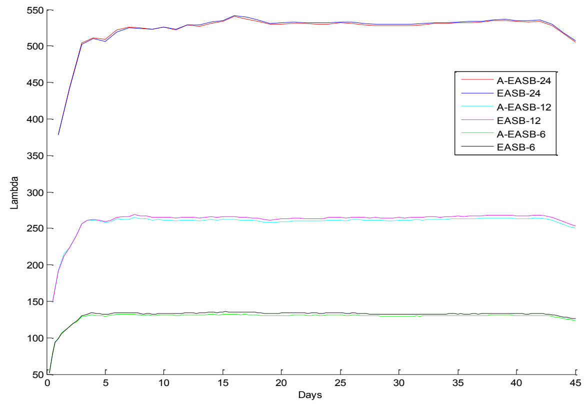

Figure 8 Total number of assigned lambdas in 6, 12 and 24 hours

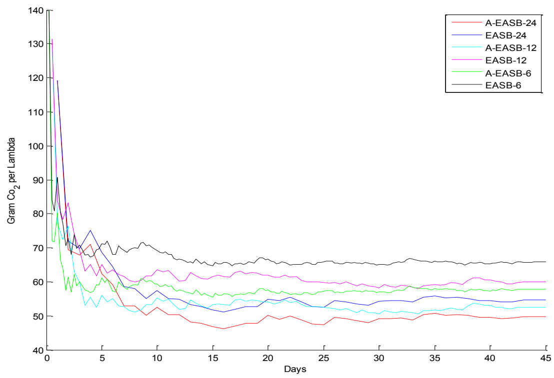

Figure 9 Emission per lambda

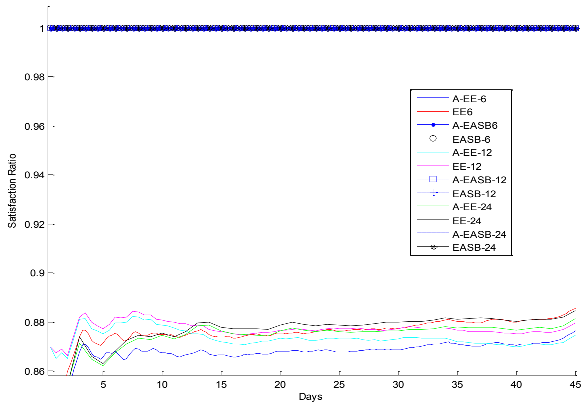

Figure 10 SLA satisfaction

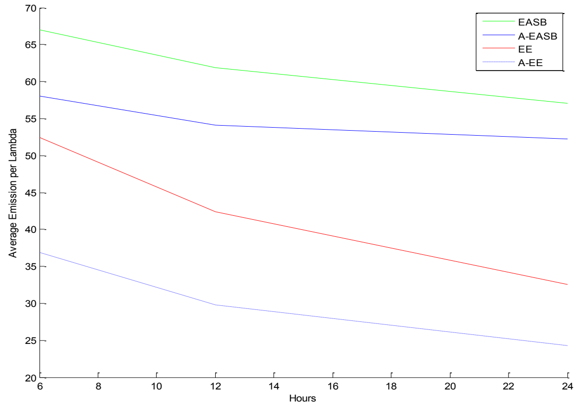

Figure 11 Average emission per lambda

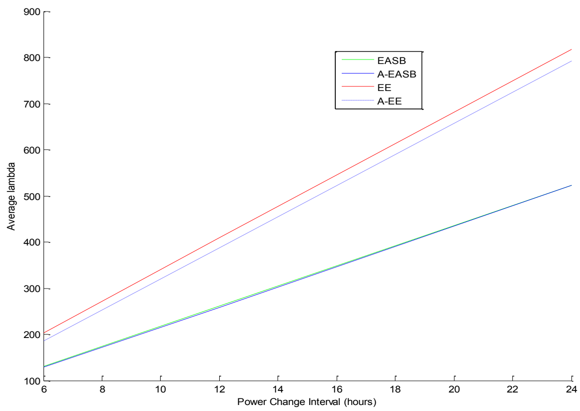

Figure 12 Total number of assigned lambdas

5. Conclusion

This paper was an extension of previous work, that introduced Hybrid Energy-aware and SLA based routing mechanism over optical network introduced. Adaptive SLA-based routing approached lowered the Co_2 emission rate while it provided the most available routes between a (*S,D*) pair of source and destination. The mechanism proposed in this paper rerouted established optical paths using an adaptive green routing algorithm after the nodes in the network were informed of changes on the emission factors of the links. As a result of employing the new energy-aware routing algorithm together with the novel path cost function, paths with the minimum Co_2 emission and less assigned network resources were selected. The algorithm presented in this paper kept Co_2 emission at the lowest level with maintaining an adaptive re-routing mechanism over the duration of connections while service level agreement requirements were still met.

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