Leveraging MPLS Fast ReRoute Paths for Distributed Green Traffic Engineering

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***Abstract*—This paper introduces a new scheme called Green MPLS Fast ReRoute (GMFRR) for enabling energy aware traffic engineering. The scheme intelligently exploits backup label switched paths, originally used for failure protection, in order to achieve power saving during the normal failure-free operation period. GMFRR works in an online and distributed fashion where each router periodically monitors its local traffic condition and cooperatively determines how to efficiently reroute traffic onto the backup paths in order to exploit opportunities for power saving through link sleeping in the primary paths. According to our performance evaluations based on the academic network GÉANT and its traffic matrices, GMFRR is able to achieve significant power saving gains, which are within 15% of the theoretical upper bound.**

***Index Terms*—Green networks, MPLS Fast ReRoute, energy efficiency, traffic engineering**

I. Introduction

Network operators are keen to find new Energy-aware Traffic Engineering (ETE) schemes to green their backbone networks for both financial and environmental reasons [1]–[3], [6]. In MPLS networks, Fast ReRoute (FRR) label switched paths are often installed to provide seamless recovery upon the failure of the links they protect. This paper introduces a new online and fully-distributed ETE scheme called Green MPLS Fast ReRoute (GMFRR) which exploits the path diversity enabled by these pre-existing and rarely-used [5] backup paths for power saving during normal network operation. The idea is to divert traffic from protected links in primary paths to their respective backup path so that these links can go to sleep and save power. The re-use of pre-existing backup paths reduces the complexity and overhead required for establishing and maintaining dedicated paths for the sole purpose of either power saving or link failure protection.

II. Problem Formulation

A logical link between router pairs in a network is usually made up of multiple bundled physical links [2]. Based on this, we propose GMFRR operations that can take place periodically at short time intervals. The actual online optimization of power saving within each periodical GMFRR optimization cycle is expressed below where o_e is the number of sleeping physical links, p_e is the power saved by one sleeping physical link, c_e is the overall capacity, f_e is the total traffic demand and α is the maximum fractional utilization of a logical link e in the whole set of logical links E of the network.

$$\text{maximize} \sum_{e=1}^{|E|} (o_e \times p_e) \quad (1)$$

subject to:

$$f_e < \alpha c_e, \quad \forall e \text{ with } \alpha = [0, 1] \quad (2)$$

Eq. (1) represents the main objective function of maximizing the total amount of power saved in a network. Eq. (2) is the constraint which prevents a logical link from being loaded above the threshold, α, due to the operation of GMFRR. In addition to (2), GMFRR needs to ensure that all traffic demands can be supported by the reduced network topology. Moreover, GMFRR does not use backup paths, determined by MPLS FRR for failure protections, if their path delay does not satisfy a defined delay requirement.

The optimization problem expressed above has been proven to be NP-hard in [3]. In this case, a computationally-efficient heuristic called Green MPLS Fast ReRoute (GMFRR) is introduced, which can be applied in an online and distributed fashion without major modifications to existing network protocols.

III. Overview of Green MPLS Fast ReRoute

Table I shows the top-level pseudo code of GMFRR where at the start of each optimization cycle, each router in the network collects the load utilization of all logical links in the network and updates its own list of links. The lists are then sorted in descending order according to utilization because this ordering allows highly-utilized links to have a higher chance to have part of their traffic rerouted so that their utilization drops and satisfies the constraint (2). The resulting list in each router is identical to each other since the same link utilization information and way of sorting are used to create the lists. Each router then traverses its own list and selects links which can be offloaded at the same time without interference with each other. Interference will arise if selected links (in the primary path) share the same link(s) in their respective backup path and are used at the same time for traffic rerouting. Since the backup paths are pre-installed before the online operation of GMFRR, the interference relationships can be pre-calculated and distributed to all routers only once before GMFRR starts. The use of concurrent traffic rerouting of multiple selected links at the same time allows GMFRR to

TABLE I
ALGORITHM FOR ONE GMFRR CYCLE

```
while (any link e in E has not been selected for offloading) then
    each router v in V do (where V is set of all routers in network)
        Broadcast_&_Collect_All_Links_Utilization
        Sort_Links_in_Descending_Order_According_to_Utilization
        Select_Non-Conflicting_Links_for_Traffic_Rerouting
        Offload_Selected_Links
        Broadcast_&_Collect_All_Links_Utilization
    end each
end while
```

run faster than it would if traffic on only one link can be rerouted at the same time without interference.

If a router find itself to be the head node of a selected link, it can attempt to reroute part of the traffic of the link to its backup path in order to save power by increasing its o_e but without decreasing the o_e of the links in the backup path. After the traffic reroute process, all routers broadcast the new link utilization and previously-unselected links are selected to have part of their traffic rerouted. After all links have been selected in the current optimization cycle, GMFRR terminates for this cycle and will be executed again at the next time interval. In subsequent optimization cycles, it is also possible for routers to restore previously diverted traffic from the backup paths to their respective protected link if this will lead to better power savings and/or lower utilization of some backup paths which have become over-utilized due to changes in the traffic demands and previous GMFRR traffic rerouting.

IV. PERFORMANCE EVALUATION

GMFRR was evaluated based on the academic network topology, GÉANT and it traffic matrices across one week [4].

A. Power Saving Gains

The power saved under GMFRR is compared with a Theoretical Upper Bound (TUB) scheme which is a Mixed Integer Linear (MIL) representation of the problem formulated in §II without the restriction of using only the predefined primary and backup paths to route traffic demands. The MIL problem was solved optimally with the help of IBM CPLEX. TUB uses multiple paths between each Source-Destination pair of the network to route traffic demands compared to a single path for GMFRR and therefore, GMFRR does not suffer from packet re-ordering. The power savings gap between TUB and GMFRR was found to be small with a maximum, mininum and average value of 14.8%, 10.4% and 11.7% respectively when a value of $\alpha = 0.7$ (i.e. a Maximum Link Utilization constraint of 70%) was used for GMFRR. This shows the efficiency of GMFRR where only pre-existing backup paths are necessary to achieve close to optimal power savings.

B. Maximum Link Utilization (MLU)

The dynamicity of the MLU resulting from the Original and GMFRR operations across the testing period is shown in Fig. 1. It can be observed that GMFRR can reduce the original peak MLU of 90.9% to 70% showing that GMFRR is successful in

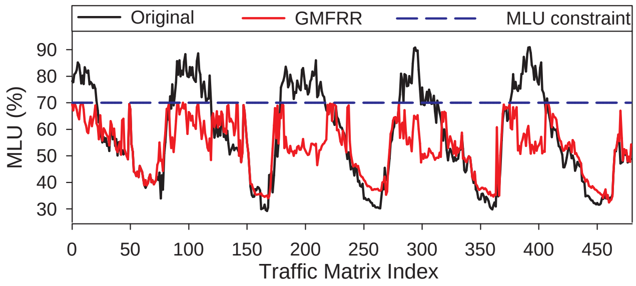

Fig. 1. Variation of MLU for Original and GMFRR.

enforcing the constraint (2) and not causing any logical link to become overloaded as a result of its power saving operations.

C. End-to-end Maximum Packet Delay (MPD)

The increase in end-to-end MPD in GÉANT due to the operation of GMFRR is very small with the increase in maximum and average MPD being 1.08% and 6.94% respectively compared to the original values. There was no change in minimum MPD. This shows that GMFRR does not adversely affect this important Quality of Service requirement.

V. CONCLUSIONS

In this paper, a new online and distributed ETE scheme called Green MPLS Fast ReRoute (GMFRR) is introduced, which is able to leverage pre-existing and rarely-used [5] backup paths for power savings. Evaluation results on the academic network GÉANT and its traffic matrices [4] show that GMFRR can achieve significant power savings, which are always within 15% of the TUB, while also decreasing the peak MLU. This indicates the excellent efficiency of GMFRR. In our future work, we will consider how link failure recovery and power savings operations can both make use of the backup paths at the same time without any conflict.

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REFERENCES

[1] A. Bianzino, C. Chaudet, D. Rossi, and J. Rougier, "A survey of green networking research," *IEEE Commun. Surveys Tutorials*, no. 99, pp. 1–18, 2010.
[2] W. Fisher, M. Suchara, and J. Rexford, "Greening backbone networks: reducing energy consumption by shutting off cables in bundled links," in *Proc. 2010 ACM SIGCOMM Workshop on Green Networking*, pp. 29–34.
[3] M. Zhang, C. Yi, B. Liu, and B. Zhang, "GreenTE: power-aware traffic engineering," in *Proc. 2010 IEEE International Conference on Network Protocols*, pp. 21–30
[4] "The TOTEM Traffic Engineering Toolbox." Available: http://totem.run.montefiore.ulg.ac.be
[5] G. Iannaccone, C. Chuah, R. Mortier, S. Bhattacharyya, and C. Diot, "Analysis of link failures in an IP backbone," in *Proc. of the 2nd ACM SIGCOMM Workshop on Internet measurment*, pp. 237242.
[6] M. Charalambides, D. Tuncer, L. Mamatas, and G. Pavlou, "Energy-Aware Adaptive Network Resource Management," in *Proc. 2013 of the IFIP/IEEE Integrated Management Symposium*