Policy-driven Traffic Management in Energy-aware ISP Networks

Viva Presentation

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Content

Introduction

Motivation

- **In 2011, EU telecom operators consumed 21.4TWh [1] and US operators consumed 5-24TWh [2]**
- **Power consumption expected to continue to rise due to the increasing popularity of bandwidth-hungry applications such as cloud computing and video-on-demand**
- **40% of the total energy consumption of networks will come from backbone networks by 2017 compared to only 10% in 2009 [3]**

[1] R. Bolla et al, “The potential impact of green technologies in next-generation wireline networks: Is there room for energy saving optimization?” *IEEE Commun. Mag.*, vol. 49, no. 8, pp. 80–86, August 2011.

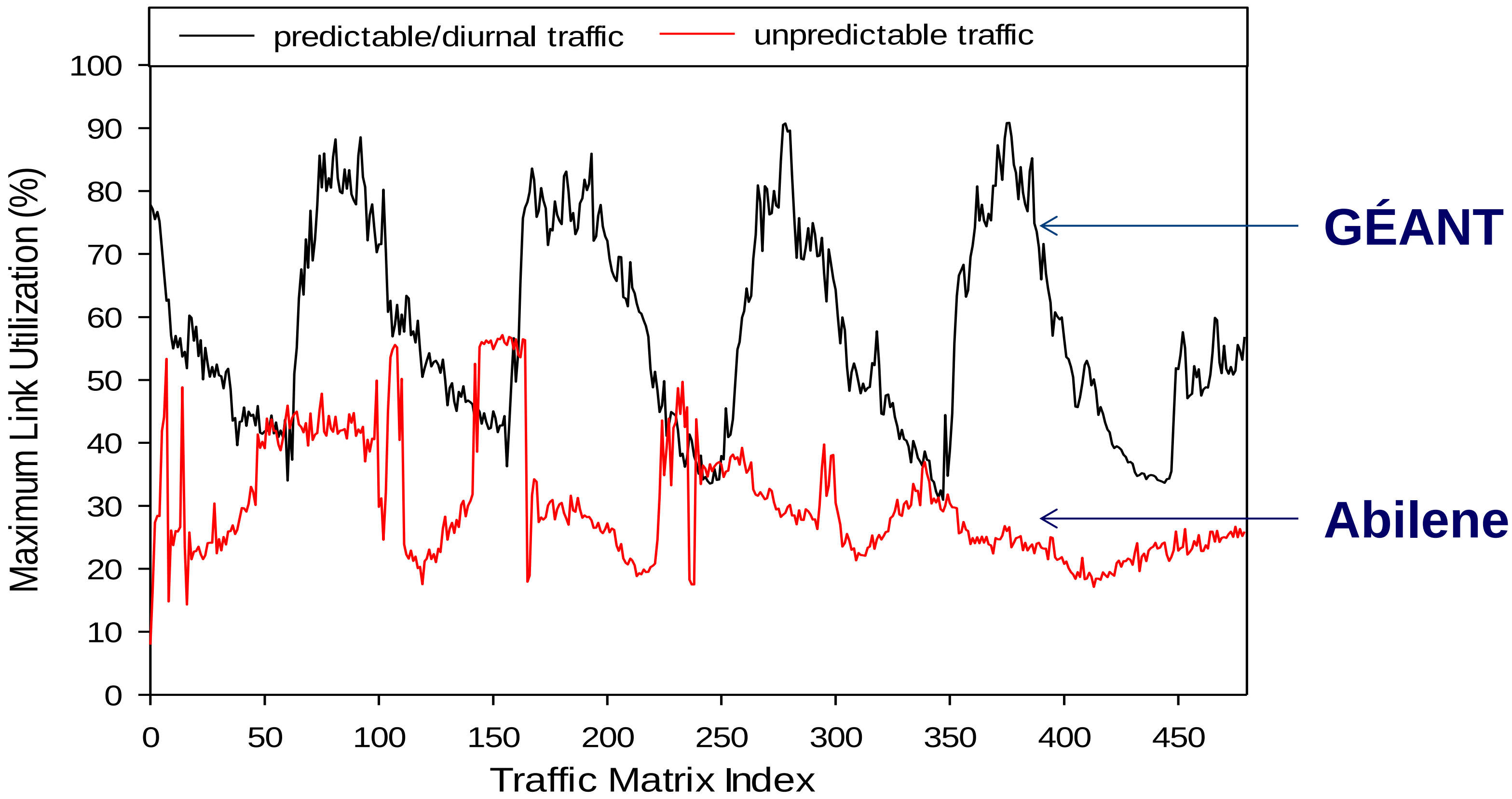
[2] S. Nedevschi et al, “Reducing network energy consumption via sleeping and rate-adaptation,” in *Proc. (2008)* NSDI’08. Berkeley, CA, USA: USENIX Association, 2008, pp. 323–336.

[3] C. Lange, “Energy-related aspects in backbone networks,” in Proc. 2009 of 35th European Conference on Optical Communication, (Wien, AU), September 2009.

Objectives (1/2)

- Objective is to improve the energy efficiency of networks by achieving a better match between traffic demands and network capacity
- Better match can be achieved by either putting network devices to sleep or reduce the operating rate of network devices
- Backbone networks can experience either regular/predicable or unpredictable variation in the traffic pattern

Objectives (2/2)



Predictable and unpredictable traffic patterns

State of the Art:
Energy-aware Traffic Engineering (ETE)

Classification of ETE Schemes

ETE schemes can be classified according to following criteria:

1) **Age of traffic matrices used: Offline or Online**

2) **Routing technology used: IP or MPLS**

3) **Energy saving technology used: Link Sleeping* or Link Rate Adaptation**

4) **Deployment type: Centralized or Distributed**

***All schemes in this thesis assume *only* link sleeping because:**

- **Current network equipment support only this mode, i.e. amount of traffic on a link does *not* significantly affect its power consumption**
- **Routers cannot be put to sleep since all routers are source and destination nodes for traffic**

Gaps in literature

- Existing ETE schemes advocate to reconfigure the IP network frequently to achieve maximum energy-efficiency but this may lead to network instabilities, e.g. forwarding loops

- ETE schemes can make the network more susceptible to packet loss during single link failures because of the reduction in spare capacity

- Network operators want to preserve their ability to do load-balancing and maintain low maximum packet delay while improving the energy-efficiency of their network

- Ease of implementation

Constraints of ETE schemes

Other network objectives that must be preserved when doing ETE are :

1) **All traffic demands must be satisfied (flow conservation)**

2) **Network must not be overloaded (low Maximum Link Utilization (MLU))**

3) **Network connectivity must be conserved, if network device sleeping is done for energy savings**

4) **Reduced and energy-efficient network topology must be robust to single link failures, both from a connectivity and capacity point of view**

5) **Maximum packet delay must be kept under the predetermined threshold set by the ISP**

Overview of 3 ETE schemes

Overview of the 3 ETE schemes

Time-driven Link Sleeping (TLS) Scheme

- **Optimizes the *number of sleeping links* X *period* of operation**
- **Operates in a time-driven and offline fashion**
- **Suits networks with *diurnal* traffic pattern**

Green Load-balancing Algorithm (GLA) Scheme

- **Optimizes the IGP *link weights* improve both the energy-efficiency and load-balancing**
- **Operates on top of *existing* ETE schemes, e.g. TLS**
- **Operates in an offline fashion**

Green Backup Paths (GBP) Scheme

- **Exploits existing backup paths to improve both the energy-efficiency and load-balancing**
- **Does *not* affect the ability of the backup paths to prevent packet loss during single link failures**
- **Operates in a *distributed* and *online* fashion**
- **Suits networks with *unpredictable* traffic demands, e.g. Abilene**

Time-driven Link Sleeping (TLS) Scheme

Objectives

- **Use only one reduced energy-efficient network topology to avoid network instabilities associated with frequent network reconfigurations**

- **Maximize the energy-efficiency by calculating a reduced network topology and its period of operation. Thus, an *optimized* trade-off between the number of sleeping links and period of operation needs to be performed**

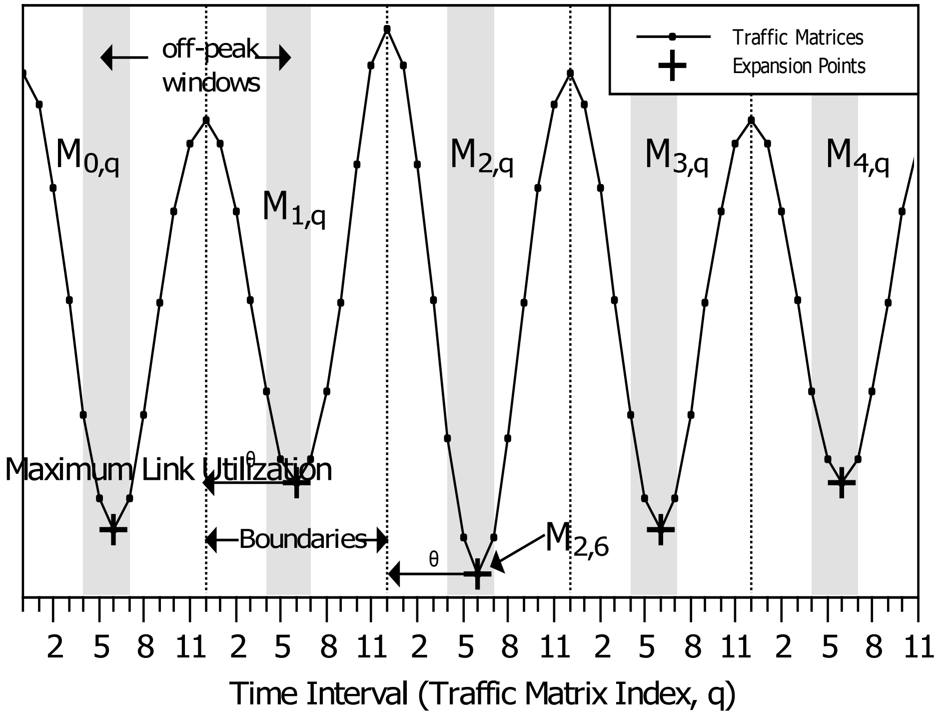
- **Ensure that the reduced topology keeps the network fully-connected**

- **Ensure that the maximum link utilization is below a predetermined threshold (set by the network operator) for the whole period of operation of the reduced network topology**

- **Ease implementation by making the starting and end time of the off-peak operation of the reduced network topology the same for every work day**

TLS Mechanism

- **Stage 1: Computation of the synthetic TM and the starting point for off-peak window size expansion**
- **Stage 2: Greedy link removal according to least-flow**
- **Stage 3: Determination of off-peak window size and the final reduced topology**



Illustrative MLU graph to show how TLS operates

Simulation Results (1/2)

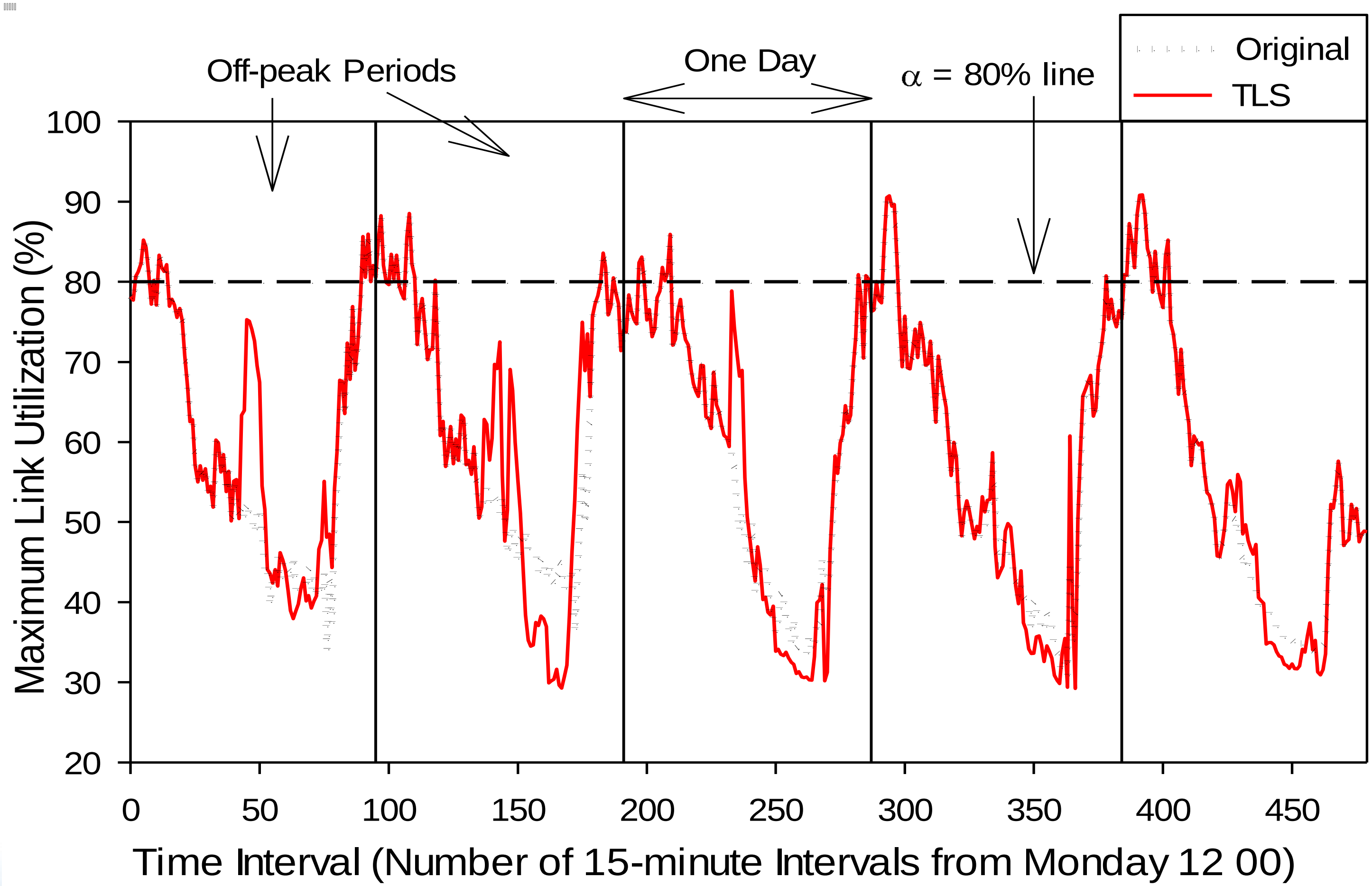
Simulated on GÉANT, an European academic network with:

- **23 Points-of-Presence**
- **74 unidirectional links of varying capacity**

MLU constraint (%)	No. of sleeping links	Total off-peak time per day (minutes)	Energy-efficiency (%)
90	33	915	28.3
80	33	600	18.6
70	33	435	13.5
60	33	330	10.2

Energy-savings results under different MLU constraints and scaling factors

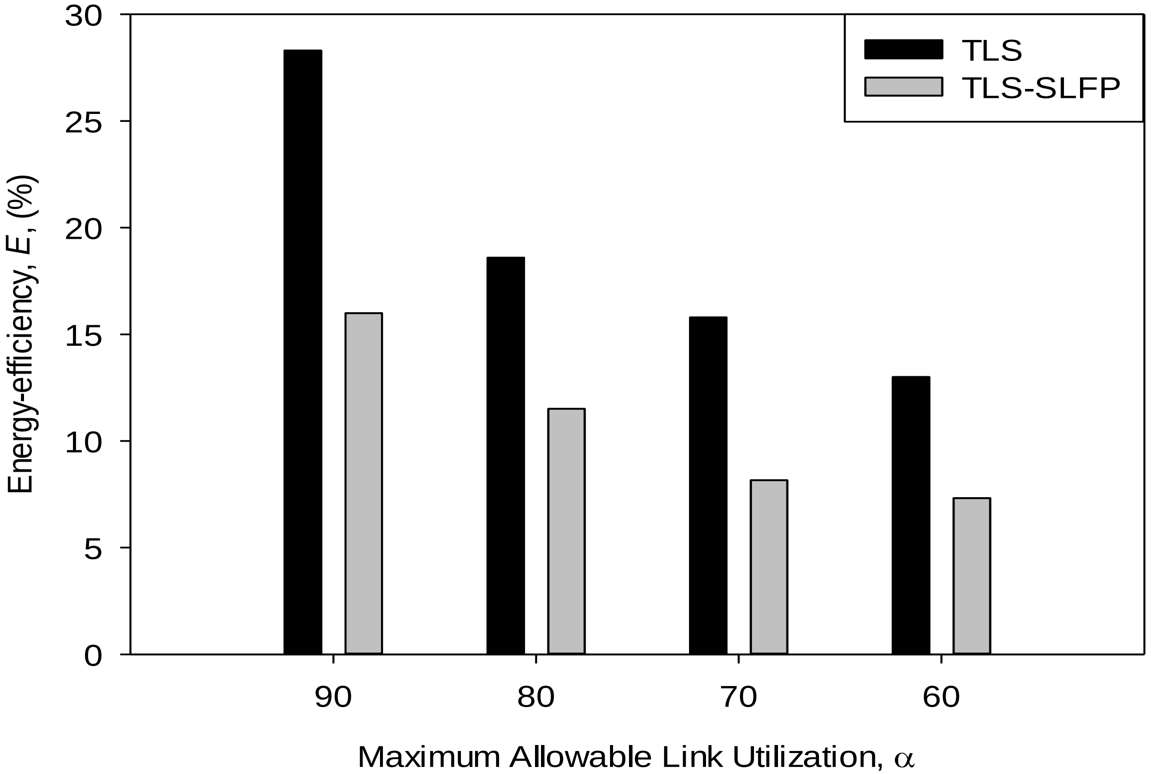
Simulation Results (2/2)



Variation of MLU with reduced topology of α=80

TLS-SLFP

TLS extended into TLS with Single Link Failure Protection (TLS-SLFP) to make the reduced topology robust to single link failures by ensuring the network is neither *disconnected* nor *overloaded* during these network scenarios

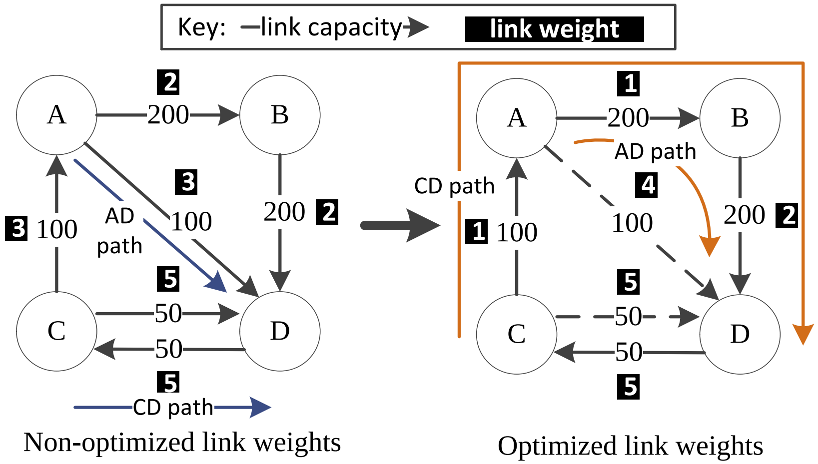


Comparison of the energy-efficiency of TLS and TLS-SLFP

Green Load-balancing Algorithm (GLA) Scheme

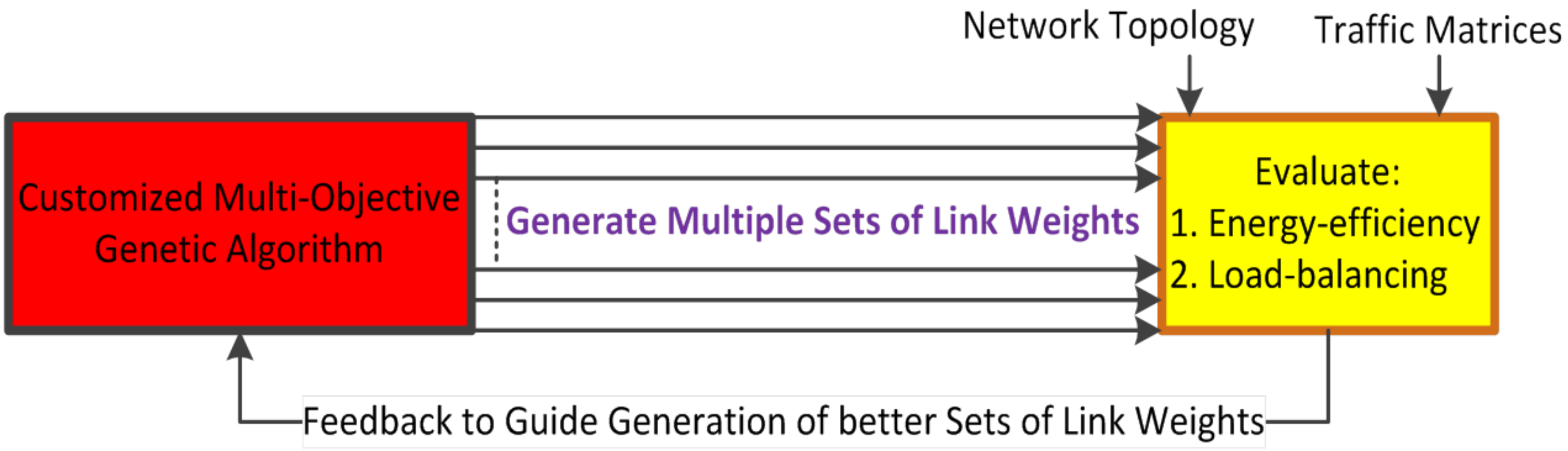
Objectives

- **Most existing ETE schemes do not re-optimize the IGP link weights after putting links to sleep.**
- **The original links weights are no longer optimized after links are put to sleep**
- **Optimize the energy-efficiency and load-balancing of existing ETE schemes by optimizing the IGP link weights**
- **Needs to respect flow conservation and maximum link utilization constraints**



Example network topology to illustrate optimization of link weights

GLA Mechanism



Basic overview of the GLA mechanism

- **3 different ETE schemes were chosen to be improved by GLA: Least-flow, Most-Power and TLS**
- **2 custom mutation and crossover operators were designed to improve the search in the solution space**

Simulation Results

Performance comparison of three sets of link weights for LF and MP ETE scheme

	IGP-WO		GLA	
	ΔU (%)	ΔE (%)	ΔU (%)	ΔE (%)
LF	-27.1	-1.17	-30.7	16.1
MP	-27.1	-14.3	-31.0	1.08

Performance of GLA for the three set of link weights

α	Default		IGP-WO		GLA	
	U(%)	E (%)	U (%)	E (%)	U (%)	E (%)
69.7	90.9	13.5	70.1	18.7	69.7	42.7
65.0	90.9	11.1	70.1	16.9	69.5	39.3
60.0	90.9	10.2	70.1	12.8	69.6	34.7

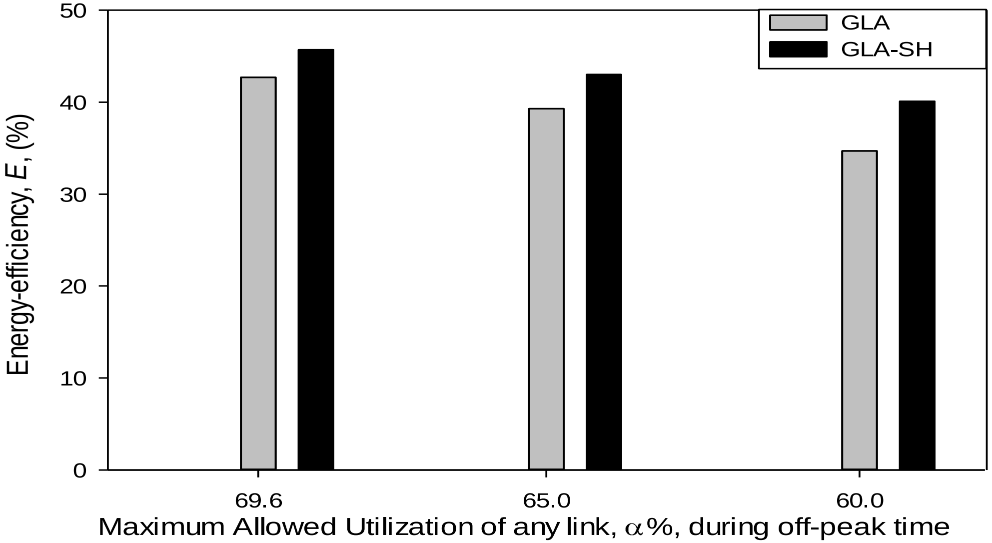
U : Maximum Link Utilization, lower is better

E : Energy-efficiency, higher is better

Δ : Change

Other GLA Features

- **GLA can be customized for a specific ETE scheme to improve further the performance. E.g. A Solution-enhancement Heuristic was added to GLA, GLA-SH, to improve TLS further**



Comparison of energy-efficiency between GLA and GLA-SH

- **It was observed that the original ETE schemes can significantly worsen the maximum packet delay when they put links to sleep in the network. Therefore, the original ETE were modified to limit the increase in the maximum packet delay**

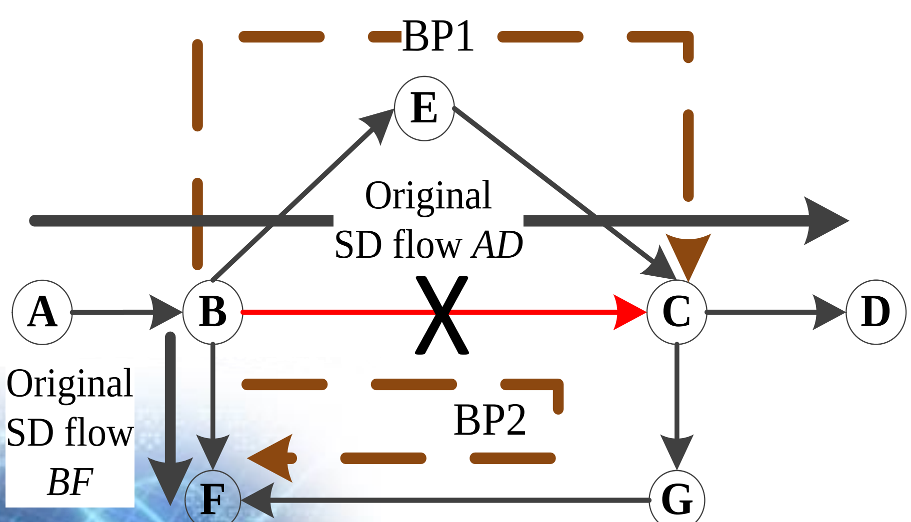
Green Backup Paths (GBP) Scheme

Objectives

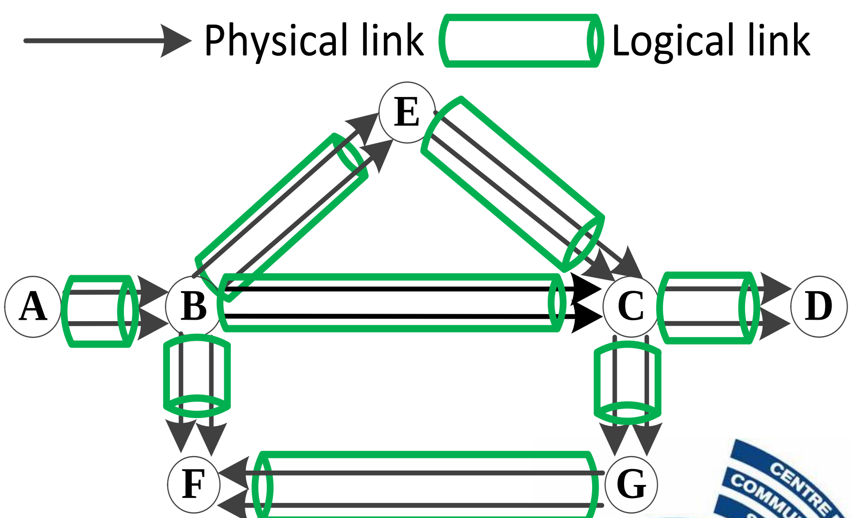
- Re-use backup paths that are installed to protect against single link failures in MPLS backbone networks to improve energy-efficiency and load-balancing

- Design an online ETE scheme which is fast/responsive by operating in a distributed and concurrent manner

- Prioritize the backup paths for failure recovery



Logical view of basic network topology to illustrate how links are protected in MPLS backbone networks



Physical view of the network where a bundle of physical links connects any two routers

GBP Mechanism

- GBP is made of two main components: an offline and online one

- Offline Component is made up of:
  - Identification of Eligible Backup Path
  - Generation of Interference-Risk Links Lists

- Online Component:

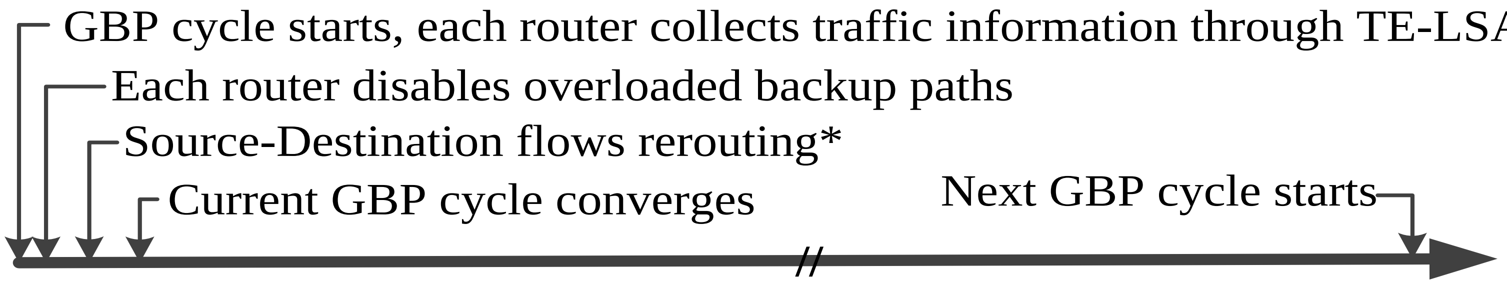
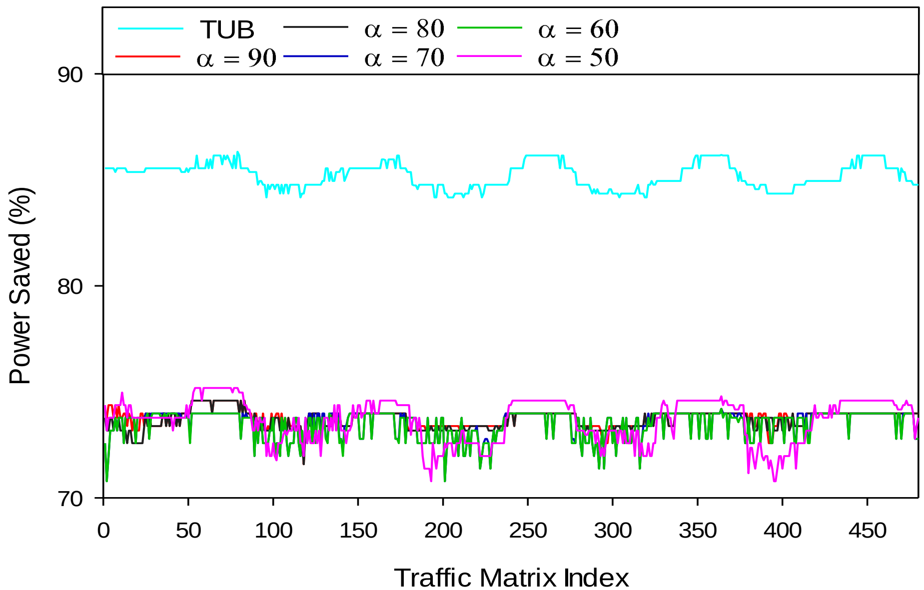


Figure 2: Timeline for the online operation of GBP.

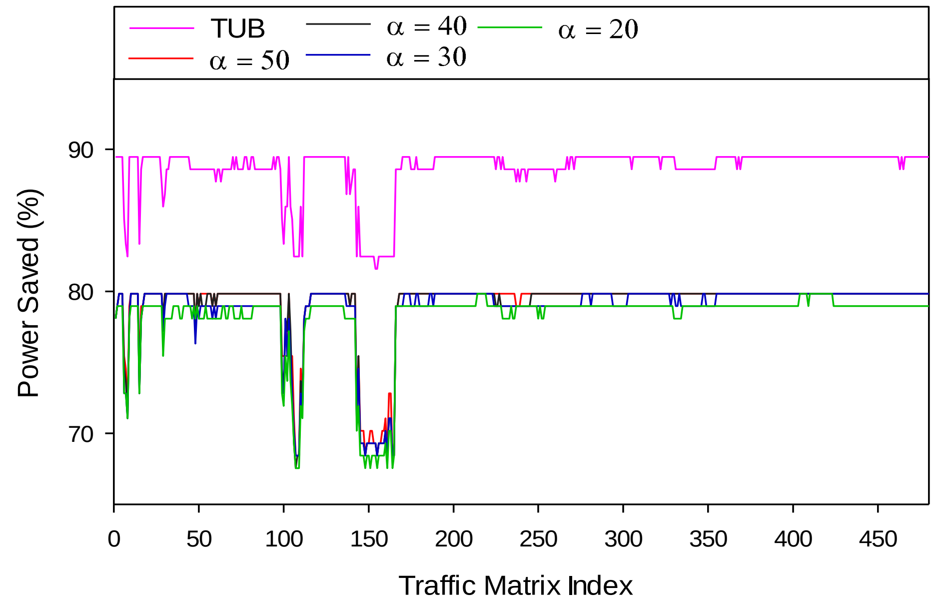
***In the flows rerouting stage:**

- Overloaded links are selected first for part of their traffic to be rerouted
- Links which are conflict-free are selected for offloading

Simulation Results



Power saved for the GÉANT topology



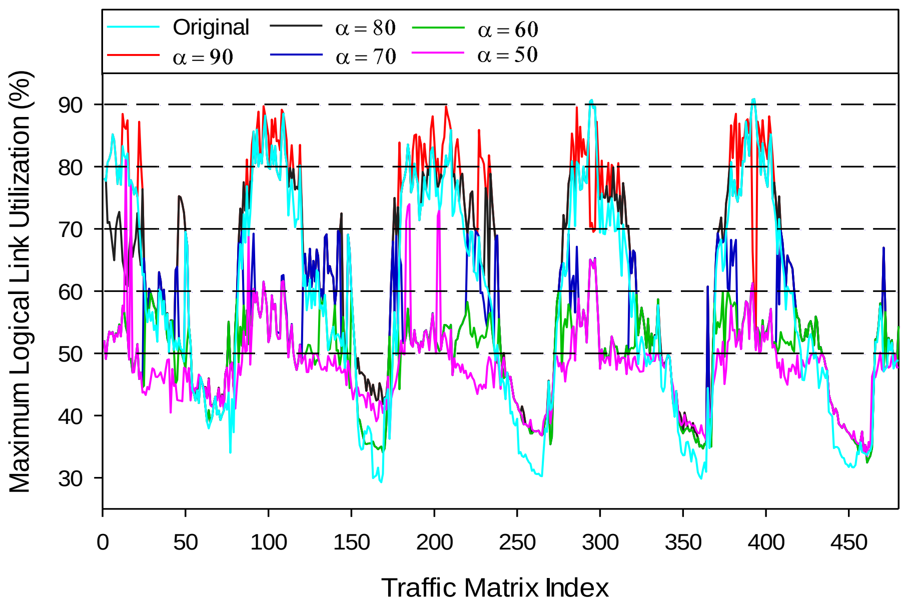
Power saved for the Abilene topology

GÉANT		Abilene	
α	***E* (%)**	**α**	***E* (%)**
90	86.6	50	89.2
80	86.5	40	89.1
70	86.2	30	88.8
60	86.2	20	88.1
50	86.4		

Energy-efficiency, E, for the GÉANT and Abilene topology

Simulation Results

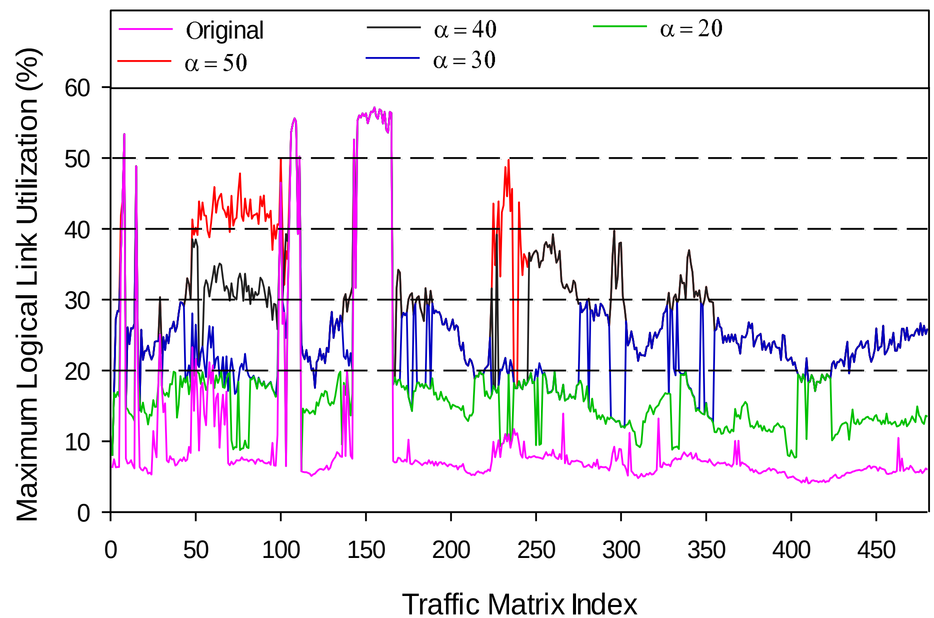
GÉANT



Variation of MLLU for Original and GBP for GÉANT topology

- **GBP was able to reduce the peak maximum link utilization for α = 90, 80 and 70 but not for 60 and 50 because of lack of spare capacity on alternate paths**

Abilene



Variation of MLLU for Original and GBP for Abilene topology

- **GBP was not able to reduce the peak maximum link utilization because of lack of spare capacity on alternate paths**

Presentation Conclusions
&
Future Work

Conclusions (1/2)

- The 3 ETE schemes designed show that it is possible to improve the energy-efficiency of a diverse range of backbone networks
- TLS has shown that it is possible to design an offline ETE scheme which can achieve significant energy savings with only 2 network topologies, thus avoiding network instabilities linked with frequent reconfigurations
- The extension to TLS, TLS-SLFP, shows that an energy-efficient reduced network topology can be robust to single link failures
- GLA shows that it is possible to improve both the energy-efficiency and load-balancing of numerous existing ETE schemes by optimizing the IGP link weights

Conclusions (2/2)

- **ETE schemes must explicitly take into account maximum packet delays because they may increase it significantly during their operation**

- **GBP has shown that it is possible to re-use existing backup paths for energy savings while not preventing the backup paths from performing their primary function, i.e. avoid packet loss during single link failures**

- **A light-weight conflict-avoidance mechanism can be designed to allow the different decision entities of an online ETE scheme to concurrently make conflict-free decisions.**

Future Work

- **Implement the proposed ETE schemes in a test bed**
- **Develop ETE schemes that can take advantage of different energy profiles**
- **Adopt a holistic view of energy consumption in the whole network, i.e. backbone, aggregation and edge segments**
- **Make ETE schemes work in collaboration with Content Delivery Networks or Information Centric Networks**

Publications (1/2)

Journals:

1. F. Francois, N. Wang, K. Moessner, S. Georgoulas and R. Schmidt, "Leveraging MPLS Backup Paths for Distributed Energy-aware Traffic Engineering," IEEE Transactions on Network and Service Management (TNSM) (under review).

2. F. Francois, N. Wang, K. Moessner, S. Georgoulas and K. Xu, "On IGP Link Weight Optimization towards joint Energy-efficiency and Load-balancing," Elsevier Computer Communications (under review).

3. F. Francois, N. Wang, K. Moessner and S. Georgoulas, "Optimizing Link Sleeping Reconfigurations in ISP Networks with Off-Peak Time Failure Protection," IEEE Transactions on Network and Service Management (TNSM), vol.10, no.2, pp.176-188, June 2013.

Publications (2/2)

Conferences:

1. F. Francois, N. Wang, K. Moessner, and S. Georgoulas, "Leveraging MPLS Fast ReRoute Paths for Distributed Green Traffic Engineering", in Proc. of 2013 IEEE International Workshop on Quality of Service (IWQoS), June 2013 (Short Paper and Poster Session).

2. F. Francois, N. Wang, K. Moessner, S. Georgoulas, and K. Xu, "Green IGP Link Weights for Energy-Efficiency and Load-balancing in IP Backbone Networks", in Proc. of 2013 of IEEE/IFIP Networking, May 2013.

3. F. Francois, N. Wang, K. Moessner, and S. Georgoulas, "Optimization for time-driven link sleeping reconfigurations in ISP backbone networks", in Proc. of 2012 IEEE/IFIP Network Operations and Management Symposium (NOMS), April 2012, pp.221-228. (Best Student Paper award).

Thank you

Any questions?