Energy-Efficient Resilient Optical Networks: Challenges and Trade-offs

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1. Introduction

- **Motivation:**
  - Resilient networks rely on a number of duplicated resources, which are unused most of the time. This is obviously not the most energy-efficient solution.
- **Shortcomings of previous technologies:**
  - First, energy efficiency has to be traded against QoS.
  - Second, network devices implementing sophisticated energy functionalities are more expensive than the conventional ones.
  - Finally, backup path use the renewable energy sources, which reduce the network carbon footprint but may not reduce the cost.
- **Two factors for energy efficient resilient design:**
  - Core networks are dimensioned assuming peak traffic levels.
  - The type of protection can be differentiated and adapted to the specific traffic type.

2. Research Topics/Open Problems

- 2.1 Long-Term Static Architecture Network Design Choices
- 2.2 Open issues in adaptation to short-term traffic dynamics
- 2.3 Strategies to meet the SLA requirements

2.1 Long-Term Static Architectures - 1

- Network Architecture
  - Current optical network architecture includes WDM (wavelength-division multiplexing) and EON (elastic optical networks).
  - WDM architectures considers single line rate (SLR) and mixed line rate (MLR).
  - EON allows flexible-bandwidth transmission and adaptive modulation.
  - The choice of a particular architecture, together with the adopted resilient scheme, will have clear effects on energy consumption.
- Embodied Energy
  - The energy consumed during the whole lifetime of an installed device needs to be considered in the design of optical networks.
  - From an energy perspective, it is especially important to minimize the number of redundant fiber cables in resilient networks.

2.1 Long-Term Static Architectures - 2

Resilience at Different Layers

- There are serval layers of optical network, which lead the resilient schemes in different layer.
- Multiple recovery schemes have been explored; however, it is not yet clear how these strategies perform from an energy efficiency view.
- The best option is to provide protection at the bottom layer; however, the drawback is poorer handling of higher layer failures.

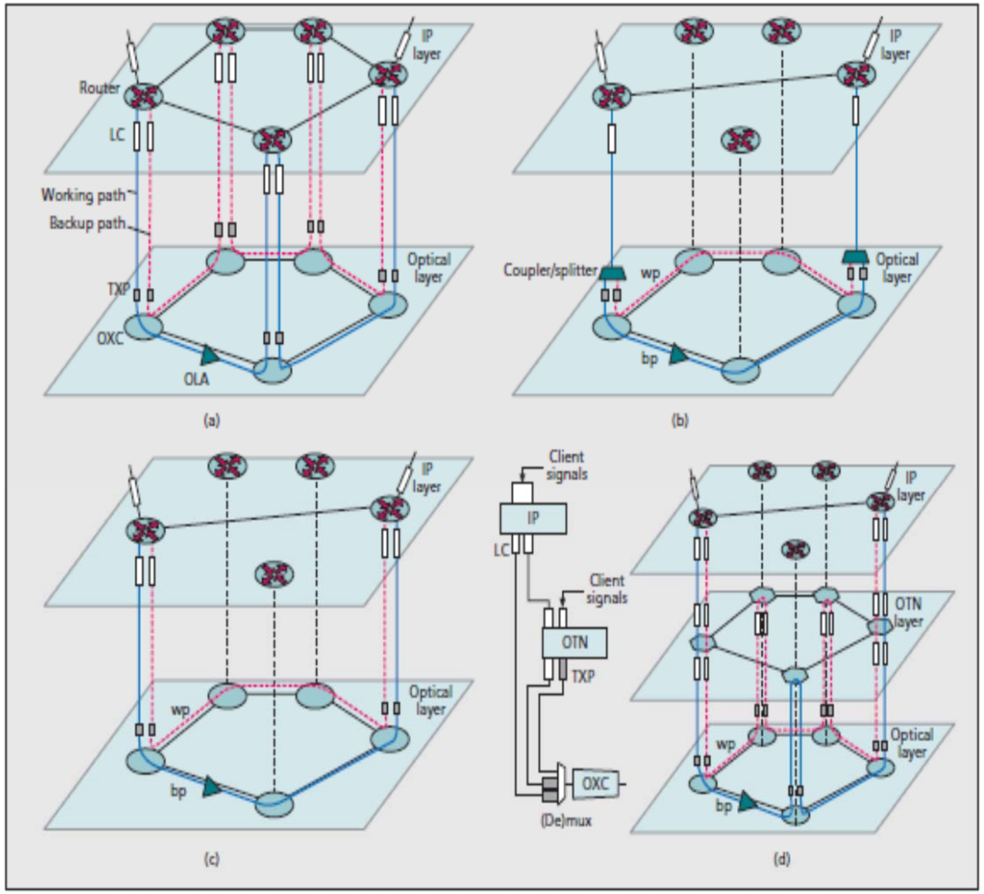

Figure 1. a) 1+1 protection at the IP layer; b) 1+1 protection at the optical layer; c) employing optical bypass at the IP layer; d) grooming at the OTN layer. LC: line card, TXP: transponder, OXC: optical cross connect, OLA: optical line amplifier, wp: working path, bp: backup path.

2.2 Short-Term Traffic Dynamics - 1

- **Novel Equipment Features**
  - Traditional energy consumption saving devices/equipment, such as sleep modes, dynamic configuration of modulation format, and so on.
  - New problems for equipment: it should use less energy cost to quickly recover failures.
- **Trade-offs in dynamic adaptation to temporal variation of traffic**
  - Traffic is always higher during the day and lower during the night. Putting idle devices into sleep or energy-saving mode.
  - Separate the fibers of backup path, and put the devices on them into sleep mode.

2.2 Short-Term Traffic Dynamics - 2

- **Geographical Traffic Distribution**
  - Geographical traffic distribution in networks covering large area may span several time zones.
  - It is possible to use idle resources from one time zone as protection resources in another time zone, because the traffic of each time zone is different in the same time.
- **Granularity of Traffic Demands**
  - This is relationship of protection and energy consumption.
  - Increasing the number of devices in each path is very helpful to protection, but more devices will bring more energy consumption.
  - Hence, traffic grooming is a very important issue in this area.

2.3 SLA Requirements - 1

- **Physical Impairments**
  - Energy saving technologies can be affected by the physical impairment, as they concentrate most of the traffic on a flew links to put unused devices into sleep mode.
- **Differentiated Quality of Protection**
  - If we use a single protection policy, the traffic will be aggregated, which has the problem like physical impairment. Hence, different schemes should be used to different requests.
- **EON/BVT**
  - EON technologies provide an extra degree of freedom in assignment traffic demands to QoP levels.
  - BVT (bandwidth variable transponder) can adapt the transmission rate to the traffic variations.

2.3 SLA Requirements - 2

- **Network Virtualization**
  - Virtualization of the network components combined with the creation of segregated virtual topologies with different architectures can help support variable QoP levels and thus reduce energy consumption by sharing the resources among different users/virtual networks.
- **Data Preemption**
  - After a disaster occurs, the prior lightpaths can be protected first, and other lightpaths should be released for the important ones.
  - Preemption-based strategies can improve energy efficiency, since powering-on extra resources is not always necessary.

3 Metrics

- **Metrics**
  - Energy efficiency: watts per bit, Joules per bit, watts per bit per second.
  - New metrics should be proposed to balance energy efficiency and resilience.

4 Conclusion

- In this article, three aspects are introduced for network:
  - Long-term traffic predications
  - Short-term traffic dynamics
  - SLA requirements
- New metrics need to be used for energy efficiency resilience evaluation.

Thank you!