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# Resiliency versus energy sustainability in optical inter-datacenter networks

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With cloud computing becoming a forefront of business models, saving in operational expenses is one of the main challenges and goals of the operators. The expenses for the operators come directly from energy consumption, and indirectly through service downtime i.e. losing customers or paying penalties. This paper considers both energy efficiency and resiliency design under different topological characteristics where datacenters are inter-connected via an elastic optical network backbone. We present a benchmark scheme which aims at minimum outage probability provisioning, and a compromising scheme which aims at resilient provisioning with minimum power consumption. The former is solely concerned with minimizing outages while the latter combines energy awareness while minimizing outages. Through simulations, we show that introducing energy awareness into outage minimized provisioning reduces the power consumption by about 7%. When compared against energy-aware provisioning, the compromising scheme can reduce outage probabilities by 45–97%. The compromising approach even improves upon the other algorithms by introducing shorter path delays. We further investigate the impact of electric price-aware and resilient inter-datacenter network design in the presence of dynamic electricity markets. We show that the electric bills of network operators can be cut up to 50% if Time of Use-awareness is adopted.



## 1. Introduction

Cloud computing is a new and growing field which allows businesses to rapidly access and utilize a distributed pool of computing power which is mainly hosted by multiple datacenters. Optical networks play a crucial role to meet the performance, elasticity and resiliency requirements of future cloud and grid systems [1]. Recently several researchers have aimed to engineer the existing optical networking technologies to fulfill the requirements of large scale cloud systems. These studies tackle various problems including virtualization [2], energy efficiency [3,4], resilience [5,6] and performance [7,8].

In [9], the primary challenges of inter-datacenter optical networks are pointed out as traffic asymmetry in downlink and uplink lines, traffic monitoring and prediction to reconfigure the virtual topology effectively, and network survivability/availability. In the same study, network survivability/availability challenges are classified in two categories as network resilience which denotes recovery from various types of failures, and rapid failure detection, prediction and prevention. As illustrated in Fig. 1b, inter-datacenter networks are consolidated with the telecom network infrastructure where data traffic is pushed from heterogeneous wired networks such as a Wireline Multi-Protocol Label Switching (MPLS) network and Wireline Optical Code Division Multiple Access (O-CDMA) network, or wireless networks such as wireless sensor network or a wireless local area network (WLAN).

Two main ways of reducing costs in inter-datacenter networks are through resiliency and through energy efficiency. To this end, optical inter-datacenter networks need to be designed by considering content replicas in datacenters in order to meet resiliency requirements. Furthermore, location and number of datacenters are other important design parameters that have significant impact on survivability [5,10]. As for the energy efficiency goals, avoiding high energy consumption for the datacenter and network operators will also avoids increased electric bills. It is worthwhile mentioning that energy-efficiency denotes power saving design and planning of the network, and reducing the carbon footprints of the datacenters and the inter-datacenter network with the ultimate goal of reduced electric bills [4].

The challenges in energy efficient design of optical transport networks have been identified in [11], and these problems have

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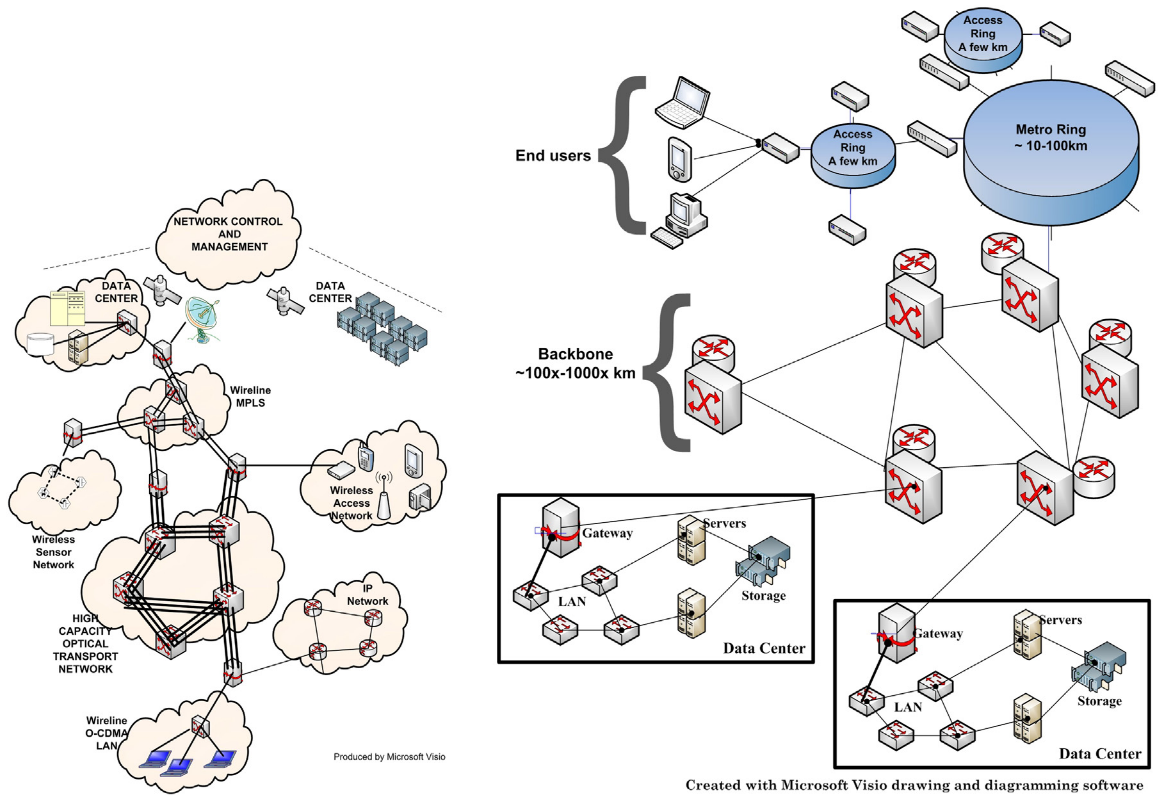


**Fig. 1.** (a) Inter-datacenter network connecting wired/wireless heterogeneous communication media, (b) hierarchical view of the inter-datacenter network interconnections.

been later widely studied in the literature in the context of energy-aware routing [12–14], component and network-based analysis [15,16], traffic grooming [17], and energy-efficient network planning and design [18,4,19,20]. In [19], energy efficient design of inter-datacenter network design and planning problems have been studied for an IP over Wavelength Division Multiplexing (WDM) network with the motivation of IP router ports being the most power hungry components in an optical inter-datacenter network. Therefore, the authors adopt the virtual topology reconfiguration concept in [21], and tailor it to an inter-datacenter environment. It is worthwhile noting that besides energy efficiency network virtualization also enables efficient delivery of services as the topology is reconfigured with respect to the changing traffic profile [22].

In [23], the requirements of a resilient core network architecture have been identified as the design of a robust connection establishment protocol, effective multi-path routing and restoration schemes, and an optimal number of transponders to be deployed at each location in order to cooperate with the protection and restoration policies. Furthermore, fault localization and detection, as well as multi-failure recovery approaches are also of paramount importance in optical core networks [24] as this problem has been tackled particularly for elastic optical networks in [25]. The study in [26] expands to the scope of resilient elastic optical networks to address disaster resilience for cloud and content-centric traffic in elastic optical networks.

Despite the advances in energy efficient and resilient optical design, several studies point out the energy-efficiency versus resiliency trade-off in core networks [27,28]. In order to address this trade-off, the authors in [27] propose resilient virtual infrastructure design under 1:1 protection for lightpaths and virtual servers whereas the study in [29] proposes enabling inter-datacenter workload migration over an elastic optical backbone so that the workload can be hosted in datacenters that consume less power and that meet the availability requirements of the demands. Furthermore, in the proposed study, route selection and spectrum assignment aims at minimum energy consumption over optical links and is also constrained to the availability requirements of the demands.

A cloud data center may consist of 15,000–25,000 servers each of which operate at around 350 W. This leads to an energy consumption of 5.25 MW/h to 8.75 MW/h [30]. By using the information provided by the U.S. energy information administration [31] and Federal Energy Regulatory Commission [32], it can be estimated that electricity cost per hour can be as high as $400/hour in a region like Lenoir, NC and it is at least $150 in regions like Houston,TX depending on the time of the day. While laying additional and backup resources are expected to introduce additional costs, such an investment is worthwhile due to the cost of downtime penalties. A recent report by Ponemon Institute states that an unplanned outage may cost up to $250 for a single data center [33]. Given these values, reducing electricity costs and avoiding unplanned outages in inter-data center networks appear to be of paramount important.

In this paper, we study optical inter-datacenter network resiliency in terms of its theoretical foundations and possible assessment techniques. Furthermore, the design of an inter-datacenter network based around optimal resiliency is thoroughly laid out with reasoning and specific design choices made for the purposes of this paper. To this end, we present a provisioning scheme called Minimum Outage Probability Provisioning in Cloud (MOPIC). Outage probability being the probability an outage will occur on the given system. We initially show the impact of the communication node on the performance of MOPIC, and compare it to a resource minimizing benchmark. Through simulations, we show that MOPIC significantly reduces the outage probability when compared to its resource minimizing counterpart. This improvement is more significant under manycast communciation mode.

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