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Spectrum engineering in flexible grid data center optical networks

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ABSTRACT

Data centers provide a volume of computation and storage resources for cloud-based services, and generate very huge traffic in data center networks. Usually, data centers are connected by ultra-long-haul WDM optical transport networks due to its advantages, such as high bandwidth, low latency, and low energy consumption. However, since the rigid bandwidth and coarse granularity, it shows inefficient spectrum utilization and inflexible accommodation of various types of traffic. Based on OFDM, a novel architecture named flexible grid optical network has been proposed, and becomes a promising technology in data center interconnections. In flexible grid optical networks, the assignment and management of spectrum resources are more flexible, and agile spectrum control and management strategies are needed. In this paper, we introduce the concept of Spectrum Engineering, which could be used to maximize spectral efficiency in flexible grid optical networks. Spectrum Defragmentation, as one of the most important aspect in Spectrum Engineering, is demonstrated by OpenFlow in flexible grid optical networks. Experimental results are reported and verify the feasibility of Spectrum Engineering.

1. Introduction

A data center refers to any large, dedicated cluster of computers that is owned and operated by a single organization. Over the last few years, data centers are crucial to provide large volumes of computing and storage resources for emerging cloud-based internet businesses, such as web search, content distribution and social networking, and are expected to be larger and more powerful not only in their computation performance but also in their bandwidth providing abilities. The resources in data centers are served to customers through an inter-connect network which is referred to as “cloud”, as shown in Fig. 1 [1].

There are two primary types of traffic in such data center networks. One is user traffic, e.g. email, video and webpage, which is typically user initiated and often served by the datacenters through the carrier networks; The other is machine-to-machine traffic, e.g. data mirroring, data protection and database synchronization, which is from one datacenter to another without exiting the datacenter cloud [2]. The traffic is so huge that high requirements and large challenges are imposed on the data center networks. Enterprises and service providers need to offer their resources and contents in datacenters under high availability, high resource utilization, low latency, and low power consumption at low cost.

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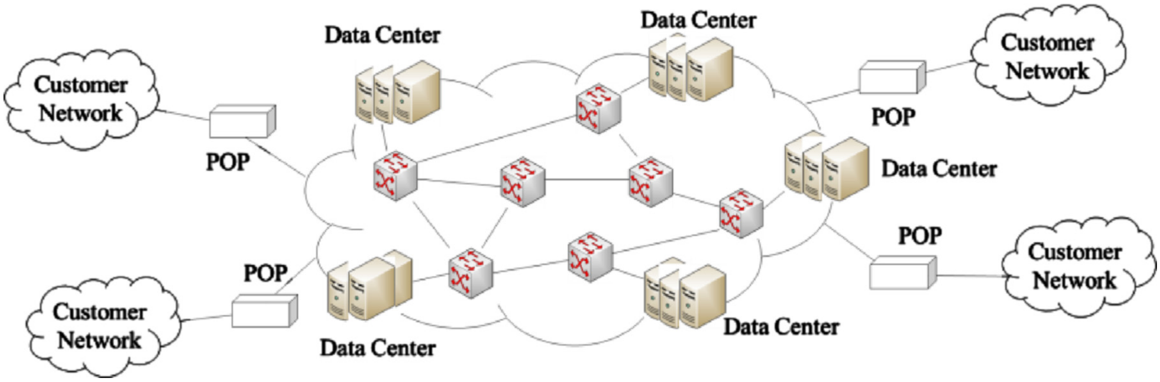

Fig. 1. Network of data centers.

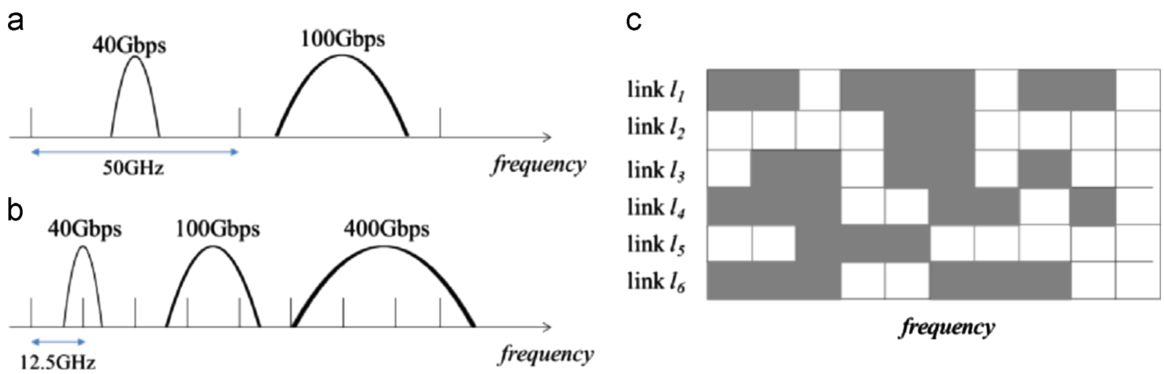

Fig. 2. (a) Conventional fixed grid (b) flexible grid (c) spectrum fragmentation in networks.

Usually, data centers are connected among themselves and to the outside world using ultra-long-haul WDM optical transport networks, given their large bandwidth capacity of the optical fiber, low power consumption rate and low latency in optical switching [3–5]. However, WDM networks have rigid bandwidth and coarse granularity, and each WDM channel occupies the same spectrum width without regard of the transmitted data rate. Since the long-haul fiber resources are scarce, expensive and time consuming to acquire or construct, we need to maximize the utilization of precious long-haul transmission fibers, and improve spectral efficiency in such optical networks [1].

Recently, Based on Optical Orthogonal Frequency Division Multiplexing (OFDM), a flexible grid optical network architecture has been proposed [6–10]. In such networks, the current DWDM rigid grid is further divided into a number of narrower segments (i.e., frequency slots), and the spectrum resource is allocated for each request based on its exact requirement. Fig. 2(a) shows the conventional fixed grid of 50 GHz, which specified by ITU-T standards; while Fig. 2(b) shows the spectrum spacing of 12.5 GHz in flexible grid optical networks, where different optical channels can span across different spectrum slots according to their data rates and transmission distances. Data center interconnected by flexible grid optical networks is a promising scenario to allocate spectral resources for applications in a dynamic, tunable and efficient control manner [11,12].

Flexible grid optical networking, which is characterized by its ultrahigh capacity, bitrate transparency, distance adaption and low power density, represents a potentially disruptive solution for overcoming emerging data center network bottlenecks [13]. There are some studies in flexible grid data center optical networks already. Ref. [10] investigates flexible bandwidth elastic optical networks designed to adaptively accommodate bursty and high capacity traffic among data centers. Data center networking architecture, algorithm and control plane are addressed in flexible bandwidth optical networks [14]. A bandwidth allocation algorithm was presented in [15] based on the network traffic fluctuations in the data center networks. Ref. [16] proposes a data centers interconnect architecture using the flex grid optical technology which enables the ability to dynamically increase and decrease the amount of optical resources assigned to connections.

In flexi-grid optical networks, the problem of Routing and Spectrum Assignment (RSA) emerges. Due to the facts that (1) different connections co-existing in the network may follow different paths and ask for different number of frequency slots, (2) even for the same request, the number of frequency slots it requests may vary significantly with time, (3) when establishing optical channels for the arriving requests, the assignment of frequency slots must x2obey not only wavelength continuity constraint but also spectrum contiguous constraint, the entire available spectrum resources are cut into many small noncontiguous spectral blocks after the process of RSA, and many unused