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Towards seamless service migration in network re-optimization for optically interconnected datacenters

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ABSTRACT

Emerging applications require datacenter networks to provide dynamic and reconfigurable services in order to adapt to the dynamicity of cloud traffic, as well as to maintain the optimality of resource utilization. In this paper, we demonstrate novel re-optimization design techniques for realizing agile and seamless service. Our main contribution is a novel integer linear programming (ILP) based approach which can minimize connection disruption, while optimizing resource utilization in a re-optimization process. We propose an ILP-based approach that integrates resource assignment and resource dependency digraph construction. We also propose a method to determine migration order. We compare the proposed ILP-based approach with a heuristic approach in terms of the number of connection disruptions and the migration process. Simulation results demonstrate the effectiveness of our approach.

1. Introduction

Driven by emerging capacity-hungry applications such as pervasive video, big data analytics, network functions virtualization (NFV), social networking, etc., operators around the world are building new cloud datacenters or adding more capacity to existing ones at an unprecedented pace. The dramatic growth in both number and scale of these datacenters (DCs) has significantly amplified the traffic volume and complexity of Datacenter Networks (DCN), and has motivated research for more advanced interconnection technologies, especially for large-scale inter-DCNs. As alternatives to packet-based interconnections, circuit-based switching technologies (e.g. optical transport network (OTN), optical path switching) are promising due to their capability of providing large capacity and right-sized switching granularity in an economical and sustainable way (e.g., cost/energy per bit). Fig. 1 shows an illustrative example of an inter-DCN based on OTN/WDM technologies. Research on this type of DCNs has been reported recently [1,2].

In addition, under the cloud DCN environment, massive data communication/service migration occurs in a highly dynamic fashion. This introduces unique challenges to DCN operation, which must leverage intelligent and automated mechanisms to adapt to the dynamicity of cloud traffic, as well as to maintain the optimality of network resource utilization. For this reason, network operators are beginning to adopt software defined networking (SDN) technology to facilitate agile and automated network control [3–6]. SDN applies a centralized controller to intelligently control and manage network resources, which enables network re-optimization to be more practical with greater operational simplicity than before. Also, with the wide deployment of cloud computing and parallel processing, the service of globally-optimized computation for complicated network problems becomes possible. Furthermore, an intelligent “network re-optimizer” can be incorporated in the operator's SDN platform to perform automated network re-optimization, either scheduled periodically, or triggered by service migration events.

Algorithm design for network re-optimization considering the optimality of both resource utilization and seamless operation is critical. The re-optimization techniques presented in this paper are generally applicable to various circuit-switched networks, such as OTN and WDM networks, and are particularly suitable for agile

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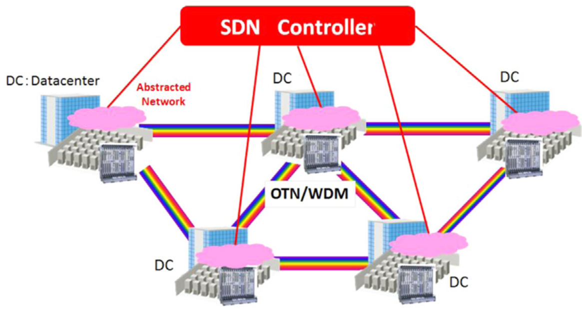

Fig. 1. An illustrative example of an inter-DCN interconnecting geographically dispersed DCs using OTN/WDM circuits.

and seamless service migration in optical inter-DCNs.

Network re-optimization generally consists of two steps: the first step is to compute new optimized routes for existing connections in the networks, and the second step is to strategically migrate the connections to new optimized routes. For providing seamless services, the migration process can be done via a "bridge" and "roll" operation [7], where new routes are first established, connections are switched to new routes, and then old routes are released. Under certain circumstances; however, disruption of existing connections may become unavoidable during network re-optimization. In this case, disrupted connections are terminated and re-established later when network resources become available, which causes service interruption for users. Hence, it is important to minimize the total number of connection disruptions during re-optimization.

Network re-optimization approaches proposed in [8,9] do not consider the connection migration process, which may result in an arbitrarily large number of connections being disrupted. The authors in [10–12] consider the migration process during re-optimization by applying a resource dependency graph [12], but these algorithms fail to achieve optimal resource utilization due to additional constraints. Furthermore, the proposed approaches in [10–12] consider the rerouting of lightpaths on fiber networks, where lightpaths are connections with equal spectrum width. Thus, they are not applicable to inter-DCNs supporting connections with different bandwidth, as in OTN [13], where lower-order optical data unit (LO-ODU) connections with varying number of tributary slots (e.g., $n \times 1.25$ Gb/s) traverse multiple higher-order optical channel data unit (HO-ODU) links. Also, in elastic optical networks [14], lightpath connections may have different number of spectrum slots (e.g., $m \times 12.5$ GHz) traversing over multiple fiber links.

Effective assignment of resources among connections is important for minimizing connection disruptions since it significantly impacts resource dependency between connections, especially when connections have different bandwidth. For example, multiple connections with lower bandwidth can be assigned onto slots that are previously-released by a connection with higher bandwidth, or a connection of higher bandwidth can be assigned onto combined slots released by multiple connections of lower bandwidth.

In this paper, we introduce a network re-optimization approach that minimizes connection disruptions for seamless service migration, while guaranteeing optimized resource utilization in inter-DCNs. Our main contribution includes a novel integer linear programming (ILP) based approach that integrates resource assignment and resource dependency graph construction, in order to minimize the number of connection disruptions. We also propose a method for determining the order of connection migrations. To the best of our knowledge, there is no existing literature that optimizes network resource utilization, while minimizing the number of connection disruptions for the case in which connections have different bandwidth. We compare the proposed ILP-based re-optimization approach with a proposed heuristic approach, and demonstrate using simulations that the ILP-based approach significantly reduces the number of disruptions.

Here, we apply our methods to circuit-based OTN networks. Our proposed methods can also be applied to WDM networks (i.e., elastic optical networks) with additional constraints, such as spectrum continuity, which will be addressed in a future publication.

The rest of this paper is organized as follows. In Section 2, we present an overview of network re-optimization in OTN networks and the issue of resource assignment. In Section 3, we describe the re-optimization schemes. Section 4 discusses the simulation model and results. Finally, we conclude the paper. Earlier versions of this paper were published in [15,16].

2. Network re-optimization and issues

Network re-optimization can be triggered by events that cause inefficient usage of network resources, such as dynamic traffic arrival and departure, and the change in network topologies due to network failures or network growth, or can be triggered by performance metrics measured, such as traffic blocking. One common objective of network re-optimization is to minimize network resource utilization as in (1):

$$\min \sum_{c \in C} \sum_{nl \in NL_c} Cost_{nl} \bullet CB_c \tag{1}$$

In Eq. (1), C represents the set of connections that must be assigned resources in a network re-optimization. NL_c represents the set of network links along the route of connection c. $Cost_{nl}$ represents the cost of a network link nl and CB_c represents the bandwidth of a connection c.

Fig. 2 shows an example of network re-optimization in an OTN network. Assume that each network link (HO-ODU) has the bandwidth of 8 tributary slots and each cost of each link is 1 ($Cost_{nl}=1$). Each connection (LO-ODU) requires 4 tributary slots ($CB_c=4$) and is depicted by a colored, bold line. Fig. 2(a) shows the existing connections and their routes with a total network utilization of 44. Fig. 2(b) shows the connection routes after network re-optimization with a total network utilization of 20, leading to more available network resources; thus, the network is able to accommodate more future connections.

Now let us discuss how to determine the sequence of connection migrations and the set of disrupted connections during re-optimization. A resource dependency digraph (RDD) [12] is applied to indicate the resource (e.g., OTN tributary slots) dependency between connections before and after re-optimization. A RDD is a directed graph, in which a vertex represents a connection, and an edge represents the dependency between a connection before re-optimization and a connection after re-optimization. There is a directional and adjacent edge between two connections (vertices), $c_i \leftarrow c_j$, if the resources occupied by a connection before re-optimization (c_i) are assigned to a connection after re-optimization (c_j).

Resource assignment between connections determines resource dependency. Fig. 3(a) shows one resource assignment solution for the re-optimization example in Fig. 2, which is called Resource Assignment Pattern I (PATTERN-I). At the network link A-D, the slots occupied by connection c_1 before re-optimization are assigned to connection c_2 after re-optimization. Hence, there is an edge directed from c_2 to c_1, corresponding to Edge I in the RDD of Fig. 3(b). Similarly, at the link D–C, connection c_1 is assigned to the slots released by c_3 and connection c_4 is assigned to the slots released by c_2, which corresponds to Edges II and III in Fig. 3(b),