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REVIEW ON INTEGRATING VIRTUAL NETWORKS INTO ELASTIC OPTICAL NETWORKS

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ABSTRACT: Recent innovations in Network Virtualization and Elastic Optical Networks (EONs) enable flexible deployment of optical networks as a service. However, embed Virtual Optical Network (VON) requests onto the physical substrate network to maximize the sharing of physical resources, which is the so called Virtual Network Embedding (VNE) problem. EONs are prone to the fragmentation of spectral resources during the process of routing and spectrum allocation. The fragmentation of spectral resources in the substrate fiber links may lead to the blocking of incoming virtual network requests. This degrades the utilization of the physical resources of the Infrastructure Providers and also, decreases the revenue of the Service Providers. In this review, different model that takes into account the spectrum alignment and relative loss in spectrum consecutiveness when mapping virtual nodes/links onto the physical substrate nodes/links. It also observes a minmax reconfiguration scheme called Relative Consecutiveness Lossaware and Misalignment-aware Virtual Network Reconfiguration (RCLM-VNR) that minimizes relative consecutiveness loss and maximizes alignment with adjacent links when reconfiguring the virtual network. It also observes elasticity and traffic load.

KEYWORDS: Virtual Network, Optical Network, Cloud, Fibers, Embedding

I. INTRODUCTION

With the emergence of cloud computing and high-bitrate video services, data center applications have presented the high burstiness and high-bandwidth characteristics, especially for the super-wavelength application beyond 100Gbit/s. In order to address the inter-data-center connection challenges, we propose to use elastic optical network (EON) to interconnect datacenters, since that technology provides finer and multiple granularity in comparison to traditional wavelength switched optical networks [1]. The key idea of EON is to allocate the necessary spectral resources with a finer granularity tailored for a variety of user connection demands. The architecture of elastic optical networks can also enable sub-wavelength, super-wavelength, multiple rate data traffic accommodations, and offers cost-effective, highly-available and energy-effective connectivity channels.

In order to support multi-tenant cloud platform co-existing hardware and improve the spectrum utilization, virtualization are considered as key enablers. In [4], they proposed an application-aware virtual data center (VDC) infrastructure provisioning method over the elastic optical networks to coordinate virtualization of optical network and IT resources in DCs, which has not been extensively studied. Since the high-speed, power-efficient, and reliable connections are mostly optically interconnection, how to embedding the virtual optical network (VON) on the physical network becomes meaningful in these days [2]. Moreover, VON embedding has its own spectrum

continuity constraints, a particular substrate path must use the same spectrum for its end-to-end virtual link and the spectrum for an elastic optical path should be allocated using consecutive frequency slots in a fiber. Thus, dynamic VON request setup and teardown operations in random fashion will inevitably lead to spectral fragmentation, which will block the new arrival of requests or force to utilize more resources in spite of sufficient spectrum being available and spectral efficiency is decreased seriously. In this work, we consider an elastic optical network, to embedding the VON request with a new dynamic mapping algorithm, which enables to split a virtual link into several traffic stream and embed on different physical paths. We assume that the guard band of VON request is negligible during the VNE simulation process because the business bandwidth of data center interconnection optical network is up to 10Gb or even more, which is much larger than guard band. Since multi-path routing may cause the inverse-multiplexed connections arriving at the destination node with differential delay (DD) and buffer provided at the receiver to compensate DD and combine the multi-paths are limited.

The recent developments in mobile technologies, data center networks and cloud computing have brought a huge amount of emerging applications and data traffic to Internet. To handle such fast applications deployment and dynamic data traffic with the current Internet, Network Virtualization has been proposed as a promising solution [3]. Network virtualization allows multiple users to simultaneously co-exist on the same physical network by sharing the physical resources. As one of the physical substrate network technologies, Elastic Optical Networks (EONs) or SLICE/FlexGrid networks are more spectrally efficient than Wavelength Division Multiplexing (WDM) networks that are traditionally used. EONs employ the orthogonal frequency division multiplexing (OFDM) technology to distribute data on just enough subcarriers.

The adjacent sub-carriers in EONs can overlap each other and EONs can support different bit rates using various modulation schemes[4]. With network virtualization, Infrastructure Providers (InPs) and Service Providers (SPs) can be separate entities SPs can lease physical resources from one or more InPs and provision a virtual optical network (VON)[5]. A typical VON is composed of several virtual nodes interconnected by virtual links. Each virtual node requires a certain amount of computing resources from the substrate node while each virtual link is a spectrum path consisting of one or multiple substrate fiber links (SFLs). The process of mapping virtual nodes/links to substrate nodes/links is called Virtual Network Embedding (VNE). Recently, the VNE problem in EONs, SLICE or Flex-Grids networks has received attention from the research communities [6].

With the progress and development of science and technology, especially in recent years, the emergence of various new Internet technologies and industries has brought about complete changes to people's lives. At the same time, these changes bring about the explosive growth of communication network traffic, the problem of insufficient network capacity and "rigidity" are becoming increasingly serious, At the same time, the emergence of various realtime services similar to VR has put forward high requirements for network bandwidth, network stability and network delay.

Network virtualization technology is widely used in fields such as computers and network systems. Network virtualization supports the construction of multiple heterogeneous networks by sharing the underlying network resources, and improves the utilization of network resources and network flexibility. It is regarded as one of the key technologies for building future networks. The core problem of network virtualization is the virtual network mapping problem (VNMP), which is how to allocate physical resources efficiently for virtual network requests.

Nowadays, most of the researches are devoted to solving vnmp problem, seeking to efficiently map more virtual networks under the condition of limited Sn resources, so as to improve the economic benefits of ISPs. However, with the rapid development of business types and traffic, network failures cause business interruption, which will bring immeasurable losses to users. Network virtualization technology uses abstraction, distribution and isolation mechanisms to virtualize nodes and links, thus building isolated coexistence networks by sharing physical infrastructure. In this way, the physical network can realize the reasonable configuration and management of physical resources according to the dynamic virtual network (VN) mapping request, realize the flexible configuration and manageability of network resources, and improve the network security and quality of service. At the same time, it can effectively alleviate the "fossilization" problem of the Internet and accelerate the innovation of future network research [7].

II. LITERATURE SURVEY

S. Hegde, R. Srinivas, D. M. Divakaran and M. Gurusamy,et.al [8] esign of datacenters is the hybrid network architecture consisting of both optical and electrical elements. In this context, the joint problem of bandwidth allocation and VM-placement, a problem that only recently received attention in all-electrical datacenter networks, poses new and different challenges not addressed yet in hybrid datacenters. In particular, we foresee two issues: (i) the number of edge-switches that can be simultaneously reached using optical paths from an edge-switch is limited by the switch size, (ii) the dynamic creation of optical paths can potentially establish a constrained optical network topology leading to poor performance. Through simulations, we demonstrate the effectiveness of not only exploiting the already established optical paths, but also of using electrical network in embedding requests of virtual networks.

Q. Wang, J. Zhang, Y. Zhao, H. Yang, Y. Yu and W. Wang, et.al [9] develop a network management (NM) system match the centralized control mechanism and propose a remote centralized control platform with cloud service in SDON. Among the experiment optical nodes, there are two flexible ROADMs for supporting flex-grid. The datacenter (DC) resources of cloud service is provided by a commercial DC far away from lab. While the usage of CPU and memory is monitored by deploying program in the DCs server, we can learn the condition of remote DC dynamic. As we know, cloud service mainly include cloud computing and cloud storage, this make remote centralized control platform distribute the cloud resource more reasonable when a service is request.

A. Zhou *et al*., [10] proposes a redundant VM placement optimization approach to enhancing the reliability of cloud services. The approach employs three algorithms.

The first algorithm selects an appropriate set of VM-hosting servers from a potentially large set of candidate host servers based upon the network topology. The second algorithm determines an optimal strategy to place the primary and backup VMs on the selected host servers with k-fault-tolerance assurance. Lastly, a heuristic is used to address the task-to-VM reassignment optimization problem, which is formulated as finding a maximum weight matching in bipartite graphs. The evaluation results show that the proposed approach outperforms four other representative methods in network resource consumption in the service recovery stage.

X. Ye, Y. Yin and L. Lan, et.al [11] energy-efficient KnEA (EEKnEA) algorithm is proposed to address this problem. EEKnEA is improved by proposing an energy-efficient-oriented population initialization strategy based on the knee point-driven evolutionary algorithm (KnEA), which is a high-performance algorithm for many-objective problems. The proposed model and performance of EEKnEA are evaluated in comparison to KnEA and other algorithms. Experimental results show that the proposed model is reasonable, and the EEKnEA algorithm outperforms its counterparts on this type of problem in terms of energy saving, load balance, and robustness.

X. Liu and D. Medhi, et.al [12] virtual network environment, a substrate network provider allocates computing and networking resources for service providers who request virtual networks to be created for particular services, and it also has the capability to provide resilient virtual network management with redundant resources, such as dynamic virtual network restoration from failures. In this papers, we consider the situation where the substrate network provider desires to have standby virtual routers ready to serve virtual networks under node failures. Such a failure can affect one or more virtual routers in multiple virtual networks. The goal of this paper is to make the optimal selection of standby virtual routers so that virtual networks can be dynamically reconfigured back to their original topologies right after the failures. We present an optimization formulation and a heuristic for this problem. By considering a number of factors, we present numerical studies to show how the optimal selection was affected by those factors, and the proposed heuristic's performance was close to the optimization model when there were sufficient standby virtual routers for each virtual network and the substrate nodes have the capability to support multiple standby virtual routers to be in service concurrently.

B. Li, W. Lu, S. Liu and Z. Zhu, et.al [13] addresses the relatively long setup latency and complicated network control and management caused by on-demand virtual network function service chain (vNF-SC) provisioning in inter-datacenter elastic optical networks. We first design a provisioning framework with resource pre-deployment to resolve the aforementioned challenge. Specifically, the framework is designed as a discrete-time system, in which the operations are performed periodically in fixed time slots (TS). Each TS includes a pre-deployment phase followed by a provisioning phase. In the pre-deployment phase, a deep-learning (DL) model is designed to predict future vNF-SC requests, then lightpath establishment and vNF deployment are performed accordingly to pre-deploy resources for the predicted requests. Then, the system proceeds to the provisioning phase, which collects dynamic vNF-SC requests from clients and serves them in real-time by steering their traffic through the required vNFs in sequence. In order to forecast the high-dimensional data of

future vNF-SC requests accurately, we design our DL model based on the long/short-term memory-based neural network and develop an effective training scheme for it. Then, the provisioning framework and DL model are optimized from several perspectives. We evaluate our proposed framework with simulations that leverage real traffic traces. The results indicate that our DL model achieves higher request prediction accuracy and lower blocking probability than two benchmarks that also predict vNF-SC requests and follow the principle of the proposed provisioning framework.

Y. Zhou, B. Ramamurthy, B. Guo and S. Huang, et.al [14] Packet and optical networks are managed independently in both current carrier networks and datacenter interconnection networks, which results in a lack of service agility and is a significant source of capital expenditure and operating expense overhead for the network operator. In our previous works, we have proposed and experimentally demonstrated a software-defined networking- based architecture (service-aware architecture) for converged control of packet and optical networks. In this paper, we first propose a concept called virtual transport link (VTL) to support dynamic link aggregation in software- defined IP over optical networks. Then, the VTL-based dynamic bandwidth adjustment (VTL-DBA) method is proposed for improving the resource utilization and for simplifying service provisioning. The feasibility of our proposals is experimentally verified on our software-defined IP over optical networks testbed. The performance of the VTL-DBA method is also evaluated based on our simulation platform in terms of resource usage, resource utilization, and blocking probability. For carrying quality guaranteed services, VTL-DBA saves 25% of transport resources on average compared with static bandwidth allocation methods, and it shows an increase of 15% in the average resource utilization. For carrying both quality guaranteed services and quality tolerant services, VTL-DBA reduces the service blocking probability to only 10% on average with higher resource utilization than static bandwidth allocation methods.

M. Batayneh, D. Schupke, M. Hoffmann, A. Kirstaedter and B. Mukherjee,et.al [15] Ethernet's success in local-area networks (LANs) is fueling the efforts to extend its reach to cover metro and long-haul networks. A key enabler for using Ethernet in the carrier's network is its ability to efficiently sup port multipoint-to-multipoint (MP2MP) services. MP2MP service is the core underlying structure to enable standard Ethernet services such as Ethernet virtual private networks (E-VPNs). Since most of the research, standardization, and development have focused on designing protection architectures for point-to-point (P2P) Ethernet connections, protecting E-VPN services is an important research problem. Among the various transport methods for realizing carrier Ethernet, the wavelength-division multiplexing (WDM) optical network is a strong candidate. Wavelength channel rates are increasing from 10 to 40 Gbits/s and even 100 Gbits/s, and they can also coexist in the same fiber. We study the problem of cost-efficient provisioning of multi-bit-rate (1/10/40/100 Gbits/s) self-protected E-VPN demands over a carrier-grade Ethernet network employing WDM optical network (Ethernet over WDM) with mixed line rates (MLRs). We study two algorithms for self-protected E-VPN provisioning. The first algorithm reforms the original E-VPN topology and increases the provisioning rates (10/40/100 Gbits/s) of the E-VPN edge demands to create excess capacity that can be used for protection (E-VPN reformation). The second algorithm routes the E-VPN edge demands using the lowest available rate (10/40/100 Gbits/s) and establishes backup capacity for protecting the E-VPN (no E-

VPN reformation). Our algorithms are tested on a 17-node German national network topology. The results show that using E-VPN reformation achieves significant cost reduction and significant improvement in the network's performance by reducing the traffic-blocking ratio.

T. Chen, J. Liu, Q. Tang, T. Huang and R. Huo, et.al [16] Network virtualization allows multiple isolated virtual networks (VNs) to share the same substrate network (SN). VN embedding (VNE) algorithms can efficiently allocate the limited SN resources to VNs and assign a unique identifier to each VN. However, the fixed bit width of VN identifier in the packet header limits the number of VNs, and extending the bit width leads to the increase of the network traffic. In this paper, we consider the label-combination method to generate VN identifiers by combining the link-grained labels with location information. This method requires the efficient allocation of labels, but the existing VN embedding works only consider the CPU and bandwidth resources. To address this issue, we propose a novel embedding model that considers the label, CPU and bandwidth resource constraints. Furthermore, two window-based heuristic algorithms called VNE-LIA and VNE-iLIA using the greedy algorithm and the proximity principle are presented to solve the VNE problem. The simulation experiments show that our proposed algorithms increase the number of VN identifiers and the revenue to cost ratio under the different resource conditions of SN.

R. Martínez *et al*.,et.al [17] Aiming at lowering both capital expenditures and operational expenditures, current networking trends on network virtualization, software-defined networking (SDN), and network function virtualization (NFV) provide an appealing scenario to flexibly deal with the increase in traffic for MNOs without overdimensioning the deployed network resources. To this end, we rely on an implemented SDN/NFV orchestrator that automatically serves MNO capacity requests by computing and allocating virtual backhaul tenants. Such backhaul tenants are built over a common physical aggregation network, formed by heterogeneous technologies (e.g., packet and optical) that may be owned by different infrastructure providers. MNO RAN traffic is transported toward a mobile core network [i.e., evolved packet core (EPC)], where required backhaul resources are tailored to the capacity needs. The EPC functions are virtualized within the cloud (vEPC), leveraging the NFV advantages. This increases MNO flexibility where cloud resources are instantiated according to EPC needs. The goal of the SDN/NFV orchestrator is to jointly allocate both network and cloud resources, deploying virtual backhaul tenants and vEPC instances for a number of MNOs with different service and capacity requirements. Each MNO's backhaul is isolated and controlled independently via a virtualized SDN (vSDN) controller deployed in the cloud. The SDN/NFV orchestrator architecture is detailed and experimentally validated in a setup provided by the Centre Tecnològic de Telecomunicacions de Catalunya and ADVA Optical Networking. Specifically, upon an MNO request, the orchestrator instantiates the vEPC and vSDN functions in the cloud and then composes the MNO's backhaul tenant over a multilayer (packet and optical) aggregation network.

P. Zhang, H. Yao and Y. Liu, et.al [18] Network virtualization can offer more flexibility and better maintainability for the current Internet through allowing multiple heterogeneous virtual networks (VNs) to share the network resource of a common infrastructure provider. The main challenge in this respect is the efficient embedding the virtual nodes and virtual links from the VN requests onto the

limited substrate network resources. The notion of storage resource can exchange bandwidth resource to some extent gives us a hint that the efficient utilization of storage resource can relieve the bandwidth resource consumption. The existing VN embedding model does not consider the storage resource constraints on substrate nodes and virtual nodes, and does not keep up with the need of actual situation. In this paper, we propose a novel VN embedding model based on 3-D resource constraints including computing, network and storage, and devise two heuristic algorithms as the baseline algorithms to deal with the VN embedding problem. To our best of our knowledge, this is the first time to propose VN embedding problem based on 3-D resources including computing, network, and storage.

Y. Liu, P. Han, J. Hou and J. Zheng, et.al [19] -Wireless (FiWi) access network is a promising network architecture to provide the constantly available connections for the collaboration of objects in the Internet of Things (IoT). The network virtualization is dominating the evolution of FiWi, i.e., virtualized FiWi access network, which shields the difference between wireless and optical subnetworks and enables the customized transmission of different types of the IoT services in a common substrate network. However, the differences between optical and wireless subnetworks pose severe obstacle on their interoperability of resource allocation. In this paper, we focus on the survivable virtual network embedding (SVNE) in the FiWi access network for the purpose of the robust IoT service provisioning even in the scenario of network component failure. Each type of the IoT service is carried on one virtual network (VN), which is characterized by not only computing the resource and bandwidth resource demands but also the connection availability requirement. A connection availability model is proposed as an indicator of the network survivability and the IoT service robustness. We aim to allocate the resource for each VN with the resource cost minimized. The optimization problem of resource allocation is formulated in the integer linear programming (ILP) model that is solved for the optimal solution in a small-scale network. A heuristic algorithm is further put forward to facilitate the use of the proposed SVNE mechanism in a large-scale network. The simulation results verify that the proposed SVNE mechanism gains significant advantages in lower resource redundancy and higher acceptance ratio of VNs.

M. Ghaleb, T. Khalifa, S. Ayoubi, K. B. Shaban and C. Assi, et.al [20] deals with the multiple link/node substrate failures that impact a multicast virtual network (MVN) in which link recovery is not feasible and node migration is mandatory. A novel restoration approach is introduced to repair the failed MVNs while maintaining their quality of service requirements (e.g., end-to-end delay and delay variations). This approach relies on reducing the search region and exploiting nodes ranking and filtering (NRF) techniques to speed up the recovery process of finding an alternative node to which to migrate. The performance is extensively evaluated against multiple failures, with and without NRF, compared with complete re-embedding technique, link failure algorithms for single link failure, and previous work for single node failure. Simulation results prove that our recovery technique achieves good restoration ratio in considerably fast execution time, low link mapping cost (gain) with a slight impact on the admission ratio.

W. Wei, H. Gu, K. Wang, X. Yu and X. Liu, et.al [21] Internet of Things (IoT), an increasing amount of data from IoT applications is moved to geo-distributed data centers (DCs) for data analysis. Massive compute-demanding applications call for a more flexible and efficient

resource allocation for uncertain and heterogeneous traffic in geo-distributed multi-DC systems. Virtual network embedding, a major part of network virtualization, facilitates to provide different kinds of businesses or services by resource sharing. Moreover, due to their elasticity, elastic optical networks are viewed as a very promising solution to support inter-DC networks. This paper focuses on the effectiveness and spectrum fragmentation problem for virtual optical network embedding in elastic optical inter-DC networks by employing multidimensional resources and a topological attribute. In the node mapping, betweenness of a physical node is considered together with multidimensional resource carrying capacity (MRCC) to identify proper matching. Specifically, to reduce the influence of a spectrum fragment, the available spectrum continuity degree is coupled with the computing capacity of a physical node as the MRCC. In the link mapping, a tightest-matching factor is employed for the selection of paths to accommodate virtual links. Compared with baseline algorithms except for the integer linear programming (ILP) solution, analytical and numerous experiments show that our solution reduces the blocking probability by 30% on average, balances the load by 15% on average and improves spectral efficiency significantly. Moreover, our proposal has a slightly lower spectral efficiency but a better blocking performance and a much better link load balance than that of the ILP formulation.

L. Nonde, T. E. H. El-Gorashi and J. M. H. Elmirghani,et.al [22] Network virtualization is widely considered to be one of the main paradigms for the future Internet architecture as it provides a number of advantages including scalability, on demand allocation of network resources, and the promise of efficient use of network resources. In this paper, we propose an energy efficient virtual network embedding (EEVNE) approach for cloud computing networks, where power savings are introduced by consolidating resources in the network and data centers. We model our approach in an IP over WDM network using mixed integer linear programming (MILP). The performance of the EEVNE approach is compared with two approaches from the literature: the bandwidth cost approach (CostVNE) and the energy aware approach (VNE-EA). The CostVNE approach optimizes the use of available bandwidth, while the VNE-EA approach minimizes the power consumption by reducing the number of activated nodes and links without taking into account the granular power consumption of the data centers and the different network devices. The results show that the EEVNE model achieves a maximum power saving of 60% (average 20%) compared to the CostVNE model under an energy inefficient data center power profile. We develop a heuristic, real-time energy optimized VNE (REOViNE), with power savings approaching those of the EEVNE model. We also compare the different approaches adopting an energy efficient data center power profile. Furthermore, we study the impact of delay and node location constraints on the energy efficiency of virtual network embedding. We also show how VNE can impact the design of optimally located data centers for minimal power consumption in cloud networks. Finally, we examine the power savings and spectral efficiency benefits that VNE offers in optical orthogonal division multiplexing networks.

C. Ma, J. Zhang, Y. Zhao, M. F. Habib, S. S. Savas and B. Mukherjee, et.al [23] Virtual networks mapped over a physical network can suffer disconnection and/or outage due to disasters. After a disaster occurs, the network operator should determine a repair schedule and then send repairmen to repair failures following the schedule. The schedule can change the

overall effect of a disaster by changing the restoration order of failed components. In this study, we introduce the traveling repairman problem to help the network operator make the schedule after a disaster. We measure the overall effect of a disaster from the damage it caused, and we define the damage as the numbers of disconnected virtual networks, failed virtual links, and failed physical links. Our objective is to find an optimal schedule for a repairman to restore the optical network with minimum damage. We first state the problem; then a mixed integer linear program (MILP) and three heuristic algorithms, namely dynamic programming (DP), the greedy algorithm (GR), and simulated annealing (SA), are proposed. Finally, simulation results show that the repair schedules using MILP and DP results get the least damage but the highest complexity; GR gets the highest damage with the lowest complexity, while SA has a good balance between damage and complexity.

C. -H. Kim, S. -Y. Jung, S. -M. Jung and S. -K. Han, et.al [24] propose and demonstrate a novel all-optical virtual private network (VPN) using a microwave photonic filter, which enables inter-communications among optical network units in a passive optical network system. In our scheme, an optical coupler based recirculating delay line is used at optical line terminal as an optical subsystem to implement a microwave photonic-bandpass filter (MP-BPF). The periodic passbands of an MP-BPF are used to transmit VPN signal, whereas stopbands are used for conventional upstream transmission. The proposed system has two critical issues, optical phase-induced intensity noise in the MP-BPF and Rayleigh back-scattering interference by a single-fiber loop back link. To overcome the issues, an RF clipping tone based spectrum-broadening technique is applied to uplink transmitter. The proposed all-optical VPN system is tolerant to wavelength of VPN optical carrier, and enables multi-VPN data transmission using multi-passbands of MP-BPF.

M. R. Rahman and R. Boutaba, et.al [25] described network virtualization can offer more flexibility and better manageability for the future Internet by allowing multiple heterogeneous virtual networks (VN) to coexist on a shared infrastructure provider (InP) network. A major challenge in this respect is the VN embedding problem that deals with the efficient mapping of virtual resources on InP network resources. Previous research focused on heuristic algorithms for the VN embedding problem assuming that the InP network remains operational at all times. In this paper, we remove this assumption by formulating the survivable virtual network embedding (SVNE) problem. We then develop a pro-active, and a hybrid policy heuristic to solve it, and a baseline policy heuristic to compare to. The hybrid policy is based on a fast re-routing strategy and utilizes a pre-reserved quota for backup on each physical link. Our evaluation results show that our proposed heuristics for SVNE outperform the baseline heuristic in terms of long term business profit for the InP, acceptance ratio, bandwidth efficiency, and response time.

W. Wang *et al*., [26] discussed the survivability problem in virtualized transport optical networks, and proposed multi-layer protection schemes for VTNS. For the first time, we demonstrated VTNS with the proposed schemes on the testbed with commercial equipments. Results showed that the proposed schemes can provide differentiated protection for VTNS as customers required, and the provider layer connection protection (PLCP) scheme was able to utilize provider's resources most efficiently.

The virtualization technique in optical networks, virtual transport network services (VTNS) has been introduced as a new kind of service in transport networks.

With VTNS, transport providers are able to provide their customers entire virtual topologies instead of traditional end-to-end connections. This letter analyzes the new characteristics (i.e., multiple operators, diversified services) aiming at the survivability problem in virtualized optical transport networks, and proposes three novel protection schemes for VTNS against the new features. For the first time, VTNS with the proposed protection schemes are demonstrated on the flexi-grid optical networks testbed with commercial optical transport equipments. Additionally, the performances of the proposed protection schemes have been evaluated via simulations.

X. Gao *et al*., [27] describe the Network Function Virtualization (NFV) provides an effective way to reduce the network provider's cost by allowing multiple Virtual Networks (VNs) to share the underlying physical infrastructure. In the NFV environment, especially when supporting multicast services over the VNs, reliability is a critical requirement since the failure of one virtual node can cause the malfunction of multiple nodes that receive multicasting data from it. In this paper, we study for the first time to the best of our knowledge how to efficiently map VNs for multicast services over both general IP networks and Orthogonal Frequency Division Multiplexing (OFDM)-based Elastic Optical Networks (EONs) while taking into consideration the max-min fairness in terms of reliability among distinct VNs. For general IP networks, we propose a Mixed Integer Linear Programming (MILP) model to determine the upper bound on the reliability with max-min fairness. In addition, an efficient heuristic, namely a reliability-aware genetic (RAG) algorithm, is developed to address reliable multicast VN mapping with a low computational complexity. By encoding multicast tree construction and link mapping into the process of path selection, taking into consideration the reliability with max-min fairness, and the networking reliability factors during mutation, RAG can globally optimize the reliability and fairness of all the multicast VN requests. For OFDM-based EONs, we extend the MILP (RAG) to optical-MILP [(O-MILP) optical RAG (O-RAG)] by considering the most efficient modulation format selection strategy, spectrum continuity, and conflict constraints. Through extensive simulations, we demonstrate that RAG (O-RAG) achieves close to the optimal reliability fairness with a much lower time complexity than the MILP (O-MILP) model. In particular, the path reliability-based mutation strategy in RAG (O-RAG) yields a significant performance improvement over other heuristic solutions in terms of reliability fairness, bandwidth (spectrum) consumption, and transmission delay.

Y. Zong *et al*., [28] proposed network virtualization has been as a promising method because of its advantages (e.g., on-demand and efficient resource allocation) to overcome the Internet ossification. Virtual network embedding (VNE) is one of the main challenges for network virtualization. Energy costs of servers in data centers (DCs) are major contributions to the power consumption in information and communication technology. Therefore, VNE should consider both acceptance ratio and power consumption. In this paper, a mixed integer linear programming model is proposed with the objective of minimizing the total power consumption in software- defined optical data center networks by reducing the active data centers and power-consuming network components. In addition, the coordinates of nodes and delay of links are considered for a more realistic scenario. Compared with the existing node ranking method, the proposed Global Topology Resource (GTR) can effectively evaluate the possibility of each DC node to host virtual nodes. Based on the GTR method, we

propose a location-aware energy efficient VNE algorithm, namely GTR-VNE. Simulation results show that GTR-VNE can obtain up to 9.3% and 5% improvement of power consumption and acceptance ratio compared with benchmarks. Furthermore, based on GTR and artificial intelligence ant colony optimization (ACO), another energy efficient algorithm, ACO-VNE, is proposed.ACO-VNE can obtain up to 28.7% improvement in power consumption compared with GTR-VNE. In addition, ACO-VNE has better performance in terms of revenue cost ratio and acceptance ratio.

L. Liang, W. Lu, M. Tornatore and Z. Zhu, et.al [29] promising solution for nextgeneration radio access networks (RANs), cloud RAN (C-RAN) still faces technical challenges due to the separate locations of the cloud-based baseband unit (BBU) pool and remote radio heads (RRHs). Fortunately, timeand wavelength-division multiplexing passive optical networks (TWDM-PONs) can efficiently bridge the communications between the BBU pool and RRHs. In this work, we address the problem of formulating virtual time division multiplexing PONs (vTDM-PONs) adaptively in a TWDM-PON-based C-RAN. However, instead of relying on a centralized approach, we develop algorithms that can work in a distributed manner. Specifically, we consider a scenario in which the optical network unit (ONU) of each RRH has the initiative to choose a proper vTDM-PON to register to based on its knowledge on the C-RAN. We formulate game theoretic models for the vTDM-PON formation for both static and dynamic operation of a C-RAN, then transform the games into weighted potential games and therefore prove the existence of Nash equilibrium (NE) points in the games. Moreover, we propose a distributed algorithm that can converge to the NE point(s) to enable each ONU to choose its vTDM-PON intelligently. As a comparison, we formulate a centralized mixed-integer linear programming model to provide the optimum vTDM-PON formation solution. Simulation results confirm the effectiveness of the design of the proposed game models and distributed algorithm.

N. Fernández *et al*.,[30] optical networking, virtual topologies have been introduced mainly to provide service providers with logical connections equipped with a reserved amount of bandwidth, which can be exploited to interconnect their equipment at the edges of the transport infrastructure. Virtual topologies are thus basically an abstraction of the real substrate, created by means of a process called virtual topology design (VTD). VTD is a complex task, affected by many parameters and constraints, and among them current traffic conditions are very relevant. Indeed, it is possible that after a certain time a virtual topology becomes inappropriate to serve current traffic. In such cases, the virtual topology can be reconfigured by creating new lightpaths or modifying or deleting existing ones, thus possibly creating some service interruptions. In this paper a new virtual topology reconfiguration technique is presented. In this technique, a cognitive entity designs and reconfigures virtual topologies by exploiting traffic forecasting solutions and taking advantage of past history. Moreover, a new transition method is also proposed to reduce the impact of instable routing tables during the reconfiguration process. We demonstrate, by means of simulation, the advantages of the proposed methods, as they reduce both the operational costs and the resources in operation while maintaining low packet loss ratio. Furthermore, we validate the operation of the proposed solutions in an emulated test bed.

F. Morales, M. Ruiz, L. Gifre, L. M. Contreras, V. Lopez and L. Velasco, et.al [31] introduction of new services requiring

large and dynamic bitrate connectivity can cause changes in the direction of the traffic in metro and even core network segments throughout the day. This leads to large overprovisioning in statically managed virtual network topologies (VNTs), which are designed to cope with the traffic forecast. To reduce expenses while ensuring the required grade of service, in this paper we propose a VNT reconfiguration approach based on data analytics for traffic prediction (VENTURE). It regularly reconfigures the VNT based on the predicted traffic, thus adapting the topology to both the current and the predicted traffic volume and direction. A machine learning algorithm based on an artificial neural network is used to provide robust and adaptive traffic models. The reconfiguration problem that takes as its input the traffic prediction is modeled mathematically, and a heuristic is proposed to solve it in practical times. To support VENTURE, we propose an architecture that allows collecting and storing data from monitoring at the routers and that is used to train predictive models for every origin-destination pair. Exhaustive simulation results of the algorithm, together with the experimental assessment of the proposed architecture, are finally presented.

L. L. Ben-Yacoub, et.al [32] provides corporate networking between geographically dispersed company sites. VPN sites consist of Local Area Networks (LANs) interconnected over a public network infrastructure, through virtual links. The goal of this work is to develop a control model able to manage traffic on these links. By maximizing bandwidth utilization on each link, an optimum balance for the allocation of bandwidth on the entire VPN can be found. The proposed model is called hierarchical bandwidth manager and is implemented in each LAN of the VPN. It is also able to cope with best-effort and guaranteed flows so that bandwidth left unused by guaranteed flows is dynamically distributed among best-effort ones. In each LAN, a tree representation is used to share the capacity of each virtual link between multiple flows in a hierarchical and distributed manner. Each node in the tree respects an inter-node bandwidth share protocol and/or is regulated through an intra-host regulation mechanism. This latter is implemented through a new technique which we call the fair shaper. An implementation of this technique in a Solaris 2.5 operating system and results of the implementation of the inter-node bandwidth share protocol in the ns network simulator.

C. -H. Kim, S. -Y. Jung and S. -K. Han, et.al [33] propose an all-optical virtual private network (VPN) supporting dynamic bandwidth allocation (DBA) in an orthogonal frequency division multiple access-based passive optical network. A microwave photonic bandpass filter (MP-BPF) is used to transmit the VPN signal without electrical conversion. The DBA is implemented by adjusting a free spectral range of the MP-BPF with corresponding subcarrier allocation. A RF clipping-tone (CT) is used to stabilize the optical channel suffered from phase induced-intensity noise and Rayleigh back-scattering noise. The DBA is experimentally verified at different two DBA scenarios in 20-km single-fiber loopback link in terms of channel error vector magnitude, spectral efficiency after adaptive modulation. Due to the CT-based channel stabilization, achievable spectral efficiency could be improved, and the feasibility of the proposed system is successfully demonstrated.

H. Jiang, Y. Wang, L. Gong and Z. Zhu,et.al [34] studied the availability-aware survivable virtual network embedding (A-SVNE) problem in optical inter datacenter networks that use wavelength-division multiplexing. With A-SVNE, we try to satisfy the availability

requirement of each virtual component (i.e., a virtual link or a virtual node) in a virtual network. We first analyze the availability of a virtual component based on the availabilities of the substrate link(s) and node(s). Then, we formulate an integer linear programming model for the A-SVNE problem and propose several time-efficient heuristics. Specifically, we design two node mapping strategies: one is sequential selection using efficient weights defined by the availability information, while the other uses auxiliary graphs to transform the problem into a classical problem in graph theory, i.e., the maximum-weight maximum clique. Finally, we use extensive simulations to compare the proposed A-SVNE algorithms with existing ones in terms of the blocking probability, availability gap, and penalty due to service-level agreement violations, and the results indicate that our algorithms perform better.

G. M. Saridis *et al*.,[35] described modern high-performance data centers are responsible for delivering a huge variety of cloud applications to the end-users, which are increasingly pushing the limits of the currently deployed computing and network infrastructure. All-optical dynamic data center network (DCN) architectures are strong candidates to overcome those adversities, especially when they are combined with an intelligent software defined control plane. In this paper, we report the first harmonious integration of an optical flexible hardware framework operated by an agile software and virtualization platform. The LIGHTNESS deeply programmable all-optical circuit and packet switched data plane is able to perform unicast/multicast switch-over on-demand, while the powerful software defined networking (SDN) control plane enables the virtualization of computing and network resources creating a virtual data center and virtual network functions (VNF) on top of the data plane. We experimentally demonstrate realistic intra DCN with deterministic latencies for both unicast and multicast, showcasing monitoring, and database migration scenarios each of which is enabled by an associated network function virtualization element. Results demonstrate a fully functional complete unification of an advanced optical data plane with an SDN control plane, promising more efficient management of the next-generation data center compute and network resources.

III. CONCLUSION

Virtual Network Embedding is a central problem to be solved when networks are virtualized. Optimizing the embed-ding of multiple virtual networks on one substrate network is computationally difficult for a number of important met-rics. Multiple algorithms approaching this problem have been discussed in the literature, so far. A formal description of the VNE problem was provided. A categorization of VNE algorithms along three distinct dimen-sions was developed. A list of optimization metrics was presented. A number of algorithmical approaches to theVNE problem was discussed. Finally, this information was used to create a taxonomy of VNE algorithms proposed in theliterature. There are a number of opportunities for future work in this area. It is to be noted, that the category of distributed VNE algorithms has received only sparse attention, so far. This provides an excellent point for future work, in particular since centralized algorithms will always be prone to the criticism of having a single-point of failure. Moreover, there are also novel directions of VNE research like energy-efficiency or security which have also been largely neglected by the scientific com-munity up to now. New work in this area will have to define appropriate new metrics for the VNE problem and develop algorithms that will optimize according to energy-saving or

security-enhancing goals. The application of virtualization to real networking environments, e.g. wireless networks, is currently being studied by the scientific community. The definition of algorithms that study the VNE problem with a focus on environment-based constraints is also an exciting branch for future research.

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