Considerations of Effective Tidal Traffic Dispatching in Software-Defined Metro IP over Optical Networks

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***Abstract*—Tidal traffic caused by the large-scale population migration between workplace during the day and residence at night are becoming a crucial problem for metro network control and management. We introduce an effective tidal traffic dispatching scheme with a novel TIDAL model based on software-defined architecture. Simulation results show that our proposed scheme can significantly reduce the network blocking probability, which help to enhance network performance.**

***Keywords*—traffic dispatching; metro networks; IP over optical networks; software-defined networking; traffic grooming.**

I. Introduction

The massive growth of data service driven by cloud computing, 4G or 5G mobile communications, and high-definition video distribution etc. put forward a series of serious problems to the agility and capacity of traditional networks. Conventional solutions, for example, adding network nodes and links, or expanding the aggregation layer will lead to an increase in network architecture complexity that threatens the network operation and maintenance. On the other hand, as the network traffic is becoming extremely dynamic and uneven in both time and spatial dimensions caused by frequent migration of large-scale network users, so network carriers are trying to upgrade their network architecture to address the problems, among which tidal traffic is the most typical and pressing one.

Originally, tidal traffic phenomenon is firstly discovered and studied in wireless networks [1]. **Tidal Traffic** is typically uneven, varying in both time and spatial domains. In fact, the tidal traffic caused by large-scale population migrating between two locations in both time and spatial domains also challenges the whole metro IP over optical networks, not only the wireless networks. As the residential areas are usually distributed surround the center of city in which working offices are intensively located, urban residents have to move between these two sites every day, which caused tidal crowds together with tidal network traffic. For example, as shown in Fig. 1, considering a common workday, during the day people use Internet at working areas generating a large number of network traffic, meanwhile there is few traffic in residential areas, and the traffic pattern is converse at night. When the peak of the tidal traffic arrives, the network infrastructure operates under extremely heavy burden in a certain period of time. As the traffic varying rapidly, the peak of tidal traffic will soon be replaced by the valley and then the network infrastructure runs almost empty. If the network capacity is enlarged merely based on the peak traffic load in each area, then there will always be quite percentage of network equipments operating with light load. So the emergence of tidal traffic results in a huge increase of the network CapEx and OpEx, challenging network carriers to improve their network management scheme as well as the intelligence of network infrastructure to adapt to the dynamic uneven traffic, especially with tidal pattern. So far, researches on tidal traffic are limited and the problem has not been addressed, because tidal traffic is an emerging phenomenon and has combined complexity with both space and time, while previous work only focus on either one dimension [2].

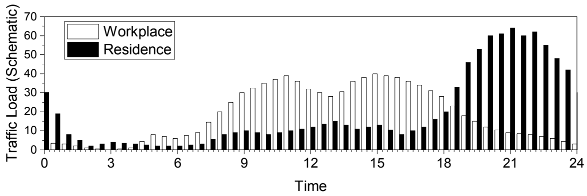
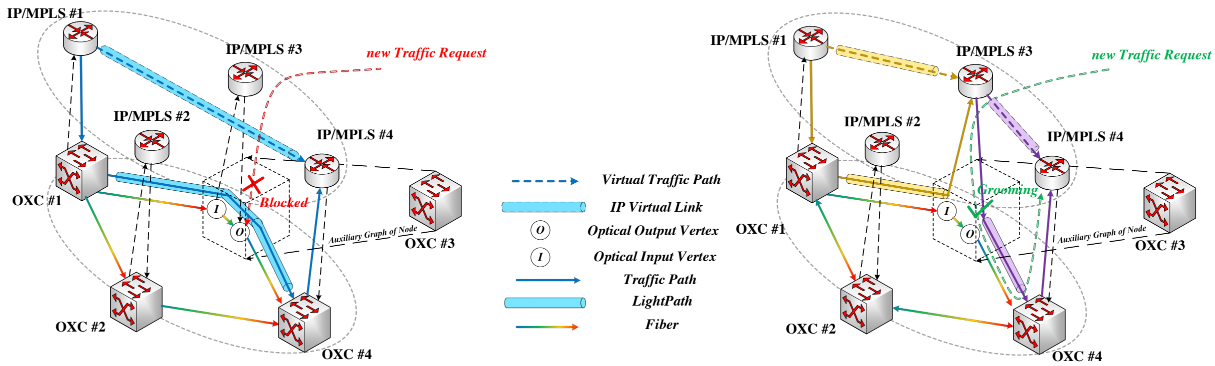


Fig. 1. Schematic graph of a typical tidal traffic

On the other hand, metro networks are generally composed of different layers, for example, optical core layer, optical aggregation layer, and IP access layer [3], and the nodes in optical layers also have mapping nodes in the virtual upper IP resource layer. Addressing the problems brought by tidal traffic needs the orchestration of both IP layer and optical layer. However, in today's commercial networks, the IP layer and the optical layer are separated operated without dynamic interaction. Optical layer only provide resources for upper IP layer according to the request of IP layer when traffic arrives. Lacking intelligent traffic-aware interaction between IP and optical layers may cause uneconomical strategies in routing or grooming procedures and influence the performance of the whole network [4]. Luckily, recent researches on Software-Defined Networking (SDN) enables us to control both IP and optical layers together to realize differential routing and grooming strategies with traffic-aware cross-layer resource provisioning [4-5].

In this paper, we address the problem of tidal traffic in metro IP over optical networks for the first time by introducing an effective traffic dispatching scheme with a novel ***T****raffic-aware* ***I****ntelligent* ***D****ifferential* ***A****llocation of* ***L****ightpath* **(TIDAL)** model based on software-defined architecture. The TIDAL model supports differential routing and grooming strategies in different nodes based on real-time traffic-aware congestion sensing results in the SDN controller. An experimental simulation in relation to network blocking probability verifies the superiority of our proposed scheme.



*Conventional strategy in **Tide-peak** areas*
*(OXC#1-4 are **Tide-peak** nodes)*

*TIDAL strategy in **Tide-peak** areas*
*(OXC#1-4 are **Tide-peak** nodes)*

Fig. 2. Illustrative example of TIDAL model in tide-peak area

II. Traffic-aware Intelligent Differential Allocation of Lightpath (TIDAL) Model

Firstly, tidal traffic can lead to the uneven distribution of network traffic in both time and spatial domains. Let the **tide-peak** area denotes the area that are under heavy traffic burden, and the **tide-valley** area denotes that under light burden.

Also, traffic in metro networks varies from each other in granularity. In previous researches, dynamic traffic grooming can utilize more fine-grained IP traffic into one lightpath and lower the network blocking probability. In conventional dynamic traffic grooming strategies, approaches such as MinTHV and MinTHP that prefer to use or setup as few lightpath as possible get better network utilization and blocking probability [6]. However, these methods only consider uniformly distributed traffic in global network topology and apply the same strategy in the whole network. In real circumstances, when considering time and spatial uneven traffic like tidal traffic, simply applying any single approach may not be effective.

The goal for TIDAL model is global optimum, and the principle of TIDAL model is to apply grooming and routing strategies as well as allocate the length of lightpath differentially in tide-peak areas and tide-valley areas. In tide-peak areas the SDN controller avoids establishing long lightpaths so as to guarantee the potential grooming opportunities for the following traffic arrivals, and in tide-valley areas, we continue to apply the conventional dynamic grooming approaches that aim to use minimum number of lightpaths to support the traffic.

Fig. 2 depicts the tide-peak part of the network. The network consists of two layers: optical layer and IP/MPLS layer. The optical layer can provide virtual links for IP layer. Each OXC and IP/MPLS node pairs denotes one IP/optical integrated node. We assume that each fiber link is directional, supporting one wavelength. OXC #3 is further described with an auxiliary graph [6] and the transmitter and receiver pairs inside the IP/optical integrated node are also considered. If there is one traffic from IP/MPLS #1 to IP/MPLS #4, conventional method will setup the least lightpath (IP#1-OXC#1-OXC#3-OXC#4-IP#4) to support the traffic, thus a one-hop lightpath is established and IP/MPLS #3 is bypassed. So when another traffic request from IP/MPLS #3 to IP/MPLS #4, neither grooming nor establishing new lightpath is accepted, and the new traffic request may be blocked. However, if we turn to our TIDAL model, we try to setup short lightpath in tide-peak areas, so the traffic #1 is supported by two lightpaths (IP#1-OXC#1-OXC#3-IP#3 & IP#3-OXC#3-OXC#4-IP#4), and the new traffic request can be groomed into the second lightpath. Therefore by establishing the lightpath as short as possible we reduce the network blocking probability in tide-peak areas.

III. Software-Defined Unified Control Architecture with TIDAL Model for Tidal Traffic

The software-defined unified control architecture for IP over optical networks enables the SDN controller to know the real-time traffic fluctuation of the whole network. As depicted in Fig. 3, the software-defined unified control architecture with TIDAL model consists of four layers. In control layer, an SDN controller is introduced to control the whole network, and the southern interface of the controller is OpenFlow. In adaption layer, an Optical Control Agent (OCA) [5] is introduced to relay the control message from the SDN controller in OpenFlow format and virtualize the relating optical networks. In IP layer, multiple services are accessed and the IP/MPLS switches are OpenFlow-enabled so as to communicate directly with the SDN controller. Particularly, the IP layer also includes the virtual IP resource layer mapped by the optical layer and the IP/MPLS switches here are controlled by the OCA. In optical layer, the topology is further divided into two metro regional rings, representing two areas between which tidal traffic happens and one metro core ring, representing the city's backbone OTN ring. Due to the unified control of the software-defined architecture, we can achieve real-time traffic-aware congestion sensing and then apply differential lightpath allocation strategies in tide-peak and tide-valley areas

A. Real-time Traffic-aware Congestion Sensing

The SDN controller collects real-time traffic message from the whole network, and decides a threshold that divides all the nodes into two parts. Those whose traffic load is above the threshold are defined as tide-peak nodes, while on the contrary others are defined as tide-valley nodes.

B. Applying Differential Lightpath Allocation Strategies

In multi-layer topology $\mathcal{G}(\mathcal{N},\mathcal{E})$ depicted in Fig. 3, the algorithm of TIDAL model calculates the optimal routing and grooming strategy for the arriving IP traffic.

Algorithm of TIDAL Model

1. **Target**: Compute a route from s to d
2. Initialize the path $P \leftarrow \emptyset$, Global Traffic Engineering Database (GTED) $T \leftarrow \emptyset$, the number of transmitter and receiver pairs on node $\mathcal{N}_0^k$ is $TR(\mathcal{N}_0^k)$
3. T collects real-time traffic situation and decides a traffic load threshold ρ_0. Nodes whose traffic load is above the ρ_0 are defined as *tide-peak* nodes $\mathcal{N}_1$, and others are defined as *tide-valley* nodes $\mathcal{N}_2$, $\mathcal{N}_1 \cup \mathcal{N}_2 = \mathcal{N}$
4. Using Dijkstra algorithm to calculate a path P_0 from s to d, and the number of elements in P_0 is p_0
5. **for** nodes $\mathcal{N}_0^k \in P_0$, $k = 1$ **to** p_0 **do**
6.   **if** $\mathcal{N}_0^k \in \mathcal{N}_1$ and $\mathcal{N}_0^{k+1} \in \mathcal{N}_2$ **then**
7.   **if** there is an existing lightpath suitable for grooming between $\mathcal{N}_0^k$ and $\mathcal{N}_0^{p_0}$ **then** grooming; **else if** there is enough empty wavelength for lightpath setup between $\mathcal{N}_0^k$ and $\mathcal{N}_0^{p_0}$, meanwhile $TR(\mathcal{N}_0^k) < TR_{max}$ and $TR(\mathcal{N}_0^{p_0}) < TR_{max}$ **then** setup a new lightpath between $\mathcal{N}_0^k$ and $\mathcal{N}_0^{p_0}$; **else** traffic blocked
8.   **for** nodes $\mathcal{N}_0^i \in P_0 \cap \mathcal{N}_1$, $i = 1$ **to** $k-1$ **do**
9.   **if** there is an existing lightpath suitable for grooming between $\mathcal{N}_0^i$ and $\mathcal{N}_0^{i+1}$ **then** grooming; **else if** there is enough empty wavelength for lightpath setup between $\mathcal{N}_0^i$ and $\mathcal{N}_0^{i+1}$, meanwhile $TR(\mathcal{N}_0^i) < TR_{max}$ and $TR(\mathcal{N}_0^{i+1}) < TR_{max}$ **then** setup a new lightpath between $\mathcal{N}_0^i$ and $\mathcal{N}_0^{i+1}$; **else** traffic blocked
10.   **end for**
11. **end for**
12. Translate the result into a series of lightpaths in optical layer and an IP path in the virtual IP resource layer.

IV. Simulation and Numerical Results

We abstract the metro IP over optical networks into the topology shown in Fig. 3. Particularly, in order to simulate the tidal traffic, we set the service area I to be tide-peak and service area II to be tide-valley, and we make OXC#6 to be the access to remote datacenters that both service layers request. Therefore the major traffic in this network are from service area I, and are generated in R#1, R#2, R#3 as well as aggregated into IP/MPLS#1, IP/MPLS#2, IP/MPLS#3, then groomed into the OXC layer and finally routed to OXC#6. The traffic is characterized by Poission arrivals as well as negative exponential holding times. Also, the transmitter and receiver pairs in each IP/optical integrated node is 32, and the fiber between each two nodes are directional with 100G capacity and carries 16 wavelengths. The whole network is assigned to be controlled by an open source SDN controller, POX.

Under these conditions, we conduct experimental simulation concentrating on the network blocking probability, and the numerical results are shown in Fig. 4. We apply MinTHV which performs the best among several conventional methods [6] to be the contrast. And by introducing the TIDAL model in our proposed traffic dispatching scheme, we can largely reduce the network blocking probability in tide-peak areas.

V. Conclusion

Tidal traffic is an emerging problem relating to the effective control and management of metro IP over optical networks with the obviously uneven distribution of traffic burden in both time and spatial domains. In this paper, we introduced an effective tidal traffic dispatching scheme with a novel TIDAL model based on software-defined unified control architecture for metro IP over optical networks to tackle the problem.

With experimental simulation, the numerical results show that the novel TIDAL model can significantly improve the network blocking probability of typical tidal traffic in metro IP over optical networks than previous approaches.

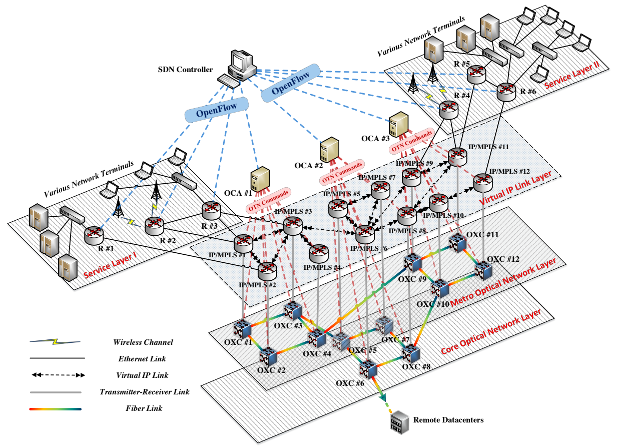


Fig. 3. Software-defined unified control architecture with TIDAL model

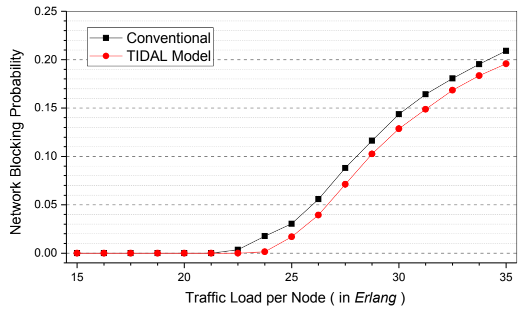


Fig. 4. Blocking probability: conventional scheme and TIDAL model scheme

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