A new teletraffic approach for network planning and evolution prediction

Ronald G. Addie, Yu Peng, Fan Li, Vyacheslav Abramov, Moshe Zukerman

Abstract

This paper outlines a new multi-layer optimization approach that considers stochastic traffic composed of heavy tailed flows for optimizing traffic engineering and grooming, network design, dimensioning and planning, and evolution prediction.

Index Terms

OCIS codes: (000.5490) Probability theory, stochastic processes, and statistics; (060.4256) Networks, network optimization

I. Introduction

It has been established that reducing the Internet's energy consumption is an important challenge and that there are opportunities to save energy by optimizing routing and choice of technology (e.g. [1]–[3]). At present, the Internet provides a large variety of services with a complex QoS requirements and traffic characteristics that exhibit a large variance of application flow sizes (e.g. [4]). The traffic is transported by a multiplicity of available technologies that operate on different layers, such as IP, MPLS, Ethernet, ATM and WDM. Therefore, it is not sufficient only to optimize the traffic routing, but there is also a need to optimize the choice of technologies/layers for the various types of traffic streams.

In this paper, we optimize both routing and choice of technology/layer for the traffic given cost structure and assuming that traffic between every origin destination (OD) pair to follow a Poisson process of heavy tailed distributed flows, in particular, the Poisson Pareto Burst process (PPBP) [5], [6]. Optimizing both routing and layers falls under the category of multi-layer network design (e.g. [7]–[9]). Existing research has focused primarily on constant (deterministic) traffic streams while in our optimization, we assume that every traffic stream between any OD pair follows a stochastic process (PPBP). The inclusion of PPBP enables the classification of flows based on their sizes and the consideration of dynamic set-up of paths for individual (large) flows and also enables designers to choose between optical network technologies, such as OBS [10], OFS [11], and OCS. For example, if for a certain PPBP end-to-end traffic stream, the flows are sufficiently large to fully utilized a full wavelength capacity, then depending on the cost (or time required) to set up individual paths dynamically for such flows, choices between OBS and OFS can be made. Such cost will also include the cost of sufficient redundancy in the network to avoid losses, or collisions, e.g. in OBS.

Lower layers consume less energy per bit transmitted by several orders of magnitude than higher layers (see Figure 1 of [12]), but can only serve efficiently large volumes of traffic. Internet traffic grows at an annually rate of 34% [13], while at the same time switching technology advance and wavelength bitrate, number of wavelengths per cable also increase. An important question is, given certain assumption on traffic growth and technology advances, what is the optimal apportionment of traffic that uses lower layers (e.g. optical bypass [1]) and avoid higher layers. Such evolutionary trends can also be demonstrated by our new optimization approach. Furthermore, assuming that in future networks IP and Transport networks are controlled and operated by a unified architecture [14], our scalable optimization can be part of such architecture to optimize core network operation.

As entering data associated with large multi-layer networks is challenging, software with friendly user interface is required, we use our Netml system (see [15] and references therein) that includes a user interface to facilitate the understanding and design of layered networks. The Netml system allows users to show and hide and edit the properties of any of individual nodes, links, and traffic-streams of a network. Visualization of the properties of links and traffic streams even in non-physical network layers is very important in order to develop layered network design algorithms.

II. The Multi Layer Optimization Problem

We consider an arbitrary multi-layer communication network in which traffic between any origin destination (OD) is modelled as a PPBP process. Costs of transmission, switching and overheads associated with setting up or maintaining virtual links are given. Transport technologies in the various layers are available in all nodes. We aim to find the optimal physical and virtual topologies and capacity of physical and virtual links that will minimize the cost of transporting the traffic subject to meeting grade of service (GOS) requirements. The particular GOS requirements are to limit overload probability on all links.

Layer 0 is the physical transmission layer. All the other layers have "horizontal" virtual topologies that span the network. Namely, we define a graph associated with each layer where the nodes are the network nodes and the edges connects these

nodes. There are three types of edges in each layer: (i) simple links, which are formed by passing the transport service from a layer below; (ii) virtual-permanent links, which are formed by transport along a series of hops using the switching technology of the layer below; (iii) and dynamic links, which in practice are formed by setting up a path in the layer below whenever a flow requires it while from the point of view of our formulation these links are universally available between all pairs of nodes (although links which carry zero traffic are allocated zero capacity).

Then in each node there is "vertical" network represented by a graph where the vertices are the technologies/layers and edges indicate connection between layers in the same node. A flow that is transported end-to-end may use different layers at different points on its path depending on cost (which also related to efficiency as discussed below). It may also require services of more than one layer at a given node. An important point is that, in general, capacities of edges in some layers comes in discrete values (e.g. WDM).

Using the multi-layer network framework of [7], we consider L layers, labeled from bottom to top: $0, \ldots, L-1$. Layer L is added on top to only represent the end-to-end traffic streams (demands). Recursively, an edge in Layer ℓ is identified with a traffic stream (demand) in Layer $\ell - 1$, for $\ell = L, L-1, \ldots, 1$.

As flow sizes are Pareto distributed, it is convenient to classify flows based on their sizes using truncated Pareto for all flow size classes except the largest ones. For example, consider "mice" (the smallest flows), "kangaroos" (mid-sized flows), "elephants" (the largest flows), then the upper bound of the mice will be the lower bound of the kangaroos, and the upper bound of the kangaroos is the lower bound of the elephants [16]. Each class can represent a separate traffic stream that may be routed differently from other classes between the same OD pair and/or use different technologies.

III. SOLUTION APPROACH

Recognizing the size of the Internet, we seek scalable solutions. We therefore focus first on an algorithm based on the shortest path principle which is prevalent in the Internet and has the key benefits of being scalable and distributed. This algorithm is a heuristic algorithm based on outsourcing demands from higher layers to lower layers, as in implementing a shortest path algorithm and capacity assignment in each layer and a fixed-point iterative algorithm [16].

Our optimization enables, by the use of dynamic links, consideration for costs associated with setting up dynamic paths. Then, certain elephant-based traffic streams may find it optimal for them to set up dynamic lightpath (as in OFS) or bursts (as in OBS) for their large flows instead of using existing paths. Such streams incur special costs associated with setting up dynamic links, but will be compensated as they can use-up an entire wavelength capacity and choose an optimal route.

Important applications of the algorithm are to enable telecom providers to choose between competing technologies that operate in the same layer (either one or the other) or to optimize their use when they both operate in the network. For the former, the algorithm will have to run twice: once with each alternative and excluding the other. For the latter, both technologies will be included in two different layers in the algorithm allowing layer bypass. In such a case, a link in Layer ℓ represents demand for Layer $\ell - 2$ instead of for Layer $\ell - 1$. If we consider a case where there are two alternative technologies in Layers $\ell - 1$ and $\ell - 2$ both used directly by Layer ℓ then Layer ℓ will have two different links between the same pair of nodes one uses a path in Layer $\ell - 1$ and the other in Layer $\ell - 2$. The shortest path algorithm in Layer l will choose the cheaper one. This will mean that we may have two alternative technologies, possibly in the same communication layer operating in the same network which we consider in two different layers in our model.

To validate our shortest-path-based scalable heuristic algorithm for smaller networks, we use a 2-D graph approach, as used, for example, by [8] and referred to there as an *auxiliary graph*. Under this approach we reconfigure the layered network as a unified graph in which each vertex represents a 2-tuple (node,layer) and the edges represent different aspects of data transport in the layered network. This "2-D graph" enables us to recast the original layered network design problem as a traditional multi-commodity flow and capacity assignment problem, for which there is already a rich literature, e.g. [17], [18].

To assign capacity on network links where the load is random, we need to know their statistical characteristics. These are derived using the parametric decomposition method (see [19] and references therein) considering end-to-end PPBP Traffic streams where PPBP processes merge and split in the network [16]. Then, having the statistics of the traffic on each link at any layer, we set link capacities using a queueing or loss model (depending on the relevant layer) according to GoS requirements. Given the link capacities and traffic statistics, we compute the flow-size dependent routing tables for each router which enables flow assignment. In our shortest-path based heuristic algorithm, at each iteration, we adjust capacities, and continue iterating until they converge to a fixed-point solution of routing, choice of layer, and capacity assignment.

IV. CONCLUSION

We have outlined a new approach whereby the network cost is optimized by having individual flows choosing the least cost for them to travel between their origin and destination. The optimization can be applied to traffic engineering, link dimensioning, and technology choices. Furthermore, it will enable prediction of the percentage role of each technology as a function of the traffic load, and for a given traffic growth this prediction can be made as a function of time.

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