Validation of Multi-Layer Network Optimization

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ABSTRACT

We consider the problem of routing and resource allocation in a multi-layer network loaded by a combination of constant bit-rate (CBR) and variable bit-rate (VBR) traffic streams. One scalable heuristic method that addresses this problem is the multi-layer market algorithm (MMA). In this paper we focus on two validation benchmarks of MMA by Integer Linear Programming (ILP). The first is based on the principle of peak rate allocation (all CBR), and the second is a modification of the first that also considers statistical multiplexing suited for inclusion of VBR traffic. The accuracy of MMA is then demonstrated for a small size problem amenable to ILP solution. In addition, we briefly discuss our recently developed method, based on the accounting principle of double-entry bookkeeping, used for verification of MMA correctness.

Keywords: Multi-layer Network Optimization, Integer Linear Programming (ILP), Statistical Multiplexing, Long-range Dependent (LRD), Poisson Pareto Burst Process (PPBP).

1. INTRODUCTION

Internet traffic is continues its tremendous growth – now at a compound annual rate of 33% [1]. In addition, telecommunication networks are becoming increasingly complex with multi-technologies and multi-layer architectures. Multi-layer optimization has been proposed as an effective mechanism for optimizing revenue and reducing cost [2]. The optimization becomes more challenging when considering all factors, such as multiple technologies, layered architecture, realistic traffic modeling, and realistic cost structure. To obtain a near optimal solution for complex multi-layer optimization problems become a critical issue.

Multi-layer network architecture relies on different technologies/layers deployed in the network, for example, IP/MPLS, ATM, SDH, and WDM [3]. This architecture successfully provides solutions on different scales and granularities of services with complex Quality of Service (QoS) requirements [4]. Therefore, it is necessary to optimize the traffic routing, as well as to make economical choices of technology/layer.

Previously, research for traffic model on the multi-layer optimization has assumed a constant demand between each end-to-end pair [5]. However, in practice, the majority of the customers generate bursty traffic. In our model, we assume traffic is a combination of constant bit-rate (CBR) and variable bit-rate (VBR) traffic streams. It justifies consideration of a range of traffic models, such as deterministic, or Gaussian, and Long Range Dependent (LRD) processes modeled by for example the Poisson Pareto Burst process (PPBP) model [6] [7]. A number of studies [8] [9] indicate that the LRD traffic from various sources represents a significant part of Internet traffic.

Multi-layer optimization problems aim to obtain a near optimal solution by minimizing network costs which include CAPEX and OPEX. We consider here the heuristic algorithm first proposed in [10] and then further discussed in [11]. We now call it Multi-layer Market Algorithm (MMA). In MMA, we consider a multi-layer network, and optimize total network cost by choosing routes in all layers and the choices of technologies/layers for each flow.

To guarantee the correctness of the optimization, a validation of the optimization algorithm is provided. In [12], we confirmed the validity of the MMA cost model for multi-layer network optimization. This validation process is based on the principle of double-entry bookkeeping used for detecting errors in accounting system [13].

We demonstrate the accuracy of MMA for a small size problem. We adopt, as a benchmark, an Integer Linear Programming (ILP) solution by which we can obtain an exact optimal solution for small networks. For the ILP benchmark, the traffic steam demands for each origin-destination pairs are assumed to be deterministic. We further modify the ILP model that also considers statistical multiplexing so it can provide a benchmark for the MMA in cases that the MMA include VBR traffic.

2. MMA

As discussed, MMA is a scalable heuristic algorithm for multi-layer network design under constant bit rate, Gaussian and long range dependent traffic [10], [11]. This algorithm provides network design by optimizing the traffic routes, link dimensioning, capacity assignment and choices of technologies in every layer. MMA is carried out in *Netml* [14], where all the data associated with a network can be visually displayed.

MMA iteratively assigns link capacities in each layer to meet the QoS constraints. It adapts shortest path routing using the link costs determined in previous iterations of routing and capacity assignment. Near the start of every iteration, the algorithm ensures that a full collection dynamic links are instituted, for each layer. The traffic streams are statistically multiplexed in each link for each layer. See [16] for more details.

The test network is the six-node network in *Netml* shown in Fig. 1. The traffic is modeled as a mixture of constant bit-rate (CBR) and variable bit-rate (VBR) streams. We assume that there are three traffic flows existing in each Origin Destination (OD) pair. In our experiment, we vary the ratio of the number of OD pairs with fixed CBR traffic to the number of OD pairs with VBR traffic to see the effects on the relative efficiency of the ILP algorithm (with all traffic forced to be fixed and deterministic) to the heuristic algorithm (which use dynamic links and statistically multiplexes the traffic).

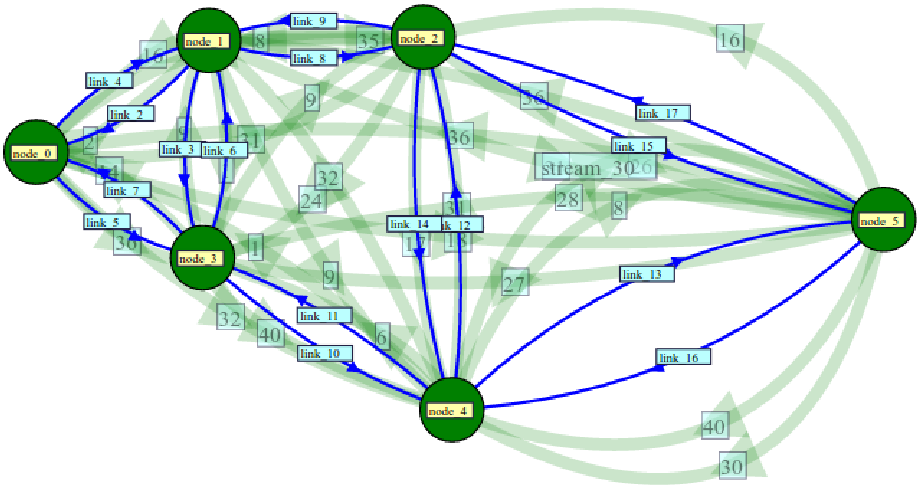

Fig. 1. Netml representation of six-node network

We have validated network cost models based on [12] and thereby verify the MMA correctness in network design optimization. The key philosophy of this validation is to ensure that total network cost calculated from traffic is the same as total network cost calculated from summing the cost of devices, which is similar to the double-entry bookkeeping principles in general accountancy. Based on this validation, a series of rules are proposed to ensure that the costs can be correctly calculated in a multilayer network design problems.

3. ILP-BASED VALIDATION

As a benchmark for MMA, we have developed a new solution based on ILP which has lower complexity than available ILP solutions [15]. We consider a 3-layer telecommunication network with six-nodes topology shown in Fig. 2. For ILP formulation, traffic treams between each end-to-end pairs are modeled as deterministic based Peak Rate Allocation (PRA). For example, for VBR traffic, the PRA can be set to be equal to the mean plus three standard deviations. In this way, all VBR traffic flows can be converted to a CBR traffic streams.

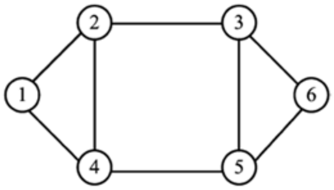

Fig. 2. Six-node network topology

In the experiment, there are 30 directional OD pairs. The mean and variance of the capacity demand of each OD pair are chosen randomly within pre-specified ranges. Then, the capacity assignments in each link and each layer are performed according to these choices.

The bandwidth required on each link is then calculated as the sum of the carried bandwidth requirements of each traffic flow. Multiple flows in an OD pair may share the routing path or have different routing paths, depending on the routing strategy, flow size or Service Level Agreement (SLA) of the flow. In the ILP formulation, flows in the same OD pair are routed independently in the top layer, and these flows can be groomed together in the lower layers to comply with the strategies in the existing deployed networks. We minimize the total network cost by sum up total port cost in all layers and transmission cost in the physical layer.

The ILP model can be further fine-tuned by considering the effect of statistical multiplexing. To achieve this fine-tuning, we still use the results of the previously described ILP model, but in each link for each layer we allocate capacity based on the principle of statistical multiplexing. In particular, the ILP with statistical multiplexing is obtained by two steps. The first step is to use the ILP with PRA to obtain the optimal routing for all the traffic streams; then in the second step we apply statistical multiplexing on each link at each layer to reduce the over-provisioning bandwidth by PRA. Note that, the result of the ILP with statistical multiplexing is still not optimal to the VBR traffic because the routing is still based on PRA, but it definitely provides a better benchmark than the ILP that does not consider statistical multiplexing at all. To solve the ILP formulations, we use a commercial ILP solver, CPLEX [17]. More details of experiments can be found in [16].

In Fig. 3, we compare the total network cost results of the ILP and MMA under various settings, namely, the ILP with PRA, the ILP with statistical multiplexing, and MMA. Fig. 3 demonstrates the benefits of using MMA. Each point in this figure is the average result value of ten experiments.

We demonstrate that in the special case of 100% CBR traffic between every OD pair, the ILP with PRA and ILP with statistical multiplexing slightly outperform MMA. However, as the percentage of VBR traffic increases, MMA increasingly outperforms the ILP solution. This is explained as follows. When both the ILP and the MMA consider PRA, the ILP optimizes the routing, while the MMA routes each traffic stream individually along shortest (least cost) path. This gives advantage to the ILP benchmarks. The cost difference between MMA and ILP benchmarks becomes smaller when the VBR traffic component starts to increase. MMA finally outperforms ILP benchmarks when VBR becomes dominant by taking the advantage of using both statistical multiplexing and dynamic links. Thus, we demonstrate that MMA is superior to both ILP benchmarks in terms of total network costs. However, we must always remember that the main benefit of the MMA is its scalability while the ILP solutions are not scalable.

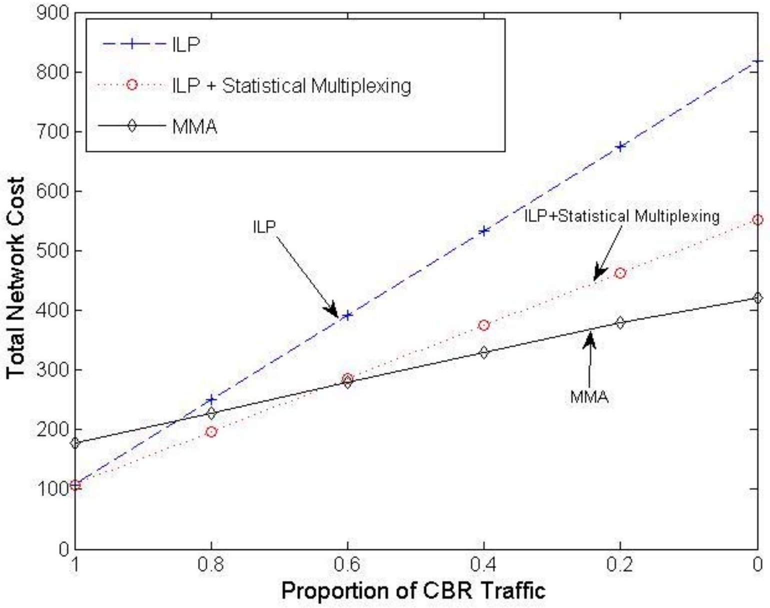

Fig. 3. Comparison results of 3 approaches for optimization of multi-layer network

5. CONCLUSION

We have provided validation means for MMA, first by ILP based the principle of Peak Rate Allocation (PRA) and then by an enhancement that considers statistical multiplexing. These validation means together with our previous approach based on double-entry bookkeeping that ensures correctness on MMA, lead to a scalable and accurate method for a multi-layer network design optimization that is applicable to realistic traffic and arbitrary network size.

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