A Survey on Dynamically Adjusting the Traffic in Network

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Abstract:

Traffic engineering plays a critical role in determining the performance and reliability of a network. A major challenge in traffic engineering is how to cope with dynamic and unpredictable changes in traffic demand. In this paper, we provide a survey of traffic engineering approaches that are aware of routing information gathered from past scenarios and we come up with a history aware traffic engineering model. Despite the fact that the connection-oriented approach targets at overcoming the constraints of the connectionless scheme, MPLS has not prevailed yet. Common intra-domain routing protocols (i.e. OSPF, IS-IS) have been and will continue to be deployed in large networks throughout the Internet. However, both approaches have not been stretched to its limits and there are many areas regarding the incorporation of history information in traffic engineering where further work can be contributed. For example, in most works described, the existence of monitoring information is simply assumed..

Index Terms—Traffic Engineering, multi protocol, network capacity, bandwidth, connectivity.

I. Introduction

The Internet today provides a collection of routers and links managed by Internet Service Providers (ISP). ISP consists of a routing path between any node pair (routers) that limits the throughput achievable between them. Traffic Engineering (TE) implements strategies for a good QoS achieve operational efficiencies and differentiate to their service offerings. TE is defined as that aspect of Internet network engineering dealing with the issue of performance evaluation and performance optimization of operational IP networks. The goal of performance optimization of operational IP networks is accomplished by routing traffic in a way to utilize network resources efficiently and reliably. TE has been used to imply many problems such as load balancing, constraint-based routing, multi-path routing, and fast re-routing. One of research area is single-path routing which can be effectively used for maximum utilization of network resources. The various algorithms discussed give solutions for effectively calculating the single-path and way to minimize delay and increase throughput. We surveyed the various techniques for traffic engineering. Especially, these works can be applied to IP network, then enhance network performance through traffic engineering to meet the QoS requirements.

We can classify the task of TE into two concepts which are intra-domain and inter-domain. The main task of the intra-domain is to optimize customer traffic routing between AS border routers within a single

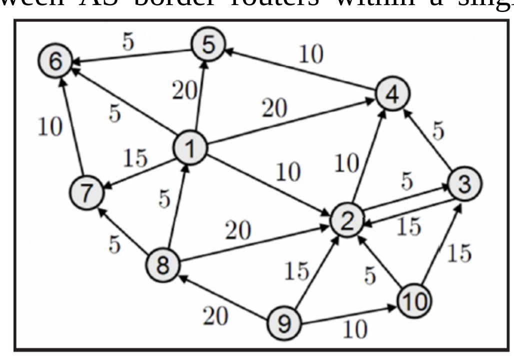

Figure 1 *Graph.*

domain. While inter-domain mainly focuses on how to select AS border router (ASBR) optimally as the ingress/egress points for inter-domain traffic that travels across the local AS.

First we should introduce shortest path problems which are the main idea of TE. Shortest path problems are among the fundamental problems studied in computational geometry, also other areas including graph algorithms, network optimization and geographical information systems (GIS). Given two points s and d on the surface of a polyhedron, find the shortest path on the surface from s (node 6) to *d* (node10). Given source nodes in a weighted directed graph *G*, shown in Fig 1, with *n* nodes and *m* arcs, the shortest path problem from *s* is finding the minimum weight paths from s to all other nodes of *G*.

From Fig1, the shortest path problem, finding the path with minimum distance, time or cost from a source to a destination, is one of the most fundamental problems in network theory. Next we introduce the offline/online traffic engineering and tools for solving problems.

Network Planning, Network Engineering, Traffic engineering

A number of terms are used in the literature to characterize the network operational functions. Network planning is a long-term process used to build a physical network for long-term traffic growth. Network engineering is another process that uses dynamic reconfiguration of links according to the status of the networks, a property that is supported by dynamically configurable circuit-switched networks. Traffic engineering is a shorter-term process used to optimize network resource utilization for traffic demands. In other words, while traffic engineering aims to map traffic to available capacity (on a relatively static topology), network engineering aims to establish capacity where the traffic needs it.

Traffic Engineering Functions

Awduche et al [2] note that a distinctive function performed by Internet traffic engineering is the control and optimization of the routing function, to steer traffic through the network in the most effective way. Traffic engineering also attempts to optimize the characteristics of the network that are visible to users (a.k.a "emergent properties") while taking economic considerations into account. The control function of TE can take two forms: proactive and reactive. A proactive TE control system takes preventive action to obviate predicted unfavorable future network states. A reactive TE control system responds correctively and perhaps adaptively to events that have already transpired in the network. Finally, measurement is a critical function of traffic engineering for operational, accounting and billing reasons.

The optimization function of traffic engineering can be achieved through capacity management and traffic management. Capacity management includes capacity planning, routing control, and resource management. Network resources of particular interest include link bandwidth, buffer space, and computational resources. Likewise, traffic management includes (a) nodal traffic control functions such as traffic conditioning, queue management, scheduling, and (b) other functions that regulate traffic flow through the network or that arbitrate access to network resources between different packets or between different traffic streams. Constraint-based routing is a generalization of QoS routing that take specified traffic attributes, network Constraint-based routing is a generalization of QoS routing that take specified traffic attributes, network constraints, and policy constraints into account when making routing decisions. Constraint-based routing is applicable to traffic aggregates as well as flows.

The control function of Internet traffic engineering responds at multiple levels of temporal resolution to network events. Certain aspects of capacity management, such as capacity planning, respond at very coarse temporal levels, ranging from days to possibly years. The introduction of automatically switched optical transport networks (e.g. based on the Multi-protocol Lambda Switching concepts) could significantly reduce the lifecycle for capacity planning by expediting provisioning of optical bandwidth. Routing control and packet level processing functions operate at finer levels of temporal resolution.

The measurement function is crucial to TE because the operational state of a network can be conclusively determined only through measurement. Measurement is also critical to the optimization function because it provides feedback data that is used by traffic engineering control subsystems. This data is used to adaptively optimize network performance in response to events and stimuli originating within and outside the network. Measurement is also needed to determine the quality of network services and to evaluate the effectiveness of traffic engineering policies as perceived by users, i.e., emergent properties of the network.

II. Related Works

Connectionless Traffic Engineering

Connectionless traffic engineering model counts on traditional Interior Gateway Protocols (IGP), such as OSPF (Open Shortest Path First) and IS-IS (Intermediate System-Intermediate system). OSPF and IS-IS are basically link state protocols based on a shortest path algorithm. They develop and maintain a full knowledge of network routers, as well as how they interconnect. This is achieved via the exchange of Link-State Advertisements (LSAs) used by routers to construct their topological databases. Depending on the link states, the algorithm produces a shortest path tree to all destinations on account of the weights assigned to the links by network administrators. Cisco suggests to use the inverse of the interface available bandwidth as default weights in order to help traffic to circumvent likelihood “hot spots” [5].

The problem of mapping traffic on physical links in connectionless traffic engineering approach boils down to selecting the least-cost routes. The desired result is obtained through the configuration of the appropriate link weights. Most of the difficulties induced in connectionless approach are related to the destination based forwarding paradigm. Data-plane (packet forwarding) mechanism and control plane (routing) functions are coupled. Owing to that, changes in one mechanism mandate changes to the other too. This means software and hardware upgrades that not applicable in large-scale Autonomous Systems (AS). Moreover, traffic source has no control over the path selection procedure. Consider the case where due to some policy/ administrative constraint or a detected network deficiency (i.e. a specified link is out of operation or experiences congestion), the path to be determined should avoid certain links. Since least-cost algorithm resolves the way incoming traffic flows into the network, it selects the shortest paths even if these are overloaded, while longer and underutilized paths are available. Thus, load balance which is a fundamental goal of traffic engineering cannot be met. This holds true even in case of Equal-Cost-Multipath (ECMP). Specifically, although ECMP allows traffic to be carried along multiple paths, the forwarding mechanism performs load sharing across these paths by equally splitting traffic among the shortest that have the same cost on the respective set of next hops.

Despite the aforementioned limitations, it is still a fact that OSPF and IS-IS routing protocols prevail across LANs. Furthermore, many extensions for improving their inefficiencies have been proposed. In particular, OSPF's functionality has been enhanced by QoS extensions described in RFC2676 [13] and in [14]. The specified additions allow supporting best effort and bandwidth guaranteed traffic through pre-computation of a minimum hop count path with the maximum available bandwidth for every destination (i.e. widest-shortest path algorithm). However, traffic engineering extensions have not been implemented yet because they require major upgrades. But still IGPs scalability and ease of deployment have made them widely expanded. The research effort that has been contributed to the area of connectionless traffic engineering is the proof of concept. In most of the work carried out, traffic engineering is accomplished indirectly by affecting link weights. Note that finding optimal link weights for a set of projected traffic demands under constraints is proved to be NP-hard problem.

In one of the earlier approaches [6], a local search algorithm has been developed in the context of a fixed network topology and projected demand matrix, so as to achieve link weights that lead to performance close to optimal general routing. The objective of this problem instance is to minimize a convex, piece-wise linear cost function. This function is based on the idea that is cheap to send a flow over a lightly loaded link while its expensive to send traffic through an overloaded link. Due to the fact that the cost function to be minimized is a sum of costs over all network links, it doesn't favour the "protection" of congested links but it also cares about minimizing loads in the rest of the network. However, changing the link weights entails a transient period when the routers flood LSAs in order to update the calculated weights as well as their routing tables with new shortest paths. This migratory status that the network undergoes during the convergence period is usually translated into formation of loops and of out-of-order arrival of TCP packets.

In order to avoid network instability caused by frequent weight changes, in [7], authors proposed a heuristic for minimizing the number of weight settings. This traffic engineering scheme is also recommended to be used as a decision support tool for reducing congestion in intra domains. The main notion behind the presented framework is to seek for a single weight setting that is good for all periodic changes in traffic load experienced during the day. It must be also mentioned that there is trade-off between the optimality achieved and the number and frequency of link weight changes.

Inspired by [6], several approaches have been proposed. In [8], a genetic algorithm for solving the OSPF weight setting problem is demonstrated. The objective and the formulation of the proposed algorithm are similar to those presented in [6]. The results obtained show that the algorithm produces good-quality solutions for most instances and that better solutions can be achieved for more extensive runs of the genetic model.

Another interesting way of addressing the issue of optimization of OSPF weights is presented in [9]. The packet loss rate has been expressed in terms of bandwidth and buffer space, and an estimate of traffic demands. On this purpose, a GI/M/1/K model has been used for the computation of packet drop probability. A fast recursive random search algorithm has been developed so that link weight optimization be performed frequently and reflect the shift in traffic demands. This scheme outperforms the local search approach adopted in [6] regarding the number of iterations needed to obtain a “good” link weight setting.

Towards the achievement of near optimal traffic engineering solutions, the authors of [12] have proposed a scheme that is based on the manipulation of the next hops for routing prefixes. In particular, for each prefix, a set of allowable next hops is defined by selecting the hops that correspond to shortest paths generated through a linear program. It is shown that for a limited number of routing prefixes for which the installment of next hops is performed, there is no significant degradation in performance and there is an important reduction in configuration overhead. The existence of a traffic matrix is also assumed.

As it can be inferred from the references cited above, the main focus is concentrated on formulating optimization problems based on an estimate of traffic matrix. In the mathematical models stated, linear or non-linear, traffic matrices are translated in terms of cost, delay or packet loss functions by the application of queuing models. By forcing the selected quality parameter to be minimized, these schemes result in the calculation of optimal link weights. Solving such problems is not an easy task and on this purpose, local search combinatorial, genetic algorithms or hybrid approaches are usually chosen. A criterion that determines the selection among these alternatives is the computational complexity. That is of crucial importance especially in cases that solutions obtained must immediately feed a dynamic traffic engineering process such as the online simulation framework used in [9].

Connection-oriented Traffic Engineering

The connection–oriented approach of traffic engineering refers basically to Multi-Protocol Label Switching (MPLS). MPLS has been actually proposed as a means to alleviate the shortcomings of the traditional, unconstrained interior gateway protocols. It has been suggested that one of the most significant reasons for MPLS is traffic engineering [10]. MPLS efficiently supports explicit route set-up between a source-destination pair and hence, the ability to distribute traffic into the network efficiently and keep it in a well-balanced state. In MPLS, packets passing through an ingress router are encapsulated with labels that are then used to forward the packets along the label switched paths (LSPs). The assignment of labels to packets is based on the concept of forwarding equivalence class (FEC). The classification into FECs is done based on the information carried in the IP header of the packets and the local routing information maintained by the ingress router.

The strong point of MPLS is the clean separation between control plane and data plane. MPLS control plane is responsible for establishing LSPs while the data plane performs label swapping operations. This de-coupling between forwarding and control plane allows the introduction of new services by simply changing the way that packets are mapped to LSPs. It also supports overlay capabilities along with all the known advantages that the overlay model has. Traffic engineering with MPLS requires the combination of constrained based routing and the use of enhanced link state IGPs [10]. In contrast to IGP protocols, MPLS allows the enforcement of administrative constraints. Another significant advantage of MPLS is the ability to collect LSP statistics that can be used for the construction of traffic matrix. In addition, it facilitates load balance through traffic splitting based on specified load ratios and it also allows path re-routing. All the above-mentioned features of MPLS pave the way for its transformation to the absolute traffic engineering mechanism. However, MPLS has also problems. Specifically, the signaling mechanism used to establish LSPs burdens the network with further load and complexity. Lastly, other problems regard the triple mapping of: incoming traffic to FECs, FECs to LSPs and LSPs onto the physical topology [10].

MPLS-based traffic engineering has been extensively researched in order to provide solutions that facilitate traffic movement through the network. The volume of the work devoted to the specified area confines our reference to the findings that are based on long-term traffic measurements. Policy-Based Routing (PBR) [11] refers to an interesting approach aware of total expected bandwidth for all source-destination pairs. PBR is aimed at pre-allocating link resources to aggregates of requests based on the multi commodity network flow problem whose objective is to maximize the amount of flow sent through the network. Therefore, towards this end, it is prone to splitting traffic over multiple paths between a source-destination pair. So, though it pays off concerning load balance and network utilization, it proves insufficient in routing high bandwidth demands.

Authors of [15] propose a history directed routing algorithm that can be applied to any connection-oriented architecture that is facilitated with the feature of explicit path routing such as MPLS or the current OSPF routing protocol supplied with QoS extensions specified in [14]. The notion is to try to identify in general how bandwidth between source-destination pairs ranged in connection requests submitted between the same endpoints in past scenarios. This information is processed in an offline mode for deciding on how to manipulate incoming traffic during the online phase. It should be stressed that it is important that the incorporation of history monitoring information in routing procedure doesn't lead to performance degradation in cases where incoming traffic is completely different to what has been provisioned.

From the algorithms reviewed, it is drawn that offline processing of monitoring information is critical for establishing the directives for accommodating incoming traffic through advanced routing control. Its advantage lies in the fact that pre-provisioning of resources is allowed while the processing cost is moved from online to offline phase. On that ground, it appears promising for implementing more sophisticated algorithms since time and computational complexity are not confinements for the offline procedure.

III. Traffic Engineering Model

On the basis of the traffic engineering taxonomies already analyzed and the research effort put in this area, we conclude to the History aware Traffic engineering framework presented in Figure 1. As depicted, the proposed model consists of two fundamental phases: the offline and the online. In the offline phase, traffic measurements are collected from the network and a traffic matrix is generated. The type of the matrix depends on the optimization objectives to be serviced and the online routing algorithms to be applied. Example measures of traffic volumes that can be represented in the traffic matrix include the average, minimum, maximum and so on. What is important to be clarified is that the incorporation of history in routing process is not based on the certainty that the traffic to appear will be close to what occurred in past. The idea is to take advantage of the strong periodicities that Internet traffic exhibits. One reason for this dependency is that most of the traffic carried during the day is professional while residential traffic dominates in the evening. Another crucial step of the offline process is the efficient manipulation of monitored data through the calculation of appropriate link weights or through path pre-computation. This preprocessing will provide feedback to the online phase. It is desirable that the integration of history into the traffic engineering mechanism should be seamless without overthrowing network stability. In this context, the inclusion of history information should be offered as an add on functionality, while its activation should be provided as an optional tool to the network administrator.

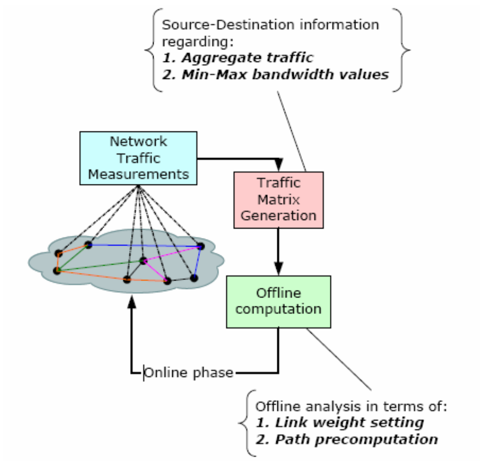

Figure 1: History aware Traffic Engineering model

IV. Conclusions

In this paper, we provide a survey of traffic engineering approaches that are aware of routing information gathered from past scenarios and we come up with a history aware traffic engineering model. Despite the fact that the connection-oriented approach targets at overcoming the constraints of the connectionless scheme, MPLS has not prevailed yet. Common intra-domain routing protocols (i.e. OSPF, IS-IS) have been and will continue to be deployed in large networks throughout the Internet. However, both approaches have not been stretched to its limits and there are many areas regarding the incorporation of history information in traffic engineering where further work can be contributed. For example, in most works described, the existence of monitoring information is simply assumed.

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