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John Ellson
Lily Cheng
Lucent Technologies

Admela Jukan
Vienna University of Technology

Anwar Elwalid
Lijun Qian
Lucent Technologies

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Closed-Loop Automatic Link Provisioning

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Abstract

Classic IP traffic engineering considers a fixed IP layer topology. In this draft, we address the limitations imposed by such static network topology. This work is motivated by introducing dynamically provisioned links to improve static IP traffic engineering constraints, and leverage the freedom of provisioning links on demand.

This draft introduces the concept of a closed-loop link provisioning process for dynamic IP link configuration in an automatically switched transport network. We identify major phases, which completes an automatic link-provisioning cycle. First in the traffic engineering phase, both network internal information and external information can be applied to proactively or reactively triggering circuit switched links. Secondly in the network design phase, we distinguish different types of link design. Finally in the choice phase, we outline a set of criteria for choosing a final link amongst a set of candidate links. The criteria are based on maximizing the value of the user network, where value is computed from: bandwidth, distance, and duration. We propose these criteria be utilized in studies of dynamic link provisioning leveraging automatically switched transport networks (ASTN).

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1. Introduction

1.1 Automatic Link Provisioning

The exponential growth of the Internet coupled with the recent advances in circuit network technologies has created the opportunity for on-demand provisioning of wavelength circuits in automatically switched transport networks (ASTN). This on-demand automatic choice and configuration of circuits to be used in the IP layer is what we here refer to as automatic link provisioning. In such a networking scenario, the fundamental issue is design, ranking, and choice of an IP link, which is to be established by the circuit-switched layer.

Up to now, much work has been done on the "circuit provisioning" side of this equation, but very little work has been done on the automatic design, ranking, and selection on demand of the new IP links.

In this draft, we discuss a closed-loop link provisioning process for an automatically switched IP over a circuit network such as an circuit network. We first define the parameters and network traffic information within the IP network, which relate to the automatic link-provisioning problem. Based on such information, we will decide on the new IP links to be established between pairs of routers. We will also give basic methodologies of choosing among various candidate IP links based on capacity, distance, and link holding times.

1.2 Terminology

In this draft, the IP link refers to the uni-directional physical connection between two IP routers. Note that usually IP links are bi-directional. Any request for a bi-directional link can then be accomplished by two requests, each for an uni-directional link. We distinguish between configurable and non-configurable IP links. A configurable IP link can be dynamically setup and released within the circuit-switched layer, thus may actively change the IP network topology.

We also distinguish between two different types of IP router ports, namely configurable IP router ports and non-configurable IP router ports. A configurable router port can support a configurable link, which can be established by using switched circuits; whereas a non-configurable router port is not capable of dynamic link establishment in the transport layer. In the limit case, all ports (hence all links) are dynamically configurable.

1.3 The Network Model

In this draft, we consider a networking scenario, where a number of IP routers are connected to a circuit-switched transport network, with which they interact in a user-provider relationship. The topology of the circuit network is hidden from the client IP network. The circuit network can be thought of as merely providing dynamically configurable IP links among the IP/MPLS routers in the client network. Here, configurability includes the ability to add a link, delete a link, and modify the parameters of a link.

We consider the IP link establishment within a single IP administrative domain, hence the choice of the signaling protocol, which will carry parameters defined in this paper, is not relevant for the time being. We also further assume that for exchanging and obtaining the network information as defined here, the only reasonable way of choosing between multiple demands for links is by co-operation between routers, which needs new protocol features and standards [newsome00].

In addition, the IP service model as defined by [te-ip-01] with the Traffic Engineering tool, which triggers a boundary client network element to issue a link configuration request towards the circuit domain (either IGP or eEGP peering) can fully support the parameter set as defined in this draft.

1.4 The Scope

By studying the particular example of the IP network (user) requesting a new link within a switched circuit network (provider), our technical approach can apply to a more general issue of any user network type, not just IP.

The performance parameters of interests for the IP links are only taken as constraints to the IP link choice. If a circuit connection setup time is too long with respect to the IP link holding time, the circuit is not considered for a setup.

In order to address the automatic link-provisioning problem, we will pursue the following questions:
- What are the limitations of static IP traffic engineering?
- What are the processes involved in automatic IP link provisioning?
- What are the performance measures involved in a IP link choice problem?
- How to choose amongst candidate IP links?

To answer the above questions, the remainder of this paper is organized as follows: Section 2 first summarizes current IP traffic engineering practice and its limitations. It further elaborates the advantages of IP traffic engineering by considering the automatically switched transport network. This section serves as our motivation of this work. Section 3 addresses our work of designing a fundamental link-provisioning process. Section 4 identifies various information and mechanisms of triggering a link provisioning request. Section 5 illustrates different link types, which can be chosen as candidate links, and their affects to the existing network. Section 6 defines performance measures related to different respects. Such performance measures can be used to quantify performance improvement of a dynamic topology. Section 7 outlines basic criteria for choosing a final link among candidate links. Finally, we summarize this work and give possible future directions in section 8.

2 Traffic Engineering: Limitations and Motivation

2.1 Classic IP/MPLS Traffic Engineering

In traditional IP/MPLS traffic engineering, the underlying network topology is assumed to be relatively static [rfc2702, te-MPLS-diff]. In particular, the links connecting the IP/MPLS routers in the backbone are typically provisioned for a long period of time due to the difficulties of rapid reconfiguration of the links.

The main objective of IP/MPLS traffic engineering is efficient mapping of traffic demands onto the network topology to maximize resource utilization while meeting QoS constraints such as delay and packet loss. The traffic demands may be obtained from measurement, projection, customer prescription, Service Level Agreement (SLA), or combination of the above. The mapping may be done in a multi-period fashion corresponding to diurnal or weekly patterns. In a MPLS network, the mapping is facilitated by establishing explicit label switched paths. In a connectionless IP network, the mapping can be attempted by adjusting IGP weights.

Traffic mapping may be performed by a TE tool, which uses the traffic demand matrix and certain constraints to obtain an optimum solution. The computation is typically done offline since it often involves extensive searches on multi-dimensional solution spaces. Alternatively, traffic mapping may be performed in a distributed fashion, which is typically determined online. Examples include a computation of constraint shortest paths between a source and a destination, and load balancing of traffic among multiple label switched paths between a source and a destination. More classification is addressed in [te-frame].

2.2 Limitation of Static Topology of IP/MPLS Traffic Engineering

Observe that the static topology of the IP/MPLS network introduces limitations. Consider first the case when traffic demands are well estimated a priori. In this case, provisioning needs to be done according to the most stringent traffic demand patterns in a given duration (even under the assumption that the best TE plan, which can take advantages of multi-period traffic pattern is used). Therefore, network resources remain under-utilized when traffic demands are light (e.g., during weekends or evenings) since provisioned links cannot be released easily.

When the traffic demands cannot be estimated accurately, network planning may not be done correctly. For example, if link provisioning is inadequate, traffic demands can exceed the required network resources. This may occur because of forecasting mismatch or the inability of provisioning the network fast enough to meet the growth in resource requirements. On the other hand, it may be necessary to over-provision the network due to the difficulties of forecasting the traffic growth accurately.

Furthermore, if the provisioning cycle (i.e., the time it takes to add resources to the network) is long, resource provisioning needs to take into account the projected traffic growth until the beginning of the next cycle. Consequently the extra network resources may be significantly under-utilized at the early part of a cycle if the projected growth is large.

These limitations motivate our work that traffic engineering must incorporate automatic link provisioning for dynamically configurable circuit networks.

2.3 Issues of IP Over Transport Networks

The problem of automatic link provisioning is more challenging than traditional static IP traffic engineering. The dynamic nature of the IP over switched circuit network introduces uncertainties. Some issues are listed below:

2.3.1 Bandwidth Mismatch

The bandwidth in the IP/MPLS networks is of finer granularity; whereas the bandwidth in the transport networks is of larger granularity. The size of an IP link may be in the order of kbps; whereas the size of a circuit link may be in units of bundled links. Hence, multiple IP links often have to be tunneled into a link to increase bandwidth utilization. Such a requirement makes the traffic-engineering problem one of the optimization problems, which may involve integer programming.

2.3.2 Time-Scale Mismatch

The holding time of an IP link is usually shorter than the holding time of an optical link, since an optical link typically contains multiple IP links. Tearing down one or more IP links may only result in the reduction of bandwidth in an optical link. Tearing down an optical link can only be done if all constituent IP links are torn down, or if the remaining IP links can be re-routed through another optical link.

2.3.3 Cost/Value

Since the establishment of a link incurs a certain cost to the client IP network, it is important that the cost is within a planned budget. This may involve re-optimization and tearing down some circuit links.

The circuit network is a limited resource, it is important that the total value of the links established from a circuit network is maximized.

2.3.4 Link Availability

A traffic engineering design, which takes advantages of multi-period traffic demands, requires tearing down and re-establishing links, or modifying link bandwidth. It is possible that the bandwidth or circuits that are released may not be available again when a new request arrives.

Regardless the aforementioned uncertainties, we recognize that automatic link provisioning is a closed-loop process. Our work is motivated by introducing this closed-loop process to dynamically provision links to improve static IP traffic engineering constraints, and leveraging the freedom of provisioning links on demand.

3. Closed-Loop Link Provisioning Process

This section addresses a closed-loop link provisioning process for dynamic link configuration in the automatically switched network. A closed-loop link provisioning process would automatically configure circuits in the circuit network (Figure 1). We identify several major phases, which completes an automatic link-provisioning process. They are traffic engineering, network design, and link choice phases. The input of this closed-loop provisioning process is the current measure state of the user network, and the result of the link choice phase is a target IP link, which can be configured as a switched circuit. The cycle is closed because changes in bandwidth or topology affect the state of the user network.

An IP network has network internal information and external information, that can be applied to proactively or reactively triggering switched links. Examples of internal information are: packet loss [rfc2680], router overload, port overload, link overload. Examples of external information are: SLA violations, or new SLAs. Such information triggers the network design to automatically configure a IP link. Depending on the triggering information, configuration can be adding, deleting circuit links, or modifying existing traffic parameters.

During the design phase, we distinguish three different types of links, which will be defined in section 5. The types are predicted by the information available from the measurements.

Finally in the choice phase, a set of criteria, for choosing a final link amongst a set of candidate links, is needed. The criteria are based on the consideration of bandwidth, distance, and duration. The design phase identifies a set of links that would satisfy some needs; whereas the choice phase chooses a final set of links based on maximizing total value.

```
             ----------------------------------
               the state of the user network
             ----------------------------|-----
                 ^         |             |
                 |         |             |
               route    reactive       proactive
              updates     data          data
                 |         |             +--------+
                 |         v                      |
               +------------+     +-----------+   |
               | traffic    |     | network   |   v
            +--| engineering|--->-| design    |-+ |
            |  +------------+     +-----------+ | |
            |                                   | |
            |                          candidates |
            |                                   | |
            |                             +-------------+
            |                             | link choice |
            |                             +-----|-------+
-------------------------- UNI -----------------|-----------
            |                                   |
            |                               connection
         connection                          request
          result                                |
            |                                   |
            |           +-------------+         |
            +---<-------| configure   |---<-----+
                        +-------------+
                            ^  |
                            |  v
             ------------------------------------
              the state of the provider network
             ------------------------------------
```

Figure 1 A Closed-loop Link Provisioning Process

For the on-demand provisioning of a new IP link, to be worth doing, the IP traffic characteristics must enable a significant sharing of resources in the provider network. Therefore, it enables a lower cost service, which can be more attractive to the IP network than a static topology.

Within the circuit layer a choice between candidate switched circuits can be made for the IP network in order to have the maximum advantages of a dynamic configuration. All circuits, which may be configured, are within the bounds requested by the IP layer, otherwise the request is rejected. For the remainder of this paper, we will address the tasks of the three phases in detail.

4. Types of Triggering Information and Triggering Mechanisms

For the traffic information that triggers the establishment of a new link, we will distinguish between the internal and external information. Based on either of these information pieces (or both), the performance measures and parameters of importance for triggering will be used in a proactive or reactive way (refer to Figure 1).

While we will define the network information sources and triggering mechanisms for new link request, the protocols and measurements for their achievement as given in [rfc2679] or [te-frame] will not be tackled here.

4.1 Triggering Information

The user network contains information, which can be used to trigger a configuration request. Such information can be either network internal information or network external information.

Network-Internal Information The internal information deals with the traffic statistics collected over a certain period of time, based on which particular traffic flows can be established according to the predictable traffic patterns. The internal information can also trigger the reconfiguration of the existing traffic patterns for more efficient service-level guarantees or network throughput. This information is reactive but can be also used predictively by assuming cyclic traffic patterns.

Network-External Information The network-external information deals with boundary to boundary traffic requests. If such a request identifies an amount of resources that is needed to predict the need for circuits. This information can be neither estimated nor measured. An example of such information might be a new QoS-contract or a new traffic request with stringent service-level agreements. In this case, for example, the predictable traffic patterns as defined by the long-term traffic measurements have to be revised. This information might come from the new IP network clients or from another administrative domain such as BGP information.

Both external and internal information may result in similar connection request, yet they differ in their origin. In the case of the network-internal information the measures of interests (e.g. packet loss) are obtained based on the measurements on routers and data collection within the network. In the case of the network-external information the needed resources can be estimated based on the service contract information related to the new traffic.

4.2 Triggering Mechanisms

Proactive information makes possible traffic shaping for particular purposes, e.g., busy hour, network overload threshold, etc. The proactive mechanism might also use the bandwidth advertising from the circuit network in order to pre-estimate the links to establish. The bandwidth advertising might be invoked periodically.

Reactive information can trigger the establishment of new links upon measured performance, such as packet loss.

4.3 How They Interact

The triggering mechanisms as previously defined are the timely response to the network information necessary for a link set-up. The network failure states are the exemption. A reactive mechanism might trigger a request for new link upon a failure. Table 1 summarizes their interaction.

	internal information	external information
proactive information	busy hour prediction	new SLA
reactive information	packet loss traffic thresholds	

Table 1 Interaction of triggering mechanism and triggering information

5. Choosing a Link Type of Candidate Links

A provider network can add or remove links from the user network. We distinguish three fundamentally different types of links, which can be constructed in response to IP network demands. As illustrated in Figure 2, there are type1, type2, and type3 links. These three types of new links differ not only in the number of hops they "bridge" in the IP layer, but also in the topology changes that occur by adding the new link. For the remaining of this section, we discuss the various effects caused by the possible new links.

```
Type1:       A     a      b      c      d      e      Z
             O-----O------O------O------O------O------O
                          *      *
                          ********

Type2:       A     a      b      c      d      e      Z
             O-----O------O------O------O------O------O
                          *             *
                          ***************

Type3:       A     a      b      c      d      e      Z
             O-----O------O------O------O------O------O
                   *                           *
                   *****************************
```

Figure 2 Three types of new links: type1, type2, type3.

In Figure 2, consider an IP (user) over an circuit (provider) network, where traffic flows from the source node A to the destination node Z. There are three different types of links, which can be configured to add capacity to this traffic flow.

Type1 The link parallels an existing link, thereby increasing the capacity of the route but not otherwise changing the topology of the user network.

Type2 The link is the shortest new link that can be added in some network path around one node. The Topology of the user network is modified and routing tables will need to be modified.

Type3 The link is the longest new link, which can be added in some network between two nodes. The Topology of the user network is modified and routing tables will need to be modified.

In the above definition, by shortest we mean the minimum reduction in hop count for a given path, and by longest we mean the maximum reduction in hop count for a given path.

The distinction between type2 and type3 is subtle. The distinction is in the reason for adding the new link. The type2 link is the one that best satisfies the reactive needs to overloads at a single node based on internal, local-only knowledge of traffic flows; whereas the type3 link is the one that best satisfies the predictive needs identified by some external contract or SLA for future traffic.

6. Performance Measures and parameters

Each link, which is requested for configuration within the circuit network will be characterized by its bandwidth, duration, and distance. We identify performance measures with respect to topology, traffic, and time. These performance measures can be used to quantify performance improvement for the automatic link provisioning networks.

6.1 Topology-related Performance Measures

Switched port utilization is defined as the ratio of the numbers of active ports capable of switching a new link within the circuit network to the total number of all IP routers ports for automatic switching.

This is a very rough measure of the load distribution over the dynamic links in the IP network provided by the circuits, since it makes no assumptions regarding the traffic.

Path length reduction is defined as the ratio of the number of hops between an IP router pair using automatically switched links established within the circuit network to the number of hops for the default routed paths between two routers without new links. For the path length reduction of a single link, the numerator of this ratio is 1.

This is a direct measure of the number of hops "bridged" by a dynamically established link. If a link is established between two neighboring router pairs, then the path length reduction equals one; otherwise, it is smaller than one. Note that if the number of hops is a criterion for service accommodation with delay constraints, this will play an important role. The traffic that traverses a large number of hops should be favored to use dynamic links.

Path length efficiency is defined as the ratio of the total number of hops for all IP router pairs using automatically switched circuit links to the total number of hops for the default routed paths.

This is an indication of the percentage of the number of hops "reduced" in the network by the automatically established links. For a network with any switched links of type2 or type3, it is less than one. In this case, it means that the network only uses up to a certain percentage of its original links. For a network without any switched links or only switched links of type1, it is one. In this case, it means that the network uses the same number of hops with or without the circuit links.

Path length saving ratio is defined as one minus path length efficiency.

This is an indication of the percentage of the number of hops "saved" in the network by using the automatically triggered links. If a network with any switched links of type2 or type3, it is greater than zero. In this case, it means that the network saves some percentage of hops. If a network without any switched links or only switched links of type1, it is zero. In this case, it means that the network doesn't save any number of hops.

Note that the aforementioned parameters: path length reduction, path length efficiency, and path length saving ratio are hop-count measures, which are by no means reflecting actual distance the traffic traveled.

6.2 Traffic-related Performance Measures

Traffic-related performance measures, which is defined below, are more directly related to bandwidth utilization and network efficiency than topology measures.

Switched port capacity utilization is defined as the ratio between the capacity used by an automatically switched link, and the total capacity available to be used by that link.

Since the capacity of an automatically switched wavelength circuit is constant and corresponds to the capacity of a channel (wavelength), the above measure is directly proportional to the encapsulation (multiplexing) and translation efficiency of the IP-data packet flows into the circuit channel signals. This measure is related to the granularity with which the IP traffic is to be reallocated over the newly established capacity.

Total switched port capacity utilization is defined as the ratio of the total capacity used by all the switched ports to the total capacity available to be used by those ports in a switched network.

While switched port capacity utilization indicates the translation efficiency for each individual automatically switched port, total switched port capacity utilization shows the efficiency for all switched ports in the network.

Traffic reallocation efficiency is defined as the ratio of the capacity taken over by a dynamic wavelength circuit (reallocated capacity) to the total capacity which has been estimated to be taken over by that link (overload capacity).

Based on the idea that a dynamically established link is supposed to accommodate those traffic flows, for which the current network load has reached a level which triggers the establishment of the circuit links, this measure refers to the capacity utilization improvement obtained by this action.

Traffic load ratio is defined as the ratio of the traffic load of an IP router before and after activation of one or more ports for automatically switched wavelength circuits.

Packet loss ratio is defined as the ratio of the packet loss of an IP router before and after activation of one or more ports for automatically switched wavelength circuits.

6.3 Duration-related Performance Measures

Traffic integration time is defined as the time over which the traffic is analyzed in order to make a triggering decision for a set-up or torn-down of an circuit.

Link set-up time is the time it takes the circuit network provider to set up the requested circuit.

Link service time refers to the user (IP) network and is the duration that the new circuit is in service.

Link tear-down time is the time it takes the circuit network provider to tear down the requested circuit.

Link holding time is the sum of the link set up time, link service time, and link tear down time.

6.4 Their Relation

Generally speaking, topology parameters are of coarse granularities related to topology changes. Traffic parameters have finer indications regarding how traffic utilizes bandwidth. Adding or deleting switched links will affect topology-related parameters. Traffic-related parameters vary depending on the time instance the performance is measured.

7. Choosing a Link

The problem of selecting a new link that best satisfies demands for bandwidth is a multi-dimensional optimization problem, i.e. one that is mathematically "hard" and probably not possible to compute perfectly, even in principle. In this paper we are proposing to split the problem into two parts: link design, and link choice.

Link design provides a set of potential links that could be set up to meet some traffic need.

Link choice ranks the set of potential links according to value (or more correctly, rate of return on investment), and then presents the reduce set of maximum value to the provider circuit network for implementation. One implication of this is that a Link design may get refused for reasons of insufficient value, not just because of blocking in the circuit layer.

The value of any Link is computed from the expected utilization of: bandwidth*distance*time. Dimensionally: bandwidth is in bits/second, distance is meters, time is seconds. For any single link the logical distance in the user's network is just 1 (meter), so the value of a link is just the number of bits that it is expected to carry in some interval of time.

The cost of a Link can be computed by the circuit network in a similar fashion, as: bandwidth*distance*time. The provider calculates using provided bandwidth rather than utilized bandwidth, and to the provider the distance is a real contributor to the cost and so is probably computed in miles or kilometers. None of this matters much since the result of this expression is multiplied by some factor to give a price, which is what the user sees. Dimensionally this price can be still bandwidth*distance*time, or it can be dollars by multiplying by a rate term. For the purpose of this paper we do not need to consider actual dollar calculations because the value-price operations (comparisons, additions, subtractions) can be made dimensionally valid by using terms that are bandwidth*distance*time.

The price of a Link then can be established when a directory lookup is performed at the UNI in preparation for possibly requesting a new Link from the circuit network. Subtracting price from value gives a number (positive or negative) which can be used to order a set of possible Link designs and thereby choose the ones that provide maximum return on investment.

A similar evaluation must be performed on existing links in order to choose Links, which provide the minimum return on investment and so should be taken down.

8. Summary

Our paper discusses the limitation of traditional IP traffic engineering. This work is motivated by introducing dynamically provisioned links to improve the constraints of existing practices and leveraging the freedom of setting up and tearing down links on demand. We approached the fundamental task of dynamic link provisioning by introducing a closed-loop process.

In the closed-loop link provisioning process, both network internal and external information can be applied to proactively and reactively triggering dynamic link setup or teardown. We have concentrated our work on a set of IP layer performance measures. Associated with the process of automatic link provisioning, we outlined a set of criteria for choosing a final link amongst a set of candidate links, which are based on considerations of bandwidth, distance, and duration. Other QoS-related parameters, such as delay in IP layer, are not considered here and are subject to future studies. Automatic link configuration changes both the network topology and network performance. In order to leverage the freedom of automatic provision links, such a closed-loop process is a crucial component of dynamic traffic engineering.

While we have studied the example of the IP network using an automatically switched transport network, the specific choice of technologies is not essential to this discussion. As discussed in [te-ip-01], our work is applicable to any dynamically switched circuits, which can be any non-packet-switched capable, such as fiber-switched paths, lambda-switched paths, or TDM-switched circuits.

9. Security Issues

This document raises no new security concerns for MPLS signaling.

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11. Author Information

John Ellson
Lucent Technologies, Inc.
101 Crawfords Corner Rd
Holmdel, NJ 07733-3030
Email: ellson@lucent.com

Lily Cheng
Lucent Technologies, Inc.

101 Crawfords Corner Rd
Holmdel, NJ 07733-3030
Email: lilycheng@lucent.com

Admela Jukan
Vienna University of Technology
Institute of Communication Networks
Favoritenstrasse 9/388
A-1040 Vienna, Austria

Anwar Elwalid
Bell Laboratories
Lucent Technologies
Murray Hill, NJ 07974, USA
hone: 908 582-7589
Email: anwar@research.bell-labs.com

Lijun Qian
Bell Laboratories
Lucent Technologies
Murray Hill, NJ 07974, USA
Phone: 908 582-4369
Email: ljqian@research.bell-labs.com