Available online at www.sciencedirect.com

ScienceDirect

Computer Networks 51 (2007) 1725–1743

Computer Networks

www.elsevier.com/locate/comnet

Multi-path routing versus tree routing for VPN bandwidth provisioning in the hose model

Gee-Swee Poo *, Haibo Wang

NTRC, School of Electrical and Electronic Engineering, Nanyang Technological University, Singapore 637598, Singapore

Received 31 May 2005; received in revised form 6 July 2006; accepted 20 September 2006
Available online 17 October 2006

Responsible Editor: L.G. Xue

Abstract

In this paper we study the bandwidth provisioning of VPN service in the hose model with multi-path routing and tree routing. We have investigated the bandwidth efficiency and blocking performance of these two routing schemes. Our study shows that without any restriction on the maximum fraction of traffic on a path (MFTP), multi-path routing often turns out to be single path routing, and only reduces the total bandwidth requirement slightly at rare combination of network topologies and hose parameters. In order to alleviate the overprovisioning problem of the hose model, we propose the concept of sub-provisioning and study the blocking performance using static reduced provisioning. The results show that with full provisioning, the two routing schemes have almost the same blocking performance. However, with sub-provisioning and the variation of the MFTP constraint, multi-path routing is capable of delivering a significant improvement in blocking performance, often better than tree routing by a few orders of magnitude. The improvement is attributed to the multiple alternative paths brought in by the MFTP constraint. With sub-provisioning, the link bandwidth availability becomes the restricting factor in admitting a connection. Having multiple paths, a connection request is able to explore available bandwidth more thoroughly in the network, thus increasing its chances of being admitted. We employ both analytical model and discrete event simulation for the blocking performance study. The analytical model is developed based on the multi-rate reduced load approximation technique and the simulation is carried out using the OPNET simulator. The close agreement between analytical and simulation results indicate the validity of the approach.

Keywords: VPN; Hose model; Multi-path routing; Tree routing; Bandwidth efficiency; Blocking performance

1. Introduction

Virtual private networks (VPNs) [1] provide cost-effective and quality-assured communication between geographically dispersed branch offices of an organization over a shared public network infrastructure. Their goal is to provide a service comparable with a private network established with leased lines.

---

* Corresponding author. Tel.: +65 67904512; fax: +65 67933318.

E-mail addresses: egspoo@ntu.edu.sg (G.-S. Poo), pg03992756@ntu.edu.sg (H. Wang).

1389-1286/$ - see front matter © 2006 Published by Elsevier B.V.
doi:10.1016/j.comnet.2006.09.008

Resource management is essential for providing quality of service (QoS) guaranteed service. Currently there are two resource management models in the context of VPN: the pipe model and the hose model [2]. With the pipe model, the customers are required to specify the traffic demand between each distinct pair of VPN endpoints, and the QoS requirements are conditioned on a pair-wise basis. Thus this model requires customers to know the exact traffic matrix. But as the number of VPN endpoints becomes large, it is very difficult or even impossible for the customers to predict the traffic matrix.

With the hose model, the interface between a VPN endpoint and the service provider's network is abstracted into a hose, comprising an aggregate ingress and egress parameter to specify its bandwidth requirements. For each VPN endpoint v, the ingress parameter $b^{-}(v)$ specifies the maximum bandwidth of traffic that this endpoint could receive from all other endpoints; and the egress parameter $b^{+}(v)$ specifies the maximum bandwidth of traffic that this endpoint could send into the network, to all other endpoints. The customer specifies QoS requirements per VPN endpoint instead of per endpoint pair, and the QoS requirements are conditioned only on the aggregate traffic.

Compared with the pipe model, the hose model provides customers with the following advantages [2,3]:

1. *Ease of specification.* Only one $b^{+}(v)$ and $b^{-}(v)$ per endpoint v needs to be specified, instead of an exact traffic matrix.
2. *Flexibility.* Hose model can accommodate various traffic matrices, thus allowing traffic from one endpoint to be dynamically and arbitrarily distributed to other endpoints, while the pipe model is restricted with a fixed traffic matrix known in priori.
3. *Multiplexing gain.* Owing to statistical multiplexing, the aggregate ingress and egress bandwidth could be less than the aggregate bandwidth of a set of pipes.
4. *Ease of characterization.* Hose requirements are easier to characterize, because the statistical variability of the individual source–destination pair is smoothed by aggregation into a hose.

The hose model could be implemented in a number of routing schemes, including tree routing, single-path routing and multi-path routing. With tree routing, all the VPN endpoints are connected via a VPN tree, and all traffic from a specific source u to a destination v follows the unique path in the tree. With single-path routing, there is also a single path joining every pair of (u, v), but the union of those paths is not necessarily a tree. With multi-path routing, for each pair (u, v) of distinct endpoints, all traffic from u to v is split among multiple paths together with a specification of the fraction of traffic on each path.

As single path routing and tree routing both have the ''one endpoint pair one single path'' property, so the discussion that applies to tree routing often applies to single-path routing as well. In addition, single-path routing could be seen as a special case of multi-path routing. Thus in the remaining part of this paper, we shall concentrate on tree routing and multi-path routing.

Besides sharing the common advantages of the hose model, tree routing and multi-path routing have their own distinct characteristics.

- The pros of tree routing are that it permits simple routing and restoration. With tree routing, there will be a small number of paths and state information. If multiprotocol label switching (MPLS) [4] is used for tree routing, there will be fewer labels and a shallower label stack. If a link fails, all paths traversing that link could be restored altogether by switching to other alternative links. The cons of tree routing include sensitivity to failures, bigger delay due to longer routing paths for some VPN endpoint pairs. Furthermore, tree routing tends to concentrate traffic together, so some links have to carry extremely high traffic, leading to potential congestion problems caused by uneven traffic distribution. In addition, the problem of computing an optimal VPN tree (with the minimum total bandwidth requirement) for general cases with different b^{+} and b^{-} values and finite link capacities is shown to be *NP*-hard [3].
- The advantages of multi-path routing are that it has built-in fault protection mechanism and admits efficient algorithms. Multi-path routing splits the traffic between a (u, v) pair among multiple paths; thus the failure of a single path will not disconnect the pair. In addition, there are known polynomial algorithms for the optimal routing computation of general cases. The weaknesses of multi-path routing stem from the increased maintenance cost and complexity asso-