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J. T. Hao
Huawei Technologies Co., Ltd
P. Maheshwari
Bharti Airtel, Ltd.
R. Huang
L. Andersson
M. Chen
Huawei Technologies Co., Ltd
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Architecture of an IP/MPLS Network with Hardened Pipes

Abstract

This document describes an IP/MPLS network that has an infrastructure that can be separated into two or more strata. For the implementation described in this document, the infrastructure has been separated into two strata: one for the "Hard Pipes", called the "Hard Pipe Stratum", and one for the normal IP/MPLS traffic, called the "Normal IP/MPLS Stratum".

This document introduces the concept of a Hard Pipe -- an MPLS Label Switched Path (LSP) or a pseudowire (PW) with a bandwidth that is guaranteed and can neither be exceeded nor infringed upon.

The Hard Pipe stratum does not use statistical multiplexing; for the LSPs and PWs set up within this stratum, the bandwidth is guaranteed end to end.

The document does not specify any new protocol or procedures. It does explain how the MPLS standards implementation has been deployed and operated to meet the requirements from operators that offer traditional Virtual Leased Line (VLL) services.

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1. Introduction

IP leased line services, Ethernet Private Line (EPL), and Time-Division Multiplexed (TDM) leased line services are commonly offered by operators worldwide.

There are customers, e.g., many enterprises, that insist on TDM leased line services. They do so regardless of the fact that the same operators often offer IP leased line services and EPL services at a lower price and with a guaranteed bandwidth.

Today we see a trend that TDM (in particular, Synchronous Digital Hierarchy / Synchronous Optical Network (SDH/SONET)) networks are gradually carrying less and less traffic, and many operators want to shut their TDM networks down to reduce costs.

In light of these trends, vendors and operators have built and deployed the Hard Pipe service described in this document. It is a way to introduce leased line service with the same characteristics as TDM leased line services in IP/MPLS networks.

Even if leased line has been the initial motivation to define the Hard Pipe technology, the Hard Pipe is by no means limited to support leased line services. When guaranteed bandwidth is the priority,

Virtual Private Wire Services (VPWS), Virtual Private LAN Services (VPLS), L3 Virtual Private Networks (L3VPN), and IP-only Private LAN Services can be mapped to a tunnel in the Hard Pipe stratum.

EPL and Ethernet Private LAN (EPLAN) are out of scope for this document.

Virtual Leased Line service is used in examples throughout this document.

The solution soon to be deployed has an Ethernet infrastructure that has been split into two parallel logical networks -- two parallel strata. The first stratum -- the Hard Pipe Stratum -- does not use statistical multiplexing, and bandwidth is guaranteed end to end. The second stratum -- the Normal IP/MPLS Stratum -- works as a normal IP/MPLS network. The two strata share the same physical network, i.e., routers and links, but the resource reserved for the Hard Pipe stratum will never be preempted by the Normal IP/MPLS stratum.

The routers will handle the traffic belonging to one stratum differently from how traffic from the other stratum is handled. This separation in traffic handling is based on support in hardware.

The reader of this document is assumed to be familiar with RFC 3031 [RFC3031] and RFC 5921 [RFC5921].

1.1. Scope

This document has the following purposes:

- o to introduce a two strata IP/MPLS network: the purpose of one of the strata is to provide capabilities for services that are, from a customer's point of view, functionally identical to TDM-like leased lines; and
- o to indicate how a router differentiates the traffic of the two strata.

1.2. Abbreviations

CC: Continuity Check

CV: Connection Verification

L-label: Leased Line label

LSP: Label Switched Path

LSR: Label Switching Router

MPLS-TP: MPLS Transport Profile

NMS: Network Management System

OAM: Operations, Administration, and Maintenance

P: Provider Router

PE: Provider Edge Router

PW: Pseudowire

T-label: Tunnel label

TDM: Time-Division Multiplexing

tLDP: Targeted LDP

VLL: Virtual Leased Line

VPLS: Virtual Private LAN Service

VPWS: Virtual Private Wire Service

2. The Stratified Network

The concept of stratified or strata networks has been around for some time. It appears to have different meaning in different contexts. The way we use the concept is that we logically assign certain characteristics to part of the network. The part of the network that has the special characteristics form one stratum, and the "remainder" forms a second stratum. The network described in this document uses a single link-layer technology, Ethernet.

In many cases, a whole physical interface is assigned to a single hard stratum, especially in the scenario where there are many physical links between two nodes.

This document does not address the network configuration possibilities for Hard Pipe and IP/MPLS strata in detail. There are configuration options, the basic configuration is that one Hard Pipe stratum and one IP/MPLS stratum are provisioned.

However, it is also possible to provision more than one Hard Pipe stratum, e.g., if customers want enhanced separation for their leased line. Even though the main driver for the Hard Pipe technology is the leased lines, any service for which an operator does not want to use statistical multiplexing will benefit from using the Hard Pipes.

2.1. The Physical Network

Consider a network with 10 routers and all the links between are 10G Ethernet, such as shown in Figure 1. This is the network topology we've used for this model and also (with topology variations) in our first deployment.

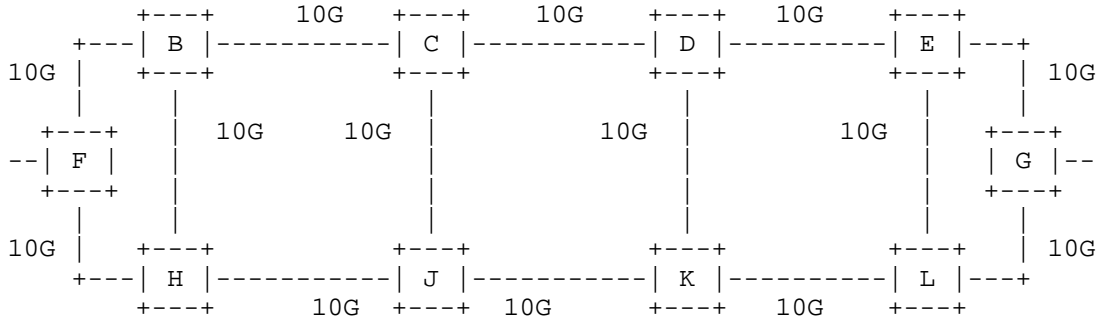


Figure 1

In this document, we use the terms "traffic matrix" or "estimated traffic matrix" to indicate an estimate of how much traffic will flow between the ingress and egress (PE) nodes. This may be translated into how much bandwidth is needed per link in the Hard Pipe stratum.

2.2. The Hard Pipe Stratum

When the intention is to define a Hard Pipe stratum, it is, for example, possible to start from an estimated traffic matrix to estimate how much bandwidth to reserve on the links of the Ethernet link-layer network for the Hard Pipes.

Note that the implication is that the normal traffic gets the remainder of the available bandwidth. Thus, the link-layer network will be split into two logical networks, or two strata -- one stratum for the hardened pipe network and the other for the "normal" IP and MPLS traffic. This is shown in Figures 2 and 3.

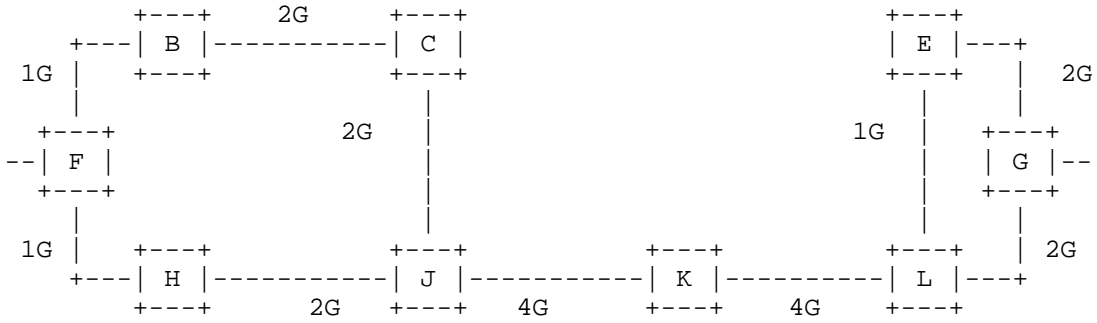


Figure 2: The Hard Pipe Stratum

It is worth noting that even if the figures in this document are drawn to indicate "bandwidth on the link", the only bandwidth information that the nodes have available is the bandwidth assigned to the Hard Pipe stratum and the Normal IP/MPLS stratum. All other information is kept on the NMS/Controller. The NMS/Controller keeps a global bandwidth resource table for the Hard Pipe stratum.

2.3. The Normal IP/MPLS Stratum

Given that the starting point is the physical network in Figure 1 and the Hard Pipe stratum as defined in Figure 2, the Normal IP/MPLS stratum will look as is shown in Figure 3:

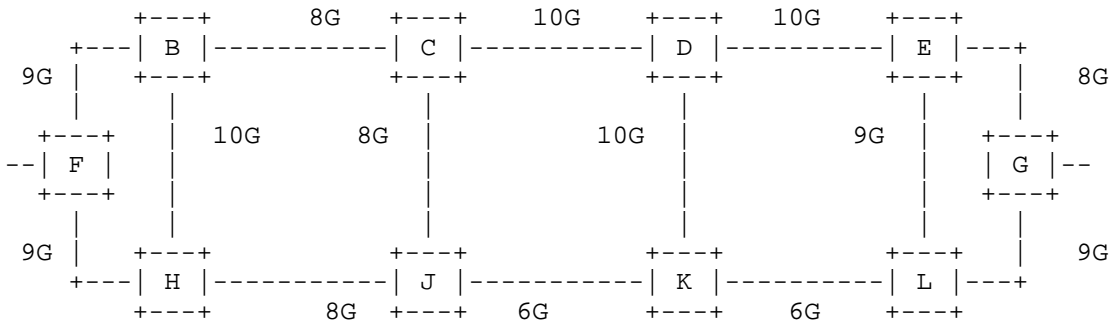


Figure 3: The Normal IP/MPLS Stratum

2.4. Stratum Networks

In this document, the concept of stratum network is used to indicate basically parallel logical networks with strictly separated resources. Traffic sent over one stratum network can not infringe on traffic in the other stratum network.

In the case described here, all the traffic in the Hard Pipe stratum is MPLS encapsulated. A number of the labels have been set aside so other applications can't allocate them and so the routers recognize them as belonging to the Hard Pipe application.

3. Configuring the Leased Lines in the Hard Pipe Stratum

When the strata are provisioned, the IP/MPLS stratum is set up exactly as any other IP/MPLS network. The one small difference between provisioning the Hard Pipe stratum and the IP/MPLS stratum is that no overbooking is done for the Hard Pipe stratum.

Overbooking and/or congestion in the IP/MPLS stratum can not affect the Hard Pipe stratum.

All labels used for the Hard Pipe stratum are "Configured Labels", i.e., labels that are provisioned and reclaimed by management actions. These management actions can be by manual actions or by an NMS/Controller or a centralized controller. For the size of network being deployed, manual configuration is not practical; we are both provisioning and reclaiming a label from an NMS/Controller.

- o If an operator wants to set up a leased line, it is first checked if there is a path available in the Hard Pipe stratum that matches the criteria (e.g., bandwidth) for the requested leased line.

- * If such a path does exist, it is checked if there is a matching MPLS tunnel available over that path.

- + If such a tunnel exists, it is used to establish the leased line by adding L-labels forming an LSP that are carried by the tunnel. L-labels are known only by the ingress and egress LSRs. They are local to the endpoints the same way that the label signaled by Targeted LDP (tLDP) is local to the endpoints of a targeted session LSP. (Here, "Targeted LDP" means LDP as defined in RFC 5036 [RFC5036], using Targeted Hello messages.)

At the same time, the available bandwidth in the Hard Pipe stratum is decremented by the bandwidth that is needed for the leased line for every hop across this stratum in the global resource table (for the Hard Pipe stratum).

- + If such a tunnel does not exist, it can be established so that the leased line can be set up as above.

- * If the path does not exist (not enough bandwidth in the Hard Pipe stratum for the leased line), available bandwidth on the links is checked to see if the stratum can be expanded to accommodate such a path.
- + If the Hard Pipe stratum can be expanded, this is done and the tunnel for the leased line is established as described above.

It is likely that other modifications of the Hard Pipe stratum, e.g., consolidating already set up Hard IP tunnels on to existing links so that room for new leased lines are created, may have implications that go well outside the leased line service, and it is currently not viewed as a fully automated operation.

- + If it is not possible to expand the Hard Pipe stratum to accommodate the new path, set up of the leased line will need to be declined.

Thus, given the existence of a viable Hard Pipe stratum, leased lines are configured in two very simple steps. First, establish a hop-by-hop tunnel (T-labels), and second, configure the leased lines (L-labels). The T-labels need to be configured on both the PE and P routers while L-labels only need to be configured on the PE routers.

Note that L-labels may be used for normal IP service [RFC3031], BGP/MPLS VPNs [RFC4364], or PWs [RFC3985].

4. Efficient State Management

The system as described here generates a very small amount of state, and most of it is kept in the NMS/Controller.

4.1. State in the Forwarding Plane

The only configured information that is actually kept on the LSRs is

- o the information needed for the label swapping procedures, i.e., incoming label to outgoing label and port, and whether the label belongs to the set of labels that are set aside for the Hard Pipe stratum tunnels; and
- o the bandwidth available for the Hard Pipe stratum and the Normal IP/MPLS stratum.

4.2. State in the NMS/Controller

The following state needs to be kept in the NMS/Controller:

- o the topology and bandwidth resources available in the Hard Pipe network; see Figure 2.
- o the total and available bandwidth per link in the Hard Pipe network; see Figure 4.
- o the T-label mappings; see Figure 5.
- o the L-label mappings; see Figure 6.
- o the reserved bandwidth, as well as other constraints and the path per L-label.

4.3. Annotations for Configuring Leased Lines

The annotations given below are neither a programming guideline nor an indication how this architecture could be implemented. It is rather an indication of how much data needs to be saved for each stratum and leased line, as well as where this data could be stored.

Considering the Hard Pipe stratum as it has been outlined in Figure 2, there is actually some additional information related to the Hard Pipe stratum that not is shown in the figure.

Looking explicitly on the link between LSR J and K we find:

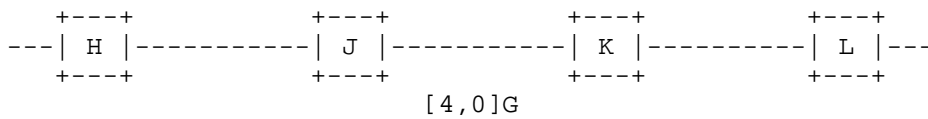


Figure 4

The annotation [4,0]G means that 4G is allocated to the stratum on the link between J and K, and of these, 0G has been allocated to a service.

If we were to allocate two tunnels labels from the labels that have been configured to work within the Hard Pipe stratum, the resource view would look like this:

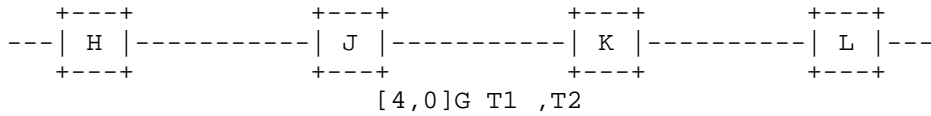


Figure 5

Note that allocating the tunnel labels does not reserve bandwidth for the tunnel from the Hard Pipe stratum.

When the L-labels are assigned, this will consume bandwidth; so we need to keep track of the bandwidth per leased line and the total of bandwidth allocated from the Hard Pipe stratum.

The annotation for the link between J and K could look like this:

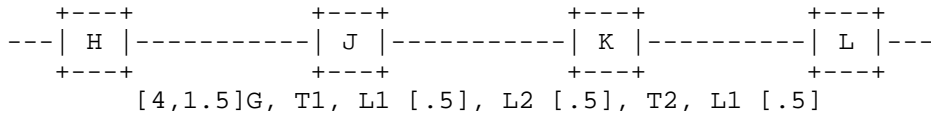


Figure 6

The line [4,1.5]G, T1, L1 [.5], L2 [.5], T2, L1 [.5] would be interpreted as follows:

The Hard Pipe stratum link between nodes J and K has 4G bandwidth allocated; of the total bandwidth, 1.5G is allocated for leased lines.

Tunnel label T1 carries two leased lines, each of 0.5G, and tunnel label T2 carries a third leased line of 0.5G.

Note that it is not necessary to keep this information in the nodes; it is held within the NMS/Controller. Also, it is not necessary to keep the bandwidth per leased line, but some operations are simplified (e.g., removing a leased line) if this is done.

5. Setting Up Leased Lines

Consider the case where an operator wants to set up a leased line of 0.4G from F to G in the Hard Pipe stratum in Figure 2.

Since there are no constraints other than bandwidth and ingress and egress PEs, the shortest path will be chosen. A tunnel will be configured from F to G over the nodes F, H, J, K, L, and G, and a Leased Line label (a) will be configured on F and G, and the available resources will be recalculated.

A second leased line of 0.3G between the same PEs is easily configured by adding a new Leased Line label (b) at the ingress and egress PEs.

After these operations, a view of the Hard Pipe stratum resources (available bandwidth) would look like this:

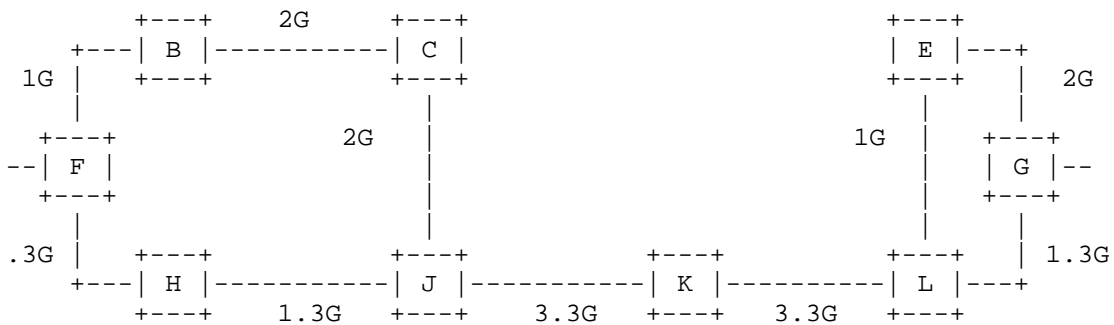


Figure 7: The Hard Pipe Stratum after Operations

If the operator now wishes to establish a new leased line with the criteria being that it should originate from F and terminate at G, have 0.4G bandwidth, and pass through node E, then analysis of the Hard Pipe stratum (after establishing the first two listed lines) and the criteria for the new leased line would give the following:

- o The existing tunnel cannot be used since it does not pass through E; a new tunnel need to be established.
- o The hop from F to H cannot be used since the available bandwidth is insufficient.
- o Since no existing tunnels meet the criteria requested, a new tunnel will be set up from F, to B, C, J, K, L, E (the criteria to pass through E), and to G.

A new L-label (c) to be carried over T2 will be configured on F and G, and the available resources of the Hard Pipe stratum will be recalculated.

6. Leased Line Protection

This leased line service uses the MPLS Transport Profile (MPLS-TP) line protection as it is defined in RFC 6378 [RFC6378] and is updated as specified in RFC 7271 [RFC7271] and RFC 7324 [RFC7324]

The CV and CC are run over the tunnels between the Maintenance Entity Group End Points (MEP) at each end, i.e., the entire tunnel is protected end to end.

In general, all of the MPLS-TP Operations, Administration, and Maintenance (OAM) as defined in RFC 6371 [RFC6371] is v applicable.

7. Security Considerations

The security considerations as defined in "Security Framework for MPLS and GMPLS Networks" (RFC 5920 [RFC5920]) and "MPLS Transport Profile (MPLS-TP) Security Framework" (RFC 6941 [RFC6941]) apply to this document.

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Authors' Addresses

JiangTao Hao
Huawei Technologies Co., Ltd
Q13 Huawei Campus
No. 156 Beiqing Road
Hai-dian District
Beijing 100095
China
Email: haojiangtao@huawei.com

Praveen Maheshwari
Bharti Airtel, Ltd.
Plot No. 16, Udyog Bihar,
Phase IV, Gurgaon - 122015
Haryana
India
Email: Praveen.Maheshwari@in.airtel.com

River Huang
Huawei Technologies Co., Ltd
Q13 Huawei Campus
No. 156 Beiqing Road
Hai-dian District
Beijing 100095
China
Email: river.huang@huawei.com

Loa Andersson
Huawei Technologies Co., Ltd
Stockholm
Sweden
Email: loa@mail01.huawei.com

Mach(Guoyi) Chen
Huawei Technologies Co., Ltd
Q14 Huawei Campus
No. 156 Beiqing Road
Hai-dian District
Beijing 100095
China
Email: mach.chen@huawei.com

