An Analysis of the Financial Benefits of Traffic Engineering and Traffic Management in Wholesale Carrier Ethernet Networks

Network Strategy Partners, LLC

MANAGEMENT CONSULTANTS TO THE NETWORKING INDUSTRY

www.nspllc.com

January, 2009

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TABLE OF CONTENTS

Executive Summary

In recent years Carrier Ethernet wholesale services have been emerging as an important service offering, as Carrier Ethernet technology is the preferred technology for next generation transport in service provider networks worldwide. Ethernet is attractive because it is:

- Ubiquitous
- Cost Effective
- Compatible with IP packet networks
- Supports port speeds from 10 Mbps to 10 Gbps

Service providers sell Ethernet wholesale services to other service providers. These services are used for backhaul of residential services or they are resold as retail Carrier Ethernet services to large and medium businesses. In this paper we analyze traffic generated by 10 Mbps, 100 Mbps, and 1 GbE Ethernet E-Line wholesale services in a hypothetical Tier 1 service provider network.

First generation Carrier Ethernet networks are based on the Ethernet VLAN/Spanning Tree architecture. While this technology is fairly simple and easy to deploy, it has significant scalability and manageability problems. For this reason there has been a great deal of work by companies and standards organizations to make Ethernet into a scalable, manageable transport technology. A focal point of this effort has been the PBB and PBB-TE standardization efforts in the IEEE and the MPLS-TP standards in the IETF.

Gridpoint Systems offers solutions for traffic engineering and resource management in service provider connection oriented Ethernet networks. Gridpoint's E-TERM management application implements a traffic engineering and resource management solution providing multi-constraint, optimal routing of Ethernet service classes across a Carrier Ethernet network. Gridpoint's Carrier Ethernet Embedded Application for switch or DWDM transport vendors implements traffic management at the edge of the network. These functions include traffic shaping and steering of service classes to optimize Ethernet Virtual Transport Resources (VTR).

This study compares the Total Cost of Ownership (TCO) of a Carrier Ethernet network implementing VLANs and spanning trees with a Gridpoint managed connection oriented Ethernet network. More specifically the model compares three alternatives:

1. **VLAN Architecture –** A Carrier Ethernet VLAN and Spanning Tree architecture with no Traffic Engineering or Traffic Management
2. **Ethernet Traffic Engineering & Resource Management (E-TERM) Architecture –** A connection oriented Carrier Ethernet architecture with Gridpoint E-TERM traffic engineering and resource management capability
3. **Ethernet Traffic Engineering, Resource Management (E-TERM) and VTR Architecture –** A connection oriented Carrier Ethernet architecture with Gridpoint E-TERM traffic engineering and resource management capability and Gridpoint Embedded Application VTR shaping capability

A detailed TCO model calculates capital and operations expenses for a typical Ethernet aggregation network in a Tier 1 service provider. The cumulative summary of the TCO for each of the three alternatives defined above is presented in Figure 1. The VLAN architecture uses significantly more network bandwidth than the E-TERM alternatives and therefore has higher capital and operations expenses. Over a five year period the E-TERM alternative results in 19% savings and the E-TERM and VTR alternative results in a 31% savings over the VLAN architecture. It should also be noted that Figure 1 represents the TCO of a single aggregation ring. Typical Tier 1 service providers have multiple aggregation rings in multiple metro areas so these numbers should be multiplied by the total number of aggregation rings to estimate the savings in the entire network.

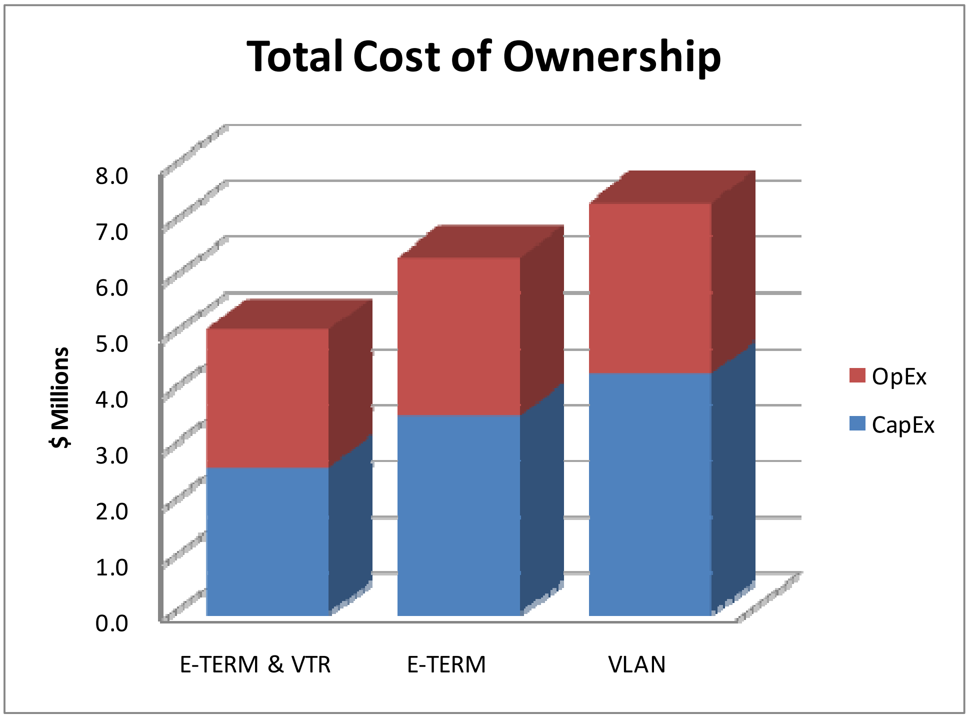


Figure 1
Cumulative Total Cost of Ownership over a Five Year Period for an Aggregation Ring

The body of this paper presents the details and value proposition of Gridpoint's approach to traffic engineering and VTR shaping, the assumptions used in the TCO model, and detailed results of the financial analysis.

Benefits of Traffic Engineering and VTR Shaping

This study demonstrates the financial benefits of implementing Gridpoint's Traffic Engineering and Resource Management (E-TERM) and Virtual Transport Resource (VTR) shaping in networks providing Carrier Ethernet wholesale services. This is done by using a Total Cost of Ownership (TCO) model to compare both the capital and operations expenses of networks with and without traffic engineering and management capabilities.

The following sections provide an overview of the benefits of traffic engineering and resource management and traffic management provided by the Gridpoint solutions.

Benefits of Traffic Engineering

First generation Carrier Ethernet networks using VLAN and various Spanning Tree technologies poorly utilize network resources for two reasons:

- All traffic is restricted to traversing an active spanning tree— over the lifespan of the tree, the active links can change. The provider must reserve bandwidth for a VLAN on all possible links which can carry the VLAN reducing overall network occupancy.
- There is no bandwidth reservation on network links for classes of service

The spanning tree problem is illustrated in Figure 2. The spanning tree protocol finds a spanning tree in a mesh network such that there are no loops. Loops in the Ethernet forwarding plane can result in broadcast storms bringing all forwarding to a halt. In a particular spanning tree, links are either forwarding or blocked. Links which are blocked are not available for Ethernet forwarding. Conversely, in a Carrier Ethernet network with traffic engineering, the spanning tree protocol is disabled and traffic is routed across the network such that link utilization is optimized.

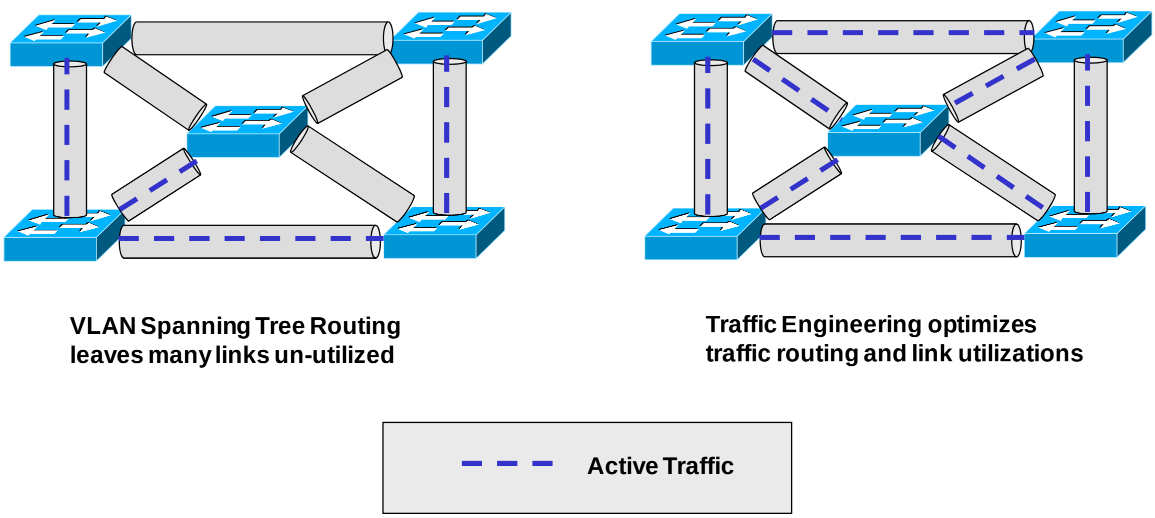


Figure 2
A Comparison of Link Utilization on a Spanning Tree Network vs. a Traffic Engineered Network

The second problem is depicted in Figure 3. In a non-traffic engineered network, bandwidth is not reserved on links for specific classes of service. Therefore, network capacity must be allocated such that average link utilization is low (not more than 50%).

This is because packet traffic is highly bursty by nature. That means that a link with an average utilization of 50% will be very busy for short intervals and unused for other intervals. Alternatively, if traffic engineering with service class bandwidth allocation is implemented, then the average link utilization can be raised. If the network is capable of CoS differentiation, bursty best effort Internet traffic will not affect the performance of stream oriented traffic such as video and voice.

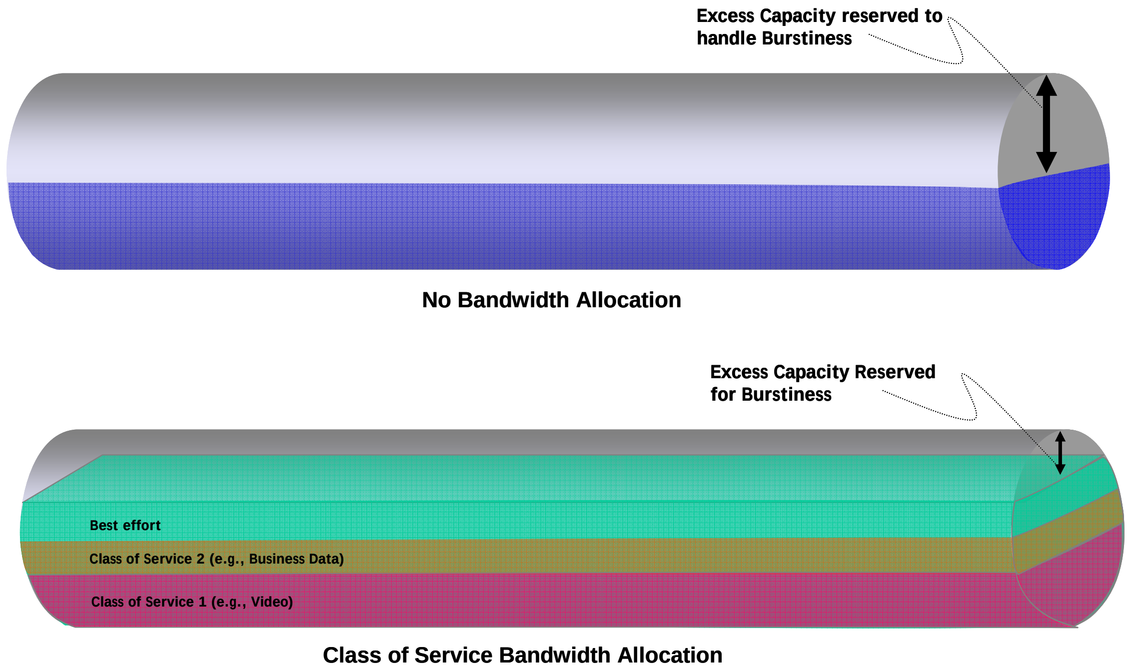


Figure 3
A Comparison of Links with Class of Service Bandwidth Allocation versus No Bandwidth Allocation

Gripoint's E-TERM controls class of service bandwidth allocation and traffic engineering to optimize link capacity assignment. This directly reduces both capital and operating expenses as will be demonstrated later in this paper.

Benefits of VTR Shaping

The key functions of Virtual Transport Resources in a network are:

- reserve a pinned transport path across a Carrier Ethernet Network
- multiplex service traffic which have the same QoS objectives across the network.
- maintain end-to-end connectivity state on behalf of the multiplex services
- monitor the end-to-end performance of the transport connection
- provide traffic management such as shaping packets at the network ingress
- provide end-to-end predictable and deterministic traffic delivery

To ensure that the pinned path meets the required QoS objectives across the network and that the appropriate resources are reserved, a management tool like the Gridpoint E-TERM is required.

Figure 4 is an example of PBB-TE traffic management; packet classification uses the I-component and packet steering uses the B-component of the PBB standard. Packets are steered towards the optimal PBB-TE tunnel using E-TERM traffic engineering rules.

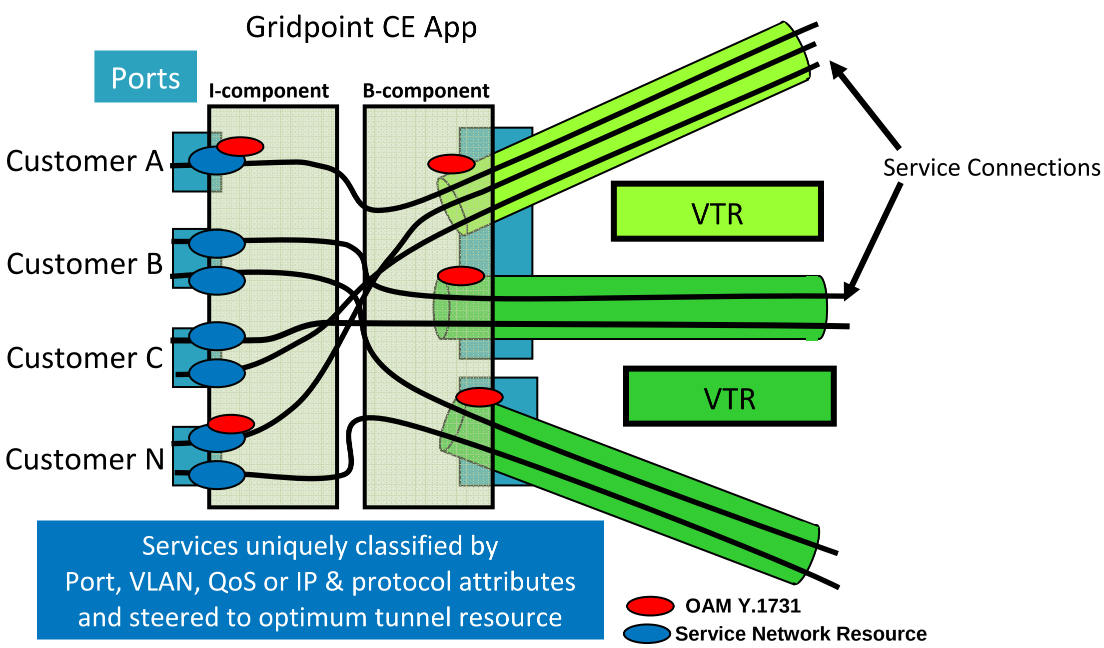


Figure 4
Service Classification and Steering using the I and B Components of a PBB Network

VTR shaping at the ingress of the network is also an important factor in optimizing network resource utilization. Figure 5 depicts a network with no VTR shaping. In this network packets are free to burst at line rate and policing on ingress may not mitigate the size of these bursts. As these packets are aggregated in network trunks, packet burstiness increases and, therefore, packet loss and Service Level Agreement (SLA) violations are a possible consequence. Alternatively, if VTR shaping is implemented at the network ingress as depicted in Figure 6, burstiness is reduced in network trunks. This reduces queuing within the network, helping to make it more predictable and thus giving better control of delay and delay variation to enable a predictable and deterministic infrastructure to be built, whilst also improving resource utilization.

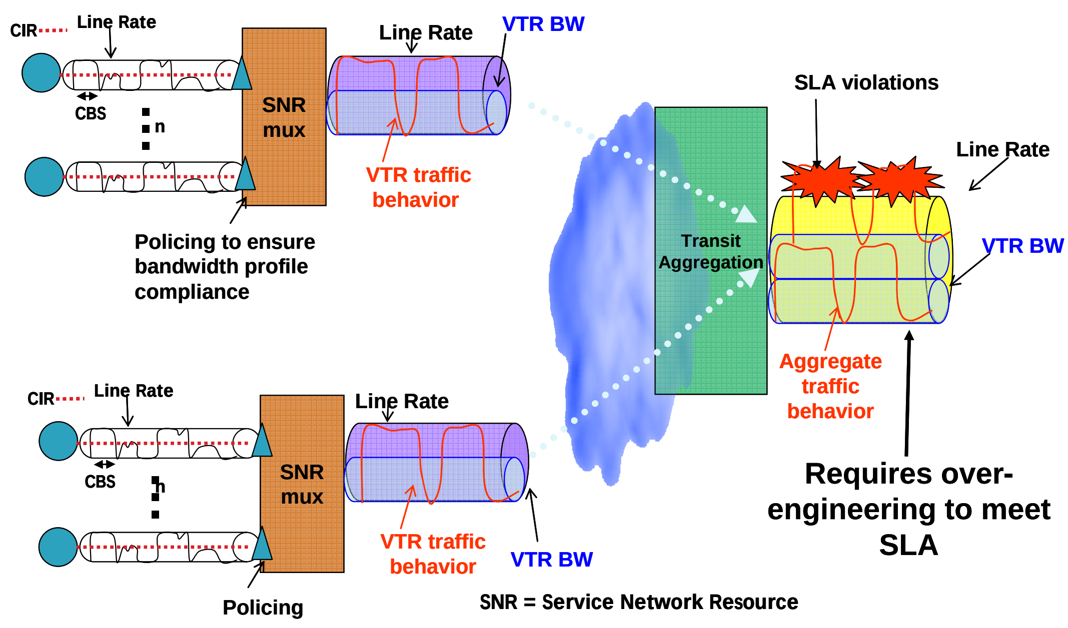


Figure 5
Aggregate Traffic Behavior without VTR shaping

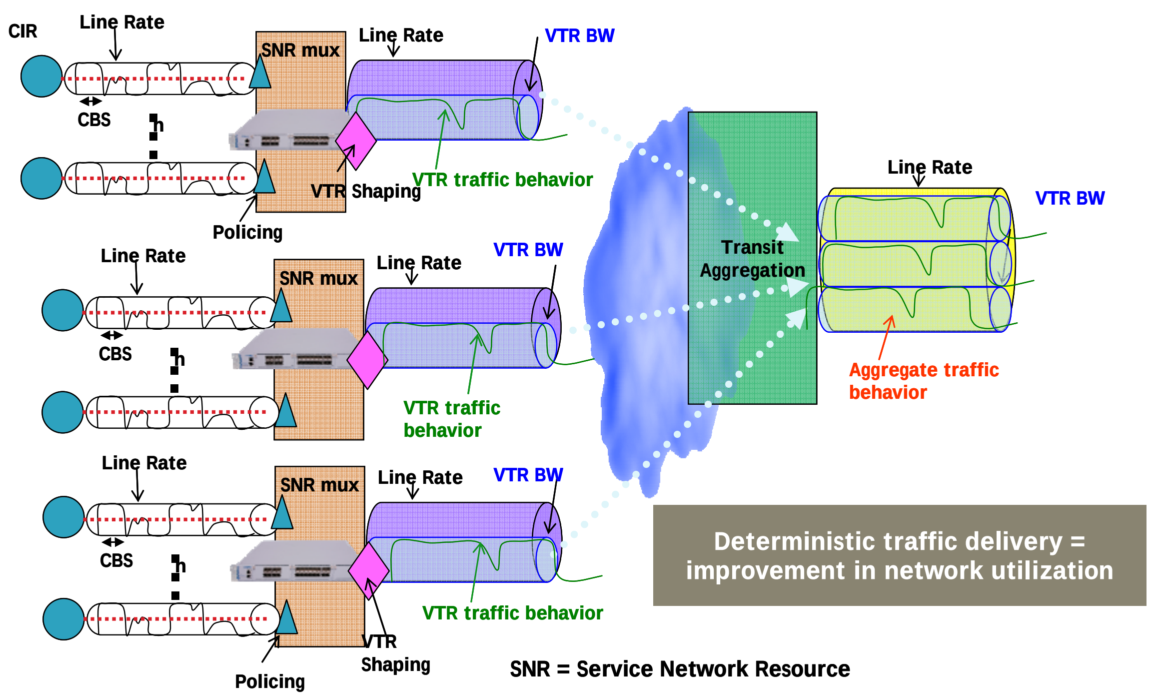


Figure 6
Aggregate Traffic Behavior with VTR shaping at the Edge

Gridpoint's VTR shaping software improves network capacity utilization and therefore directly reduces network capital and operating expenses.

TCO Model Framework and Assumptions

In order to quantify the financial benefits of Traffic Engineering and VTR shaping a Total Cost of Ownership (TCO) model is used to compare three alternatives:

1. **VLAN Architecture –** A Carrier Ethernet VLAN and Spanning Tree architecture with no Traffic Engineering or Traffic Management
2. **Traffic Engineering & Resource Management (TERM) Architecture** – A connection oriented Carrier Ethernet architecture with Gridpoint E-TERM traffic engineering and resource management capability
3. **Traffic Engineering, Resource Management (TERM) and VTR Architecture** – A connection oriented Carrier Ethernet architecture with Gridpoint E-TERM traffic engineering and resource management capability and Gridpoint Embedded Application VTR shaping capability

The details regarding each of these alternatives and the network architecture and service assumptions used in the TCO model are described in the following sections.

Network Architecture Assumptions

The Carrier Ethernet wholesale services TCO analysis models a hypothetical Carrier Ethernet aggregation network for a Tier 1 service provider. The analysis models a single aggregation ring in a metro area as represented in Figure 7. This network is a DWDM ring that interconnects two large Central Offices (COs), three medium COs, and three small COs.

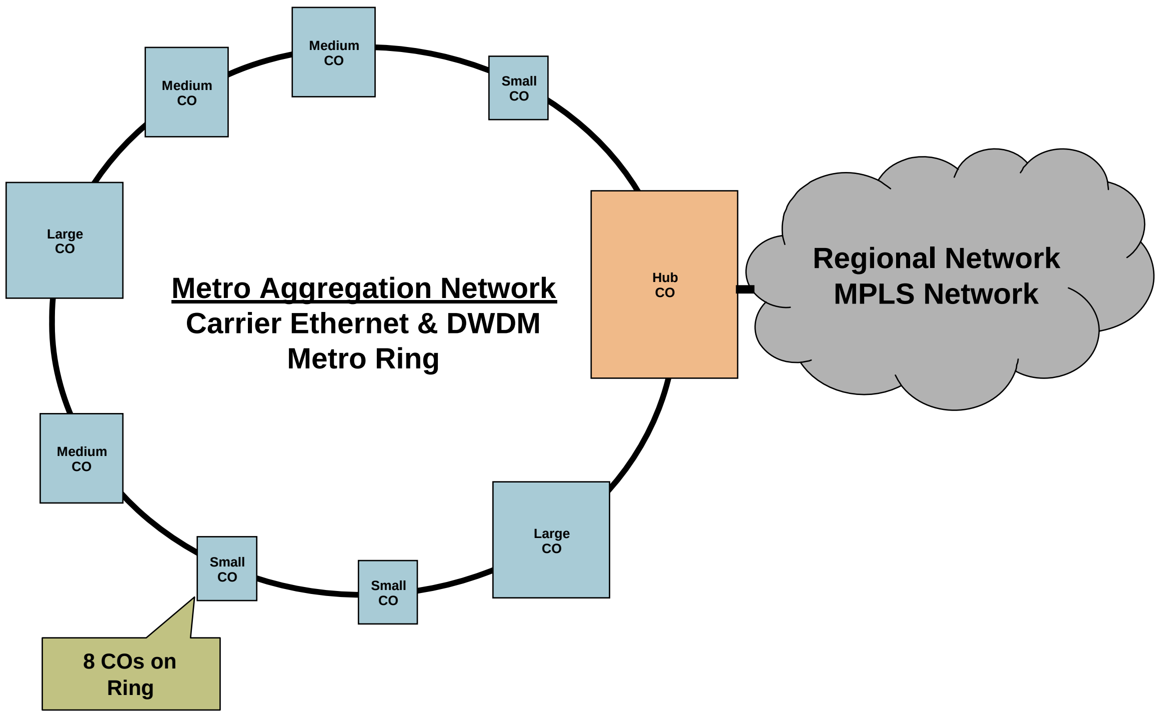


Figure 7
Tier 1 Service Provider Metro Aggregation Ring of Small, Medium, and Large COs

The architecture and physical topology of the Carrier Ethernet aggregation ring is specified in Figure 8. A DWDM metro aggregation ring combined with Carrier Ethernet switching infrastructure is used for packet transport. For large and medium COs a standalone switch provides 1 GbE interfaces to CO equipment[1] and connects to the DWDM transport using 10 GbE. The model calculates the capital expense for both the Carrier Ethernet switching infrastructure and the transponders used in the DWDM transport equipment. In the small COs a Carrier Ethernet blade is integrated into the DWDM transport and provides 1 GbE interfaces to CO equipment. The logical Carrier Ethernet network is represented in
Figure 9. Ethernet switches and blades are connected to the Hub CO using a 10 GbE hub and spoke topology over the DWDM ring. The Hub CO is the point of interconnection with the regional MPLS network and IP service edge routers.

[1] A standalone switch is needed in large and medium COs to support large numbers of GbE ports.

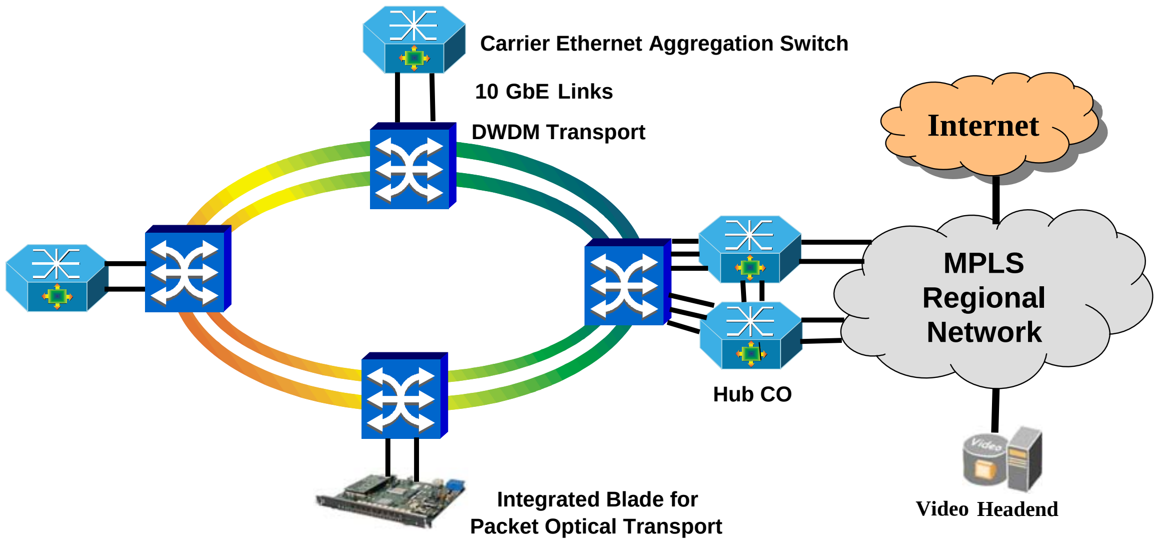


Figure 8
Carrier Ethernet Aggregation Network Physical Topology

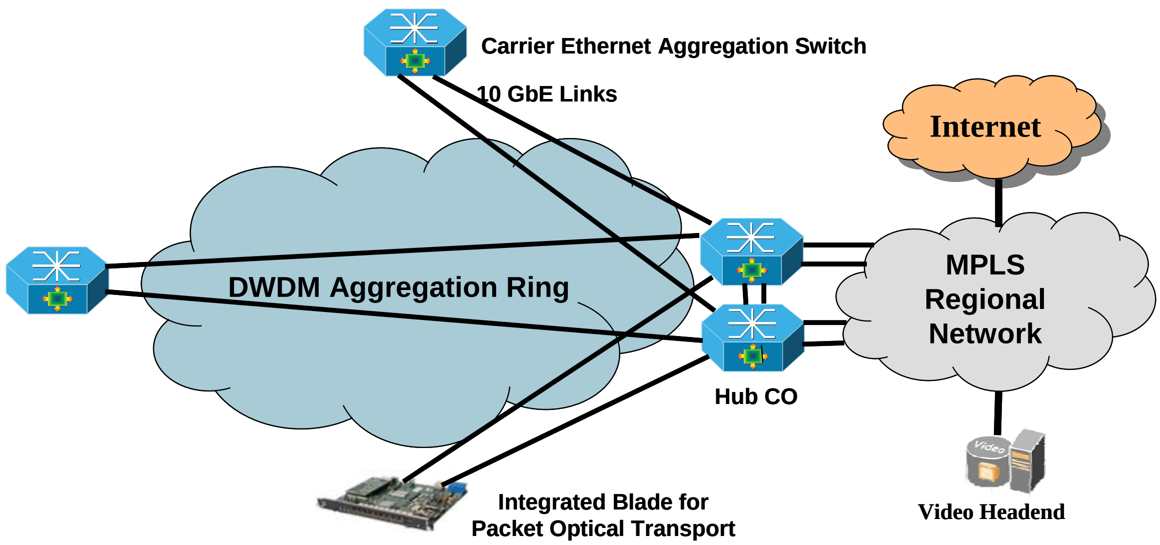


Figure 9
Carrier Ethernet Aggregation Network Logical Topology

Overview of the VLAN Architecture

In order to measure the financial benefits of traffic engineering and traffic management, it is necessary to determine the TCO of the base case: the VLAN architecture. VLAN Carrier Ethernet networks typically use Q-in-Q or similar approaches to encapsulate customer VLAN tags inside service provider VLAN tags. The path available for customer traffic is dependent on the active spanning tree associated with the providers VLAN Packets which are routed using the Spanning Tree Protocol. The VLAN architecture has no traffic engineering and limited traffic management.

The traffic models always allocate network capacity to support at least one link failure (this is true for all TCO scenarios) so for the VLAN network the capacity engineering rule is that the average link utilization during a failure should always be less than or equal to 50% because traffic is very bursty. Thus, if the average link utilization is 50%, sometimes the channel will be congested and other times there will be no traffic at all. In order to ensure that bursty Internet traffic does not interfere with video and other stream oriented traffic, it is necessary to have excess capacity available.

Overview of Gridpoint's E-TERM

The Gridpoint Ethernet Traffic Engineering and Resource Management (E-TERM) is portable software designed to enable scaling of multi-vendor, multi-technology and multi-domain Carrier Ethernet networks by creating an abstracted "off network" traffic engineering layer (see Figure 10). This provides service providers with path planning, traffic engineering and resource management capabilities across multi-vendor and multi-technology Ethernet infrastructures. The E-TERM's innovative algorithms enable service providers to compute QoS compliant, resource optimized paths in large scale networks in seconds.

As a result of E-TERM traffic engineering and service class bandwidth allocation, average link utilizations in the failure scenario can be increased to 80%. An aggregation CO has two redundant links to the hub CO (see Figure 9); if one link fails, then the maximum average utilization on the surviving link is 80%. By comparison, the spanning tree algorithm for a particular VLAN only allows one link to be used in normal operation and the redundant link becomes active if the primary fails. Also the average link utilization in the spanning tree network should not be more than 50% because there is no traffic engineering or bandwidth allocation for service classes. Service class bandwidth allocation allows for tighter packing of the pipe with data services.

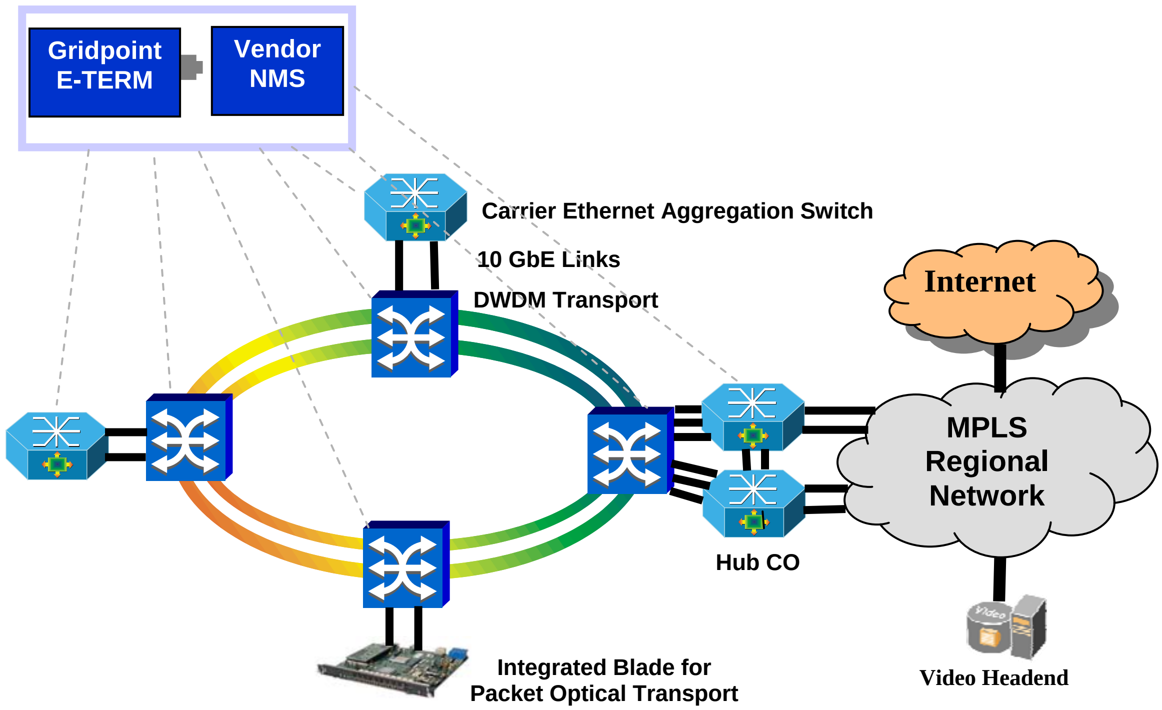


Figure 10
Example of Gridpoint E-TERM Control in a Carrier Ethernet Network

Overview of Gridpoint's Embedded Application

Gridpoint offers an embedded application and hardware reference design for Carrier Ethernet traffic management. The embedded software can be integrated into a Carrier Ethernet blade on a DWDM system or on a blade in a Carrier Ethernet switch. The embedded application provides VTR shaping at the edge and steering of service classes to optimal VTRs allocated by the E-TERM. The functional capabilities of the embedded application are depicted in Figure 4, Figure 5, and Figure 6.

VTR shaping at the edge of the network reduces burstiness in network trunks and therefore the effective bandwidth needed on the link, reducing the capacity used on the link. Effective bandwidth is reduced because the burstiness of the traffic is reduced by traffic shaping at the edge of the network. The concept of effective bandwidth and the equations used to calculate effective bandwidth are presented in the following section.

Wholesale Carrier Ethernet Services and Traffic Projections

The analysis focuses on wholesale Carrier Ethernet services. For the purposes of this study, a hypothetical network with projections for wholesale services specified in Table 1 is created. Projections for Carrier Ethernet services at speeds of 10 Mbps, 100 Mbps, and 1 Gbps are provided for large, medium, and small Central Offices over a five-year period.

		Carrier Ethernet Port Distribution				
Service	Port Speed (Mbps)	Year 1	Year 2	Year 3	Year 4	Year 5
Large Central Office	10	27	30	33	37	41
	100	29	32	35	39	43
	1000	19	21	23	26	29
Medium Central Office	10	17	18	20	22	25
	100	18	20	22	25	28
	1000	8	8	8	9	10
Small Central Office	10	13	14	15	17	19
	100	16	17	18	20	22
	1000	3	3	3	4	5

Table 1
Projection of Wholesale Carrier Ethernet Ports and Services

These Ethernet port projections are used in concert with an equivalent bandwidth calculation to forecast network traffic and capacity requirements over the five year period in this study. Equivalent bandwidth is defined as the bandwidth necessary to minimize latency over Ethernet virtual circuits. For virtual circuits with no burstiness (smooth traffic flows) the equivalent bandwidth is equal to the average data rate of the virtual circuit. For bursty virtual circuits, equivalent bandwidth is larger than the average data rate. Bandwidth must be larger to ensure no performance degradation due to statistically overlapping bursts of traffic at peak rates. For the purposes of this paper the Generic Connection Admission Control (GCAC) algorithm developed in the ATM PNNI specification[2] is used to calculate equivalent bandwidth (EBW). The algorithm used for calculating EBW is:

Mean_Data_Rate * (1 + LN(Peak_Data_Rate/Mean_Data_Rate))

For each of the three alternatives in this study, mean data rate assumptions and calculations for EBW are presented in Table 1. It is assumed that wholesale Ethernet services have fairly high levels of utilization since wholesale services are usually comprised of aggregated retail services. Therefore, mean data rates for wholesale services are assumed to be half of the Ethernet port speed. For the VLAN and E-TERM (without VTR) alternatives there is no traffic shaping – when frames burst into the network they burst at the port speed. Therefore the equivalent bandwidth is calculated using the ATM GCAC equation with the peak rate set to the port speed. In contrast, the VTR solution provides aggregate traffic shaping at the edge of the network, smoothing traffic and reducing peak bursts to the mean rate. Therefore the EBW for the E-TERM and VTR alternative is equal to the mean data rate of the Ethernet port.

The EBW projections are combined with the Wholesale port forecasts to calculate Ethernet traffic on the network over the five year period of this study. The network

[2] The GCAC algorithm is specified in the ATM Forum Private Network-Network Interface Specification Version 1.0 - http://www.ipmplsforum.org/ftp/pub/approved-specs/af-pnni-0055.000.pdf

bandwidth and capacity requirements derived from this forecast are presented in the following section.

Carrier Ethernet Equivalent Bandwidth Projections				
Port Speed (Mbps)	Mean Data Rate (Mbps)	EBW - VLAN (Mbps)	EBW - E-TERM (Mbps)	EBW - E-TERM & VTR (Mbps)
10	5	8	8	5
100	50	85	85	50
1000	500	847	847	500

Table 2
Equivalent Bandwidth required for each of the three alternatives

Comparison of Bandwidth Requirements Across the Models

Using the Ethernet wholesale port projections and EBW calculations presented in the previous section, network bandwidth and capacity requirements are forecasted for the models. The aggregate bandwidth requirements and Ethernet capacity requirements are presented in Figure 11. The aggregate bandwidth requirements are a projection of the total EBW required to support the Carrier Ethernet wholesale services over the five year period in the study. The protected capacity requirements specify the Carrier Ethernet capacity required for dual 10 GbE Ethernet links from each Central Office to the aggregation hub (see Figure 9). Therefore, if 150 Gbps of equivalent bandwidth is required, then 30 X 10 GbE Ethernet circuits are required (or 300 Gbps) of protected Ethernet capacity.

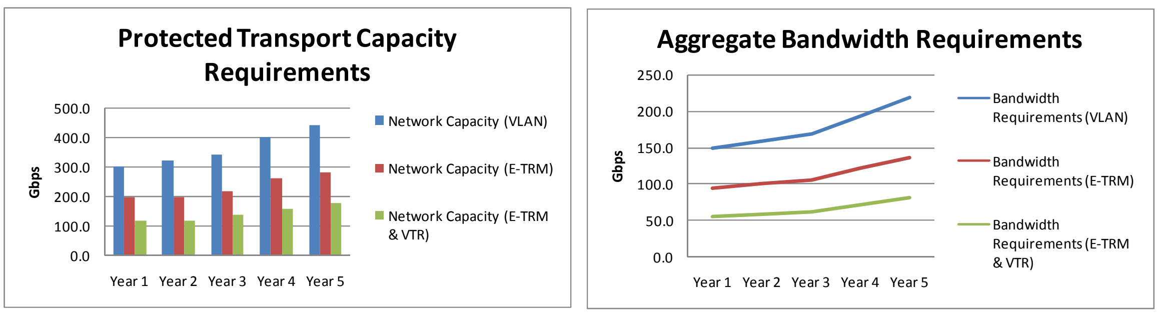
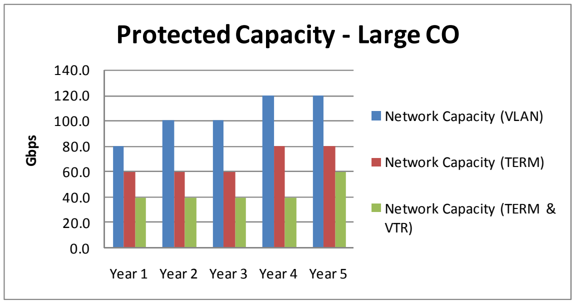


Figure 11
Total Aggregate Bandwidth Requirements and Protected Capacity Requirements for the Carrier Ethernet Aggregation Ring

Similarly, aggregate bandwidth and protected capacity requirements for a large Central Office is displayed in Figure 12. The aggregate bandwidth is the total equivalent bandwidth required for wholesale services into and out of the large CO. The protected capacity is the capacity of all protected 10 GbE Ethernet connections from the large CO to the aggregation hub.

Both bandwidth and capacity savings generated by the E-TERM and E-TERM and VTR solutions are substantial. These savings translate directly to CapEx and OpEx savings that are quantified in the following section of this paper.



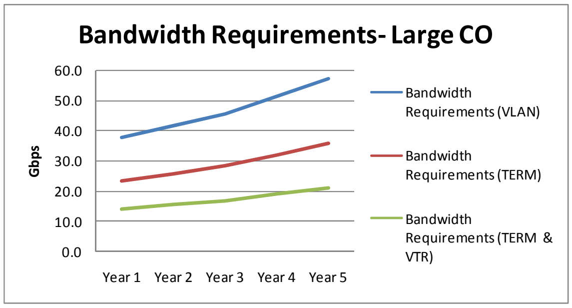


Figure 12
Bandwidth and Protected Capacity Requirements for a large Central Office

TCO Comparison

Using the assumptions specified above, a financial model is used to compare the Total Cost of Ownership (TCO) of each of the three alternatives over a five-year period for a single aggregation ring. It should be noted that most Tier 1 service providers have multiple aggregation rings in a metro area. These numbers, therefore, should be multiplied by the number of aggregation rings in each metro area and again by the number of metro areas in the national or international network. This provides a cost assessment of the entire network. In this paper only the costs associated with a *single* aggregation ring are presented to simplify the analysis.

The model calculates the network capacity required to satisfy the specified demand for Ethernet wholesale services, configures the Ethernet switches and DWDM transponders, and calculates capital and operations expenses. Operations expenses are calculated using a Network Strategy Partners operations model that has be refined over many years.

A summary of the cumulative TCO over five years is presented in Figure 13; capital and operations expenses are broken out. The TCO of each alternative, E-TERM and VTR, E-TERM, and VLAN, for each year is compared in Figure 14. The analysis shows that over the five-year period the cumulative TCO of the E-TERM and VTR solution is 31% less expensive than the VLAN architecture and the E-TERM approach is 19% lower than the VLAN solution.

Capital expenses consist of costs for Carrier Ethernet switches as well as DWDM transponders. A summary of the five-year cumulative CapEx cost break down is presented in Figure 15. This analysis does not consider the cost of shared DWDM equipment (chassis, amplifiers, dispersion compensation units, etc.) as these costs are shared among many legacy circuit based services. Capital expenses for each year in the five-year analysis are presented in Figure 16. This analysis shows how bandwidth savings due to traffic engineering and traffic management reduces the cost of on-going capital investments.

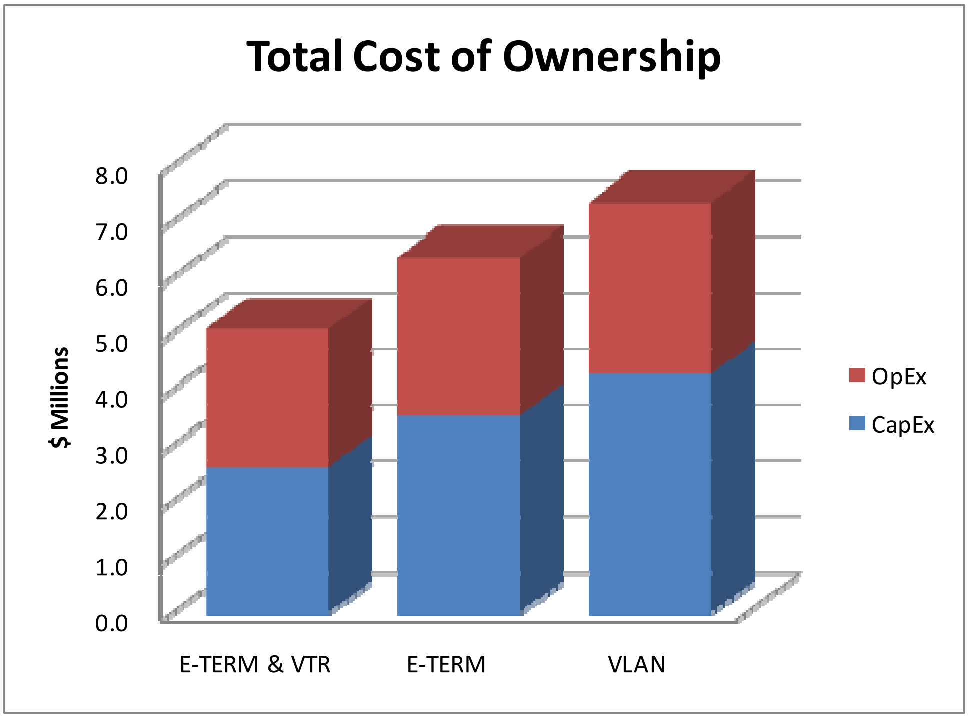


Figure 13
Five-Year TCO Comparison of the E-TERM and VTR, E-TERM, and VLAN Solutions

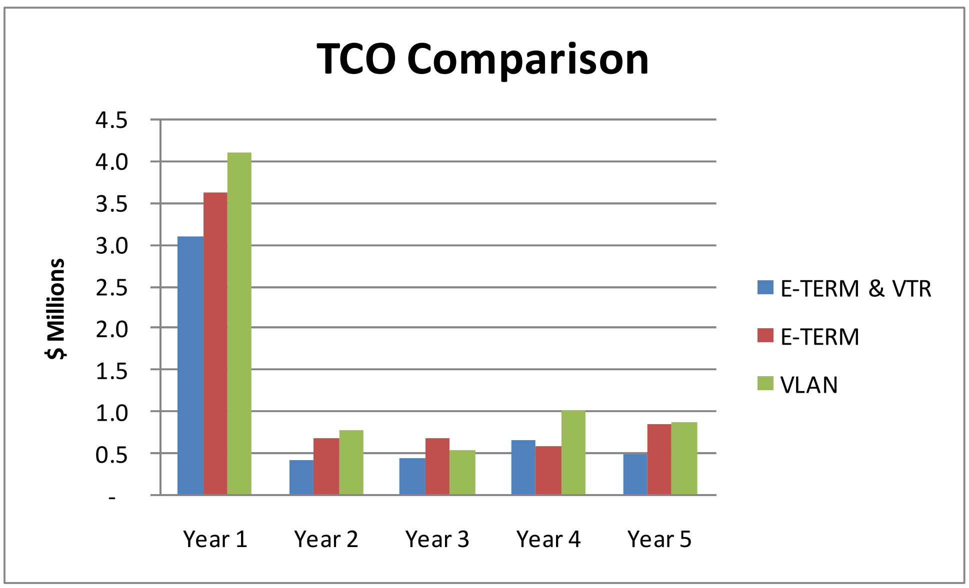


Figure 14
Comparison of the TCO for E-TERM and VTR, E-TERM, and the VLAN Alternatives over Five-Years

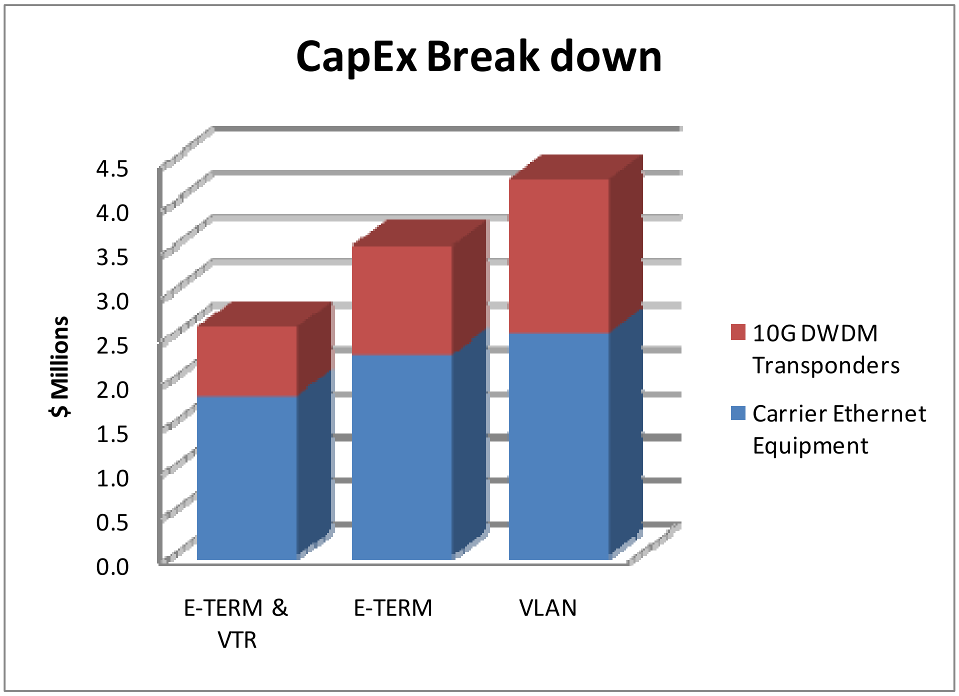


Figure 15
Cumulative CapEx Break Down of Carrier Ethernet Equipment and DWDM Transponders

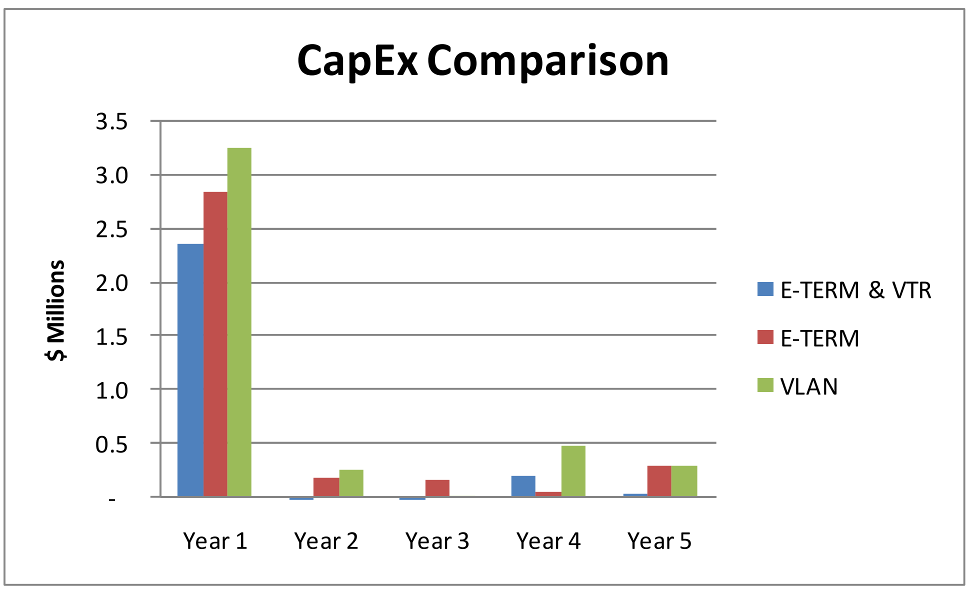


Figure 16
Comparison of CapEx for E-TERM and VTR, E-TERM, and VLAN Alternatives over the Five-Year Period

The cumulative operations expenses are broken down in Figure 17 and each of the categories of OpEx is defined in Table 3. The OpEx considered in this analysis are expenses associated with operating the Carrier Ethernet switching equipment. The analysis does not consider OpEx associated with network transport expenses, fiber plant maintenance, and depreciation. Transport expenses in this model are accounted for by calculating the CapEx required for 10G DWDM transponders. The OpEx model used in this analysis is driven by multiple factors including the man hours required to operate equipment, salary levels for technicians and engineers, environmental expenses, and vendor service contracts. Operations expenses are also driven by the number of switches and cards in the network and the capital expenses (driving the cost of service contracts). The VLAN architecture requires more network capacity and therefore more equipment than the E-TERM and E-TERM and VTR alternatives; resulting in increased CapEx and OpEx.

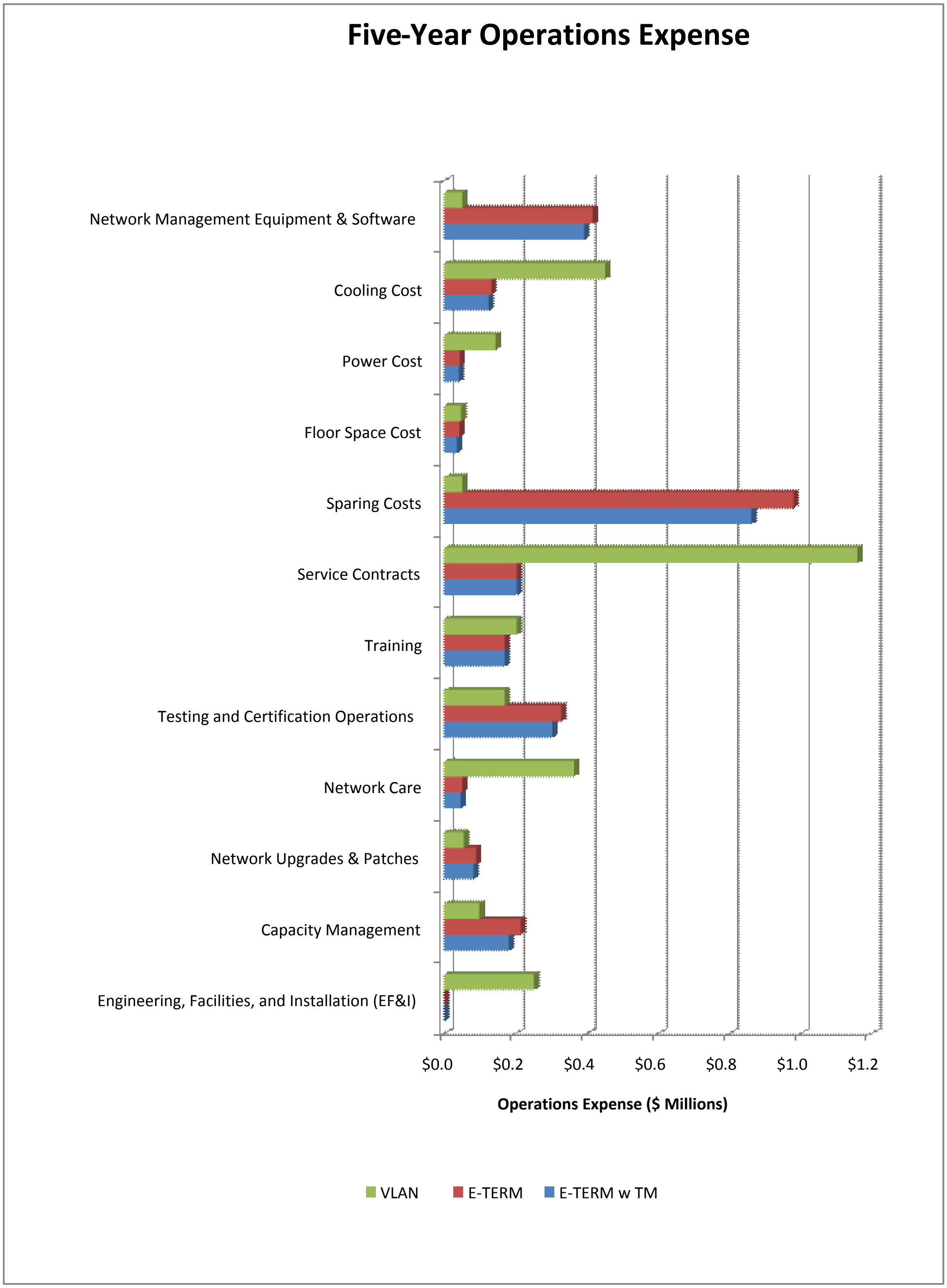


Figure 17
Five-Year Operations Expense

Operations Expense	Definition
Engineering, Facilities, and Installation (EF&I)	This is the cost of engineering, facilities, and installation of network equipment.
Capacity Management	Capacity management is the engineering function of planning and provisioning additional network capacity.
Network Upgrades & Patches	This includes both hardware and software upgrades to the network.
Network Care	This includes network provisioning, surveillance, monitoring, data collection, maintenance, and fault isolation.
Testing and Certification Operations	Testing and certification is needed for all new hardware and software releases that go into the production network.
Testing and Certification Capital	This is capital equipment required for the test lab.
Training	Training expenses are required initially and also on an on-going basis.
Network Management Equipment and Software	This is all the hardware and software required to manage the network.
Network Transport Costs	This is the recurring cost of network transport
Service Contracts	These are vendor service contracts required for on-going support of network equipment.
Sparing Costs	These costs are associated with line card spares.
Floor Space Cost	These costs are associated with the floor space cost/square meter in the CO.
Power Cost	This is the electric utility bill to power equipment.
Cooling Cost	This is the cost of operating the cooling equipment

Table 3
Categories of Operations Expenses Characterized in the NSP TCO model

Conclusion

This study has demonstrated the financial benefits of traffic engineering and traffic management for service providers building networks for wholesale Carrier Ethernet services. E-TERM (Ethernet Traffic Engineering and Resource Management) allows Ethernet services to be mapped into service classes based on service attributes. VTR (Virtual Transport Resources) is a Gridpoint embedded application providing traffic shaping at the edge of the network. Both of these capabilities have been analyzed and compared with the base case: a VLAN spanning tree architecture. E-TERM and E-TERM combined with VTR offer significant reductions in the need for network transport capacity. This translates directly to both CapEx and OpEx savings.