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Backbone Capacity Planning Methodology and Process

A Technical Paper prepared for the Society of Cable Telecommunications Engineers
By

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Overview

Capacity planning at a typical cable MSO can be partitioned into three components: CMTS, access network, and backbone. HSD traffic traverses all three components and serves as the capacity linkage among them. Certain types of traffic, such as commercial, might not touch all three components. Capacity planning at each component has its own unique focus, methodology, process, and tools. This paper focuses on capacity planning for the backbone network.

Capacity planning in the backbone is based on failure state instead of steady state. The objective is to have enough capacity to sustain the network under a failure scenario during times of peak utilization. The network failures taken into consideration are usually single-point failures, including link failure, shared risk link group (SRLG) failure, and sometimes, node failure. Comprehensive failure analysis of a non-trivial network requires a network modeling tool.

To understand how traffic will be rerouted during various failure states, a network model and a traffic matrix are needed. A network model is built by parsing network device configurations using a network modeling tool. A traffic matrix usually comes from flow data or tunnel statistics. When such data is not available or incomplete, the traffic matrix can be constructed by a network modeling tool through demand deduction on interface utilization. A future traffic matrix is constructed by applying growth rate projections to the current traffic matrix. The current network model needs to be updated with planned network changes and upgrades. Failure simulation can be done on the updated network model with a future traffic matrix to derive a layer-3 circuit capacity plan.

The layer-3 circuit capacity plan is used to derive the router equipment capacity plan, such as new routers and line cards. With multi-layer modeling, the layer-3 circuit capacity plan can also be translated directly into layer-1 demands to derive a transport equipment and fiber capacity plan.

The objective of this paper is to provide a complete treatment of the backbone capacity planning methodology, process and tools with sufficient details. Common challenges are discussed, and mitigation strategies are presented[1].

[1] For confidentiality reasons, all data presented in this paper are anonymized and are included for illustration purposes only.

Contents

Introduction

When a cable MSO operates in widely dispersed geographical locations, it usually makes economic sense to build its own backbone to transport data between locations. As we all know, data traffic keeps increasing every year [1]. The question is how much future network capacity will be needed to support the traffic growth, with the consideration of possible failures in a network. This paper attempts to answer the question by introducing the Time Warner Cable (TWC) backbone capacity planning methodology and process.

In a backbone network, there are mainly three types of network elements relevant to capacity planning: IP routers, IP links and optical equipment. An IP router forwards IP packets to their destinations on a hop-by-hop basis. An IP link connects two IP routers. Optical equipment employs light wavelengths to transmit data over fiber. Each element has a certain capacity limit which cannot be exceeded. Some common capacity measurements are listed in Figure 1.

Network Element	Capacity Measurement
IP Router	Total port count
IP Link	Total bandwidth
Optical equipment	Total number of wavelengths

Figure 1. Network Elements and Capacity Measurements

Data collection is the starting point of capacity planning process. Collecting as much relevant data as possible, including router configuration files, traffic statistics (or traffic stats for short), data flow information, and CMTS statistics helps to form a rich history of how much capacity has been gradually built into the backbone and how the capacity has been consumed by data traffic. Based on the history, it is then possible to project the future capacity requirements through comprehensive analysis.

To project future capacity requirements, the traffic growth needs to be considered in conjunction with network design goals and guidelines. At TWC, the backbone is designed to sustain a single network element failure, such as a link failure or a router failure. Obviously, such design requires extra capacity to be installed around failure points. In order to determine the additional capacity requirements, network modeling tools are used to perform comprehensive failure simulation analysis. Most modeling tools automatically discover the network elements and understand how a network reacts to a failure. These tools can simulate all possible failures and record the capacity impacts of each failure. The worst case scenarios are selected to project the needed capacity to mitigate the worst failure cases. Once required capacity is determined, it can be translated to equipment planning to determine if new router hardware and optical gears are needed.

A high level backbone capacity planning process flow is illustrated in Figure 2. In the following sections, each process will be described in detail.

Network Modeling → Growth Projection → Failure Simulation → Bandwidth and Equipment planning

Figure 2.Typical Backbone Capacity Planning Process Flow

Network Modeling

Network modeling abstracts network elements and their relationships from an actual network into an informational model. In addition, network modeling also captures the traffic dynamics of a network and models such dynamics with a set of representative statistics. Therefore, a network model has two major pieces. One is the network topological model including routers, links and various properties associated with them. The other piece is the traffic model on top of the topological model.

Topological Model

Most planning tools automatically discover network elements to build a topological model. This is performed by periodically collecting router configuration files and parsing them to extract topological information, which can be visualized through a topological map, as shown in Figure 3.

One of the technical challenges is that the network is constantly changing. Network failure event like fiber cuts does happen. Planned events such as capacity augmentation or router upgrades as Business As Usual (BAU) activities change the network on a regular basis. The modeling tool may fail to collect data due to, for example, access errors. Consequently, the topological model generated by auto-discovery may keep changing and some changes are not desired. When the topological model changes, it has a ripple effect to other business activities such as data reporting and forecasting. To avoid spending time and effort adjusting business activities to match auto-discovery results, a database was created to store a more stable topological model which serves as an extra layer to filter out noise from the auto-discovery function. The database is used for many business purposes and it is also periodically checked against the auto-discovery results to keep the model up to date.

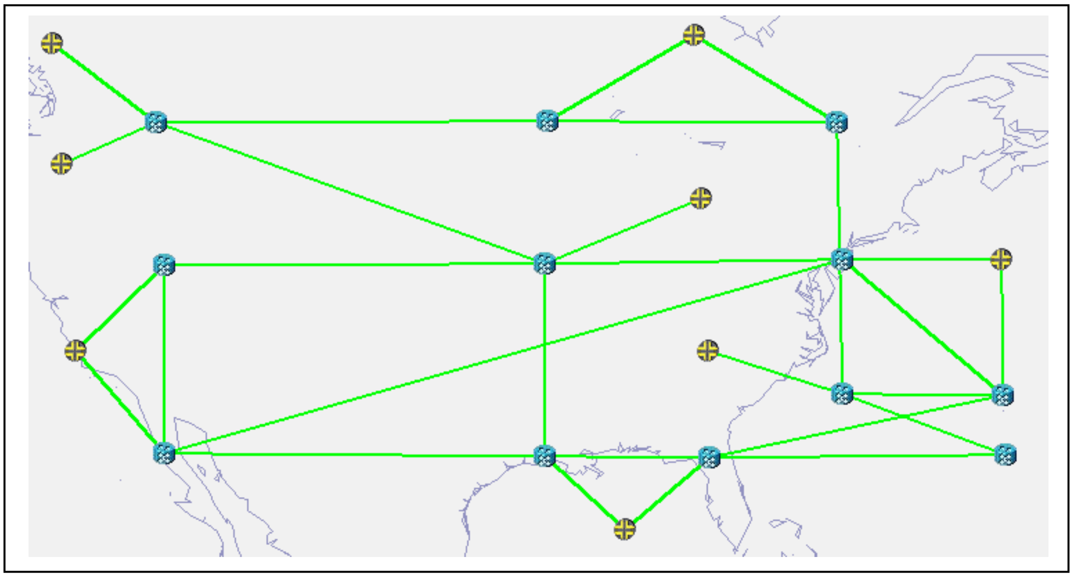


Figure 3. Topological Map Example

Traffic Model

The traffic model provides the foundation for traffic growth analysis and failure simulation analysis. Therefore, another key activity in capacity planning is to model traffic characteristics and patterns as accurately as possible. Without an accurate traffic model, the quality of the mathematical trending analysis tool or simulation software will not matter.

Discovering and understanding traffic patterns improves capacity planning practices. A good traffic model should reflect discovered patterns. Consider that a typical cable customer surfing the Internet or watching an online video, will download much more content than is uploaded. This end user behavior determines an important traffic pattern seen by most cable MSOs: the data traffic is bi-directional, but the traffic volume is asymmetric. From a backbone point of view, the majority of traffic is coming from the Internet, traversing the backbone, and then sinking in regions or markets, as illustrated in Figure 4.

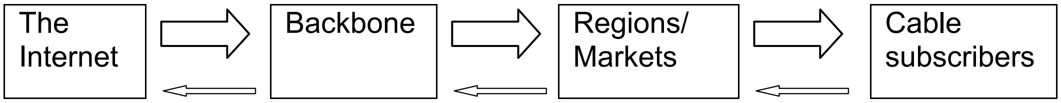


Figure 4. More Downloading than Uploading

Another traffic pattern is also related to end user behavior. Because most cable customers use their home networks in the evenings, traffic traversing the backbone increases after 7pm local time, peaks at about 11pm-12am, and then slowly decreases after midnight. For this reason, the FCC defines the utilization peak hours as 7pm to 11pm [2]. Figure 5 shows how traffic volume changes during a typical day.

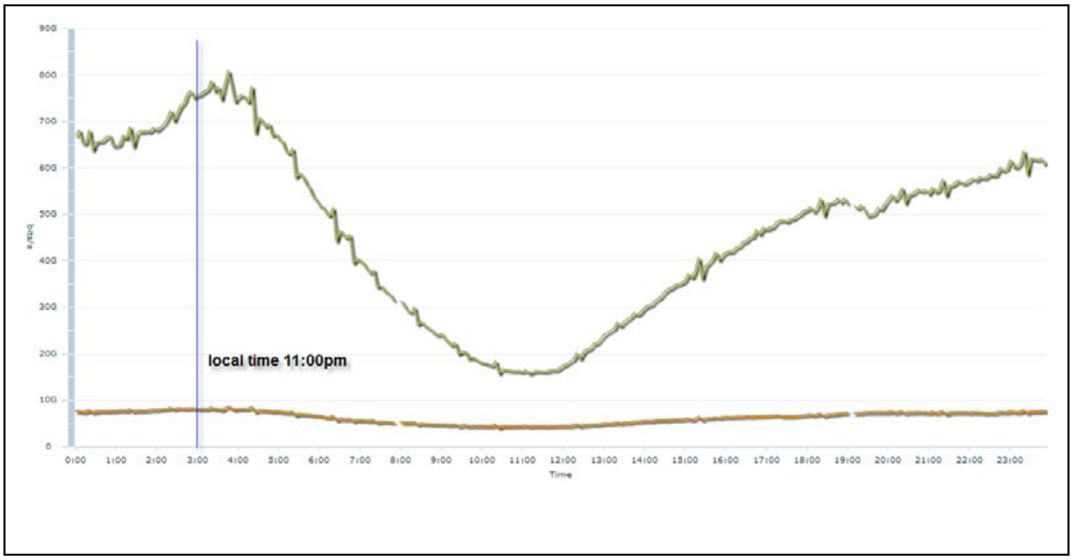


Figure 5. Backbone Traffic Volume Change during a Typical Day

Finally, end user behavior also drives seasonal traffic changes. Generally traffic grows faster in winter than in summer, as illustrated in Figure 6. One of the explanations is most people tend to spend more time outdoors or vacationing in the summer and have less access to or time to spend on the Internet.

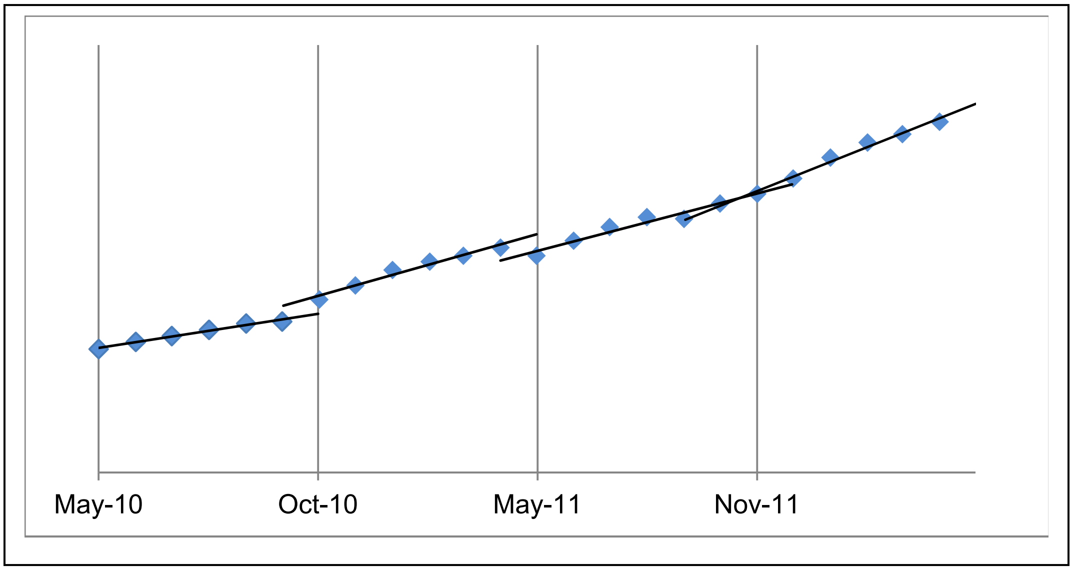
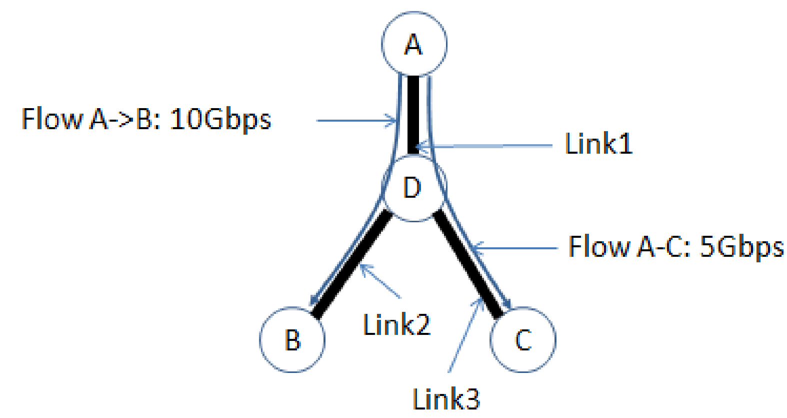


Figure 6. Seasonal Traffic Volume Change

A traffic model is built primarily using two elements: the interface statistics (or interface stats for short), and the traffic matrix. These two elements measure the same traffic traversing the backbone but from different perspectives, as explained in detail in Figure 7. The interface stats are collected from individual network interfaces on a router (commonly via SNMP), which provides a capacity utilization view on the bandwidth consumption. The traffic matrix collects traffic flow information focusing on where the packets originate from and where they go. A traffic matrix is more often employed by failure simulation analysis so that the simulation software knows how to reroute traffic during a failure event.



Traffic Matrix

dest. \ src	A
B	10Gbps
C	5Gbps

Interface Stats Table

Link1	15Gbps
Link2	10Gbps
Link3	5Gbps

Figure 7. Traffic matrix and Traffic Stats

(In this three-node network, there are two flows, one from A to B and the other from A to C, with bandwidth consumption of 10Gbps and 5Gbps respectively. The traffic matrix table (left) has the flow stats while the interface stats table (right) tracks the interface stats by summing the flow bandwidth traversing each link.)

One way to obtain a traffic matrix is through collecting NetFlow [3] statistics on routers. The other way is to collect tunnel statistics, such as MPLS LSP stats[2]. However, when NetFlow data or tunnel stats are unavailable or incomplete, a traffic matrix must be derived from interface stats. Such a process is called Demand Deduction.

[2] A Label Switched Path (LSP) is a tunnel built using Multiprotocol Label Switching (MPLS) Protocol. When a LSP is built between two end points where the traffic enter a MSO backbone and exit to a market, such LSP traffic stats can be used directly in a traffic matrix.

In essence, the demand deduction process is a "guessing" process that derives a traffic matrix from known interface stats. The process starts with a candidate traffic matrix, or *seed matrix*, to calculate what the interface stats would be under such a traffic demand. The difference between the generated interface stats and the actual stats is noted. Then the process repeats itself with a new candidate traffic matrix which is constantly adjusted. When the difference cannot be further reduced, a "best fit" traffic matrix is produced which fits the known interface stats better than any others. Most modern network modeling tools support a Demand Deduction type feature.

Growth Projection

Projecting future traffic growth is probably one of the most important tasks for capacity planning. From a business perspective, growth projections have a direct impact on budget planning, equipment planning, project schedules, and sometimes influences network architectural design as well. Therefore, getting an accurate growth projection is crucial.

A typical growth projection process begins with analyzing historical traffic stats. It is important to collect correct and consistent data. For example, some traffic may traverse multiple backbone links, and double-counting needs to be avoided. One possible practice involves narrowing the selection of historical traffic stats to a set of backbone links which connect the backbone and regions. By doing so, only traffic sent to the regions is considered without being double counted

Once the historical data is collected, a trendline analysis can be performed to project future traffic growth. Figure 8 illustrates such an analysis with artificial time series data representing the monthly traffic load on the backbone. The green dashed line shows the linear trendline with R-squared (R^2), a parameter indicating the goodness of fit, as 0.9785. The orange curved line shows the quadratic polynomial trendline with R^2 as 0.9934. The R^2, or *coefficient of determination*, is used to measure the goodness of fit and the predictive performance of a trendline. The larger the R^2, the better the fit[3]. For this reason, a polynomial trendline is preferred over a linear one in this example. With a trendline, we are able to estimate future values as well as the future growth rate. Tools such as Microsoft Excel have built-in trendline functions which make analysis easier.

[3] In some cases, if a trendline overfits a known data set, it may result in a large R^2 but poor predictive performance.

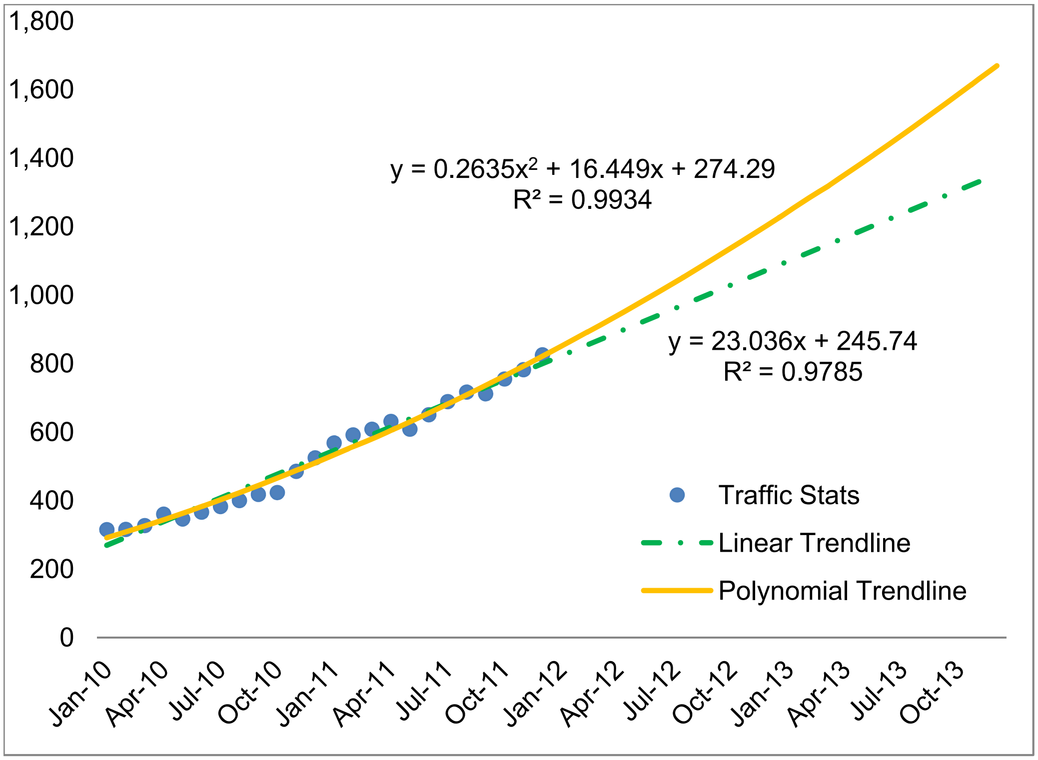


Figure 8. Trendline Analysis Example

However, trendline analysis has limitations. Future events such as business acquisitions, innovative applications, new product offerings, or network architectural changes may introduce new traffic into the backbone and it is impossible for a pure mathematical model to include all future possibilities. Therefore, extra headroom may need to be planned to accommodate extra traffic growth. Exactly how much headroom will be needed often requires input from different business groups.

Failure Simulation and Capacity Forecast

Because most networks are built to tolerate some level of failure, capacity planning must forecast the network capacity accordingly. Different levels of failure tolerance lead to different capacity requirements. For example, it requires a lot more capacity to prepare for a POP failure than for a fiber cut. A clear goal that identifies the required level of failure tolerance must be defined first.

Once the goal is clear, the network routing protocols must be thoroughly understood to route the traffic around a failure point. Network modeling tools provide essential functionality in this regard. These tools parse network configurations or passively participate in routing. By doing so, the tool gains the key information on how a network reacts to failures.

For failure simulation and capacity forecasting, a network model and a (set of) growth rate are the main inputs. To ensure the accuracy, all the inputs should be thoroughly verified. The next step is to apply the growth rate to the traffic matrix. Then the simulation software is used to run the failure simulation to fail links and routers one by one. For each failure scenario, the bandwidth requirements on all non-failed links are assessed and recorded. The final bandwidth requirement for a particular link is determined by the largest requirement from all simulated failure scenarios which affect the link. This is to ensure the planned capacity will have enough room to handle the worst case failure scenario. The last step is to collect results from the failure simulation and to translate them to equipment planning and optical planning. For example, the bandwidth requirements can be easily translated to port counts. If the port count on a router exceeds its maximum port density, a new router or some form of router expansion may be needed.

Traffic Model Selection

One of the technical challenges is to select a high quality and high fidelity traffic model, which is a critical input to the process. One important reason is that network traffic changes all the time, and it is very difficult to model such a fluid and dynamic element. One way to obtain a traffic model is to take a snapshot of the network to capture interface stats and flow information at a particular time, but if a single snapshot is used as the model, there is no simple way to ensure that it is representative of all time. If multiple snapshots are taken, which one would be the best? In a dynamic environment, it may not be possible to capture a perfect traffic model so instead the traffic model is approximated. The *monthly peak hour p95* is one option. In other words, all traffic stats from non-peak hours are discarded in the monthly p95 calculation. By counting peak hours only, the focus is on the capacity requirement when the network is “stressed”. Using a monthly p95 provides a better baseline that is more resistant to noise and is not specific to a particular day.

There are some known limitations to this approach. By using p95 over a longer time period, the implicit assumption is all backbone links reach their peak utilization at exact same time, which is unlikely in reality. In other words, the capacity forecast may be artificially inflated with this approach. Continued experimentation and research will be needed so adjustments and improvements can be made to this approach.

Layer-1 Modeling and Forecast

Another technical challenge is modeling the optical transportation layer. Because the systems that manage layer-1 optical equipment are often different from those that manage routers, it is a challenge to share the information and to fuse the data from the different systems. However, it is important to model the layer-1 optical layer and integrate it with layer-3 model.

A topological model at layer-1 can be very different from the one at layer-3. A direct layer-3 link, for example between two routers in Los Angeles and New York, may go through multiple optical links, or optical segments, at layer-1. On the other hand, an optical segment may have multiple layer-3 links multiplexed on top of it. Therefore, when a fiber gets cut, it may affect multiple layer-3 links. In the planning terms, a set of layer-3 links which are affected by the same fiber cut is often called a Shared Risk Link Group or SRLG for short. It is very important to have a correct SRLG in place for failure simulation analysis. However, to date, SRLG generation is still a manual process which is error-prone and hard to maintain.

Similarly, when the bandwidth requirement on a layer-3 link is available, it needs to be translated to the capacity requirement for the underlying optical equipment as well. For the same reason, the translation is another manual process. Modeling tool vendors have been encouraged to develop features that advance the current practice by automating SRLG generation and the generation of optical forecasts.

Conclusions

In this paper, the backbone capacity planning practice at TWC was introduced. One take-away point is the utmost importance of the quality and the fidelity of the inputs to the process, especially the traffic model. It requires a substantial work to improve the tools and the process in that regard. It is also hoped that this paper serves as a starting point for further discussion on how some technical challenges may be addressed and how the processes and methodologies may be improved.

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[3] NetFlow, [Online]. Available: http://en.wikipedia.org/wiki/NetFlow.

Abbreviations and Acronyms

AS	Autonomous System
BAU	Business As Usual
CMTS	Cable Modem Termination System
FCC	Federal Communications Commission
GUI	Graphical User Interface
IP	Internet Protocol
LSP	Label Switched Path
MPLS	Multiprotocol Label Switching
POP	Point of Presence
SNMP	Simple Network Management Protocol
TWC	Time Warner Cable