Smarter Networks with Passive Optical LANs

Innovating enterprise infrastructure and lowering TCO

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Introduction

In the 1980s and 1990s optical communications revolutionized long-haul transmission. Today, the long distance and underwater communications are the backbone of every major provider consisting of optical fiber. The technology has shown to be vastly superior to copper in terms of bandwidth, range, consumed power, longevity and reliability. Recent advances in the manufacturing and commercialization of Passive Optical components are now extending these capabilities to the edge and campus networks. Buildings that have been traditionally wired with CAT 5/6 copper are facing a fantastic opportunity from the emergence of Passive Optical LAN technology along the same lines as: reduced infrastructure footprint and costs, reduced power requirements, future-proof bandwidth, greener infrastructure, safer and higher security and better reliability.

Why Passive Optical LAN

A Passive Optical LAN is an ideal solution for new infrastructure projects and the upgrade of existing infrastructure for the following reasons:

Guaranteed Bandwidth: Today's enterprise traffic patterns fueled by server and data center consolidation, virtual desktop infrastructure (VDI), bring your own device (BYOD), mobile and cloud computing, are better served by a centralized switch model compared to traditional workgroup technologies with layered active switches.

Future-proof: Passive Optical LANs offer a future-proof upgrade path to safer, greener, higher security and bandwidths over the same fiber infrastructure.

CAPEX and OPEX Savings: Passive Optical LANs replace the active Intermediate Distribution Frame (IDF) equipment (aggregation Ethernet switches) with passive components, reducing space, energy and cooling requirements, as well as lower installation costs. Passive Optical LANs replace traditional copper wiring with fiber saving space and weight. Passive Optical LANs require simpler management and offer advanced capabilities that can be easily integrated with campus-wide provisioning and management applications.

This paper offers a study of the Passive Optical LAN technology and its implications for cabling infrastructure projects. We demonstrate enterprise traffic patterns using network traffic captured in a large enterprise campus. We will then discuss traditional LAN architecture, Passive Optical LAN components, Total Cost of Ownership (TCO) analysis (and further implications on network management), real estate and energy consumption. We demonstrate that the Passive Optical architecture is vastly superior to traditional copper cable-based LANs in terms of deployment flexibility, ease of management, environment friendliness, capital and operating costs.

Understanding enterprise network traffic patterns

When planning a LAN design, either green-field deployment or legacy infrastructure upgrade, it is critical to understand the network traffic characteristics in enterprise environments. Few research studies have been done to explore traffic inside the enterprise because most work has been on wide area Internet traffic measurement. Most of the studies of enterprise traffic reported in the literature are usually over a decade old and focus on individual LANs rather than whole sites.

We analyze network traffic patterns using network traffic data captured in one satellite site of a large enterprise. The site has about 1500 employees with each having an office and about 30 conference rooms. Each employee has an IP phone and most have only one desktop computer or laptop computer. The networking setup of this site is what can be found typically in large enterprises. The core switch routes external traffic to the Internet Service Provider and forwards internal traffic to the corresponding server site which might not be in the building and could be remote to the site.

We observe most traffic does go through the core switch which implies very little peer to peer traffic. This is typical in an enterprise environment since most of the enterprise applications are client-server based and servers are hosted in remote data centers.

For bandwidth consumption of different applications, email and Web traffic consumes more than 74% of the bandwidth, followed by file transfer since the organization uses a distributed file system and online conference which is commonly used to share screens. A small portion of the file transfer is induced by Cloud services which appear mostly in the HTTP traffic since the Cloud service user interface is Web-based. Figure 1 demonstrates the top applications based on bandwidth usage.

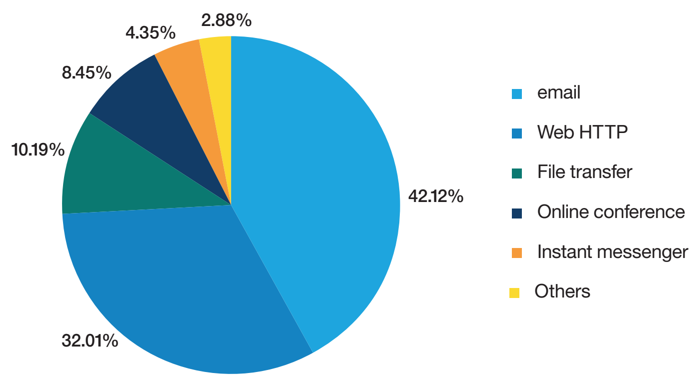

Figure 1: Bandwidth Consumption of Enterprise Applications

While bandwidth consumption by individual user does not vary widely except for a few heavy users, peak bandwidth usage by individual user is quite different from one to the other. We categorized peak bandwidth usages into five categories. Figure 2 illustrates the percentage of user population for each peak bandwidth usage category. The results show that most users had a peak bandwidth usage less than 50 Mbps and almost all users took less than 80 Mbps. A further investigation discovered those who reached more than 50 Mbps bandwidth seemed to be doing file transfers from the enterprise distributed file system and downloads from the enterprise network. We also noticed the email tool utilizes a greedy algorithm for attachment download which grabbed the maximum available bandwidth.

In the environment we found, no size limitations in email attachments and big file downloads were very common. This usage pattern suggests that peak bandwidth observed might be higher than enterprises which have less file transfer demands. We also observed about 0.1% traffic goes beyond 80 Mbps which was also caused by file download.

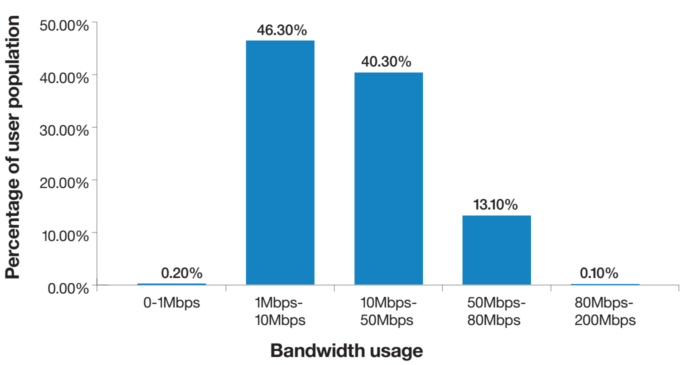

Figure 2: Peak Bandwidth Usage by Individual User

We analyzed the average bandwidth utilization for the most common applications. For Web applications, since all of them use HTTP protocol and the same communication ports, it was unlikely to differentiate based on network log data. For example, lots of Cloud accesses are performed through Web interfaces. For those applications, we measured the bandwidth utilization by running the real application and real workload. The following table shows the typical enterprise applications and their network bandwidth consumption:

Application	Configuration	Bandwidth utilization
VoIP phone	64 Kbps setup	~ 100 Kbps
Video surveillance	High Definition MPEG4	~ 6 Mbps
Email	2 minutes refreshing	50 ~ 500 Kbps
Web Browsing	Non-video Web sites	50 ~ 300 Kbps
Video conference	720p	~ 2 Mbps
Online video	720p	~ 2 Mbps
Cloud access	Data storage, enterprise application	50 ~ 200 Kbps
Virtual desktop (VDI)	1080p full screen display	500 Kbps ~ 2 Mbps

The measurement results imply the following observations:

1. The enterprise traffic was very much hub-and-spoke-based, with nearly all application resources residing centrally and accessed remotely or via other types of non-local protocols.
2. There was constant increase in HTTP-based traffic needing to go outside the enterprise network.

This trend was accompanied with the acceleration of IT consolidation in the past three to five years—data centers have reduced, branch office servers have migrated back to central data centers, servers themselves are consolidated through the use of virtualization. Gartner Research predicts that the trend of less local traffic will continue and by 2016 less than 10% traffic will be local. With understanding of such traffic flows, there is a strong suggestion that usage patterns that spawned decentralized computing and gave birth to LANs are shifting back to a centralized model and this usage demands a new architecture and economic justification.

Rethinking active switch-based LAN architecture

Traditional LAN infrastructures are based on layered active switches commonly referred to as two-tier or three-tier design. In a typical enterprise LAN setup, a group of individual computers connect to a hub or an access layer switch.

The access layer switch forwards the network packages initiated from individual computers to the distribution layer switch. Finally the package gets forwarded to the core switch and routed to the destination. If the destination is connected to the same switch, network traffic will be routed to the destination without going through upper layer switches. Figure 3 illustrates this layered architecture and typical organization of the devices.

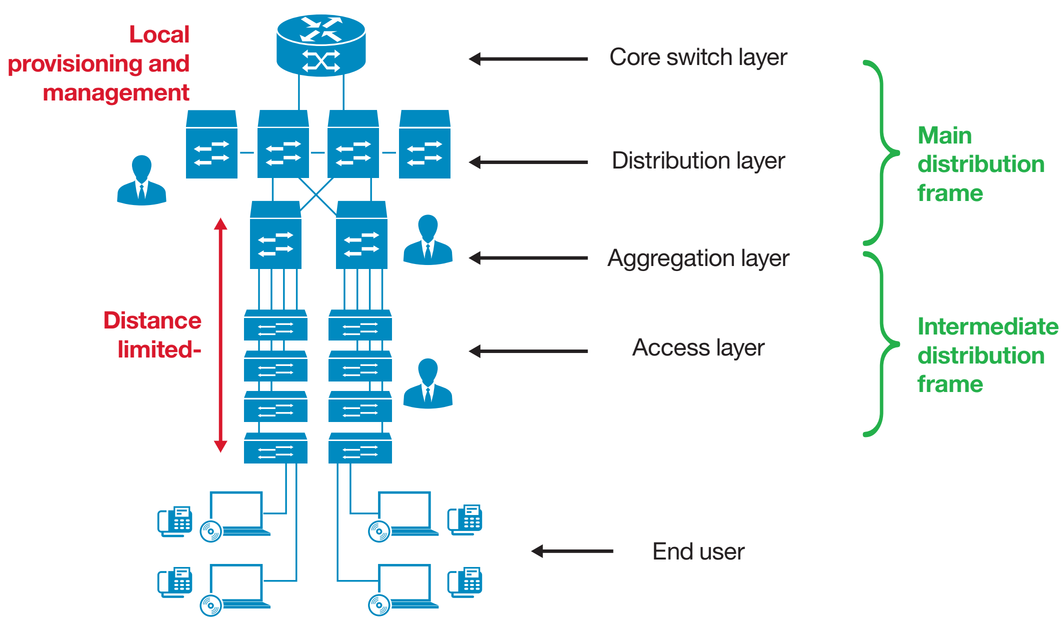

Figure 3: Traditional LAN Architecture

This layered architecture is further complicated by building structures while being implemented. To map the different layers to building or campus structures, the concepts of Main Distribution Frame (MDF) and Intermediate Distribution Frame (IDF) are commonly used. MDF usually refers to the main computer room for servers and core switches. IDF is a remote room or closet with access layer switches. The design of IDF is limited by a few factors including cable length limit, power consumption, cooling and density of end users. Those factors have been incorporated into building designs by architects to compete with the maximum usable square footage of each building.

The fundamental limitation in this layered architecture is mainly due to the characteristics of the copper cable which is commonly used to connect the workstation and access layer switches. The limitations includes:

Length limitation of copper cable—since the high-frequency signal transmitted in the copper wire degrades with length; the maximum length for a copper cable link between two active devices is 100 meters (328 feet). In a typical installation, this would translate to 90 meters (300 feet) of solid "horizontal" cabling between the patch panel and the wall jack, plus 5 meters (16.5 feet) of stranded patch cable at each end between each jack and the attached device. Exceeding the patch cabling length or maximum cable length will cause signal loss.

Bandwidth of copper cable—the speed of data transfer used by copper LANs has increased significantly from 10 Mbps a decade ago to 1Gbps with 10Gbps on the horizon. However, in order to accomplish those speeds, the systems have evolved from 10MHz radio frequency in CAT 3 cable to 500MHz today in CAT 6A. Each evolution was also accompanied by a physical cable upgrade. In addition, when high radio frequencies are being transferred, more sophisticated cable construction is needed for physical cables. Some may need special processes such as noise-canceling to filter out the cross-talk interference when the outgoing signal and incoming signal are not balanced.

Physical structure of copper cable—in today's LAN deployment, workers spend significant time laying out the Ethernet cables nicely and tightly. Nevertheless, Ethernet cables get messy and bulky very easily. The first impression for most switch closets or machine rooms is that it is full of Ethernet cables. Moreover, the weight of copper cable can be significant as well. A 1,000 foot CAT 6 cable on average weights 24 pounds and CAT 6A cables are about 49 pounds per 1,000 feet, while fiber optic cables are less than 12 pounds per 1,000 feet. For the same length of cable, fiber optic cables use 50% less plastic than a traditional copper LAN and no copper. Figure 4 shows an example switch closet appearance burdened with complexity, weight and plastic material.

Installation rules of copper cable—Installation of copper cable is a rather delicate task with lots of consideration including wiring routes and clearance from power wires. The high frequency signal transmitted via copper cable is very sensitive to noises generated by other cables or devices. There are many rules regarding copper Ethernet cable deployment. For example, Ethernet cables must be kept a certain distance away from all power wires and must be orthogonal to power cables when crossing power wires. This makes the cost of copper cable installation rather expensive.

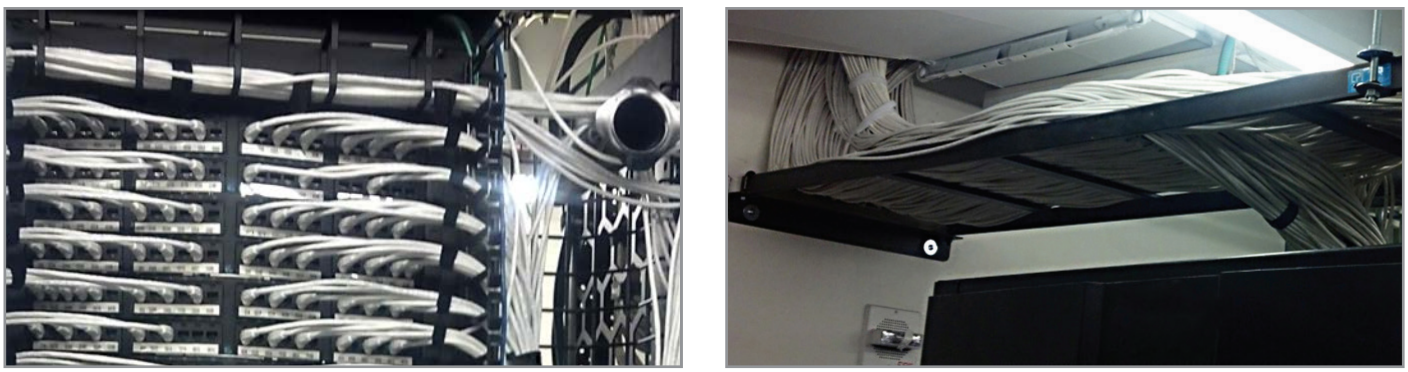

Figure 4: A switch closet of a small company. The left side picture shows the main switch rack with huge bundles of cables intertwined with each other. The right side picture shows the huge bundle of cables going to riser channels and lateral ceilings from the rack.

Another main limitation of the traditional LAN architecture is the complexity of network management. For example, setting up a Virtual LAN (VLAN) in a layered infrastructure requires changes of multiple switches and creates complex mapping between the ports and switches. This process is very labor intensive and prone to human error. Monitoring of network traffic will need to be deployed across all the layered switches, if both in-network and out-network packets are to be captured.

Passive Optical LAN as an emerging LAN architecture

Passive Optical LAN overcomes all the limitations found in traditional copper-based Ethernet implementations as follows:

- Optical fiber cable used in Passive Optical LAN can travel for a distance of up to 20km ~ 30km.
- Fiber cable structure is much lighter than copper-based cables.
- Use of bend-insensitive fiber radically diminishes bend radii therefore, diminishing cable tray and pathways requirements.
- Passive nature of the intermediate splitter eliminates the need of power and cooling.
- Single management console provides consolidated access to all devices and network ports in the network.

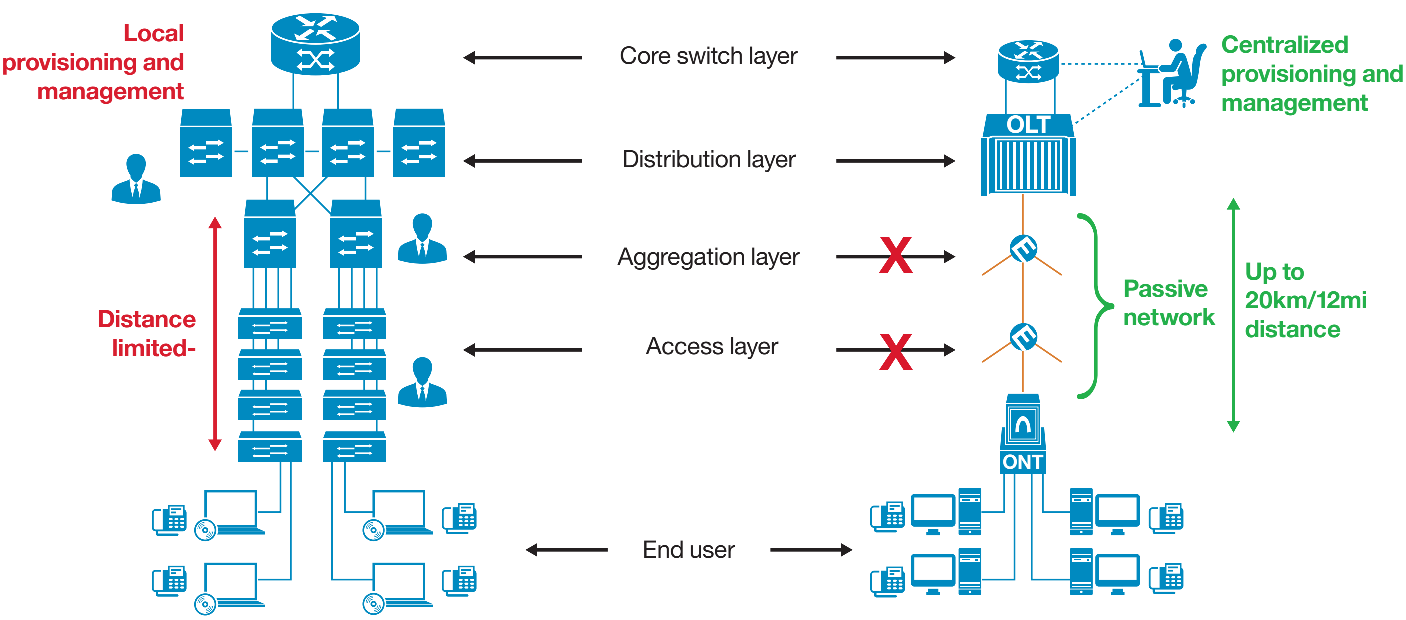

Figure 5: Traditional LAN Architecture vs. Passive Optical LAN Architecture

The main components in a Passive Optical LAN architecture are the Optical Network Terminal (ONT), the passive splitter and the Optical Line Terminal (OLT). The ONT connects computer devices into the Passive Optical LAN network via the Ethernet ports on the unit. Electrical signals from computer devices get converted to an optical signal in the ONT. Optical splitters simply split the light signal multiple ways to ONTs and transmit the multiplexed signal to the OLT. The OLT aggregates all optical signals from the ONTs and converts them back to electrical signals for the core router. The OLT may also have a range of built-in functionalities such as integrated Ethernet bridging, VLAN capability, end-user authentication and security filtering, etc. Figure 5 shows the corresponding layers in traditional LAN architecture and in Passive Optical LAN architecture. Switches in the access layer and building aggregation layer are replaced by a Passive Optical splitter and those two layers do not exist anymore in Passive Optical LAN architecture.

An OLT may support 8 ~ 72 fiber ports with each port connecting a fiber cable to the splitter. The splitter can support different splitting ratios with 1:32 or less being the recommended split ratio. Therefore, each OLT port supports 32 ONTs. Different ONT configurations are available ranging from 2 to 24 Ethernet ports, multiple analog voice ports, coaxial video ports and even wireless support. If only 4 devices are attached to each ONT, an OLT with 72 ports will be able to support 9216 devices.

In field deployment, splitters can be placed in IDF closets, or can be placed in ceilings or beside electrical panels, since no cooling is required for splitters. Depending on application and usage, vendors usually provide a wide range of ONTs to meet different needs.

Case Study: a Recent Passive Optical LAN Deployment

In the past years, the IBM Site and Facilities Services team has successfully deployed Passive Optical LAN projects yielding millions of dollars in Total Cost of Ownership savings for customers. The main benefits our customers have realized include:

- Lower capital expenditures
- Reduced operational expenditures
- Easier network management
- More usable floor space
- Less building design steps
- Decreased power consumption
- Reduced cooling cost

We share a model of a mid-sized company with four floors in the building; each floor has two IDF/riser closets. Each IDF supports 100 cubicles and eight office/conference rooms. Each cubicle requires two Power over Ethernet (PoE) ports and each office needs 4 PoE ports. There are 15 wireless access points per floor. The total number of PoE ports is 1916.

Total Cost of Ownership (TCO)

Using the requirements described above, we use a hypothesis model developed by multiple parties in the industry to calculate the Total Cost of Ownership of a solution using legacy copper cable, layered switches and Passive Optical LAN network. The cost of each category is listed in Figure 6. The solution using a Passive Optical LAN network has a capital expenditure of USD465,588 while the cost for a copper network is USD736,224, resulting in 37% savings. The Passive Optical LAN network also has lower annual operating expense with USD100,598 vs. USD167,709, a 40% saving. The net TCO for Passive Optical LAN technology for one year is about USD566,186 and over five years will be USD891,898. On average, the Total Cost of Ownership for using Passive Optical LAN technology over 5 years will be 38% less than traditional copper LAN networks.

Capital Costs	**Traditional LAN**		**Passive Optical LAN**		**Savings**
Lateral	US$	268,800	US$	260,806	3%
Riser Closet/Workgroup Switches	US$	374,139	US$	43,200	88.45%
Main Equipment Room	US$	93,286	US$	161,582	-73.21%
Data Center	US$	-	US$	-	
Total CAPEX	US$	**736,224**	US$	**465,588**	**36.76%**

Operating Expenses	**Year 1**		**Year 1**		
Capacity Management	US$	7,800	US$	2,640	66.15%
Network Upgrades & Patches	US$	7,920	US$	1,920	75.76%
Network Regular Maintenance	US$	38,281	US$	18,670	51.23%
Testing and Certification Operations	US$	8,000	US$	9,600	-20.00%
Training	US$	15,840	US$	20,480	-29.29%
Service Contracts	US$	42,021	US$	27,671	34.15%
Sparing Costs	US$	8,404	US$	4,861	42.16%
Floor Space Cost	US$	3,733	US$	942	74.77%
Power Cost	US$	11,248	US$	8,246	26.69%
Cooling Cost	US$	8,197	US$	1,767	78.45%
Network Management Equipment & Software	US$	16,266	US$	3,802	76.62%
Total Annual Operating Expenses	US$	**167,709**	US$	**100,598**	**40.02%**

Total First Year Expenses (CAPEX+OPEX)	US$	**903,933**	US$	**566,186**	**37.36%**

Figure 6: Costs of Traditional LAN Network vs. Passive Optical LAN Network

Capital Expenditures

The main cost in capital expenditure is to acquire the equipment and initial installation. We calculate the cost in three categories: lateral cost, riser closet or IDF and main equipment room or MDF. Lateral cost includes material and installation of CAT 6 cables from the IDF and wall plates if using a traditional LAN network or material and installation of fiber cables from the IDF and ONT units if using a Passive Optical LAN network.

The main capital saving of a Passive Optical LAN network comes from the installation and equipment in the riser closets. It eliminates the use of multiple edge switches by replacing them with Passive Optical splitters. In this implementation, we were able to leverage much of the existing infrastructure for cable installation such as cable ladder tray and could easily access the open ceiling to distribute the cables. Therefore, the lateral cost is quite low for CAT 6 cables comparing to some other projects we deployed. The reduction in the quantity of cables and the size of cable bundles are astonishing. Figure 7 shows a picture taken before the original CAT 5 cables are removed. The yellow fiber cable bundle is a Passive Optical LAN implementation. The number of end users and devices supported by the Passive Optical LAN fiber cabling is a factor of six larger than those supported by the CAT 5 copper cables. There are a few factors in the capital expenditure that need to be highlighted:

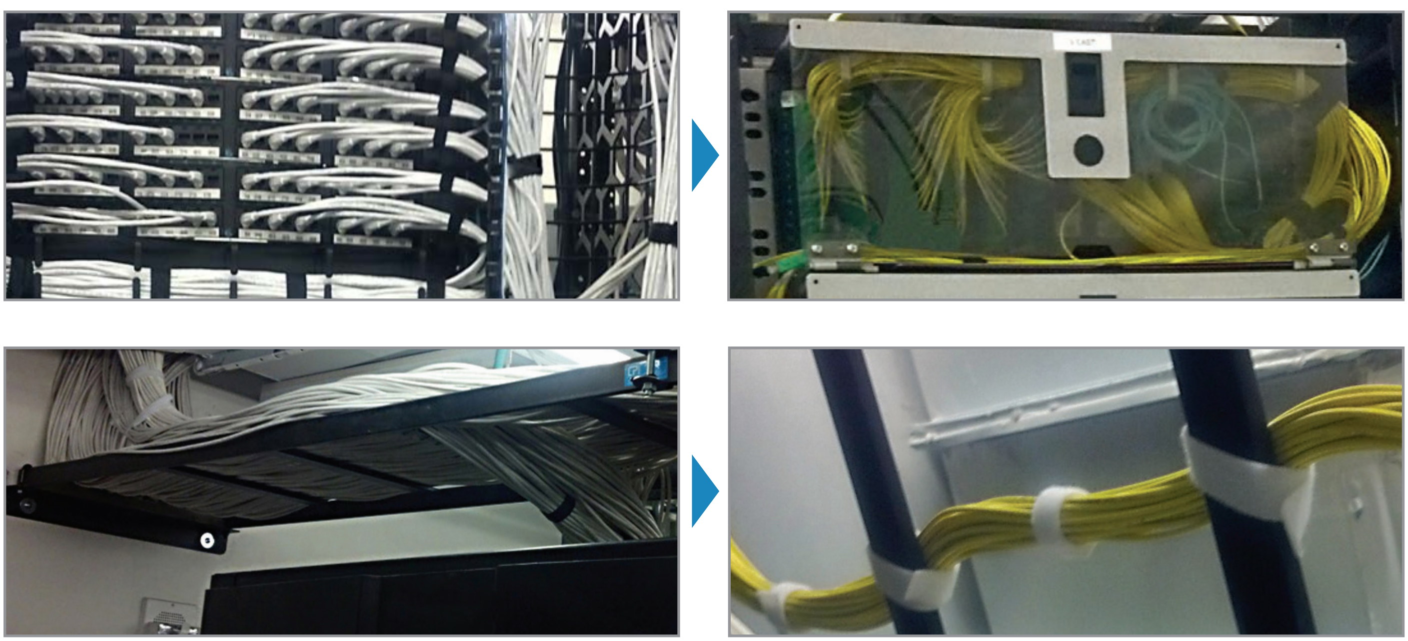

Figure 7: Cable size of CAT 5 vs. optical fiber Implemented in the same building infrastructure. The rack and cables at the left side were an early LAN implementation supporting one half floor. The yellow cables at the right side are the Passive Optical LAN implementation to replace the original LAN implementation — supporting three and one half floors.

Material costs

Material used in fiber optic cable was significantly less than material used in copper cable. If we only calculated the horizontal distribution cables, one half or even one third of the cables were needed to provide the same number of Ethernet outlets. The fiber cable itself is much thinner than the CAT 5 or CAT 6/6A cables. In this installation case, the Passive Optical LAN solution resulted in a reduction of 3,000 pounds less plastic than CAT 6 cables and 10,500 pounds less than CAT 6A cables and a reduction of 3,000 pounds of copper. The glass used in fiber only weights about 15 pounds in this solution.

Construction costs

The fiber cable infrastructure costs substantially less to install than a copper-based LAN system, since there are fewer cables to install. For example, if we are using a 4-port ONT, all four devices only need one fiber cable for support while traditional solutions require four home run copper cables. The new technologies, such as bend-insensitive single-mode fiber, have much better tensile strengths than CAT 5/6 copper cable. Improved termination tools and the possibility of using pre-connected fiber also have significantly reduced the cost of fiber installation. Fiber cables are much lighter and require fewer cables per Ethernet port, making the wiring structure simpler which may result in using a J holder instead of a traditional ladder channel.

What is also important is that construction labor cost varies significantly depending on the living cost of the area. Among the states in the US, cost per cable drop can vary from less than one hundred dollars to several hundred dollars. In our TCO model, we used industry standard labor cost in the area. The cost differential is usually larger for areas with higher labor costs. However, in areas with lower labor costs, the cost savings are still positive due to decreased material costs.

The impact of capital expenditure can be more sensitive in existing infrastructure upgrades where old cables need to be removed before installing the new ones. Copper Ethernet cabling has experienced a few generations with new ones on the horizon already. This has an impact on all enterprises but is extremely significant in businesses where each upgrade is mandatory or commonly practiced such as in the healthcare industry.

Operational expenditures

Operational cost for LAN infrastructure is one of the biggest expense sources for all enterprises. We discuss and compare the cost of the two solutions in terms of network management, floor space requirement, power and cooling cost.

Network management

The typical network maintenance tasks include:

- Capacity management such as provisioning a new workstation/port, removing a disposed workstation/port, creation and modification of IP addresses and virtual LAN setup, configuration of any L2 services like quality of service etc.
- Upgrades and patches to keep all the hardware, firmware and management software up to date and replacement of defective devices
- Regular care such as monitoring and fixing any alerts or defects, checking and fixing any problems within the chassis
- Testing and certification of all devices, cables and connections
- Management equipment and software

In addition to maintenance costs, expenses on service contracts, training courses and sparing needs to be included, which are usually offered by network solution providers and/or device vendors as a certain percentage of the entire contract value.

The Passive Optical LAN solution has a lower cost in all categories except testing and training. Testing was about 20% higher than traditional architecture and training was about 30% higher. We expect such costs will get lower as more people get familiar with the architecture. Costs for capacity management, upgrades, patches and management equipment are significantly lower with a Passive Optical LAN solution than with a traditional solution. This is due to the Passive Optical LAN network eliminating all the active switches in the access layer and distribution layer. The only active device in the Passive Optical LAN solution which requires maintenance and provides management interface is the OLT. Using the built-in provisioning features provided in the OLT, it provides a single interface for well-defined control and monitoring of the quality of service offered to individual users of the shared infrastructure, including dedicated bandwidth and bandwidth restrictions.

The remaining expense sources, floor space, power and cooling are essentially the major contributors of the cost savings in total operational expenditures. The Passive Optical LAN solution reduces floor space used for networking by approximately 69% and reduces the cooling energy cost by approximately 74% since all the splitters are passive and require no cooling.

Floor space saving

In a traditional network, floor space design is primarily impacted by the use of dedicated IDF rooms on multiple floors. The Passive Optical LAN solution eliminates the need for a dedicated IDF because the passive nature of the splitters and the long distance capability of fiber cable. Splitters do not require any cooling so they can be put in a very small closet on the floors, in enclosures behind walls, shared with the electrical closets, in raised floor architecture or even in the ceiling space. The only communication closet needed for Passive Optical LAN is the main distribution frame. In this deployment, each building floor is about 20,000 square feet, which traditionally requires 100–200 square feet to hold the two IDF closets. Such floor space can be easily converted to usable rooms contributing to extra revenue generation.

The saving for a large campus with multiple floors or multiple buildings is bigger than a small campus. Since each fiber cable can reach up to 12 miles from the main switch closets to the user outlets, it is feasible to have only one full size MDF in one building to serve the entire campus. For example, in one of our other deployments which consists of 25 floors with similar square footage on each floor, the Passive Optical LAN solution was able to save almost 90% of IDF floor space than previously used by the copper based solution.

Power and cooling consumption reduction

There are many aspects of power consumption reduction in the Passive Optical LAN solution. Power savings resulting from the reduction of cooling and electronic devices in IDF closets is quite straightforward. This reflects a reduction of power circuits, HVAC equipment provided by the building infrastructure and operational savings with reduced cooling loads. We have observed an approximate 74% cost reduction from the elimination of cooling in IDF closets.

Besides the energy savings from minimal cooling requirements, most Passive Optical LAN equipment is inherently energy efficient. Because a large number of Ethernet endpoints can be supported from one single OLT, ranging from a few hundred to a few thousands depending on the ports the OLT has, power consumption of the OLT is much lower than a comparable traditional distribution switch. Similarly ONTs also consume less power per Ethernet port than a comparable intermediate workgroup switch. In this deployment, we have observed about 26% less power consumption in the Passive Optical LAN network.

Another aspect of power saving comes from Power over Ethernet (PoE) support. For PoE devices, the low voltage power is supplied via the same network cable which is used for the Ethernet signals. This is common today for VoIP phones and Wireless Access Points. Because of the resistance of copper, some of the power is lost in the cable especially with long distance wiring of the cable. With Passive Optical LAN, PoE can be supported from the ONTs which are physically very close to the PoE device. Consequently less power is lost in transmission when using the Passive Optical LAN solution than the traditional copper-based solution. Compared to other power saving factors, this factor is not significant but can reach about 1,000 kilowatt-hours in the deployment described here.

Towards Smarter infrastructure & green buildings

Passive Optical LAN technology provides multiple smarter building needs via the same cable infrastructure including Ethernet, phone, video surveillance, wireless access points and various controls. The OLT is not only the central switch for network traffic but also a control center for smarter infrastructure and a monitoring data warehouse for advanced smarter building analytics.

Many of the features in Passive Optical LAN are essential to green building initiatives developed by many countries. In the U.S., the Green Building Council (USGBC) has a point-based program called Leadership in Energy and Environment Design (LEED), which covers both new and existing buildings to maximize building operational efficiencies while minimizing environmental impact. Often LEED certified buildings qualify for tax rebates, zoning allowances and other incentives. Since Passive Optical LAN directly contributes to energy savings, indirectly to cooling infrastructure, reducing harmful greenhouse gas emissions, increasing asset value, decreasing materials used for cabling and waste sent to landfills, it contributes to LEED certification in many of these aspects.

Deploy Passive Optical LAN to Realize Immediate Payback

With the commercialization of Passive Optical LAN technology, it has quickly demonstrated the advantages as one of the most revolutionary technologies in the networking era. It adequately accommodates all the demands required by modern enterprise applications with much lower cost than traditional LAN implementations. The energy-efficient nature of the solution inherently qualifies as a green technology. The rich, built-in advanced capabilities provide a seamless enablement for smart buildings and campuses.

IBM can help you get started with a Passive Optical LAN design and implementation project that can provide immediate payback. In our experience, the leading-edge but tested Passive Optical LAN solution provides the foundation to maximize your investment today and enables the savings to continue year after year, potentially unlocking business value as never before. IBM has proven capabilities in Passive Optical LANs, including design, implementation, and support, that help our clients achieve their desired outcomes and deliver value. You can leverage the experience of a service provider that invests in developing innovative service solutions based on thousands of implementations on a global basis to help you gain business value and benefits faster from Passive Optical LAN.

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IBM Facilities Cabling Services:

ibm.com/services/us/en/it-services/facilities-cabling-services.html

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