IBM Global Technology Services
Thought Leadership White Paper

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Smarter Networks with Passive Optical LANs

Help reduce TCO and accelerate innovation for your enterprise infrastructure

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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 local-area network (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:

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-ready: Passive Optical LANs can offer an 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, helping to reduce 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 more 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 how the Passive Optical architecture can provide significant advantages 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 explored traffic inside the enterprise, because most work has been on wide-area Internet traffic measurement. Most studies of enterprise traffic 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 internet protocol (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 that 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.

Considering bandwidth consumption of different applications, email and web traffic consumes more than 74 percent of the bandwidth. This is 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.

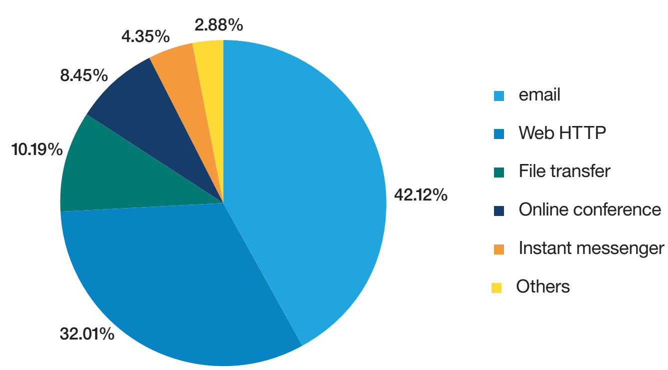

Figure 1. Bandwidth Consumption of Enterprise Applications

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. Further investigation revealed that 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, it was common to see no size limitations in email attachments and big file downloads. This usage pattern suggests that peak bandwidth observed might be higher than enterprises with fewer file transfer demands. We also observed about 0.1 percent of traffic goes beyond 80 Mbps, also a result of large file downloads.

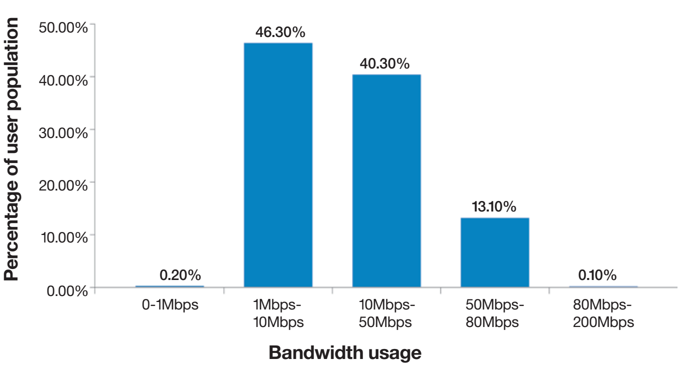

Figure 2. Peak Bandwidth Usage by Individual User

We analyzed the average bandwidth utilization for the most common applications. Web applications, however, were unlikely to be differentiated based on network log data since all of them use HTTP protocol and the same communication ports For example many 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
Voice-over IP (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 websites	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—the number of data centers in use has been reduced, branch office servers have migrated back to central data centers, and servers themselves are consolidated through the use of virtualization. Gartner Research predicts that the trend of less local traffic will continue, and that by 2016 less than 10 percent of traffic will be local. Understanding such traffic flows, there is a strong implication 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 designs. 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.

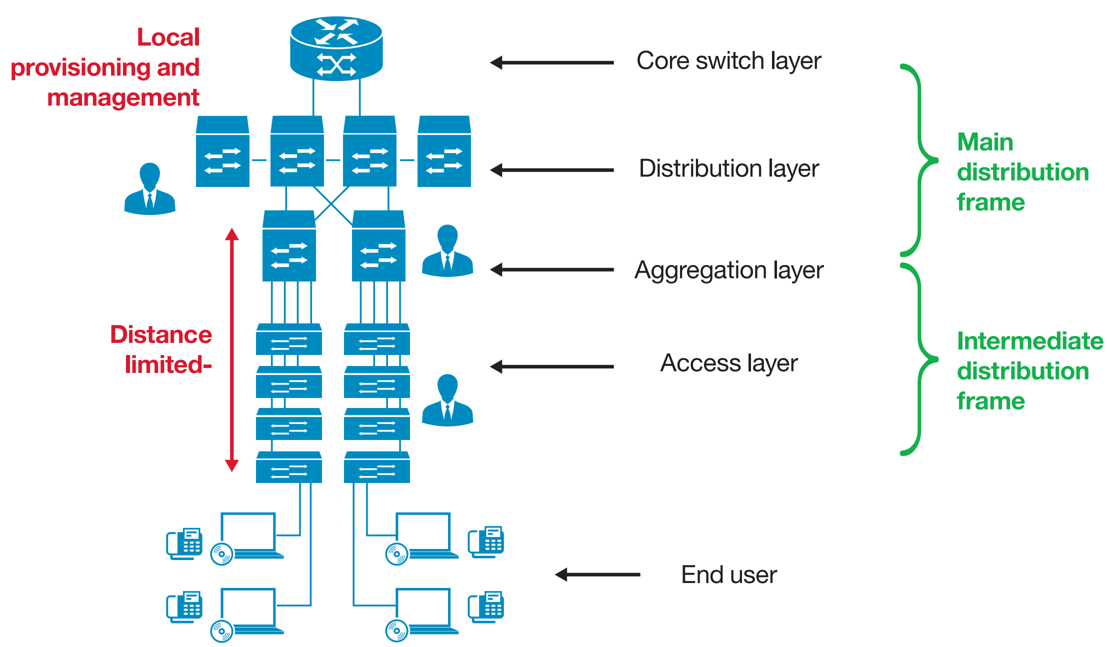

Figure 3. Traditional LAN Architecture

Implementation of this layered architecture is further complicated by building structures. 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. Limitations related to the cable include:

Length 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 1 Gbps with 10 Gbps on the horizon. However, in order to accomplish those speeds, the systems have evolved from 10 MHz radio frequency in CAT 3 cable to 500 MHz 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 capabilities 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 of most switch closets or machine rooms is that they are full of Ethernet cables. Moreover, the weight of copper cable can be significant as well. A 1,000 foot CAT 6 cable, on average, weighs 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 percent 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 that requires 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 process of installing copper cable rather tedious and expensive.

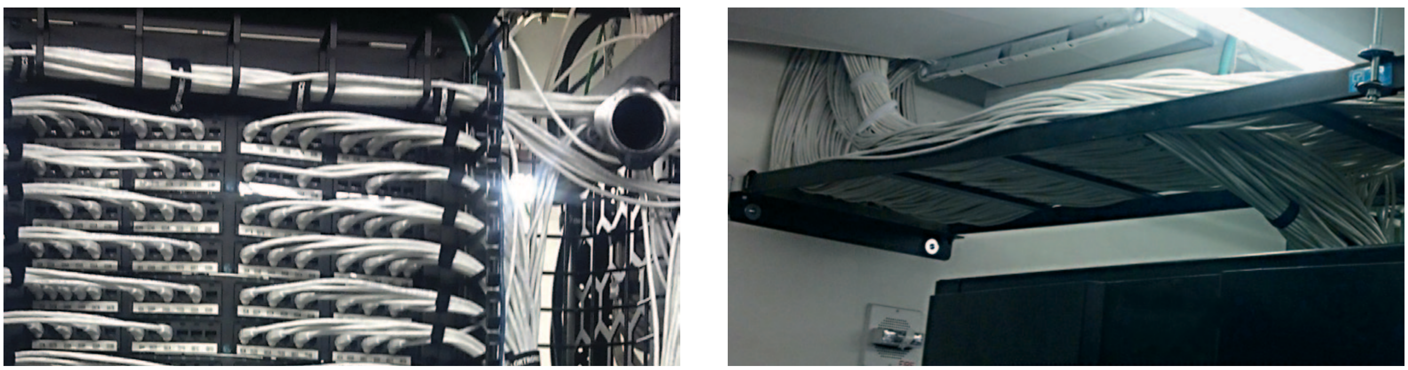

Figure 4. A switch closet of a small company. The left side picture shows the main switch rack with huge bundles of cables intertwined with each other. The right side picture shows the huge bundle of cables going to riser channels and lateral ceilings from the rack.

The complexity of network management also puts limitations on traditional LAN architectures. 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. You will need to monitor network traffic across all of the layered switches if both in-network and out-network packets are to be captured.

Passive Optical LAN as an emerging LAN architecture

The following properties enable Passive Optical LAN to overcome many of the limitations found in traditional copper-based Ethernet implementations:

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

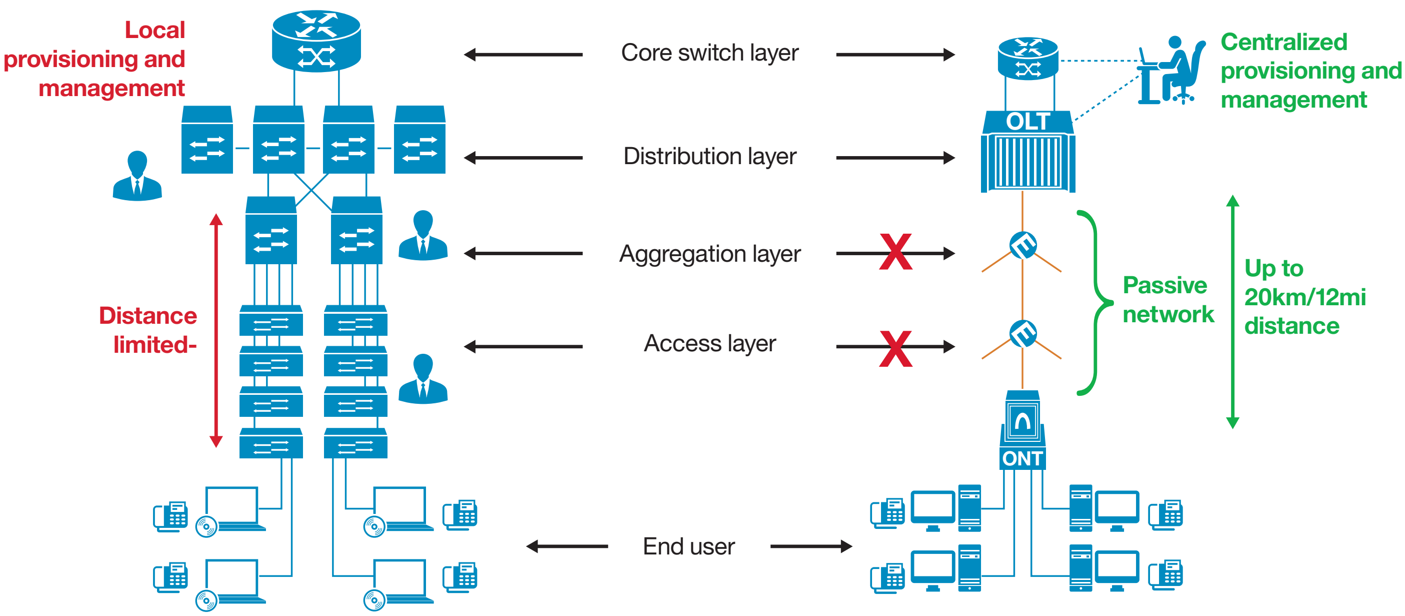

Figure 5. Traditional LAN Architecture vs. Passive Optical LAN Architecture

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 1 to 24 Ethernet ports, multiple analog voice ports, coaxial video ports and even wireless support. If only four devices are attached to each ONT, an OLT with 72 GPON ports will be able to support 9,216 devices.

In field deployment, splitters can be placed in IDF closets or 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
- Fewer building design steps
- Decreased power consumption
- Reduced cooling cost

Our model midsized company shows 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 ports, and each office needs four ports. There are 15 wireless access points per floor. The total required number of ports is 1920. An aggregate core uplink capacity of 20 Gb is required.

Total cost of ownership (TCO)

Given the requirements described above, we can use a POL TCO comparison tool developed by IBM Research and based on POL equipment specifications from multiple vendors 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 an estimated capital expenditure of US$580,500, while the cost for a copper network is approximately US$1,085,700, resulting in 46 percent savings. The Passive Optical LAN network also has lower annual operating expense, at approximately US$33,300 as opposed to US$80,400, netting a possible 58 percent projected savings. The estimated TCO for Passive Optical LAN technology for one year is about US$613,800, and over five years will be US$746,300. On average, the approximate Total Cost of Ownership for using Passive Optical LAN technology over five years may be up to 47 percent less than traditional copper LAN networks.

Capital Costs	Traditional LAN		Passive Optical LAN		Savings
Electronics (Core)	US$	156,900	US$	127,300	18%
Electronics (Access)	US$	510,800	US$	227,500	55%
Cabling	US$	403,200	US$	220,300	45%
Management Software	US$	14,800	US$	5,400	63%
Total CAPEX	**US$**	**1,085,700**	**US$**	**580,500**	**46%**

Operating Expenses	Year 1		Year 1		
Support	US$	25,500	US$	15,900	37%
Energy	US$	54,900	US$	17,400	68%
Total Annual Operating Expenses	**US$**	**80,400**	**US$**	**33,300**	**58%**

Total First Year Expenses (CAPEX+OPEX)	**US$**	**1,166,100**	**US$**	**613,800**	**47%**

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

Capital expenditures

Acquiring and installing the equipment is a main capital expenditure. We calculate the cost in four categories: Cabling, access and IDF electronics, core electronics and management software. Cabling 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 can help eliminate 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 the cable ladder tray, and we could easily access the open ceiling to distribute the cables. Therefore, the lateral cost is quite low for CAT 6 cables compared to some other projects we deployed. The reduction in the quantity of cables and the size of cable bundles is 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 should be highlighted:

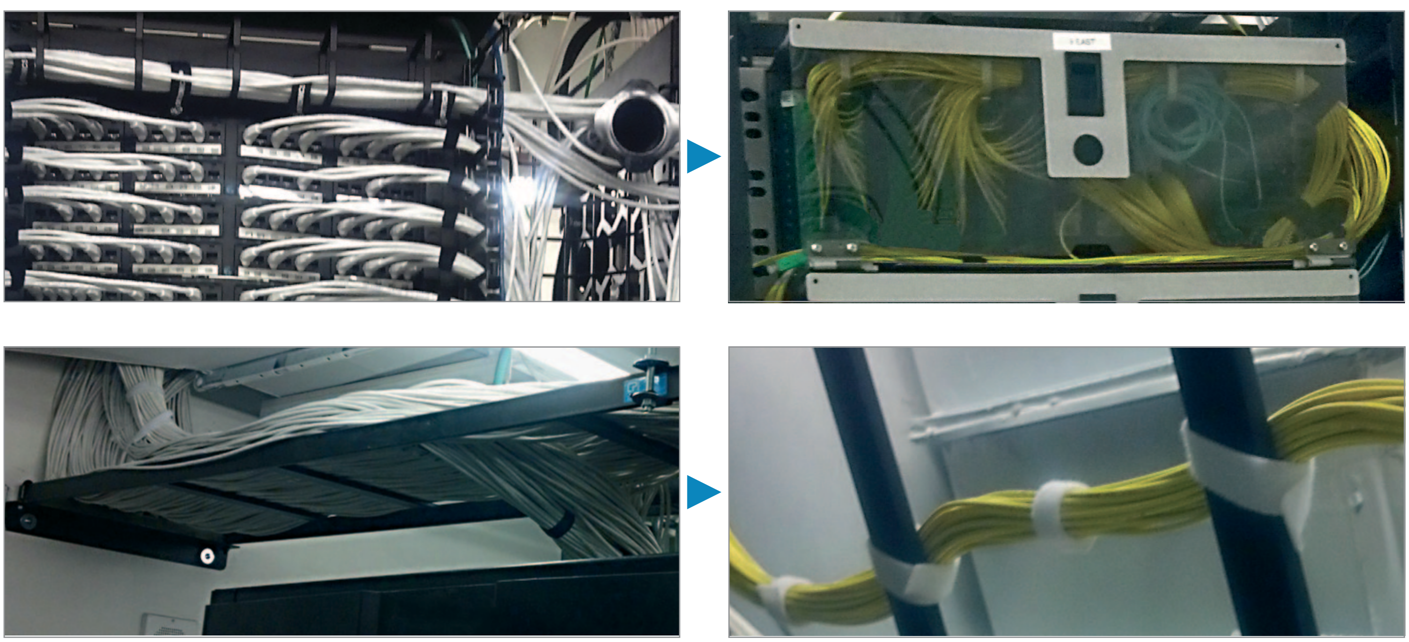

Figure 7. Cable size of CAT 5 vs. optical fiber Implemented in the same building infrastructure. The rack and cables at the left side were an early LAN implementation supporting one half floor. The yellow cables at the right side are the Passive Optical LAN implementation to replace the original LAN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

Material costs

Significantly less fiber optic cable was needed than copper cable, resulting in fewer materials needed for Passive Optical LAN installation. Using fiber optic 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, and 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 used 3,000 pounds less plastic than CAT 6 cables and 10,500 pounds less than CAT 6A cables and 3,000 pounds less of copper. The glass used in fiber only weighs 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 enable us to use a J holder instead of a traditional ladder channel.

What is also important is that construction labor cost varies significantly depending on the cost of living in 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. 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 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 support, floor space requirement, power and cooling cost.

Network support

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 level-2 (L2) services, including 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 of equipment and software

The Passive Optical LAN solution has a lower cost in all categories except testing and training. Testing was about 20 percent higher than traditional architecture, and training was about 30 percent 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 that 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 can reduce floor space used for networking by approximately 69 percent and cooling energy cost by approximately 74 percent, 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. With a Passive Optical LAN solution, the passive nature of the splitters and the long distance capability of fiber cable eliminate the need for a dedicated IDF. Splitters do not require any cooling, so they can be put in a very small closet on the floor, 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, of which 100 - 200 square feet is usually required to hold the two IDF closets. This floor space, unused with a Passive Optical LAN solution, can be easily converted to usable rooms to help generate extra revenue for the business.

The potential savings is greater for a large campus with multiple floors or multiple buildings than for 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 free up almost 90 percent of IDF floor space 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 reducing cooling and electronic devices in IDF closets is quite straightforward. This is a result of fewer power circuits, HVAC equipment provided by the building infrastructure and operational savings from reduced cooling loads. We have observed an approximate 81 percent 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 what ports the OLT has, power consumption of the OLT can be much lower than that of 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 58 percent 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 that 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 with the traditional copper-based solution. Compared to other power saving features, this factor is not significant, but it can reach about 1,000 kilowatt-hours in the deployment described here.

Towards smarter infrastructure and 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 US, 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, and indirectly to cooling infrastructure, it can help reduce harmful greenhouse gas emissions, increase asset value, decrease materials used for cabling and waste sent to landfills, enabling companies manage requirements for LEED certification in many of these aspects.

Deploy Passive Optical LAN to realize near-immediate payback

With the commercialization of Passive Optical LAN technology, it has quickly demonstrated advantages as one of the most revolutionary technologies in the networking era. It can adequately accommodate the demands of modern enterprise applications for a 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 near-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 near-immediate payback. In our experience, the leading-edge but tested Passive Optical LAN solution provides the foundation to optimize your investment today and enables the savings to continue year after year, potentially unlocking previously unseen business value. IBM has tested capabilities in various aspects of Passive Optical LANs, including design, implementation and support, that allow us to help our clients achieve their desired outcomes and deliver value. You can leverage the experience of a service provider that invests in development of thousands of innovative service solutions around the globe to help you gain business value and benefits more rapidly 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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