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The Tolly Group White Paper

Migrating to Fiber:

The Case for Centralized LAN Cabling

A white paper commissioned by 3M.

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3M White Paper: Migrating to Fiber: The Case for Centralized LAN Cabling
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The Tolly Group provides strategic consulting, independent testing, and industry analysis. It offers a full range of services designed to furnish end-users, vendors, and service providers with authoritative, unbiased information. The Tolly Group is recognized worldwide for its expertise in assessing leading-edge technologies.

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1. Introduction

Historically, choosing between fiber-optic cabling and unshielded twisted pair (UTP) copper cabling for the horizontal infrastructure meant choosing between performance (favoring fiber) and cost (favoring copper). Of course, over the years, the distinctions between the two cabling technologies have dissolved: Copper cabling, once perceived as a technological “dead end” at 100 MHz, now seems destined for continued growth in its bandwidth capacity from today’s category 5e through category 6 and 7. Likewise, new technologies in fiber have brought the costs of passive fiber components nearly into line with those of copper.

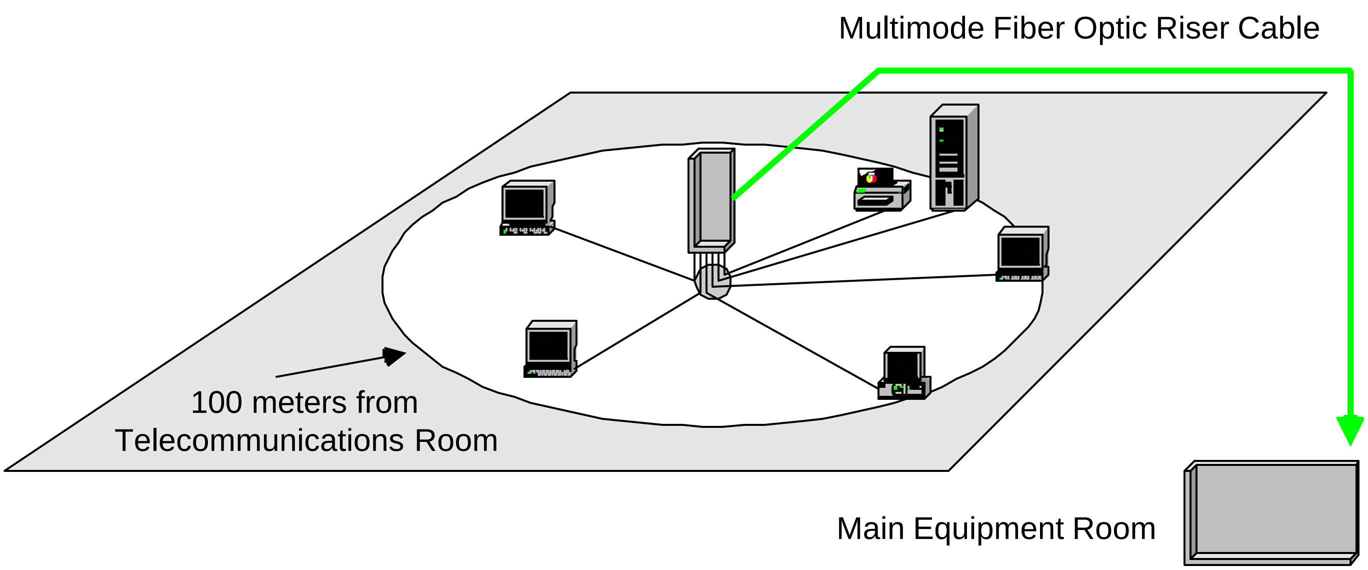
However, all of this notwithstanding, the prices of active fiber-optic components – particularly fiber NICs and switch ports – have traditionally been considerably higher than those of copper. Indeed, the difference has historically ranged from a few hundred dollars per port to more than a thousand dollars per port for high-end Gigabit Ethernet devices. For many users, the perceived minor advantage in fiber’s performance is completely overshadowed by its prohibitive costs.

This disparity in costs is largely attributable to the erroneous presumption that fiber-optic networks should be designed exactly like copper infrastructures. It’s perhaps not surprising, then, that carrying over all the extra design constraints of copper networks to a fiber-optic design results in higher fiber-optic prices. However, designing fiber-optic networks based upon the design characteristics of fiber often will save thousands of dollars compared to copper. This paper examines the design characteristics favorable to fiber and explores the ideal layout for a fiber-based network. In addition, this white paper compares the costs of building designs using copper and fiber.

2. Distributed Cabling

Traditionally, the high costs of fiber-optic cable dictated that users deploy copper cable on the horizontal (i.e., between the telecommunications room and the workstation) where connections were the most numerous. These workgroup and departmental copper connections would converge on a telecommunications room, where a few uplinks would connect to the backbone. Figure 1 illustrates a typical distributed network design.

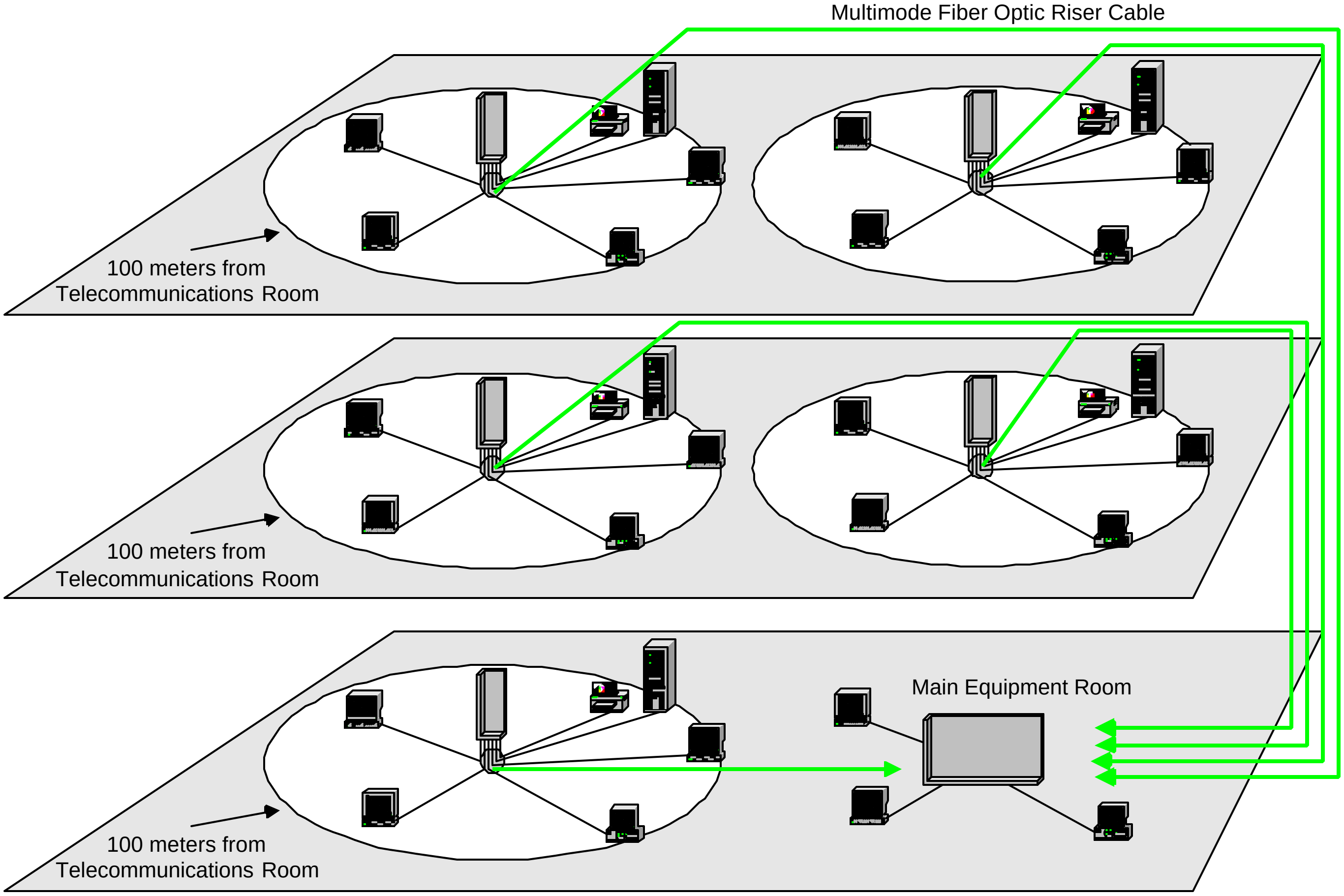
Distributed Network Design



Source: The Tolly Group, 2000 Figure 1

This design accommodates the 100-meter limit of UTP copper cable. Likewise, if workstations exceed this 100-meter distance, users will need multiple telecommunications rooms, as shown in figure 2.

Distributed Network Design: Multiple Telecommunications Rooms



Source: The Tolly Group, 2000 Figure 2

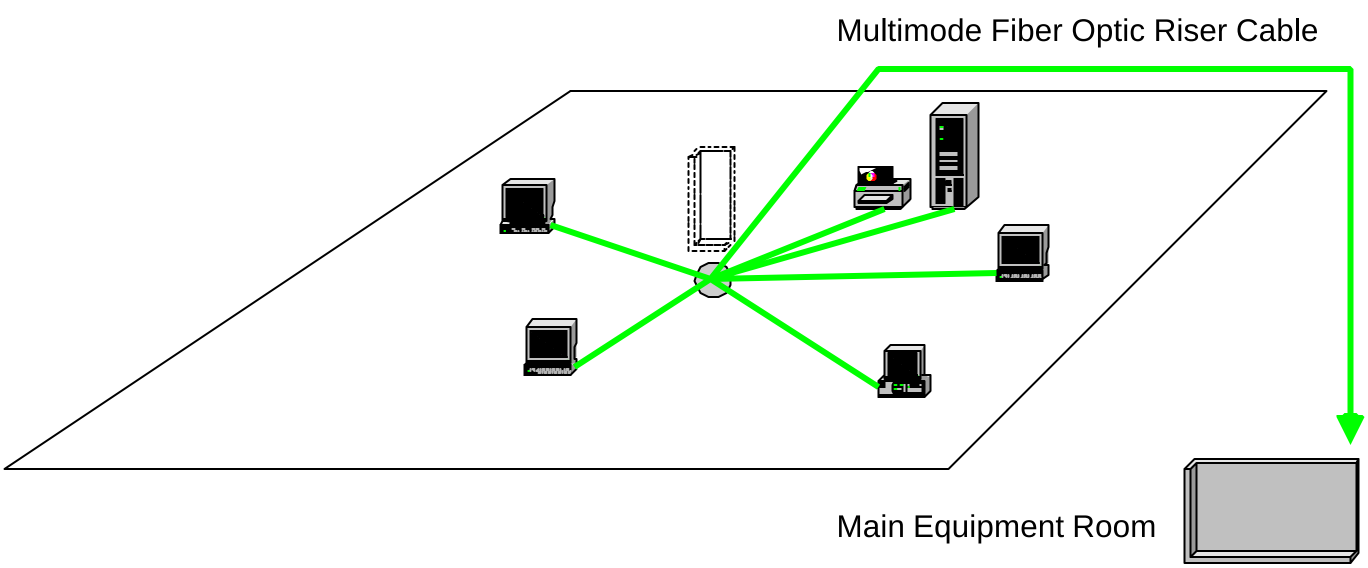
As the figures illustrate, a distributed cabling design involves connecting UTP copper cabling on the horizontal with fiber on the vertical, which, in turn, necessitates media conversion in the telecommunications room. Typically, this consists of hubs or switches with high-speed uplinks – such as 10BASE-T connections to the desktop and a 100BASE-FX connection to the backbone.

3. Centralized Cabling

Users who deploy fiber-optic cable on the horizontal are not bound by copper's 100-meter limitation, nor do they require media conversion from one physical medium to the other. Instead, those users can connect the horizontal fiber runs directly to the fiber in the backbone, thereby circumventing switches, bridges, routers, etc., in the telecommunications room.[1] As we'll see, this approach, known as "centralized cabling," can yield enormous savings.

Figure 3 shows a sample workgroup with direct connections to the backbone via a high fiber-count riser cable.

Centralized Network Design



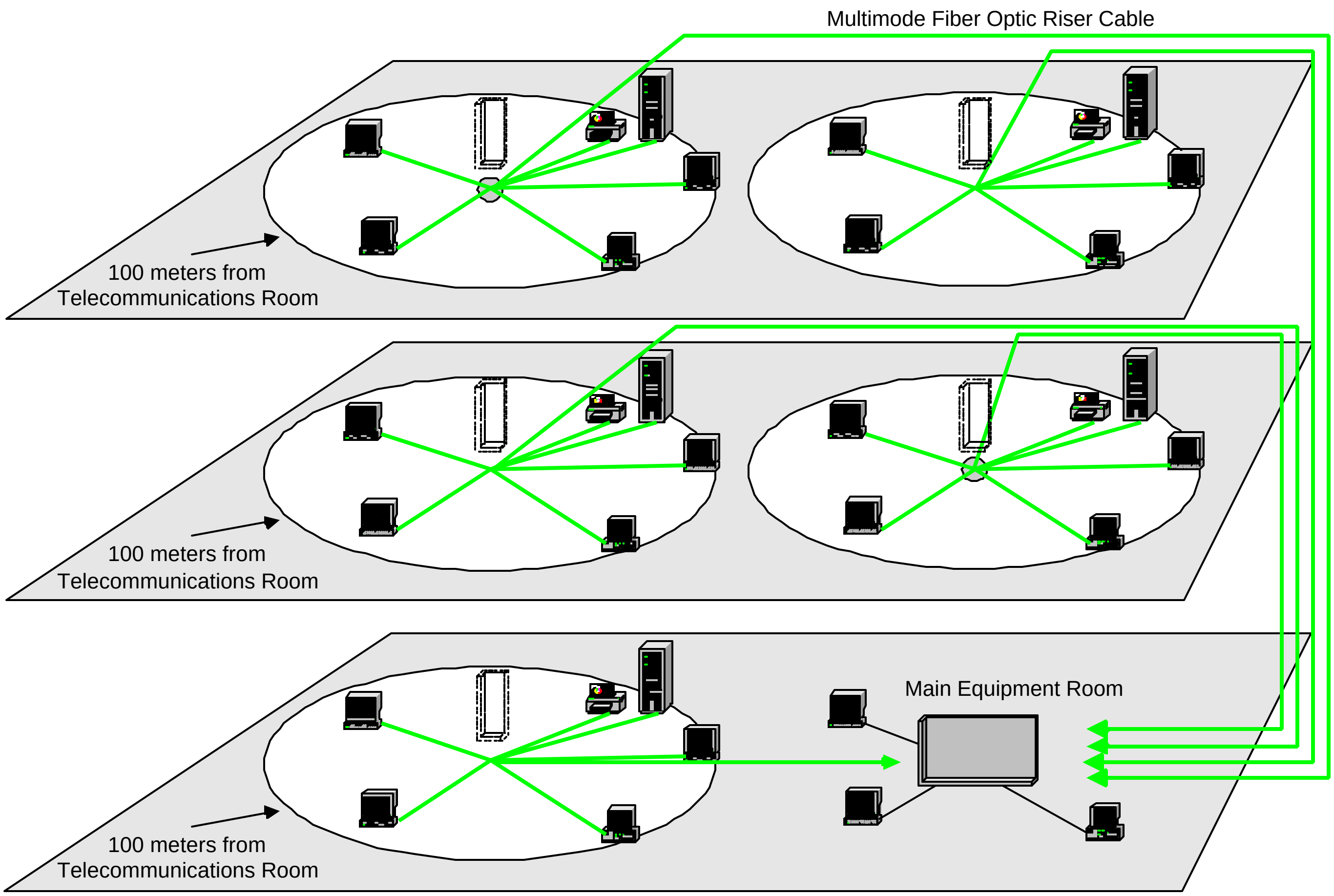
Source: The Tolly Group, 2000

Figure 3

In some cases, users may wish to consolidate the fibers in more than one telecommunications room before connecting them to the risers, although multimode fiber supports distances long enough to make this entirely optional. Figure 4 illustrates a sample network in which a customer has installed (or retained) multiple telecommunications rooms in the network but, through centralized cabling, still removed two telecommunications rooms.

[1] The TIA/EIA draft document SP-4425-B, to be published as TIA/EIA-568-B.1 Commercial Building Telecommunications Cabling Standard, limits pull-through connections to no more than 100 meters but allows longer distances with an interconnection or splice in the telecommunications room.

Centralized Network Design: Multiple Telecommunications Rooms



Source: The Tolly Group, 2000 Figure 4

In this new design, a single fiber-optic uplink to the telecommunications room is replaced by one or more high fiber-count cables with dedicated fiber connections to each workstation. In other words, switch ports in the telecommunications rooms are centralized within the main equipment room.

4. Initial Costs

Users can leverage a number of very large cost savings by shrinking and even eliminating some of the telecommunications rooms in their campuses. Of course, such a migration to a centralized architecture usually coincides with upgrading the network infrastructure or when re-creating the network infrastructure "from scratch." However, the cost savings are adequately compelling that some users may initiate a migration to a centralized design even when no network changes were planned previously.

Depending upon the particular customer environment, the savings – including both the telecommunications room and the associated internetworking hardware – can total tens of thousands of dollars and occasionally hundreds of thousands.

4.1. Telecommunications room[2]

The costs of telecommunications rooms across the campus can easily reach five or six figures, depending upon the size of the closets, the number of closets, and local hardware and labor costs. Included in these costs are the floors, walls, shelves, power and lighting, air conditioning ducts and uninterruptible power supplies. For instance, management at an office building with five telecommunications rooms located 34 meters from the data center could pay more than $160,000 in costs just for the closets, or more than $32,000 per closet, not including LAN switches.

In fact, the cost savings accrued by eliminating telecommunications rooms alone can more than offset the additional costs of new, dedicated fiber links from each workstation to the main equipment room.

Apparently complicating the cost picture is that the total costs of telecommunications rooms transcend the capital/hardware costs above to include the associated costs of maintaining multiple, disparate closets versus a single central data center with shared personnel and hardware resources. On the other hand, fiber switch ports in high-port-density modular switches in the data center will cost more than copper ports in workgroup switches within the telecommunications room.

In other words, there is no simple calculation to determine the relative costs of these two components. However, The Tolly Group has projected the costs associated with two buildings using (a) a distributed architecture with copper horizontals versus (b) a centralized architecture with fiber horizontals.

The first model consists of a 60,000-square foot building with 267 users. A distributed architecture with five telecommunications rooms and one main equipment room incurs an average per-user cost of $962.76 for category 5e cabling and $972.85 for category 6 cabling. These costs include horizontal hardware, telecommunications rooms, risers and the main equipment room.[3] By contrast, a centralized model with fiber requires only two telecommunications rooms and one main equipment room for an aggregate cost of only $806.80 per user. (See Appendices A, B, C and D.) This translates to an aggregate savings of more than $40,000 in hardware costs alone.

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[2] The telecommunications room was formerly called "telecommunications closet" by the TIA/EIA. Data communications personnel often refer to it as a "wiring closet."

[3] The costs presented in this white paper compare (a) street prices for components in a distributed network to (b) list prices in a centralized network, including list prices for 3M equipment.

The second model consists of a 240,000-square foot building with 1,067 users. A distributed architecture with 23 telecommunications rooms and one main equipment room incurs an average per-user cost of $996 for category 5e cabling and $1,006.10 for category 6 cabling. By contrast, a centralized model with fiber requires only 11 telecommunications rooms and one main equipment room for an aggregate cost of only $773.09 per user. This translates to an aggregate savings of more than $235,000 in hardware costs.

These models are based upon 20,000 square feet per floor, 225 square feet per user, 34 meters between telecommunications room and main equipment room, a two-to-one reduction in telecommunications rooms per floor excluding the basement (in which the main equipment room serves as one of the two telecommunications rooms). Both the 60,000 square-foot and the 240,000 square-foot models include (a) a 10' by 11' telecommunications room at an estimated cost of $32,226.35 per room in a distributed architecture and (b) a 2.5' by 4' (shallow) telecommunications room at an estimated cost of $13,328.25 per room in a centralized architecture. The 60,000 square-foot model also includes a 20' by 20' main equipment room at an estimated cost of $33,361.90 in a distributed architecture, and a 20' by 22' main equipment room (to accommodate more switch ports and cables) at an estimated cost of $37,428.30 in a centralized system. The 240,000 square-foot model also includes a 30' by 40' main equipment room at an estimated cost of $47,629.40 in a distributed architecture, and a 34' by 40' main equipment room (to accommodate more switch ports and cables) at an estimated cost of $56,893.20 in a centralized system. Figure 5 summarizes the costs.

Summary of Telecommunications Room and Main Equipment Room Costs

60,000-square foot building	Size	Cost
Telecommunications Room, Distributed Architecture	10' x 11'	$32,226.35
Telecommunications Room, Centralized Architecture	2.5' x 4'	$13,328.25
Main Equipment Room, Distributed Architecture	20' x 20'	$33,361.90
Main Equipment Room, Centralized Architecture	20' x 22'	$37,428.30

240,000-square foot building	Size	Cost
Telecommunications Room, Distributed Architecture	10’ x 11’	$32,226.35
Telecommunications Room, Centralized Architecture	2.5’ x 4’	$13,328.25
Main Equipment Room, Distributed Architecture	30’ x 40’	$47,629.40
Main Equipment Room, Centralized Architecture	34’ x 40’	$56,893.20

Source: The Tolly Group, 2000 Figure 5

The distributed model presumes that backbone connections are Gigabit Ethernet, whereas the centralized model uses the collapsed backbone design in which Fast Ethernet switches in the Main Equipment Room (MER) are connected to one another via Gigabit Ethernet links between them. (Appendix A provides more detail on the specific cost models and suppositions about costs.)

4.2. Limitations

In some cases, users who migrate existing buildings from a distributed cabling system to a centralized system may not be able to leverage all of the benefits associated with elimination of telecommunications rooms. This can occur when those rooms (a) contain hardware that cannot be reused or resold; (b) are located such that floor space cannot be easily reused, (c) would introduce significant building costs to make necessary modifications or (d) represent the only telecommunications rooms on the floor.[4] However, even partial reclamation of telecommunications room space can result in major cost savings.

[4] ANSI/TIA/EIA 569-A, the TIA/EIA Commercial Building Standard for Telecommunications Pathways and Spaces, requires at least one telecommunications room per floor.

5. Recurring costs

In addition to savings in hardware costs, removing or reducing telecommunications rooms can also yield other corollary savings, as well.

5.1.1. Environmental control

Eliminating the telecommunications room also means consolidating the recurring environmental costs of clean, uninterrupted power, and of heating, ventilation and air conditioning within the main equipment room. Clearly, centralizing this equipment in a single physical location allows far more efficient delivery of air conditioning, better network management and control, and tighter system security. Specific cost savings will depend upon a number of elements that will vary depending upon local hardware and labor costs, as well as individual customer/vendor sales agreements. However, the costs can run into the thousands of dollars.

5.1.2. Spare hardware

Costs associated with spare hardware can be reduced by consolidating switch ports to a single location, since fewer spares are required to support fewer devices. Consider a campus with 10 telecommunications rooms. Such a configuration may require three spare switch modules located strategically across the campus. Compare this with a centralized campus network architecture in which all connections terminate on a single switch in the data center. This latter configuration very well might require only one or two spare modules. Likewise, rather than providing Gigabit Ethernet uplinks to the main equipment room in the distributed model, a centralized model allows users to connect directly to a backbone switch and leverage the bandwidth of the switch backplane. In the former case, the Gigabit Ethernet uplink limits throughput to 10 wire-speed connections; in the latter case, all Fast Ethernet connections can operate at wire-speed (presuming that the switch is non-blocking).

5.1.3. Maintenance and Availability

Users can also enjoy faster troubleshooting and problem resolution in a centralized network architecture. Consolidating equipment in a single physical location means placing the systems under the direct control of the most highly-trained personnel in the organization, rather than relegating such tasks to department personnel with little knowledge or experience in network management. It also means that network management can be done with physical access to the system, rather than relying upon remote monitoring and management that may be unreliable during a remote system failure.

Perhaps one of the most compelling attractions of centralized cabling is that the absence of active components between the user and the backbone translates into a single physical segment terminating in the data center. That means that network support personnel can test physical connectivity end-to-end. By contrast, identifying physical-layer problems in a distributed cabling system often requires sending qualified support personnel to the location of the link in question, either on another floor or across the campus in another building. Clearly, delivering the physical link to the data center can facilitate the troubleshooting process significantly.

Expediting repair and minimizing downtime naturally translates into increasing productivity, revenues and customer satisfaction. Therefore, along with a reduction in support costs, the reduction in active components can increase revenue at the same time.

5.1.4. Summary

All of this means that, in addition to significant capital savings associated with centralized cabling, users will continue to enjoy reduced recurring costs over the life of the cable installation, as well. These costs are difficult to generalize as they largely are dependent upon customer-specific conditions (unlike capital costs that are subject to standards and therefore remain relatively consistent across different installations). However, depending upon factors such as the cost of environmental control, clean power, support contracts, downtime, and regional hourly costs for support and repair personnel, users can expect to reap significant savings in a centralized architecture over time versus a distributed model.

6. Challenges of Centralized Cabling

6.1. Gigabit Ethernet

One of the first issues that users will encounter when deploying fiber-optic cable is the potential problem of supporting Gigabit Ethernet: Some early low-grade fiber-optic cable suffered from an anomaly known as a "center-line dip" that was invisible with LED transmissions (e.g., Ethernet, Fast Ethernet, FDDI) but became problematic with Gigabit Ethernet's requirement for lasers. However, once the fiber-optic community recognized this problem, vendors began correcting the manufacturing process and producing cables that are free from center-line dips.

3M Insight

3M Volition cable uses Corning Inc. glass with no centerline dip, and no requirement for a mode-conditioning patch cord.

In fact, the IEEE 802.3z Gigabit Ethernet standard specifies maximum distances based upon the presence of this anomaly.[5] Certainly today's cables, free from such problems, can support distances significantly longer than those identified in the standards, as many vendors are now regularly demonstrating through a number of benchmarks. Of course, even older, low-quality cables that *do* suffer from center-line dips still can support Gigabit Ethernet at distances more than five times that of category 5e UTP copper cabling.

3M Insight

3M Volition cable meets all IEEE attenuation guidelines for Gigabit Ethernet. Furthermore, 3M Volition cable uses Corning InfiniCor glass supporting distances of up to 600 meters for 1000BASE-SX.

6.2. Port Density

Consolidating multiple workgroup ports into a single centralized switch can present some major port-density problems for sites using traditional SC or ST fiber-optic connectors. This is a product of the relative size of fiber versus copper connectors: Since fiber terminations are roughly twice the size of copper, the maximum port densities of these fiber-optic connections are roughly half that of copper.

In a traditional distributed cabling design, this was not much of an issue. After all, large numbers of users in each workgroup or department would be consolidated onto a single LAN switch in the telecommunications room with a single uplink to the data center. However, replacing that uplink with multiple fiber-optic connections potentially means adding significantly to the real estate.

First, larger ports mean low-port densities. That translates to fewer users per module and, consequently, fewer users per switch. Suddenly, low-port density means more modules, more switches, more power, more support contracts, more management overhead, etc.

3M Insight

3M's Volition product line provides a fully-standardized small form factor fiber optic interface that occupies the same space as an RJ-45 copper connector.

In response to this problem, the cabling industry has introduced a number of small-form-factor, high-density solutions that deliver fiber connectivity within the same port space as their copper counterparts.

[5] SP-4425-B references the IEEE-standard distances but does not include them as part of the normative draft.

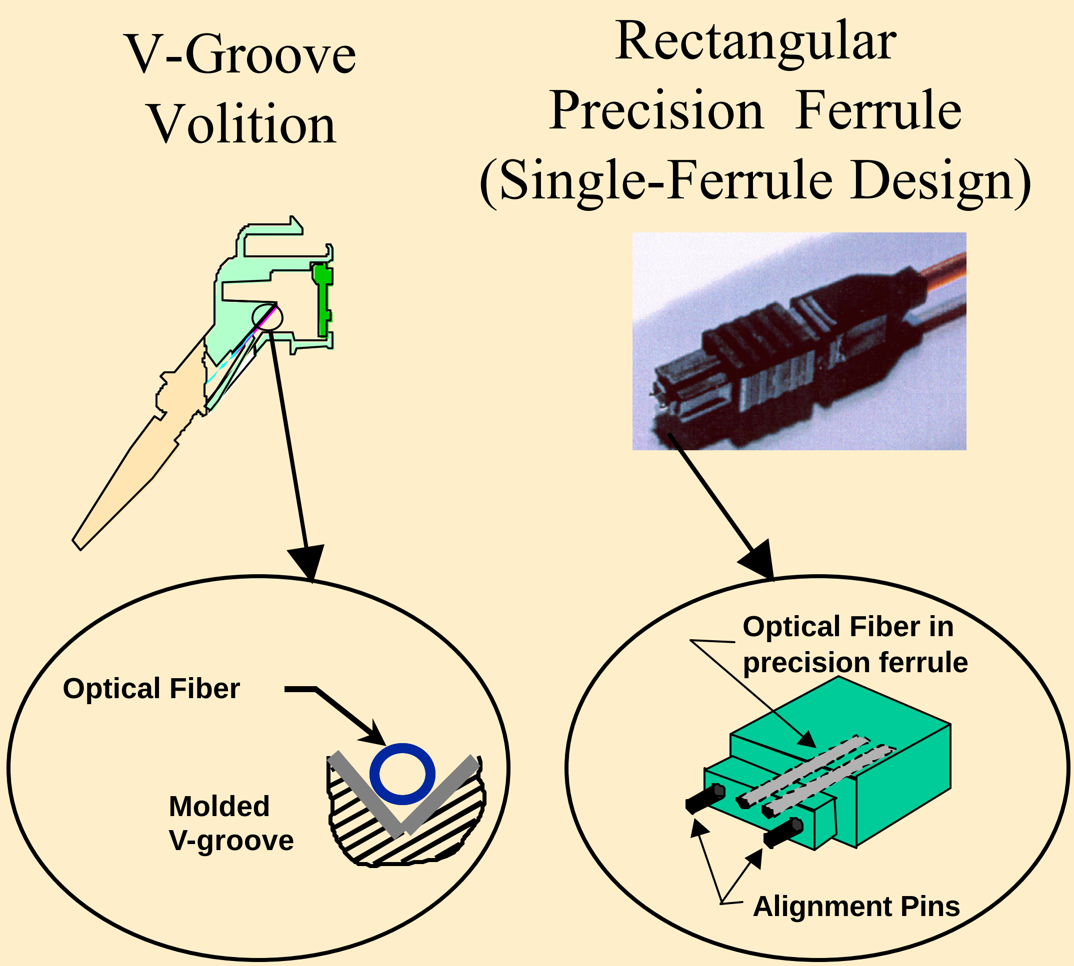
6.3. Port Costs

3M offers these products at prices significantly lower than those of traditional fiber. For instance, a fully-populated 3M Volition VOL-4000 switch (32 ports of Fast Ethernet) would cost just under $270 per port, or roughly half the lowest fiber-optic per-port prices of most Fast Ethernet switches with ST or SC connectors. This is due in part to V-groove technology that avoids the costly dual-ferrule approach used in other small-form-factor products. The latter requires both fiber-ferrule alignment and radial alignment to ensure mating of both fibers. See 3M Insight, below.

This reduction in per-port costs for fiber translates to an overall savings in the centralized model versus a distributed model. Clearly, products that use more expensive implementations show a less favorable cost comparison.

3M Insight

V-groove technology avoids the costly single-ferrule approach used in other small form-factor products. The latter requires both fiber-ferrule alignment and radial alignment to ensure mating of both fibers.

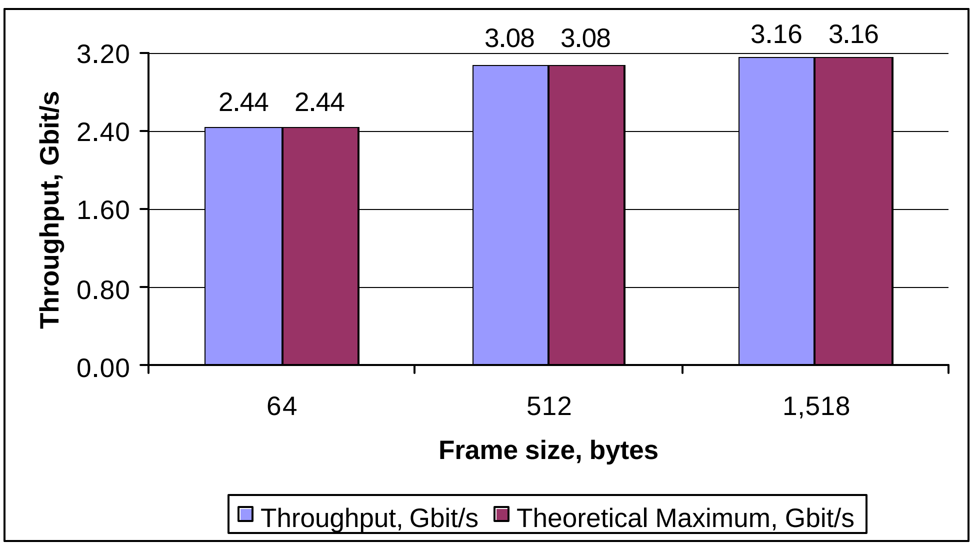


7. Performance

Even if next-generation fiber connectors can deliver the same port density as copper, there is still the issue of the components behind the interface. Specifically, the industry is already quite familiar with the performance of adapters and switches from the leading vendors and, in most, cases, those products offer wire-speed or near-wire-speed performance. Not surprisingly, then, users will be justifiably reluctant to forego products from the more familiar vendors and instead install fiber-optic products with new technologies (e.g., 3M's Volition and VF-45) unless and until they have objective, accurate, third-party benchmark performance data on such products.

The Tolly Group conducted a series of benchmarks on the 3M VOL-4000 Fast Ethernet switch and the VOL-N100VF Volition NIC. The tests demonstrate wire-speed, zero-loss switching performance, regardless of frame size. See figure 6.

VOL-4000 (VF-45 Multimode Fiber Optic) 32-Port Fast Ethernet Switch Layer 2 Fast Ethernet Wire-Speed Switching Performance



Source: The Tolly Group, 2000

Figure 6

The tests also demonstrated latency (First In, First Out, i.e., including insertion delay) of less than one hundredth of a millisecond with the smallest frame size, and approximately one-eighth of a millisecond with the largest frame size. This translates to a Last In, First Out latency (i.e., subtracting the insertion delay) of no more than five *micro*seconds above the insertion delay. See figure 7.

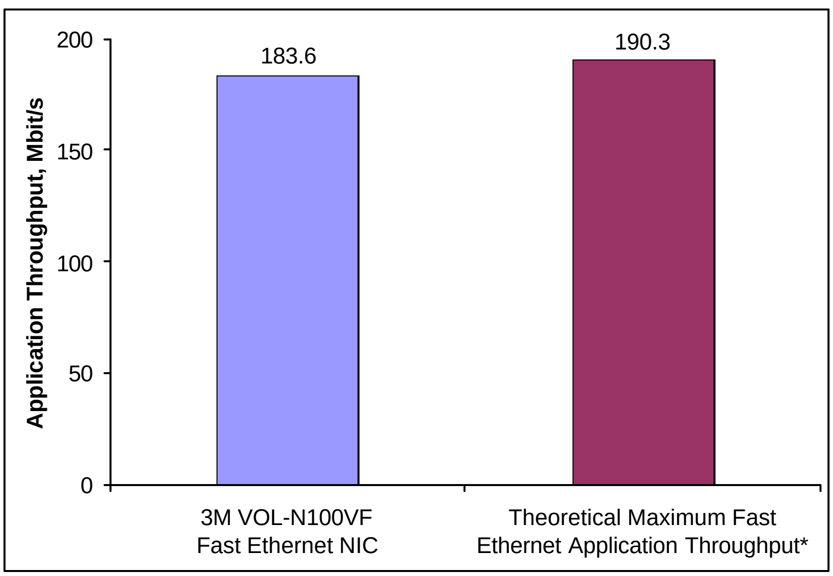
VOL-4000 (VF-45 Multimode Fiber Optic) 32-Port Fast Ethernet Switch Latency

3M VOL-4000 Fast Ethernet Frame Latency, Microseconds, at 1% Theoretical Maximum Unidirectional Load	FIFO Latency, microseconds	Insertion Delay, microseconds	LILO Latency, microseconds
64-byte Frames	9.40	5.76	3.64
512-byte Frames	45.60	41.60	4.00
1,518-byte Frames	127.10	122.08	5.02

Source: The Tolly Group, 2000 Figure 7

The tests also demonstrated that VF-45-enabled NICs also can deliver wire-speed performance. Specifically, The Tolly Group tested 3M Volition NICs (VOL-N100VF) and observed application throughput of more than 180 Mbit/s on a single, full-duplex Fast Ethernet NIC. Unlike the packet-per-second tests referenced above, these tests focused on effective user data, excluding framing, headers, acknowledgements, etc. Based upon even the absolute minimum overhead required, the 3M Volition adapter still delivered 96.5% of the theoretical maximum application throughput of a full-duplex Fast Ethernet connection. See figure 8.

VOL-N100VF (VF-45 Multimode Fiber Optic) NIC, Full-Duplex Fast Ethernet Application Throughput



Source: The Tolly Group, 2000 Figure 8

* Maximum throughput based upon Fast Ethernet framing and packet overhead (e.g., MAC, IP, TCP, CRC, etc.).

8. Upgrades

In many cases, the most significant obstacle to fiber-optic technology is the dramatic change that it introduces to the existing network . As an example, consider the process of upgrading from, say, category 5 to category 5e copper: Even while the cable is replaced, existing network adapters can operate over both the older category 5 cables and the newly-installed category 5e cables. Likewise, switches, routers, servers, etc. can connect over either cable plant. That means that users can migrate to the new technology gradually, replacing components in a “phased” approach.. Those users may decide, after the category 5e migration is complete, that they then want to prototype some IEEE 802.3ab Gigabit Ethernet connections over copper.

By contrast, upgrading a network from category 5 UTP to fiber-optic cabling means that, as each new run is installed, new fiber-optic NICs and switch ports are required at the same time. After all, a network connection is either copper or fiber – not both. By contrast, an upgrade to category 5e represents a potential improvement in performance but requires no other immediate modifications to the network. In the worst case, upgrading to fiber may mean providing for both copper and fiber switches and routers in the telecommunications room, adding to the maintenance of the network until the transition is complete.

Of course, this really represents a “worst-case” situation. In fact, this depiction of a wholesale “all-or-nothing” adoption of fiber is perhaps somewhat exaggerated. In most cases, fiber-optic solutions also can be deployed in a “phased” approach through the use of media converters. These devices simply provide connectivity between devices on different physical media.[6]

Perhaps an even greater cost consideration is that of additional future upgrades. Specifically, users who deploy UTP cabling on the horizontal have grown accustomed to upgrading their cabling as often as every five years from, say, category 3 to category 5 to category 5e and soon to category 6. In each, the upgrades were intended to “future-proof” the network based upon projections of future bandwidth requirements. Instead, history has demonstrated that users’ needs seem to expand to fill all available bandwidth.

Likewise, there is no guarantee that fiber-optic cable will deliver all the bandwidth that users will ever need. However, at 20 times the bandwidth of category 6 and 50 times the bandwidth of category 5, fiber is likely to forestall network upgrades for a considerably longer time.[7] The implications of foregoing an additional (and ultimately redundant) installation of 200 nodes to category 6 then later to fiber, based upon the prices cited earlier, would mean a cost savings of over $7,500 in cabling hardware alone (see Appendix A). Furthermore, at an hourly labor charge of $50 per hour and a requirement for 15 minutes per category 6 termination (excluding running the new cable), this equates to an additional savings of $2,500 in termination costs. In other words, the costs of the additional cabling and termination exceed $10,000 for this 200-node network, and this excludes the costs associated with running the cables through interducts, conduits, raceways, etc.

Clearly, obviating an unnecessary upgrade can save customers hundreds of thousands of dollars, depending upon the installation. This consideration alone makes fiber a compelling choice.

[6] Technically, they provide connectivity up to the PHY layer (the upper half of the OSI Physical Layer). As such, they provide no error checking and, consequently, introduce minimal delay.

[7] Although this document focuses upon category 5e and 6 only, it is interesting that multimode fiber delivers more than eight times the proposed bandwidth of category 7 cable.

9. Summary

Fiber optic cabling has long held an advantage over copper in bandwidth, distance and reliability. With the advent of new centralized LAN cabling designs, fiber now enjoys a cost advantage as well: Reducing the size of telecommunications rooms, and even removing many of them, throughout the campus means significant reductions in quantifiable, capital costs, plus additional savings in recurring costs.

Moreover, today's lower fiber component costs and new media converters enable customers to migrate gradually from copper to fiber. These lower costs are partly attributable to simplified connector design and high-density, small-form-factor connectors. These new technological advances abolish the long-standing tenet that deploying fiber in the horizontal necessitated a forklift upgrade.

Finally, cost benefits aside, customers concerned about the performance of the current generation of fiber optic "active" components will be encouraged to discover wire-speed performance from both NICs and switches alike.

Traditional assumptions about the costs of fiber optic cabling must now yield to new network designs that, by leveraging fiber's longer distances, enable the reduction and elimination of costly telecomm rooms and, in so doing, effect profound costs savings. To the list of fiber's well-known benefits of exceptionally high bandwidth and immunity to electrical interference, we can now add the benefit of significant cost reductions.

10. References

3M Volition Home Page: www.3m.com/volition

Corning, Inc. White Paper on measuring laser multimode performance (Requires approved registration, then choose document "WP4062"): http://www.corningfiber.com/products/infinicor-cl_tech.htm

Relevant Standards: IEEE 802.ab (Gigabit Ethernet over Copper), IEEE 802.3z (Gigabit Ethernet over Fiber), TIA/EIA SP-4425-B (Commercial Building Telecommunications Cabling Standard, Draft 8.0), ANSI/TIA/EIA 569-A (Commercial Building Telecommunications Cabling Standard).

11. Appendices

11.1. Appendix A: Calculation of Centralized and Distributed Telecommunications Rooms and Main Equipment Room Costs

11.1.1. Comparison of horizontal cabling costs

			Category 5e UTP		Category 6 UTP		Volition Fiber	
Component	Metric	Qty.	Unit Price	Total	Unit Price	Total	Unit Price	Total
How far is it from the telecommunications closet to the workstation?	***Meters***	33.3	$0.29	$9.66	$0.37	$12.32	$0.33	$10.99
How much does a Channel Jack cost?	***$ US***	1	$2.79	$2.79	$3.50	$3.50	$2.64	$2.64
How much does a patch panel cost per port (total cost/number of ports)?	***$ US***	1	$3.08	$3.08	$3.58	$3.58	$2.88	$2.88
How much does a 10-ft. patch cord cost?	***$ US***	2	$3.99	$7.98	$6.40	$12.80	$11.00	$22.00
How much does a wall plate/jack/socket assembly cost?	***$ US***	1	$5.40	$5.40	$6.80	$6.80	$6.07	$6.07
Total				$28.91		$39.00		$44.58

A B C D

11.1.2. Cost of Telecommunications Rooms and Main Equipment Room, 60,000-square foot building, 20,000-square feet per floor, formulas only[8]

A	B	C	D
	Units	Enter data here	
Main Equipment Room			
What is the cost of the equipment room in a distributed system?		33361.9	
What is the cost of the equipment room in a centralized system?		37428.3	
Telecommunications Room			
How many telecommunications room are there in the distributed system?	Number	5	
What is the cost of the telecommunications room in a distributed system?	$ US	32226.35	
How many telecommunications rooms are there in the centralized system?	Number	2	
What is the total user-occupied floor space of the building	Number	60000	
How many square feet does a user occupy on average	Number	225	

[8] Calculations are provided here to illustrate the process through which cost models were developed. To interpret formula calculations, the first row displayed is Row 1. No rows are hidden. Therefore, all row numbers are sequential.

What is the cost of the telecommunications room in a centralized system?	$ US	13328.25
How many users connect to/through the telecommunications rooms?	Number	=C10/C11
How far is it from the telecommunications closet to the Main Crossconnect?	Meters	=110*12/39

NIC Pricing

What is the cost of a 100Base-T NIC?	$ US	20
What is the cost of a Volition VF-45 Fast Ethernet adapter?	$ US	150

Switch Pricing

Telecommunications Closet, Fast Ethernet with Gigabit Ethernet uplink

How much does a switch chassis for the telecommunications closet cost?	$ US	0
How much does a switch module for the telecommunications closet cost?	$ US	1169.99
How many ports are there in the switch module in the telecommunications closet?	Number	16

Main Equipment Room, Distributed Model, Gigabit Ethernet

How much does a switch chassis for the main communications room closet cost?	$ US	0
How much does a switch module for the main communications room cost?	$ US	8200
How many ports are there in the switch module in the main communications room ?	Number	6

Main Equipment Room, Centralized Model, Fast Ethernet VF-45

How much does a Volition VOL-5000 switch chassis cost?	$ US	=3033+1120+1120
How much does a Volition VOL-5000 switch module cost?	$ US	1766.88
How many ports are there in the Volition VOL-5000 switch module?	Number	8
How many slots are there in the Volition VOL-5000 switch?	Number	6

Riser Cable

What is the cost of a single-pair riser cable per meter?	$ US	1.11	
How many fiber pairs are in each multi-fiber riser cable bundle?	Number	12	
What is the cost of the riser cable bundle per meter?	$ US		=2.95*(39/12)

Switch pricing

What is the price per port for a modular Fast Ethernet switch with 100BASE-T ports and 1 1000Base-SX uplink for the telecommunications closet?	$ US	=(C22+C27*ROUNDUP((C24/D13/C7),0))/(D13/C7)
What is the price per port for a modular Gigabit Ethernet switch with 1000BASE-SX ports for the main communications room?	$ US	=(C26+C27*ROUNDUP(C7/C28,0))/C7
What is the price per port for a Volition VF-45 Fast Ethernet switch with enough VF-45 for all users in the network?	$ US	=(C30*ROUNDUP((D13/C32/C33),0)+C31*ROUNDUP((D13/C32),0))/D13
Cost of a distributed Cat 5e system, per user	$ US	=C17+'Horizontal Cable and Components'!E8+((C7*C8)+(D42*C7))/D13+D41
Cost of a distributed Cat 6 system, per user	$ US	=C17+'Horizontal Cable and Components'!G8+((C7*C8)+(D42*C7))/D13+D41
Cost of a centralized Volition multimode fiber optic system, per user	$ US	=C18+'Horizontal Cable and Components'!I8+C9*C12/D13+(ROUNDUP(D13/C37,0))*D38*C14/D13+D43
Aggregate Savings v. Cat 5e		=(D45-D47)*(C10/C11)
Aggregate Savings v. Cat 6		=(D46-D47)*(C10/C11)

11.1.3. Cost of Telecommunications Rooms and Main Equipment Room, 60,000-square foot building, 20,000-square feet per floor, values

	Units	Enter data here	
Main Equipment Room			
What is the cost of the equipment room in a distributed system?		$33,361.90	
What is the cost of the equipment room in a centralized system?		$37,428.30	
Telecommunications Room			
How many telecommunications room are there in the distributed system?	Number	5	
What is the cost of the telecommunications room in a distributed system?	$ US	$32,226.35	
How many telecommunications rooms are there in the centralized system?	Number	2	
What is the total user-occupied floor space of the building	Number	60000	
How many square feet does a user occupy on average	Number	225	
What is the cost of the telecommunications room in a centralized system?	$ US	$13,328.25	
How many users connect to/through the telecommunications rooms?	Number		267
How far is it from the telecommunications closet to the Main Crossconnect?	Meters	34	
NIC Pricing			
What is the cost of a 100Base-T NIC?	$ US	$20.00	
What is the cost of a Volition VF-45 Fast Ethernet adapter?	$ US	$150.00	

Switch Pricing

Telecommunications Closet, Fast Ethernet with Gigabit Ethernet uplink

How much does a switch chassis for the telecommunications closet cost?	$ US	$0.00
How much does a switch module for the telecommunications closet cost?	$ US	$1,169.99
How many ports are there in the switch module in the telecommunications closet?	Number	16

Main Equipment Room, Distributed Model, Gigabit Ethernet

How much does a switch chassis for the main communications room closet cost?	$ US	$0.00
How much does a switch module for the main communications room cost?	$ US	$8,200.00
How many ports are there in the switch module in the main communications room ?	Number	6

Main Equipment Room, Centralized Model, Fast Ethernet VF-45

How much does a Volition VOL-5000 switch chassis cost?	$ US	$5,273.00
How much does a Volition VOL-5000 switch module cost?	$ US	$1,766.88
How many ports are there in the Volition VOL-5000 switch module?	Number	8
How many slots are there in the Volition VOL-5000 switch?	Number	6

Riser Cable

What is the cost of a single-pair riser cable per meter?	$ US	$1.11	
How many fiber pairs are in each multi-fiber riser cable bundle?	Number	12	
What is the cost of the riser cable bundle per meter?	$ US		$9.59

Switch pricing

What is the price per port for a modular Fast Ethernet switch with 100BASE-T ports and 1 1000Base-SX uplink for the telecommunications closet?	$ US		$153.75

What is the price per port for a modular Gigabit Ethernet switch with 1000BASE-SX ports for the main communications room?	$ US	$1,640.00
What is the price per port for a Volition VF-45 Fast Ethernet switch with enough VF-45 for all users in the network?	$ US	$343.92
Cost of a distributed Cat 5e system, per user	$ US	$962.76
Cost of a distributed Cat 6 system, per user	$ US	$972.85
Cost of a centralized Volition multimode fiber optic system, per user	$ US	$806.80
Aggregate Savings v. Cat 5e		$41,587.56
Aggregate Savings v. Cat 6		$44,279.30

11.1.4. Cost of Telecommunications Rooms and Main Equipment Room, 240,000-square foot building, 20,000-square feet per floor, formulas only

A	B	C	D
	Units	Enter data here	
Main Equipment Room			
What is the cost of the equipment room in a distributed system?		47629.4	
What is the cost of the equipment room in a centralized system?		56893.2	
Telecommunications Room			
How many telecommunications room are there in the distributed system?	Number	23	
What is the cost of the telecommunications room in a distributed system?	$ US	32226.35	
How many telecommunications rooms are there in the centralized system?	Number	13	
What is the total user-occupied floor space of the building	Number	240000	
How many square feet does a user occupy on average	Number	225	
What is the cost of the telecommunications room in a centralized system?	$ US	13328.25	

How many users connect to/through the telecommunications rooms?	Number	=C10/C11
How far is it from the telecommunications closet to the Main Crossconnect?	Meters	=110*12/39

NIC Pricing

What is the cost of a 100Base-T NIC?	$ US	20
What is the cost of a Volition VF-45 Fast Ethernet adapter?	$ US	150

Switch Pricing

Telecommunications Closet, Fast Ethernet with Gigabit Ethernet uplink

How much does a switch chassis for the telecommunications closet cost?	$ US	0
How much does a switch module for the telecommunications closet cost?	$ US	1169.99
How many ports are there in the switch module in the telecommunications closet?	Number	16

Main Equipment Room, Distributed Model, Gigabit Ethernet

How much does a switch chassis for the main communications room closet cost?	$ US	0

How much does a switch module for the main communications room cost?	$ US	8200	
How many ports are there in the switch module in the main communications room ?	Number	6	

Main Equipment Room, Centralized Model, Fast Ethernet VF-45

How much does a Volition VOL-5000 switch chassis cost?	$ US	=3033+1120+1120	
How much does a Volition VOL-5000 switch module cost?	$ US	1766.88	
How many ports are there in the Volition VOL-5000 switch module?	Number	8	
How many slots are there in the Volition VOL-5000 switch?	Number	6	

Riser Cable

What is the cost of a single-pair riser cable per meter?	$ US	1.11	
How many fiber pairs are in each multi-fiber riser cable bundle?	Number	12	
What is the cost of the riser cable bundle per meter?	$ US		=2.95*(39/12)

Switch pricing

What is the price per port for a modular Fast Ethernet switch with 100BASE-T ports and 1 1000Base-SX uplink for the telecommunications closet?	$ US		=(C22+C27*ROUNDUP((C24/D13/C7),0))/(D13/C7)

What is the price per port for a modular Gigabit Ethernet switch with 1000BASE-SX ports for the main communications room?	$ US	=(C26+C27*ROUNDUP(C7/C28,0))/C7
What is the price per port for a Volition VF-45 Fast Ethernet switch with enough VF-45 for all users in the network?	$ US	=(C30*ROUNDUP((D13/C32/C33),0)+C31*ROUNDUP((D13/C32),0))/D13
Cost of a distributed Cat 5e system, per user	$ US	=C17+'Horizontal Cable and Components'!E8+((C7*C8)+(D42*C7)+C4)/D13+D41
Cost of a distributed Cat 6 system, per user	$ US	=C17+'Horizontal Cable and Components'!G8+((C7*C8)+(D42*C7)+C4)/D13+D41
Cost of a centralized Volition multimode fiber optic system, per user	$ US	=C18+'Horizontal Cable and Components'!I8+C9*C12/D13+(ROUNDUP(D13/C37,0))*D38*C14/D13+C5/D13+D43
Aggregate Savings v. Cat 5e		=(D45-D47)*(C10/C11)
Aggregate Savings v. Cat 6		=(D46-D47)*(C10/C11)

11.1.5. Cost of Telecommunications Rooms and Main Equipment Room, 240,000-square foot building, 20,000-square feet per floor, values

	Units	Enter data here	
Main Equipment Room			
What is the cost of the equipment room in a distributed system?		$47,629.40	
What is the cost of the equipment room in a centralized system?		$56,893.20	
Telecommunications Room			
How many telecommunications room are there in the distributed system?	Number	23	
What is the cost of the telecommunications room in a distributed system?	$ US	$32,226.35	
How many telecommunications rooms are there in the centralized system?	Number	13	
What is the total user-occupied floor space of the building	Number	240000	
How many square feet does a user occupy on average	Number	225	
What is the cost of the telecommunications room in a centralized system?	$ US	$13,328.25	
How many users connect to/through the telecommunications rooms?	Number		1,067
How far is it from the telecommunications closet to the Main Crossconnect?	Meters	34	
NIC Pricing			
What is the cost of a 100Base-T NIC?	$ US	$20.00	
What is the cost of a Volition VF-45 Fast Ethernet adapter?	$ US	$150.00	

Switch Pricing

Telecommunications Closet, Fast Ethernet with Gigabit Ethernet uplink

How much does a switch chassis for the telecommunications closet cost?	$ US	$0.00
How much does a switch module for the telecommunications closet cost?	$ US	$1,169.99
How many ports are there in the switch module in the telecommunications closet?	Number	16

Main Equipment Room, Distributed Model, Gigabit Ethernet

How much does a switch chassis for the main communications room closet cost?	$ US	$0.00
How much does a switch module for the main communications room cost?	$ US	$8,200.00
How many ports are there in the switch module in the main communications room ?	Number	6

Main Equipment Room, Centralized Model, Fast Ethernet VF-45

How much does a Volition VOL-5000 switch chassis cost?	$ US	$5,273.00
How much does a Volition VOL-5000 switch module cost?	$ US	$1,766.88
How many ports are there in the Volition VOL-5000 switch module?	Number	8
How many slots are there in the Volition VOL-5000 switch?	Number	6

Riser Cable

What is the cost of a single-pair riser cable per meter?	$ US	$1.11	
How many fiber pairs are in each multi-fiber riser cable bundle?	Number	12	
What is the cost of the riser cable bundle per meter?	$ US		$9.59

Switch pricing

What is the price per port for a modular Fast Ethernet switch with 100BASE-T ports and 1 1000Base-SX uplink for the telecommunications closet?	$ US		$176.81

What is the price per port for a modular Gigabit Ethernet switch with 1000BASE-SX ports for the main communications room?	$ US	$1,426.09
What is the price per port for a Volition VF-45 Fast Ethernet switch with enough VF-45 for all users in the network?	$ US	$335.66
Cost of a distributed Cat 5e system, per user	$ US	$996.00
Cost of a distributed Cat 6 system, per user	$ US	$1,006.10
Cost of a centralized Volition multimode fiber optic system, per user	$ US	$773.09
Aggregate Savings v. Cat 5e		$237,770.11
Aggregate Savings v. Cat 6		$248,537.05

11.1.6. Other cost notes

For the Telecommunications room Fast Ethernet switch, The Tolly Group based its price on an Addtron Technology ATS-16 16-port 100BASE-TX Fast Ethernet switch with two 1000BASE-SX Gigabit Ethernet uplinks priced at $1,169.99 from MicroWarehouse (http://www.warehouse.com).

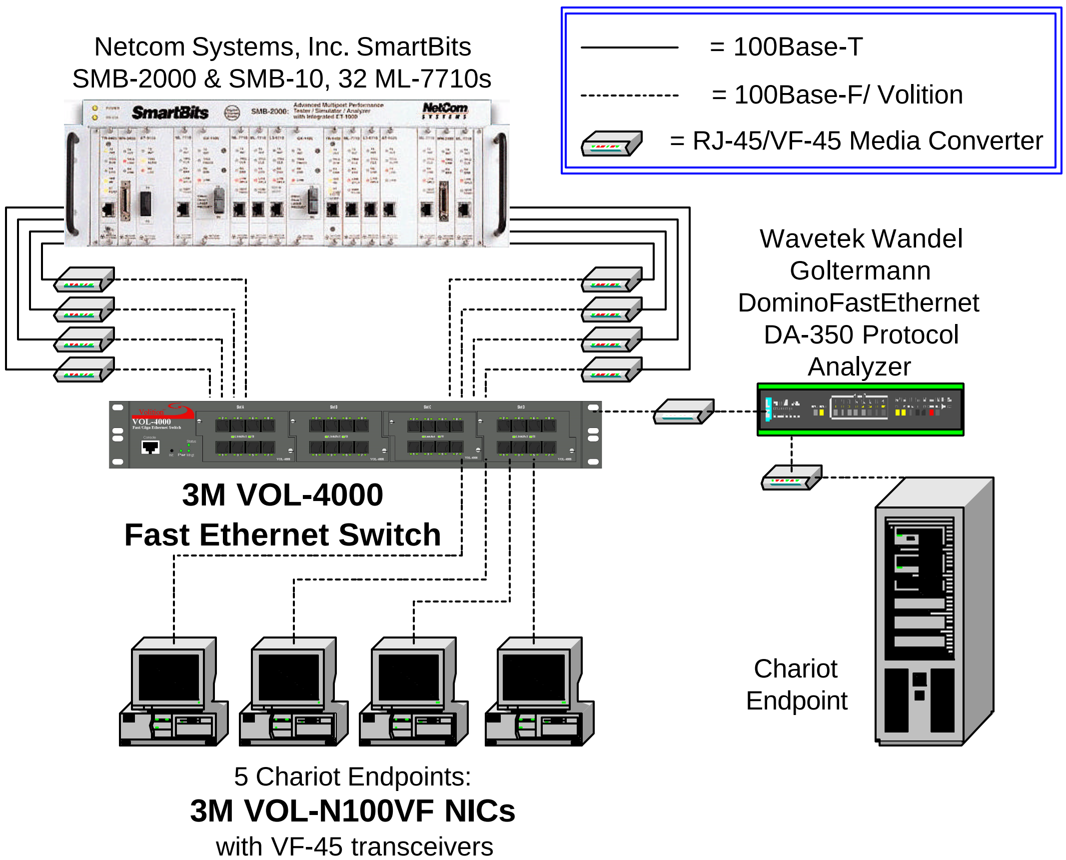
For the Main Equipment Room Gigabit Ethernet switch, The Tolly Group based its calculation upon a Hewlett-Packard Co. ProCurve 6208M-SX Gigabit Ethernet switch equipped with eight 1000BASE-SX ports priced at $9,189.99 from MicroWarehouse. The Tolly Group then compared this with the price of an Intel Corp. Express Gigabit Switch model ES1000SRPUS equipped with seven 1000BASE-SX interfaces and an available slot for additional ports. Based upon this price and the possibility of volume discounts for larger port count purchases, The Tolly Group discounted the price of this switch to $8,200.

The Tolly Group used list prices for all 3M equipment, including $150 for a VOL-N100VF NIC, $3,033 for a VOL-5000 chassis plus $1,120 for each of two 1000BASE-SX Gigabit Ethernet uplinks, $1,766.88 for an eight-port 100BASE-F Fast Ethernet module for the VOL-5000.

11.2. Appendix B: Test Methodology

The Tolly Group benchmarked the throughput, latency and head-of-line blocking of 3M's VOL-4000 version 4.14 Fast Ethernet switch with a Netcom Systems, Inc. SmartBits SMB-2000 and SMB-10 equipped with 32 Multi-Layer ML-7710 10/100 Mbit/s Ethernet interfaces, Firmware 6.61, running Netcom's SmartApps version 2.30 Beta Build 14 and Advanced Switch Test version 2.10. The Tolly Group connected each ML-7710 to a 3M VOL-0213 Fast Ethernet VF-45/RJ-45 Media Converter chassis equipped with VOL-0208 100BASE-TX/FX (1300 nm) media converters. The following illustration depicts the logical placement of devices within the test bed.

Volition Test Bed: VOL-4000 Fast Ethernet Switch and VOL-N100VF Fast Ethernet NIC



Source: The Tolly Group, 2000

For throughput tests, The Tolly Group verified that the VOL-4000 delivers zero-loss (<0.001%) steady-state bidirectional throughput at an offered load of 100% of the theoretical maximum PPS rate for full-duplex Fast Ethernet at frame sizes of 64 bytes, 512 bytes and 1,518 bytes, including cyclic redundancy check (CRC). The Tolly Group initiated the streams on all 32 ports simultaneously and performed three 60-second iterations.

For latency tests, The Tolly Group verified that latency remained only marginally measured latency of 16 unidirectional streams (16 ingress ports, 16 egress ports, non-mesh configuration) at 1% and 50% of the theoretical maximum PPS rate for frames of 64 bytes, 512 bytes and 1,518 bytes.

For head-of-line blocking tests, The Tolly Group congested one egress switch port by directing traffic to it from two ingress ports. A third stream shared one of the ingress ports but was destined for another egress port. The Tolly Group verified that the congestion did not cause any loss in throughput for the stream destined for the uncongested port. In other words, the VOL-4000 switch does not suffer from head-of-line blocking.

The Tolly Group then benchmarked the performance of the 3M VOL-N100VF Volition Fast Ethernet NIC version 2.21 installed in a Microsoft Corp. Windows NT Server 4.0 SP5 when transferring data to and from five Fast Ethernet clients across a VOL-4000 switch. The Tolly Group used Ganymede Software, Inc.'s Chariot 3.1 and Endpoint 3.3 to simulate simultaneous file uploads and downloads of 1,000,000 bytes each. The specific Chariot scripts appear on The Tolly Group's Web site; one of the 10 Chariot pairs (five uploads, five downloads) appears in this document as Appendix C. Tests showed an effective data throughput (excluding headers, trailers, acknowledgments, etc.) of 183 Mbit/s. Subtracting frame overhead for MAC, IP and TCP headers, plus framing, interface gap, etc., this translates to 96.5% of the theoretical maximum bidirectional throughput of Fast Ethernet.

11.3. Appendix C: Chariot Script for VOL-N100VF NIC Performance Benchmark

```
          CHARIOT, BY GANYMEDE SOFTWARE INC.


SUMMARY - C:\GANYMEDE\CHARIOT\TESTS\3M\ME5TR01A.TST

Console version      3.1
Console build level  523
Console product type Chariot
Filename             C:\Ganymede\Chariot\Tests\3M\me5tr01a.tst
Run start time       Thursday, March 30, 2000, 5:00:14 PM
Run end time         Thursday, March 30, 2000, 5:03:14 PM
Elapsed time         00:03:00
How the test ended   Ran to completion
Number of pairs      10


RUN OPTIONS

End type                                         Run for a fixed duration
Duration                                         00:03:00
Reporting type                                   Batch
Automatically poll endpoints                     No
Stop run upon initialization failure             Yes
Connect timeout during test (minutes)            0
Stop test after this many running pairs fail     1
Collect endpoint CPU utilization                 No
Validate data upon receipt                       No
Use a new seed for random variables on every run Yes
_______________________________________________________________________________


GROUP: ALL PAIRS / PAIR: 1

Endpoint 1               200.100.50.10
Endpoint 2               200.100.50.1
Network Protocol         TCP
Service Quality
Script Name              filesndl.scr
Pair Comment
Console Knows Endpoint 1 200.100.50.10
Console Protocol         TCP
Console Service Quality  n/a


Script
filesndl.scr, version 3.1 -- File Send, Long Connection

Endpoint 1                      Endpoint 2
------------------------------ ---------------------------------
SLEEP
  initial_delay=0
CONNECT_INITIATE                CONNECT_ACCEPT
  port_number=AUTO                port_number=AUTO
LOOP                            LOOP
  number_of_timing_records=100    number_of_timing_records=100
  START_TIMER
  LOOP                            LOOP
    transactions_per_record=1       transactions_per_record=1
    SEND                            RECEIVE
      file_size=1000000               file_size=1000000
      send_buffer_size=DEFAULT        receive_buffer_size=DEFAULT
      send_datatype=NOCOMPRESS
      send_data_rate=UNLIMITED
```

```
    CONFIRM_REQUEST                CONFIRM_ACKNOWLEDGE
    INCREMENT_TRANSACTION
  END_LOOP                       END_LOOP
  END_TIMER
  SLEEP
    transaction_delay=0
END_LOOP                       END_LOOP
DISCONNECT                     DISCONNECT


Variable Name                 Value Description
------------------------ ---------- --------------------------------------
initial_delay                     0 Pause before the first transaction
number_of_timing_records        100 How many timing records to generate
transactions_per_record           1 Transactions per timing record
file_size                   1000000 How many bytes in the transferred file
send_buffer_size            DEFAULT How many bytes of data in each SEND
receive_buffer_size         DEFAULT How many bytes of data in each RECEIVE
transaction_delay                 0 Milliseconds to pause
send_datatype            NOCOMPRESS What type of data to send
send_data_rate            UNLIMITED How fast to send data
port_number                    AUTO What port to use between endpoints
_______________________________________________________________________________
```