Designing a Reliable Cabling Infrastructure for Healthcare Facilities

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Hospitals and other medical facilities face the daunting challenges of managing information. As patient records, diagnostic information, and even the operating theater all increasingly rely on networked electronics, the amount of data that must be created, transmitted, managed, and stored has grown dramatically. In addition, regulations requiring high levels of data security to protect patient privacy add an additional layer of complexity to information management.

Figure 1. Operating rooms require high cable density and multiple network ports to accommodate needs.

Network Drivers in Medical Applications

Digital Connectivity: Medical equipment is increasingly becoming electronic and digital. A clear example is the x-ray, now filmless and digital. One consequence of this digitalization of equipment is the ability for equipment to be interconnected and IP networked so that information can be moved around and shared. An x-ray film is a discrete thing; a digital x-ray can be transmitted to any number of other pieces of equipment, from local computer to locations anywhere in the world. Soon, nearly everything that happens in a hospital will require a network connection.

Electronic Medical Records (EMRs): While the vast majority of medical recordkeeping is computerized, the push for universal and uniform records is viewed as an important step to cost control and better patient care. As EMRs contain a single repository for a patient's complete medical history, the storage requirements grow. The same digital x-ray can be part of the record. The Health Information Technology for Economic and Clinical Health (HITECH) initiative has a goal of creating a single structure for all medical records to become digital by 2014 to ensure compatibility in creating and accessing patient records.

Exploding Storage Requirements: If it's digital, it can be stored on the network. As is true with other businesses, the amount of data that must be stored grows exponentially. The need to access the data drives the bandwidth needs of the network. A typical MRI study generates 200 images, requiring about 40 megabtyes (MB) uncompressed. A multislice CT study can generate over 2 gigabytes (GB) of data. Figure 2 shows typical storage requirements for different radiological studies, based on individual studies and 100,000 studies per year.

The medical industry is standardizing on managing such records through Picture Archiving and Communications Systems (PACS), again with the aim of facilitating storage, access, and interoperability.

Disk mirroring and other means of keeping multiple copies of records for backup and security reasons also place demands on bandwidth.

Vast storage requirements necessitate higher data rates in the network. The network must be able to move large files around quickly, while also handling routine transactions like e-mail.

Modality	Uncompressed		Lossless Compressed 2.5 to 1 Ratio	
	MB per Study (Avg.)	GB per Year	MB per Study (Avg.)	GB per Year
Angiography	15	45	6	18
Digital Radiology	42	2688	17	1075
Computerized Tomography	52	1040	21	426
Magnetic Resonance	39	195	16	78
Nuclear Medicine	1.3	3.9	0.5	1.6
Ultrasound	18	90	7	36
Total TB per 100,000 studies	4.1 TB		1.6 TB	

Source: Edward M. Smith, "Storage Management: What Radiologists Need to Know," Applied Radiology, 38(5) 13-15.

Figure 2. Storage requirements for radiological studies

Long-Distance Collaboration: Think video. Real-time telemedical collaboration requires crisp streaming video, whether locally or across the globe, with sufficient resolution for the purposes at hand. High resolution means higher bandwidth and low network latency. This allows for multilocation collaboration among various medical professionals for patient consulting and procedures. This increases the level of patient care along with educational opportunities.

IP Everywhere: The success of Internet Protocol (IP) means that nearly all communication needs can be handled by a single network. Beyond standard data, other systems can run over an IP network: security, access control, building automation, video and television—if it can be done digitally, it can be transmitted over an IP-based network. While hospitals will normally segregate applications, particularly the medical and nonmedical, the fact remains that the prevalence of IP means there are more bits and bytes being transmitted and the need for greater data speeds.

Confidentiality: The Health Insurance Portability and Accountability Act (HIPAA) of 1996 together with the HITECH requirements for maintaining the privacy and confidentiality of patient information require both physical and application security, backup procedures, and hospital policies.

To meet these challenges, hospital networks are being driven by two main trends:

- Higher bandwidth: From transmitting MRI images to video consultations, networks must work at higher speeds to deliver services. Networks will be looking to support 10 Gb/s speeds in critical areas, with 40G or 100G in the core to ensure bandwidth availability.
- More connections: As more and more equipment is network-enabled, more network outlets must be provided for users. The port density in any given area depends on the area's function, but network administrators are learning that a few extra outlets are better than too few. More connected equipment obviously also means more bandwidth is needed.

Faster data rates are obviously needed to support delivery of data in a timely matter, especially real-time medical data.

Figure 3 shows theoretical transfer time to transmit 1 GB. The times are best case and are for total transmission, not just the data. The overhead of header information in the Ethernet frame (which can in some cases exceed the length of the data in the frame), network architecture, congestion, and other factors can significantly slow the actual time to transfer data.

Ethernet Speed	Approximate Time to Transfer 1 Gigabyte (minutes)
10 Mb/s	14
100 Mb/s	1.4
1 Gb/s	0.14
10 Gb/s	0.014

Figure 3. High-speed data networks are required to ensure fast, efficient transfers of information.

This paper addresses the structured cabling systems required to support the network. The cabling infrastructure, from racks and cabinets to cable and connectors, must not only meet today's needs, but those that are evolving on the horizon.

The bottom line is that the network is increasingly vital to the hospital and higher data rates are required to handle the growing data. The structured cabling system must be designed and installed to meet these realities. ANSI/TIA-1179, the Healthcare Facility Telecommunications Cabling Systems standard, addresses the special requirements of cabling systems in healthcare facilities.

Standardizing Cabling for the Healthcare Environment

There are generic standards for buildings to address the architecture of the cabling system and recommend best practices for cross connects, cabling distances, cable and connector performance specifications, and all the other details for achieving a high-performance network. ANSI/TIA-568-C is the primary example of a generic standard whose recommendations form best practices for cabling systems.

A typical network in a typical business is largely a cookie cutter affair. With some exceptions, all work areas have the same network connectivity. Businesses standardize on providing the same connectivity to each office. Schools similarly standardize classrooms. Likewise, retail stores often install the same network in every new store. Even variations tend to be small: four data ports instead of two. Generic cabling standards, like ANSI/TIA-568-C, rightly recognize that an extremely wide swathe of applications can beneficially adopt the standards.

Hospitals are not as easily cabled with this cookie-cutter approach. Different areas of the hospital have significantly different connectivity needs. Offices areas may require four ports, exam rooms 10 ports, MRI suites 20 ports, and operating rooms 40 or more ports. As a result, the TIA has issued ANSI/TIA-1179 to address the specific needs of healthcare facilities.

Work Areas

ANSI/TIA-1179 recognizes hospital and medical facilities have different needs in the number of network connections required and the related density of cables run to a multitude of areas. The standard identifies eleven application-specific types of work areas:

- Ambulatory care
- Caregiver
- Critical care
- Diagnostic and treatment
- Emergency
- Facilities
- Operations
- Patient services
- Service/support
- Surgery/procedures/operating rooms
- Women's health

Each of these work areas has further subareas with varying cable densities, yielding a total of about 75 areas. To paint with a broad stroke: areas dealing directly with patient care and treatment have higher cable densities than areas dealing with administration or facilities.

- **Low density:** 2 to 6 outlets
- **Medium density:** 6 to 12 outlets
- **High density:** more than 14 outlets

Figure 4 summarizes the cable density recommendations of ANSI/TIA-1179. For high-density applications, the "fourteen" number for high-density areas will often be quite conservative. Some new operating rooms have upwards of 50 outlets to support the increasing needs for connectivity.

Main Work Area	Cable Density/Subarea		
	Low (2 – 6)	Medium (6 – 12)	High (>14)
Patient Services	Consultation Family Lounge Waiting Room	Administration Registration Library	Nurse's Station Patient Room
Surgery, Procedures, Operating Rooms	Sterile Zone Sub-Sterile Zone	Anesthesia Offices Patient Prep Patient Hold Patient Recovery	Intensive Care Room Operating Room
Emergency	Ambulance Bay	Evaluation Exam Room	Observation Procedure Rooms
Ambulatory Care	Biopsy Patient Holding X-Ray	Exam Room Mammography Procedure Room	Out-Patient Surgery Room
Women's Health	Lactation Ultrasound	Nursery	Labor/Delivery Room Infant Bay
Diagnostic/Treatment	Fluoroscopy Radiation Processing Radiograph X-Ray	Lab	CT Scanner Linear Accelerator MRI Operating Rooms Procedure Rooms Simulator
Caregiver	Exam Room Galley Soiled Utility	Charting Clean Utility Nourishment Reading Room Workroom	Nurse's Station
Service/Support		Blood Bank Pharmacy	Anesthesia
Facilities	Building Utility Room Communications/Technology Room Electrical Room Elevator Machine Room Janitor Closet Mechanical Room Specialty Storage	Fire Command	Security Office Command
Operations	Cafeteria General Storage General Office Laundry Locker Rooms Lounge On-Call Suite Retail Areas	Administration Central Sterile Conference Room	
Critical Care			ICU Neonatal ICU Recovery

Figure 4. Recommended cabling densities for different work areas as defined in the ANSI/TIA-1179.

While it is normal practice to gang several ports into a single outlet, ports can be spread around the area as appropriate. For example, ports for biomedical equipment can be located on each side of a patient bed, while ports for television or other ancillary needs can be across the room and at ceiling height. In operating rooms, outlets are even included in booms over the table.

Outlets in the work areas should be clearly and easily identified by function. Since most hospitals will install many separate networks—biomedical, television, phone, security, etc.—fast and easy identification is critical, especially when attaching medical equipment. The outlet jacks themselves are available color coded as are snap-in icons (Figure 5). Visual identification is essential for end users. For network administrators and technicians, additional identification for purposes of network administration is recommended.

For operating rooms, critical care, and other areas, stainless steel faceplates are available to make cleaning and sterilization easier.

Figure 5. Color-coded multimedia outlets allow easy port identification.

Multiple user telecommunication outlet assemblies (MUTOAs) provide a flexible approach for areas that might experience frequent re-arrangements or for retrofit applications. These provide a centralized patching area within specific spaces that are fully accessible. Offering up to 24 ports, MUTOAs should be permanently mounted on the wall or in an architectural column. Figure 6 shows a MUTOA. (Note that ANSI/TIA-1179 only recommends MUTOAs for retrofits, not recommended for new hospitals)

Figure 6. MUTOAs offer a flexible approach to providing multiple outlets.

One possible way to simplify cabling is to run multifiber pairs to the work area. The fibers connect to a workgroup switch dedicated to that area. The switch then connects to the individual outlets. (Theoretically, users could connect directly to the switch, but this is a poor practice to be avoided.) While this approach drastically cuts the number of lines running from the horizontal cross connect, it doesn't satisfy the needs of segmenting network functions, so additional cables will still be needed for building alarms, TV, and the like. Costs also need to be considered when looking at the structured cabling deployment of running all cabling homerun to the telecommunications rooms versus extending the switching fabric to the work areas. Extending the switching to the work area will also require more advanced switch management and operations. This approach is also commonly referred to as zone distribution.

Recommended Best Cabling Practices for the Future

The varying cable densities underscore the importance of careful planning. In planning, be generous in the number of outlets made available, especially in critical areas like patient rooms or operating rooms. The definite trend is toward the need for more connectivity, not less.

Likewise, the thirst for bandwidth will remain hard to quench. Not that long ago, Fast Ethernet at 100 Mb/s prevailed. Today, it's Gigabit Ethernet, with 10 Gigabit Ethernet growing rapidly. As mentioned, some hospitals are even planning to deploy 40G and 100G in the core (data center) for interconnecting servers and storage.

A prudent eye toward the future means installing the best cable available. This is especially important in areas dealing with patient care, from diagnostics to surgery. These areas are the ones where sufficient bandwidth capacity must be available for tomorrow's needs.

Specifically, the following cables are the recommended choices and supported by ANSI/TIA-1179:

- **Category 6 or 6A UTP, which can support 10G Ethernet at distances to 90 m in the horizontal or 100 m when considering the full channel (including patch cords).**
- **Laser-optimized (OM3 or OM4) multimode fiber. Multimode fiber can be used both for backbone and horizontal cabling needs. For 10G Ethernet, OM3 fiber allows runs of 300 m, while OM4 supports 550 m.**
- **Single-mode fiber is typically only used where distances preclude the use of multimode fiber, such as between buildings. The cost of transceivers for single-mode fiber is significantly higher than those for multimode fiber.**

The choice of Category 6A cable over Category 6 is a means of ensuring you are ready for future needs and capable of migrating to 10G to support future networking and bandwidth needs. The main distinction between Category 6 and 6A is bandwidth. Bandwidth is specified by industry standards. Vendors of high quality cable typically offer cables that exceed the bandwidth specified in ANSI/TIA-568-C, which translates in additional performance margins—or headroom—in the cable's performance. Figure 7 compares Category 6/6A offerings from Berk-Tek, a Nexans Company, to demonstrate how cables can exceed the basic performance requirements of standards.

Cable diameter can also be an issue in routing a large number of cables through crowded pathway and spaces. Cable designers must manage tradeoffs between minimizing cable diameter and achieving performance goals. (Note that while higher category cables have larger diameters, there exists difference among vendors.)

Cable	ANSI/ TIA-568-C Bandwidth (MHz)	Usable (Specified) Bandwidth (MHz)	Diameter	
			Patchcord	Plenum
LANmark™-1000 Category 6	250	250	0.224	0.226
LANmark-2000 Category 6	250	400	0.247	0.220
LANmark-10G2 Category 6A	500	625	0.290	0.300

Figure 7. Cables offering performance headroom provide a better margin in performance.

For fiber, flexible options also exist in achieving different levels of performance. The preferred choice is 50/125-µm laser-optimized fiber, which is designed for optimum use with low-cost electronics. Laser-optimized fiber is available in two performance levels, OM3 and OM4 (Figure 8). The fiber bandwidth translates into the allowable distances the cable can be run. While allowable distances are two to three times longer for Gigabit Ethernet than for 10G Ethernet, remaining within 300 m recommendations of ANSI/TIA-1179 when planning and only go longer distances in special cases is a good practice.

Fiber	Type	Transmission Distance (m) @ 850 nm		Bandwidth @ 850 nm (min.)
		1G Ethernet	10G Ethernet	
GIGAlite™-10	OM3	1000	300	2000
GIGAlite 10-FB	OM4	1040	550	4700
GIGAlite 10-XB	OM4+	1210	600	4900

Figure 8. The main types of multimode fiber for hospital networks.

Fiber optic cables can be run either as pairs or as multifiber array cables. Multifiber cables terminated with industry-standard MTP®/MPO array connectors simplify use of fiber in the network. The cables significantly reduce congestion in pathways, provide the highest port densities (12 fibers in a 0.5 x 0.3-inch area), and simplify system design, installation, and management. While fiber ribbon cables are popular for array connections, new reduced-diameter cables, such as Berk-Tek's MDP (Micro Data Center Plenum) cable, are setting a new standard in convenience. Cassette modules, like the one in Figure 9, provide an easy breakout from the array cable to individual ports.

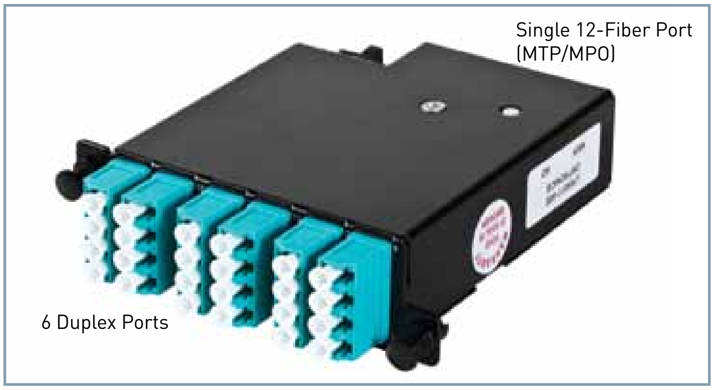

Figure 9. Modular fiber cassettes make it easy to transition between array backbone cables and fiber pairs.

Topologies

Structured cabling systems for hospitals use the same topologies as other applications. The most common is the hierarchical star shown in Figure 10. The topology defines three levels of cable distribution:

- **Main cross connect (MC) is the first level of backbone cabling, serving as a termination point for incoming services and a central hub for connecting all parts of the network. The main cross connect is typically located in the equipment room, where the main servers, storage, routers, and switches reside.**

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- **Intermediate cross connect (IC) separates two levels of backbone cable. In large installations, it is more convenient to have an intermediate cross connect feeding several horizontal cross connects. As shown in Figure 10, the standard does not require an IC. The IC is typically located in a telecommunications room.**
- **Horizontal cross connect (HC) marks the transition between the backbone cable and the horizontal cable to users. It is located in a telecommunications room or a telecommunications enclosure.**

Each level of cross connect can include active network equipment or it can simply be a transition point from one cable level to another. For reasons of flexibility and redundancy, ICs can also connect to one another directly to provide a secondary backup path.

In most hospitals, several networks will "overlay" this topology, each with its own cross connect, to keep medical and nonmedical networks separate. Different networks can also be physically separated by dividing equipment rooms into different areas. Hospital and network administrators may wish to apply a higher level of physical security to the medical network. This would prevent outside service providers, such as telephone or cable TV, from having access to the other network equipment and cabling.

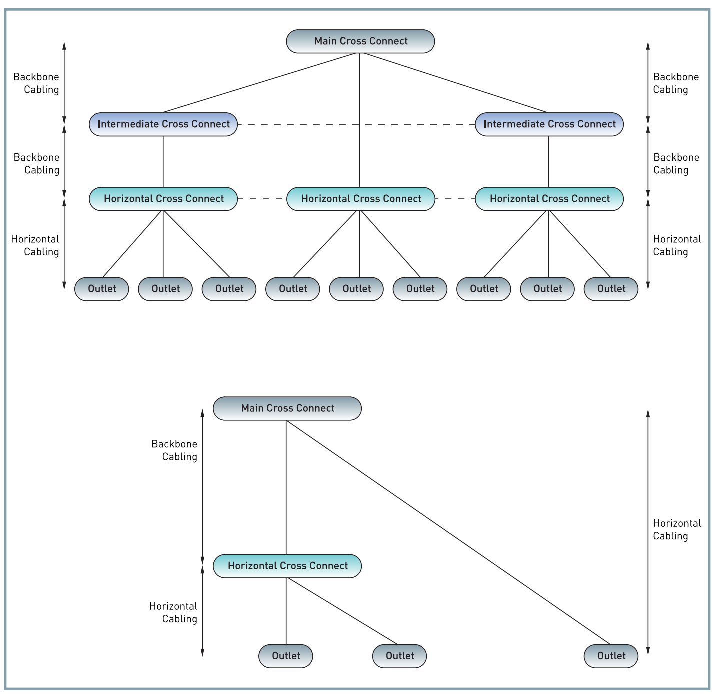

Figure 10. Hierarchical star topology for cabling systems as recommended by ANSI/TIA-1179.

Telecommunications Rooms

Equipment rooms and telecommunication rooms are typically larger than those used in premises networks. Be generous in sizing a room, allowing for 100% growth.

Racks, patch panels, and fiber-management hardware should offer great convenience in managing the cables. This includes such issues as supporting cable vertically in the rack, limiting bend radii, eliminating any stress on the point of connection, and enabling easier moves, adds, or changes (MACs).
The cabling density in hospital applications and high-density servers mean that racks need to accommodate both more equipment and more interconnections. A Mighty Mo® 10 rack from Legrand|Ortronics, for example, can support up to 1340 network ports. It also allows up to 48 patch cords per vertical rack unit on each side to ensure availability of cabling without clutter or mess. Figure 11 shows a typical high-density installation.

In designing for high-density configurations, look for racks and cabinets with generous cable-routing capabilities on both the front and the back. Deep management channels not only accommodate a larger number of cables, they make them easier to manage—such as tracing an individual cable or adding new cables.

Choosing the right rack and cable pathway components can save money in the long run. Make sure racks and trays can handle future weight requirements. A fully loaded enterprise-level switch can weigh 1600 pounds. While a two-post rack might be fine for patch panels, a four-post rack is the better choice for equipment.

Figure 11. Effective cable management in high-density configurations must prevent stresses on equipment ports while still accommodating MACs

Pathways

Routing cable from the entrance facility to the user outlet requires consideration of the special needs of hospitals. Because of the critical nature of the many applications, redundancy is often built into the systems, with more than one pathway delivering cables to work areas. Similarly, segregating cables by application and network function is advisable. In separating cables by function in the pathways, color coding or other means of visually identifying cables simplifies installation and maintenance.

Spaces for running cable in hospitals can be at a premium since cables must share space with gas delivery, pneumatic tubes, and other needs that distinguish medical facilities from other buildings.

An additional concern in routing cable is infection control requirements. The sophisticated air filtering and area segregation cannot be compromised by the cabling system. The need to avoid atmospheric contamination may require special cables with filled or blocked construction and low-gassing materials. Infection control policies may limit access to the cabling system for MACs in sensitive areas. These policies may, for example, forbid deployment of patch cords from one area of the hospital to another for safety reasons. Other policies may place strict rules limiting access to the pathways (plenum spaces for example) for reasons of health and safety. Thus, even lifting a ceiling tile may require careful scheduling.

High-voltage wiring and highly sensitive gases and fluids will be encased in closed conduits in their pathways. Therefore, open cable trays (Figure 12) offer a clean and convenient way to route low-voltage communications cable through pathways. They prevent accumulation of debris during and after installation and are available in stainless steel. The open structure makes it easy to ensure correct separation of cables by visual inspection. It can also reduce crosstalk or other electrical performance negative influencers.

Figure 12. Open cable trays are recommended for pathways for communications cable.

Electromagnetic Interference

Electrical noise must also be figured into the cable and pathway design. Some areas of hospitals, such as radiology, can generate high magnetic fields that translate into electromagnetic interference (EMI). Whatever the source, EMI must be dealt with to preserve signal integrity on cables. At the least, EMI can cause excessive retransmission of data, lowering the effectiveness of the network. Worse, though, is the possibility of EMI causing errors in medical equipment, leading to faulty readings, missed diagnoses, or malfunction in treatment equipment.

EMI can be reduced in several ways.

- **Shielded cable:** While shielded cables are an excellent way to reduce the effects of EMI, they are not popular in the United States, but are gaining some acceptance in the healthcare and other environments.
- **Optical fibers:** Fiber is inherently immune to EMI, allowing it to be run close to noise sources.
- **Rerouting:** Radiated EMI reduces with distance, so routing cables away from noise sources is advisable.
- **Shielded conduits:** Pathways themselves can be shielded to isolate the cables.
- **Shielded rooms/equipment:** The interference-inducing equipment itself can be shielded, either at the equipment or room level. Similarly, areas with very sensitive monitoring needs may be shielded from their surroundings. Some rooms, such as those involved in epilepsy monitoring, are RF shielded and all cables into the room pass through an EMI filter.

Look to the Channel, Not the Parts

In the end, it is not the performance of individual components that is important, but the end-to-end performance of the components working together—the channel. The aim of the channel is to achieve zero bit errors caused by the cabling system.

Buy the Components or the System? Through standards, you should be able to mix and match components from different vendors—cable from vendor A, connectors from B, patch panels from C—and have no problems. And this will work most of the time. Buying a system has three distinct advantages: (1) it ensures performance headroom, (2) it brings a healthy warranty (such as the 25 years for NetClear® systems) that guarantees the system will meet performance goals and applications assurance, and (3) it gives you peace of mind by having a single source ready to support the cabling system.

Look for systems that have performance claims verified by an independent testing agency. The system should provide adequate headroom above the standard. Headroom equals peace of mind. Over time and many MACs, inadvertent tight bends, or rough handling of patch cords, the cable system's performance can degrade somewhat. Headroom is the extra margin that ensures your network keeps peak performance for years to come.

A system-level approach does not mean a single vendor who offers everything. It means that all the components are designed and tested to optimize performance. The NetClear solution, for example, is an alliance between Berk-Tek, a Nexans Company, for cable and Legrand|Ortronics for connectors and cable-management hardware. A close partnership between the companies allows each to lend its expertise in achieving system performance and providing systems with the guaranteed headroom shown in Figure 13.

NetClear System	Headroom (dB)	
	Crosstalk	Return Loss
GT2 (Category 6)	5	3
GT3 (Premium Category 6)	8	6
GTX (Category 6A)	0	0

Figure 13. Cabling systems should provide generous headroom and zero bit errors in the channel.

Buy or Make? Ordering pre-terminated cable assemblies offers products that have been factory made and tested. While field termination is possible, it has several drawbacks. The higher the performance level of the cable, the more important correct termination procedures for connectors becomes. Once terminated, each cable should be tested to characterize its performance. Cable assemblies eliminate these needs.

While patch cords are usually bought as assemblies, backbone and horizontal cables can also be specified and installed as assemblies. The biggest drawback is that you need to be able to confidently specify lengths. Coming up a few inches short because of the need to route around an unforeseen duct is obviously a problem. Careful planning is mandatory.

Conclusion

The growth of networks and hosting of new applications and equipment in healthcare facilities challenges the network infrastructure. Because hospital network requirements are unique—such as the high number of outlets in operating rooms and patient rooms—network planners and administrators should look to ANSI/TIA-1179 for recommendation and advice on creating a high-performance structured cabling system. The system should use the best-available components and tested solutions to meet not only today's requirements but those of the future as well.

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