The Challenge
At Strong Memorial

Identify, Solve PACS Network Performance Issues

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Background

Strong Memorial Hospital in Rochester, N.Y., is a 750-bed regional referral center and teaching hospital associated with the University of Rochester Medical Center. In order to take advantage of the efficiencies offered by digital imaging technology, Strong is implementing a PACS network that will handle about 85 percent of the hospital's 240,000 imaging studies a year. During deployment of the first phase of the PACS, however, several performance problems surfaced and the network was identified as the cause of lost productivity.

Performance Issues Described

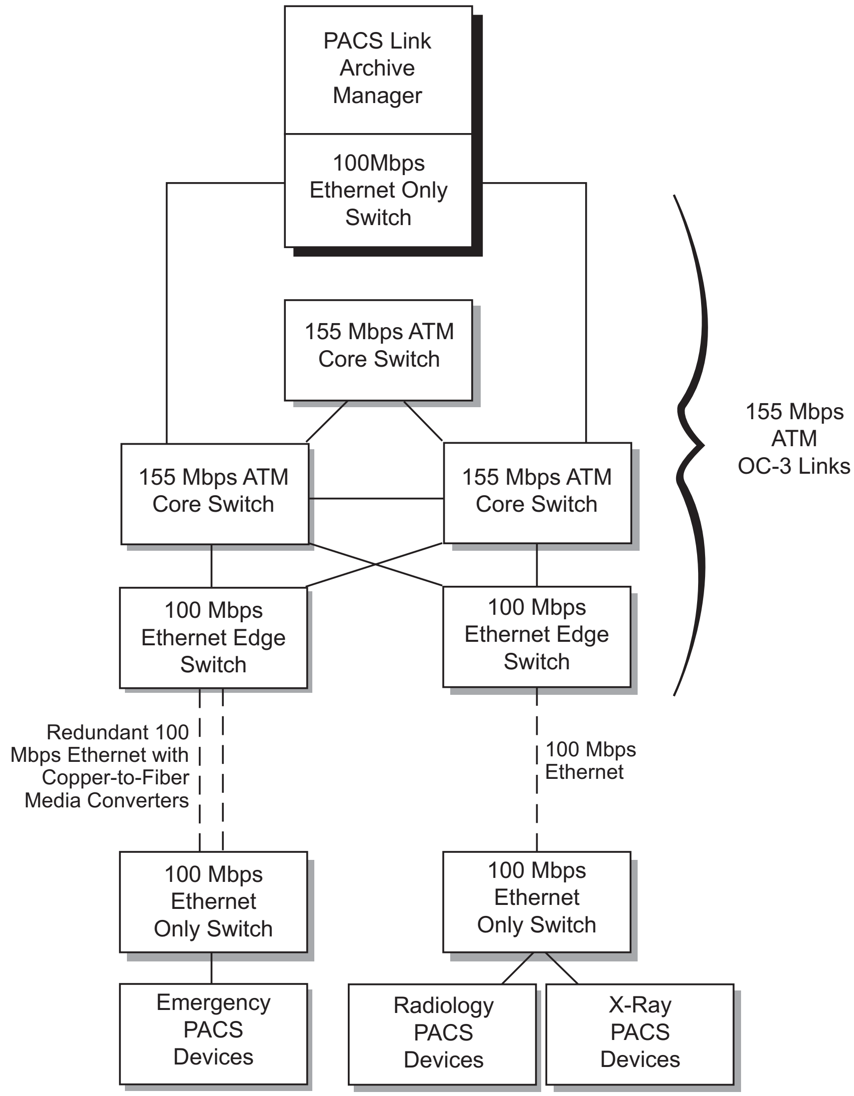
Strong Memorial began experiencing troubling network performance and equipment reliability problems after installing computed radiography (CR) systems, Kodak PACS Link servers, which route digital image files to multiple network locations, and diagnostic workstations in its emergency and radiology departments.

- CR systems were intermittently failing to deliver images to destination devices, but retransmission generally resulted in delivery.
- CR system output to dry laser imagers averaged two to three minutes, and occasionally took eight minutes.
- Diagnostic workstations were experiencing dropped connections, screen freezes and excessive image display times.

Network Assessment Begins

In response to these problems, Strong requested that consultants from Kodak Imaging Network Services assess the network to resolve delivery failures and make recommendations to improve network performance.

The scope of the evaluation was limited to the PACS portion of the network. Assessment began with weekly meetings between the Strong PACS IT team and Kodak imaging network consultants. A review was conducted of how the PACS devices were connected to the network. A map of the institutional network indicated that data was required to travel across the larger insitutional network, which contained connections for 7,500 nodes. A plan of action was formulated in which the team first concentrated on resolving CR transmission failures in the emergency department, and then began assessing network performance issues.



Strong Memorial PACS Link Network Configuration

Strong Memorial's PACS network is a flat, layer-2 network that uses inter-link switching to connect four departments: emergency, radiology, X-ray control and archival storage. Cabletron SecureFast VLAN technology is used on the 100 Mbps Ethernet switches to end devices using 155 Mbps OC-3 and 100 Mbps Ethernet uplinks in the ER to create virtual LANs by logically grouping switch ports and endpoints.

Assessment of CR Transmission Failures

The two CR systems in the emergency department were each averaging 100 to 200 image scans per day, and were frequently used simultaneously. Transmission failures of CR studies occurred three to 10 times each day, but retransmissions were generally successful after a delay. Network analyzers were used to test the cable plant and showed no physical link problems other than noise.

Autonegotiation During Session Establishment

The study identified a duplex and speed mismatch, which can cause communication failures and excessive message retransmission. Kodak PACS devices are set to automatically negotiate duplex and speed settings during device session establishment, however Strong had disabled autonegotiation on its switch ports.

These settings were corrected on the CR systems and PACS Link 9410 servers in X-ray control and ER, and performance immediately improved. The CR systems in the ER, however, continued to experience intermittent failures.

ARP Packet Loss During Session Establishment

As part of an earlier troubleshooting effort, the CR systems on X-ray control's network switch were moved to Radiology's network switch. This change eliminated CR transmission failures in x-ray control. Further investigation revealed that Cabletron SecureFast

VLAN technology was employed on the network switches in the ER, but not on the switch in radiology. Because of this, the SecureFast switch technology became suspect.

To determine the cause of CR failures in the ER, Kodak consultants mirrored the CR system's switch port to a spare switch port and attached a network analyzer to capture packet CR data over a 24-hour period. This data was then compared to the CR system's image delivery log maintained by the Kodak Medical Image Manager. The log revealed that all transmission failures, except one, were caused by a Destination Unreachable/Open Connection failure. This problem was identified as a communication session established between devices and was suspected.

Kodak's analysis of packet data revealed that the CR system was issuing ARP broadcast requests, but ARP responses from destination devices were not being returned. ARP broadcasts are used in layer-2 networks to map IP addresses to physical addresses. When a device sends an ARP broadcast request it normally floods communications to all layer-2 switch ports and the attached devices. Each device listens and the device that owns the IP address responds with an ARP request response. This response includes its IP address and physical address, which are then mapped into an ARP table. Without this mapping, devices cannot communicate. Packet data showed that the emergency department's switch was intermittently discarding ARP broadcast requests.

To validate that destination devices were not receiving ARP broadcasts, network analyzers were attached to the CR system's switch blade and to the switch blade of a PACS Link 9410 destination device. The captured data revealed an ARP broadcast packet entering the switch from the CR system, but not exiting the switch to the PACS Link 9410.

To further test the ARP packet loss theory, the static IP-physical address pairs were entered into the ARP tables for the CR system and destination devices that images were sent to. The ER's second CR system configuration was not changed. Conditions were then observed for a period of time. Under normal network conditions of 100 packets per second (pps), the remediated CR did not fail, while the unremediated CR continued to fail. When network activity peaked at 300 pps, however, the remediated CR again began experiencing intermittent transmission failures.

Based on these findings, Strong elected to set up static ARP tables with fixed IP addresses for all PACS equipment. The Strong IS department also contacted Cabletron to report ARP broadcast packet loss during times of peak network activity and received a firmware patch to handle packet loss during times of peak network activity.

Sharing of SSCP Processes On the DICOM Server

The CR system's image delivery log revealed one Open Connection failure between the CR system and the DICOM server, with 40 retry attempts before a timeout. During this same time period, captured data revealed that the alternate CR was transferring image data to the DICOM server, suggesting CR contention for a shared resource.

The DICOM server has eight SSCP (Storage Service Class Provider) listener processes that are used by sending devices to establish server communications. These processes can be shared, but when one device is sending, the alternate device cannot access the SSCP process. In Strong's DICOM configuration, both CRs in the ER were sharing the same SSCP process, resulting in contention and Open Connection failure. The SSCP processes on the DICOM server were reconfigured to eliminate this contention point.

It was determined that a DICOM server should never be configured with more than eight SSCP processes and that PACS devices should never share SSCP processes.

Assessment of Slow Device and Network Performance

With device failures resolved, Kodak Imaging Network Services engineers and the hospital's PACS IT team began their assessment into the cause of slow device and network performance by placing a network monitor on radiology's DICOM Server. Data was captured for approximately three hours.

Flat layer-2 networks use broadcast/multicast packets to establish communications and move data between devices. Broadcast traffic observed in radiology averaged 100 pps, with peak activity of 300 pps. Two multicasting (point-to-multipoint) broadcasts were also observed during the three-hour time period. Cumulatively, the network could conceivably experience peak broadcast/ multicast activity in excess of 1,000 pps.

While this amount of activity may not seem significant considering the processing speed of today's computing devices, PACS applications are processor-intensive given the size of digital image files. When a PACS device receives a broadcast/multicast packet, it must suspend application processing to service the packet interrupt. Excessive broadcast/multicast activity can negatively impact PACS device performance.

Multiple Protocol Stacks Increase Broadcast Traffic

Network traces also revealed multiple protocol stack configurations on PACS equipment and general computing devices in Strong's network, adding additional and unnecessary broadcast traffic to the network. If a Windows device has IP and NetBEUI protocol stacks enabled, for example, Windows sends browser announcement broadcasts in both formats. Configured properly, network devices generally requires only one protocol stack. Multiple protocol stacks create unnecessary broadcast traffic, increasing network congestion.

Traffic Volume on a 100 Gbps Ethernet Only Switch

Traffic volume to and from the DICOM Server in Radiology was measured at approximately 8GB during the three-hour period. The bulk of this traffic came from the digital image archive (6.9GB), four CR systems (673MB), a CT scanner (57MB), and multicast broadcast (258MB). The radiology study server added another 7.8GB to network volume. Traffic to and from other PACS servers (CADEP, Clinical Access and a second DICOM server) was not measured. The sheer volume of traffic, coupled with broadcast/multicast broadcasts in excess of 1,000 pps during times of peak activity, will reduce PACS device performance on a 100 Mbps Ethernet switch.

PACS Device Transmission Speeds and Inter-Switch Link Bandwidth

Properly configured PACS devices can transmit data at speeds up to 90 Mbps; therefore, a 100 Mbps Ethernet uplinks for the connections between switches can become congested if more than one device becomes active. Such was the case in the ER where two CR systems were often used simultaneously to scan images to two DICOM servers. Add to this congestion the presence of broadcast/multicast traffic and other PACS devices on the switch, and network congestion was inevitable. Strong's layer-2 Ethernet Switches (100 Gbps) were not capable of supporting the bandwidth required by PACS devices.

Network Architecture And Network Performance

Normal PACS workflow has modalities sending images to the digital archive first, which then transmits the image to DICOM and/or CADEP servers that forward the images to servers for viewing by radiologists at diagnostic workstations. This workflow illustrates that a PACS network is server-centric, and does not lend itself well to distributed networks. A single 10MB CR image file, for example, can generate in excess of 70MB of network traffic as the image it routed across links from server to server.

The ideal PACS network should be highly fault tolerant, scalable, core/edge design with redundant high-speed inter-switch links. In this configuration, most PACS servers can be located at the core, keeping to a minimum the number of inter-switch links necessary for PACS data to travel and reducing network congestion.

In the Strong Memorial PACS network, a CR image captured in the ER had to travel across three inter-switch links to reach the digital archive and then another three inter-switch links to reach a DICOM server in radiology. If sent directly to radiology, the image had to cross four inter-switch links. In either case, images had to travel across single 100 Mbps inter-switch links shared by multiple PACS devices. There was simply too much inter-link traffic, which resulted in network congestion and slow performance.

Summary of Recommendations

Kodak Imaging Network Services engineers generally recommend a separate imaging network to support a PACS. By isolating the imaging network from the larger enterprise network, broadcast and multicast traffic from general computing devices can be kept to a minimum. Also, it is often less expensive to build a separate imaging network than retrofit an existing enterprise network in support of PACS. Further, with pending HIPAA restrictions on patient confidentiality, it is much easier to protect PACS data on a segregated network.

Kodak engineers made several recommendations to strengthen the current network infrastructure. These recommendations were tempered with the caution that as more PACS devices were brought online, they could get caught in constant upgrade cycles because the existing network hardware lacked the high density, port speed and backplane capacity required by PACS.

Kodak engineers recommended that a separate network, with the latest wire-speed layer-3 switching and high density, high port speed (Gigabit) capabilities, be installed to support the hospital's PACS performance goals. Since the assessment, the PACS IT staff has elected to build a separate LAN that will support both current and future PACS requirements, and all previous degradations in performance have been resolved.

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