Radiology: “Killer App” for Next Generation Networks?

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The core principles of digital radiology were well developed by the end of the 1980 s. During the following decade tremendous improvements in computer technology enabled realization of those principles at an affordable cost. In this decade work can focus on highly distributed radiology in the context of the integrated health care enterprise. Over the same period computer networking has evolved from a relatively obscure field used by a small number of researchers across low-speed serial links to a pervasive technology that affects nearly all facets of society. Development directions in network technology will ultimately provide end-to-end data paths with speeds that match or exceed the speeds of data paths within the local network and even within workstations. This article describes key developments in Next Generation Networks, potential obstacles, and scenarios in which digital radiology can become a “killer app” that helps to drive deployment of new network infrastructure.

KEY WORDS: Digital radiology, PACS, next generation networks

THE CONCEPT OF “PHOTO-ELECTRONIC” radiology originated in the late 1970s, born perhaps of the use of computing in conjunction with Nuclear Medicine, the development of the computed tomography (CT) scanner, and the application of CCD memories and computers in Digital Subtraction.¹⁻³ These ideas resonated in an era of explosive growth, leading to the development of integrated circuits; advances in software engineering, computer graphics, and image processing; and, of course, computer networking. By the time of the first conference in the field, held in Newport Beach, CA, January 18-21, 1982 the name Picture Archiving and Communications System (PACS) reflected the system concept. By the late 1980s most of the now-familiar regular conferences and societies had been established, and the totally digital radiology department was a

common goal around the world.⁴ Although the technology to implement the concepts was not available then (at least, affordably), core principles of digital radiology were well developed by the end of the decade.

Among PACS researchers the vision was clear to create a system in which radiological images were captured in digital form, moved from the imaging modality to a hierarchical archiving system and on to diagnostic soft-copy reading workstations and clinical review workstations, with the swift and error-free transfer of images over a digital communications network. The issues faced were also clear. Computer systems and components were primitive. For example, for the Arizona Viewing Console, a joint research effort of the University of Arizona and Toshiba, developed starting in 1983 and displayed at the annual meeting of RSNA (Radiological Society of North America) in 1986, most of the major system components had to be custom-built.⁵ The image-processing engine, base image and display memories, user interface hardware, and disk controller were all built in house because no commercial products would support the requirements that had been elicited from our radiologists. The workstation even featured touch-screen control on the command monitor (color) and two 1024 × 1536 image display monitors. It provided the capability to

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process and window/level separate images independently, and images could be dragged around the screen at the end of a finger in real-time. Much of the software was written in assembly language. A follow-up version of the workstation [was migrated the software to C running under the OS-9 real-time operating system], and an Ethernet interface was added to the system. At this time (late 1980s) an Ethernet interface for a VAX computer cost \$10 k, and the user was likely to have to write custom drivers. Clearly, this level of custom development can counter to the core PACS principle of improving the cost-effectiveness of radiology.

During this period UNIX was displacing VAX/VMS and the mini-computer paradigm was evolving to UNIX workstations, based on Reduced Instruction Set Computers (RISC), in a networked environment. UNIX was the environment in which the development of what would become the dominant network protocols (TCP/IP) was taking place. Researchers and vendors alike moved their development to UNIX platforms. Although, this was an improvement, the costs were still high, with workstations commonly priced at about \$50 k.

These changes not only influenced the platforms used for PACS workstations (and modalities), they also influenced the development of communications. Radiology benefited from the strong and dedicated efforts to develop a communication standard, perhaps one of the most central factors in the growth of PACS. However, the early effort,⁶ while incorporating the newly developed layered concept from computer networking, was firmly grounded in the old approach to communications. The physical and data link layers (layers 1 & 2) of the standard very closely resembled DR11 W interfaces and specified a 50-pin physical connector.

Important work in the research community took the messaging format of the ACR-NEMA (American College of Radiology–National Electrical Manufacturers Association) and put it on top of either raw Ethernet frames (layers 1 & 2), or the developing TCP/IP stack (layers 3 & 4) leading to real-world experience with the standard.⁷ At Arizona what may have been the first ACR-NEMA based interconnection between two vendors took place at the end of the 1980s. It involved testing between the Arizona

Viewing Console fitted with an Agfa-Matrix ACR-NEMA interface and a Toshiba ACR-NEMA Network Interface Unit (NIU) that converted the data to an optical protocol and sent it across a fiber-optic star coupler to another Toshiba NIU.^{8,9} The second NIU had an ACR-NEMA connection to a second research system, the Multi-taper Imager, also built by researchers at Arizona.¹⁰ The evaluation of that prototype provided recommendations that added to the work of others to propel ACR-NEMA toward basing the lower 4 layers (physical, data link, network, and transport) on open standards and developing the standard as a suite of standards governing the various aspects of PACS rather than a single "data link" standard.

There was much discussion of ISO/OSI, which influenced what became DICOM (digital imaging and communication in medicine), even though OSI (Open Systems Interconnect) developed much too slowly to compete with TCP/IP. UNIX workstations served the general-purpose image viewing workstation application well for many years and entrenched themselves as the core platform for imaging modalities, especially CT and magnetic resonance (MR). At Arizona, as elsewhere, UNIX workstations linked with the promising new network technology of FDDI (Fiber Distributed Data Interface) served well to distribute CR images directly to multiple intensive care units (ICUs). A prototype system, implemented in 1992 under a grant from Fuji Medical Systems, used the new DEC Alpha 64-bit processors to clearly demonstrate the feasibility of an image distribution system based entirely on off-the shelf commercial equipment for both the workstations and the network. Only the application software was custom. Although not DICOM compliant (because the system was designed and implemented prior to the DICOM standard), the system also applied object-orientation and was integrated with the hospital HIS/RIS.¹¹⁻¹³ With a 100 Mbps fiber-optic network, CR images were available in the ICU in a matter of seconds from the time they were processed by the CR unit. What was intended as a 6-month demonstration project in one ICU was extended to three units and was in clinical operation until 1999, when Y2 K concerns led

to its retirement. This work was an example of the trend through the 1990s, in which the era of completely custom PACS workstations evolved to commercial equipment with custom software applications.

Cost continued to be a factor, however, and the PC (personal computer) began making inroads, though PCS were hampered by an unsophisticated operating system. An important niche was the teleradiology arena, where a PC at home with a modem did not require the sophistication of a multi-monitor diagnostic workstation. The platform cost and the market momentum for development of components (CPUs, buses, and interface), along with the low cost of software, ensured that the PC would ultimately displace the UNIX workstation. At Arizona, we considered the release of Windows NT to be the final enabler for the transition to PC-based workstations. This was due in part to the more "UNIX-like" support for concurrent processes, but Windows NT also permitted better support for networking.

EVOLUTION OF THE NETWORK

Over the same period, computer networking evolved from a relatively obscure field used by a small number of researchers across low-speed serial links to a pervasive technology that affects nearly all facets of society. In the 1960s in the United States the Public Switched Telephone Network (PSTN) consisted of some 20,000 switching centers, most of which were Class 5 central offices, in a hierarchical network with 10 Class 1 regional switching centers. The network was all circuit-switched using electro-mechanical switches. Circuit switching means that a dedicated physical path was established across the network between each pair of phones for the entire duration of the call. During the 1970s work was done on techniques such as PCM (Pulse Code Modulation) and the development of the T-carrier system (e.g., T1&T3) to carry voice traffic as digital signals, beginning the transition of the PSTN to a network in which digital rather than analog information was switched. However, these techniques were used to aggregate traffic between central offices, and the local loop between the central office and the customer was still analog. It was not until

the mid-seventies that T1 lines were offered as a service to telephone customers. During the same period, work on modulation/demodulation (modem) technology was also progressing rapidly to support digital data transmission between customer locations.

By 1980 the ARPANET, forebear of the Internet, consisted of about 200 nodes connected at speeds up to 56 kbps, and the total capacity of the network was roughly 10 Mbps. By comparison, the PSTN connected some 100 million telephones and had an aggregate capacity of about a Terabit/s. As with PACS, the concepts were there, but the technology lagged. In 1983 the ARPANET had grown to some 1,000 nodes, still linked at 56 kbps. Routing in the network was commonly performed by VAX 11/780 computers that cost \$400 k. The Internet reached 2000 nodes by 1986, but the backbone would not be fully 1.5 Mbps (T1 speed) until 1988, with the completion of the NSFNET backbone upgrade. Three years later the backbone reached 45 Mbps (T3 speed) with 500,000 nodes, and in another two years the U.S. Internet was at 2 million nodes, and the process of commercialization began with the creation of the first Commercial Internet Exchange.^{14,15}

META-PACS RESEARCH

A simplified view of key aspects of that evolution is illustrated in Figures 1, 2, and 3. In Figure 1 the top diagram shows the primitive PACS where the focus is on the radiology department connected over a local network. Here the emphasis is on seamless multi-vendor connection of imaging equipment, display workstations, and an archive. The middle diagram of Figure 1 illustrates the next stage of development, still within the hospital, but extending image access to other units (especially ICUs), the technology advanced to 100 Mbps networking. The imaging network may be integrated but is more likely separate from the general HIS/RIS network. The bottom diagram in Figure 1 shows a typical situation with teleradiology workstations as stand-alone add-ons. Figure 2 presents two diagrams illustrating the next evolution with the increased availability of the Internet. In the top diagram the 100 Mbps enterprise network provides a firewall-protected

Fig 1. Early development paths in PACS. IE: integrated enterprise; WS: workstation.

Fig 2. Improved PACS enterprise networks.

access to an external teleradiology client; although the traffic may share the network, the teleradiology is still largely stand-alone with

faxed base transfer of orders and reports. The bottom panel illustrates the scenario with greater integration and, potentially, some

Fig 3. The meta-PACS environment.

component of archiving services for remote clients and with the hospital network expanded to 1 Gbps. In both cases the links to the external network (public Internet or private network) are typically much slower than the enterprise networks. Figure 3 illustrates the environment for Meta-PACS and an example Next Generation Network (NGN) based on an Optical Transport Network providing Lambda services. That is, this network allows customers to subscribe to a wavelength, and it routes connections through the network lightpaths, with each path providing 10 to 40 Gbps. The example shows a scenario in which a radiology service provider employs the services of a storage archive service provider (ASP).

The evolution in computing, networking, and PACS has created a technical environment in which we can realize the original visions of early PACS researchers. That vision remains true, although the evolution has also been influenced by Web technologies (e.g., HTTP, browsers, XML, etc.), which have expanded the concept beyond the creation of the digital radiology department.¹⁶⁻¹⁹ PACS itself can arguably be considered a commercial product—and a very expensive one—and, like modalities and other large-scale systems, one of the most important line items in the quote is the one for Service and

Support. Essentially, PACS is no longer a subject for basic research (not to be confused with basic imaging research or modality development). There is, of course, still ample ground for research to apply the continuing stream of developments in Web technology, and workstation user interfaces will continue to sport varieties of “look-and-feel” that will go in and out of fashion.

So what is the research topic for Meta-PACS? In this decade, work can focus on highly distributed radiology in the context of the Integrated Healthcare Enterprise and the use of the developing NGN to extend the concept beyond the enterprise to national and international scale, collaborative health care systems. Development directions in network technology will ultimately provide end-to-end data paths with speeds that match or exceed the speeds of data paths within the local network, and even within workstations. This speed will allow concepts originally envisioned to apply within a department or hospital to be extended to multi-organizational systems, and it will also enable new service concepts to be developed.

As we think about Meta-PACS, there are some critical questions to ask. What are NGNs and why will they enable these possibilities? What are potential obstacles? How can radiol-

ogy play a role and become a "killer application"?

NEXT GENERATION NETWORKS

The term Next Generation Network, referring to the convergence of telecommunications network infrastructure, has traditionally been composed of distinct infrastructure elements. These are the PSTN (voice) network and the data network (Internet). We may also separate out the wireless voice network. Although these networks often share some physical infrastructure (e.g., fiber trunks), the switching equipment and functions are still primarily handled by separate equipment. NGNs bring all three of these networks together into a common packet-switched infrastructure. This intelligent, highly efficient infrastructure will deliver universal access and a host of new technologies, applications, and service opportunities.

The factors that have contributed to this vision since the end of the 1990s include the large-scale deployment of optical backbone infrastructure using DWDM (Dense Wavelength Division Multiplexing) during the telecommunications boom that ended by 2001. There is also steady pressure to move to all packet-switched transport. This change is similar to the evolution to digital transport that took place in the PSTN during the 1970s. This evolution depends heavily on the increasing deployment of MPLS (Multi-protocol Label Switching) to allow the packet-switched network to traffic with real-time characteristics best supported by circuit switching. Hand in hand with MPLS is the development of Quality of Service (QoS) techniques to guarantee that network resources will sustain the traffic for a specific application with appropriate bandwidth, delay, and jitter characteristics. *Bandwidth* refers to the appropriate data rate, *delay* refers to the time lag for the traffic to pass through the network between the sender and the receiver, and *jitter* refers to the variation in that delay. For some applications, such as remote robotic control, we may be sending just small control packets, and so we may not need large amounts of bandwidth, but it may be critical that we have minimal delay. For applications such as voice we may be able to tolerate relatively large delay (e.g., 250 ms),

but a large amount of jitter (i.e., changes in the delay) cannot be tolerated. In both of these examples we must also ensure in-order delivery of packets.

There is still debate among international standards bodies about the meaning of NGNs, but there are widely accepted requirements including (1) the need for open application programming interfaces (APIs), (2) support for many kinds of services with various characteristics (real time/non-real time, low or high data rates, different QoS demands) such as data, video, multimedia, and voice, and (3) a generally high capability for mobility (or "nomadicity").²⁰

For many network researchers, the Holy Grail is the all-optical-IP network in which data traverses the wide area network entirely in photonic form and does not go through repeated optical-electrical-optical (OEO) conversions. Developments in MEMS (micro-electrical mechanical systems) based mirror systems are supporting the development of large-scale optical cross-connect switches, which are being coupled with DWDM (Dense Wavelength Division Multiplexing) and GMPLS (Generalized Multi-protocol Label Switching). In this case, the "labels" are lambda's (i.e., different frequencies of light). It is possible that much of the backbone will be all optical in the near future, with 160 wavelengths (at 40 Gbps per wavelength) carried across a single fiber.^{21,22}

OBSTACLES AND DRIVERS

When we think about networks and their relationship to applications like widely distributed radiology services, it is important to remember that there are different regions of "the network" once we get outside of our own building local area network. It is useful to describe these as the "Backbone," the "Middle Mile," and the "Last Mile." The Backbone, also called the Core, is the very high capacity infrastructure operated by telecommunications carriers. This is where much of the investment and development has been focused recently, especially with the deployment of fiber-optics during the telecom boom of the late 1990s. There is some debate about "over capacity" in

this portion of the network, but clearly this is the key area for the realization of convergence.

The Middle Mile is a newer, Internet-related concept that refers to shared infrastructure linking outlying central offices (especially in rural areas) where an Internet Service Provider (ISP) may offer service to customer through major switching centers where the ISP links to an Internet Backbone Provider (IBP). That is, the Middle Mile is the infrastructure between the Backbone and the serving office where customers access the network.²³

The Last Mile is the highly publicized stretch between the local central office and the customer premises (whether home or corporate). There has been great discussion about the bandwidth gap in the last mile and the economic realities of building out new capacity. Various “flavors” of DSL (Digital Subscriber Line) were thought to be the favorite, but the end of the telecom boom saw many DSL providers go under. Cable access providers have moved into the gap strongly, and there is robust growth in consumer Internet access via cable modem. Hints of a telecom recovery may also give DSL a chance to become competitive again.²⁴

Both the Last Mile and the Middle Mile present major obstacles for rural hospitals seeking to use the network for advanced services. The small market size and high cost related to distance make delivery of broadband Internet access to these areas uneconomical. In fact, according to a cost study by the National Electrical Contractors Association, the shortfall between deployment cost and revenues generated will actually increase with greater penetration of rural markets by ISPs.

Densely populated urban areas do not face this problem, and the prospects for affordable high-speed access for urban healthcare facilities continue to be good. In major urban centers, telecommunications carriers continue to invest in the deployment of metropolitan gigabit Ethernet infrastructure. Hospitals in these environments can potentially be tightly coupled to the Backbone and have close to the equivalent of LAN linkages. Unfortunately, these are often not the hospitals faced with an inability to attract radiologists and are more positioned to provide services. Hospitals in smaller commu-

nities and rural areas, where the need is highest, sit across the double-walled moat of the Middle Mile/Last Mile bandwidth gap.

In the telecommunications world voice is still the killer app in terms of revenue generation, in spite of cut-throat competition that has driven prices to very low levels. The technologies that have grown successfully are those that provide ubiquitous services (e.g., cell-phones) needed by everyone. These services attract a number of competitors, driving prices down and further expanding the ability of consumers to acquire services.

However, unlike cell-phones and games, Radiology is not a direct consumer-oriented service, although direct marketing to consumers via mobile scanners at shopping centers appears to be growing. And of course, no matter how many megabytes of radiology images are being pushed around the network, individual exams do not generate direct revenue for the telecom carriers. There are, however, some factors that could push Radiology into “Stealth” killer app status.

SCENARIOS FOR RADIOLOGY AS A “KILLER APP”

1. The Shortage. Radiologists are in short supply, and the need for service is growing. This is especially true for rural settings where hospitals find it increasingly difficult to attract radiologists. Factors include isolation and an inability to compete with urban compensation rates. This factor drives up the demand for radiology services provided by remote image-reading centers. In turn this increases the demand for network bandwidth in those areas. The Middle Mile and Last Mile problem rules in this realm but the bandwidth demands of Radiology add to the pressure on telecom providers.
2. Teleradiology (RIP). The old model of teleradiology in which a cover sheet (“order”) is faxed, an image is sent over a point-to-point link, and a report is faxed back tomorrow or the next day should be increasingly unacceptable. This approach is prone to failure, errors, lost reports, and the potential unauthorized release of patient information. In addition, quality of care

concerns must drive Service Level Agreements (SLAs) in which radiology service providers guarantee minimum turn-around times, for example stat reports for a trauma case must be returned in 30 minutes or less to potentially avoid an expensive helicopter evacuation from a rural hospital to a trauma center. If the bandwidth available does not support the reliable transmission of a cervical spine CT exam in less than 10 minutes there is little chance of meeting the SLA. We want the NGN available at rural hospitals to support unification of teleradiology and radiology into simply "digital radiology." Optical Transport Networks providing Lambda services allow the creation of multi-organizational networks in which the WAN component is no longer a bottleneck. When the communications infrastructure is not an issue, PACS moves into the realm of very-large-scale software systems, and application integration and the creation of newly enabled applications are the focus of research. As the capabilities of modalities (especially multi-slice computed tomography) to generate very large quantities of data (8 Gbps) grow, the network traffic load will demand NGN types of services.

3. IHE. New service models based on the elimination of bandwidth bottlenecks require the continued advancement of IHE for both clinical and nonclinical service improvement. IHE should apply whether the sending site is upstairs or across the state, not only for the order and report transmission but also for billing efficiency.
4. Integrated Healthcare Services Delivery. Factors 1 through 3 above, combined with NGN, enable the concept of an integrated health care services delivery system that crosses organizational boundaries. This type of service is already growing in large organizations such as the military, Veterans Administration, and US Public Health Service, along with large health management organizations. Related systems, within the federal government can potentially aggregate services such as image reading and archiving at regional imaging centers to achieve national scale efficiencies and provide redundant storage. But these organizations do not

operate in a vacuum and they often interact with external providers. Transparent access to distributed repositories on an authorized, as-needed basis can reduce the potential for the release of patient confidential information. Federal agencies are also likely to be key customers of the telecom providers and will be able to add pressure for build-out of the network.

5. New Services. Imaging services distributed over an NGN lend themselves to the development of new service offerings such as centralized image fusion services or centralized computer-aided diagnosis centers. Perhaps more mundane is the potential for improved vendor service delivery and maintenance support. Additional new services and opportunities for standardization can be supported. For example, if an organization employs an archiving ASP and after some years chooses to change ASP there should be an "Archive Mass Transfer" protocol that can provide reliable, confirmed migration of an entire multi-Terabyte archive from one vendor to another.

Radiology can be a driver because PACS is well established as a distributed, network-centric application. The work in PACS over the last two decades, coupled with the growth of IHE and collaboration with HIMSS (Healthcare Information and Management Systems Society) and HL7 (Health Level 7), has played an important role in educating the medical community about the importance of standards-based communications and interoperability. Radiology can be a driver because it is an everyday, day-in/day-out application with demanding data characteristics.

CONCLUSIONS

We have seen how PACS research and development has paralleled developments in computing and networking to grow explosively in twenty years to both realize the visions of what digital radiology could be, and to adopt new technologies to create a vision for new services. The voice network is of course over 100 years old, but it has undergone an even more radical evolution during the same twenty

years. The history of PACS research and the key role of radiology in the development of new health services that address important services and satisfy rural outreach suggest that radiology offers great potential as a “killer application” to drive NGN deployment. However, we have to avoid the mindset that killer apps are only consumer-oriented, high-market-hype, entertainment-oriented concepts. PACS/radiology takes on the role of a killer app by methodically building a foundation of standards for integration and rapid exploitation of technology developments.

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