Design and Implementation of a Regional PACS

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***Abstract* — For a period of 10-15 years (2005 - 2020), the number of PACS (Picture Archiving and Communication System) systems offered on the market has increased more than 10 times. Despite this growth, some of the main disadvantages of this class of systems persist: the systems are complex and expensive to acquire, replace, maintain, or repair and to connect them in a regional map. This paper aims to show an approach that allows us to build a regional PACS connecting several hospital and maintaining medical information exchange.**

***Index Terms* — regional PACS; DICOM standard; interoperability; medical requirements.**

I. Introduction

Over the past few years, there has been a continuous growth in the clinical application of PACS to reduce costs and improve patient care, a trend that has continued and for a long time will be one of the main social forces affecting the speed of changes in medical infrastructure. The PACS (Picture Archiving and Communication System) is a comprehensive system that is responsible for the electronic storage and distribution of medical images in hospitals and medical facilities. Since the concept of computer medical application has developed substantially in the last 20 years, this has further developed the definition of PACS. Now the term "PACS" means "an interinstitutional computer system that manages the acquisition, transmission, storage, distribution, display and interpretation of medical images". As such, the system is highly integrated with:

- Devices for acquiring and displaying medical images – for the current generation of devices is typical that they are already entirely digital, i.e. modern PACS does not work with analog imaging devices
- Radiology department information system as the main provider of medical images
- The Hospitals Information Systems (HIS) using medical images in clinical practice.

Over the past few years, there has been a continuous growth in PACS implementations in medical practice, mainly due to several potential major advantages:

- improved usage scenarios and easier way of operation
- improved capacity of input-output requests to work with images – increase speed of electronic archiving devices
- reducing the response time of the processing request system
- increased number of possible image manipulations by the system
- increased performance of image processing
- remote and simultaneous access to image data
- improved computer archiving using new algorithms for indexing and search by various features
- handling images obtained from digital or analog radiological machines
- reducing costs and increasing the operating time due to the modular way of development, allowing reducing the cost of changing the medical imaging equipment in the radiological departments.
- improvements for cost-effectiveness due to reduced costs for computers and communication infrastructure – more and more operating systems and general purpose protocols are being used.

Particularly important for the development of PACS in recent years has been the trend for increasing use of medical standards for storage and transmission of medical images, with the DICOM standard being the highest prevalence. At present, DICOM (Digital Imaging and Communications in Medicine) is no longer just a standard for image storage from medical imaging devices. DICOM is the international standard for transmitting, storing, extracting, printing, processing and displaying medical information for images: (source: Medical.nema.org)

- Make medical image information interoperable
- Integrates image acquisition devices, PACS, workstations, VNA systems (VNA – Vendor Neutral Architecture) and medical imaging printers from various manufacturers
- Responses to developing technologies and medical image needs based on active development, change and maintenance
- Download, install and use is free of charge.

In last 10-15 years (2005-2020), the number of PACS systems in order increased with systems offering various functions and capabilities. Although PACS is no longer considered a new technology (many technological and operational problems for integration into electronic medical practice have already been solved), some negative aspects of this class of systems continue to exist: Systems are complex and expensive for acquisition, replacement, maintenance or repair. In addition, that despite the continuous use of increasingly new programming technologies. Therefore, the efficiency of the use of PACS decreases.

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PACS continue to be complex for installation and maintenance, often having increased infrastructure requirements such as architecture and components, which, combined with the price, is a serious choice problem. In addition, migration from one system to another is a very complex and expensive process, i.e. PACS is purchased and installed only with a long-lasting perspective of use without replacement. All this requires even more careful choice of a system according to the long-term needs and requirements of the particular client – the main characteristics of the system should be analyzed, as well as a comparison between the characteristics of different products. It is recommended that PACS can be installed by the end-user before purchasing to perform technical and clinical acceptability tests. This will provide the necessary data to ensure that the system meets the buyer's expectations, needs and infrastructure. It is particularly important to know that changes in computer technology and their impact on PACS also require a change in the prechecks and analyses carried out before accepting a PACS as the main one.

The purpose of this paper is to provide the intermediate results of the installation and the initial operation of regional PACS in the context of the National Scientific Program "e-Health in Bulgaria" works.

The paper has the following structure:

- Introduction
- Main components of PACS
- Structure of regional PACS and hospital PACS
- Initial structure of protection of hospital and regional PACS
- Conclusion.

II. Main Components Of PACS

The history of the development of PACS goes through several stages. Perhaps the most important characteristic of all these stages was that the systems were oriented towards the practically identical infrastructure architectures [1]-[4]. This trend of the similarity of the infrastructure is preserved, notwithstanding the increase in the use of newer programming technologies and newer types of medical devices.

At present, the infrastructure on which PACS is based has a number of physical components (Fig. 1):

- First side – devices generating digital medical images that are distributed and stored by PACS.
- Second side – all images viewing infrastructure.

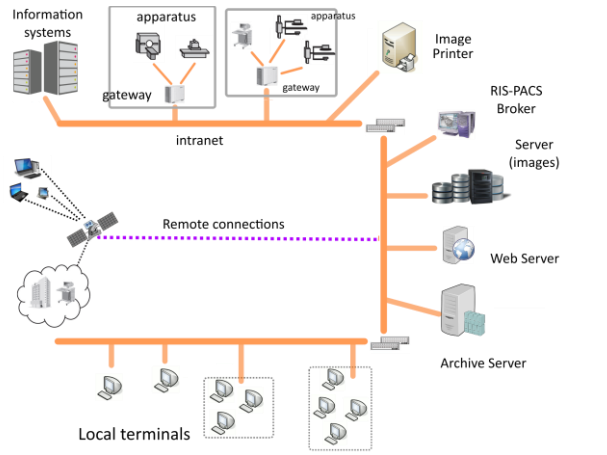

Fig. 1 PACS infrastructure – adapted from [x4]

One of the main features by which modern PACS is compared is the ability to change this basic infrastructure by removing or adding new nodes and communication buses.

1.1. Medical imaging apparata

Digital imaging devices include computerized tomography/scanners (CT), magnetic resonance imaging (MRI), ultrasonography, digital radiography, digital angiography, digital fluoroscopy, and digital mammography. Most often these devices are separate, and these separated components are connected to the common system by an internal network system (intranet). In addition, devices for transforming from projection radiography, traditionally filled with analogue screen-film detectors and recorded on film/plates in digital format, are also available. Most often, devices in a departments are connected to a gateway, which ensures the connection to the internal network. Much less often the direct connection of the device to the internal network is used.

If the device does not support the PACS storage format, a local server is used to convert to the PACS format.

With regard to interfaces and opportunities for direct integration into PACS, digital devices of this kind shall provide the following options:

- Receiving demographic information for the patient from Regional Information Systems
- Ability to check and correct the image for quality control
- Descriptions of DICOM (IOD) information objects for transferring apparatus parameters, e.g. cathode tube voltage in X-ray apparatus (kVp), exposure time and others
- Application of study-specific image processing.

1.2. Image server

The image server is actually a server for managing a database of images, with additional text information added to the images. This is one of the two key components of PACS. The technical solution to which modern implementations are most often targeted are a central computer (recommended multiple high-speed processors), HDD extensible storage (possibly RAID structured), big RAM and multi-layer cache memory. The software installed on this computer shall ensure that the information, images and their formats are monitored, and the image attributes, information for the image sources, and time of image changes are monitored also. In the case of expected very large data volumes, some PACS implementations use a broker as an intermediate layer between two or more databases of that type.

Less common architecture is decentralized or distributed PACS, where server functionality is distributed, as well as image repositories (local databases connected to elements of the decentralized or distributed system).

1.3. Archiving system

The archiving system is an important component of PACS and is responsible for electronic data archiving for images and accompanying data. Improvements in storage devices, along with the use of smart data search and extraction software, removed as the main problem the extension of this PACS functionality. The main storage are hard drives. Their storage capacity is constantly increasing (the creation of hundreds of

terabytes of volume repositories is no longer a technical, but an economic and infrastructure problem).

The technical solution is often based on a quick access archive and a long-term archive (where the access time is much greater). Dividing the system into short- and long-term archives is primarily an economic solution, as the rapid access technology required for the recently archived images is more expensive.

A duplication of the archive is also used as protection for recovery after some kind disasters.

It should be noted that rapid changes in storage technologies reduce the price of devices twice over a period from 5 years. Thus, scalability and workload estimates make the archive system a key purchase consideration for PACS acquisition. Therefore, it is imperative to make a realistic estimate of the expected volume of data and images, workload (i.e. transfer per unit to and from the repository), the annual increase in stored data and access points to PACS, which can launch procedures for access to the archive.

It is important to check whether archiving will be implemented in automatic mode or will always be manually activated.

1.4. Broker for communication with RIS and other information systems of image generating departments

Another essential element of PACS infrastructure is a communication broker with other information systems. Integration with other information systems and the ability to display appropriate data are crucial to the success of using PACS. At workstation level, images can only be used if they are related to patient information. Current technological solutions offer possible ways to address many of these problems.

The relationship between RIS (RIS – Radiology Information System) and PACS is the most critical. This is determined by an increasing spread of RIS-based architecture, which is in connection with the other information systems of the hospital or health facility. The reason is the increased number of digital image sources and large image volumes, i.e. the inefficiency of transferring raw images to a central server, then returning to the medical image investigation. Most modern RIS are developed, installed and used independently of PACS, but they can be connected to PACS. Most often manufacturers use the HL7 standard for the connection between RIS and PACS. In such cases, in order to reduce excess data and consequently discrepancies in the data on different server archives, most PACS rely on RIS as the main source of patient information. This requires a stable PACS connection to RIS – most often via a "broker" where relevant data are converted from HL7 to DICOM or vice versa.

Radiology is not the only department where medical images are generated – endoscopy, cardiology departments, Doppler machines, pathology, ultrasound diagnostics, etc. Many of these devices generate large and complex single images or sets of images, and some generate high-resolution videos. In addition to these images, clinicians integrate information obtained from images with other clinical data to make decisions for the patient. This is also a large data stream and images that need to be managed within the PACS.

1.5. Terminal Workstations

The terminal workstation (i.e. the computer viewer for medical images) is another element of the PACS infrastructure. This element is probably PACS's most visible element, because this is where existing PACS-managed images are used by medical staff in their practice.

Displaying images in PACS is a flexible and dynamic process in which medical personnel directly interact with the image displayed on a workstation. The workstation has two main components: Software and hardware. The characteristics of a workstation are valid only for this particular combination of device and software.

At the hardware level, the main problem is related to the features of the monitors and the ability of PACS to visualize images of one and the same quality regardless of the monitor.

This option is one of the problems of most PACS – mostly PACSes work with the default setting of the workstation according to the configuration of the installed OS and the module for visualization of medical images. In our practice we have seen very few specialized and exactly tuned imaging monitors in radiology departments.

In PACS environment view stations are used for a variety of purposes, including primary reading, consulting and review. In order to determine the requirements, it is useful to identify the requirements for the apparatus based on its use:

- primary class device – used by radiological departments;
- secondary class device – in the medical practices of other specialists.

In general terms, the main specifications of the display can be grouped into three areas:

- Ergonomics – positioning (on a stand or on a wall), possibilities for changing the angle and changing height, geometric dimensions of the screen, distance to user, room lighting, etc.
- Physical characteristics: Resolution, inter-pixel distances along both axes, refresh rate, geometric distortion, anti-reflective coating, etc.
- Optical characteristics – contrast, maximum illumination, irregularity of illumination, depth of gray (number of shades of gray), chromaticity, quantity of defective pixels, angular variation of illumination, contrast to single pixels and others.

It is also important to know if additional workstations have additional functions such as brightness stabilization, image shape recognition, image mapping, autocalibration, remote calibration, ambient light sensor (external or internal), brightness remote control and contrast.

At software level, PACS's graphical user interfaces (GUIs) allow different functionality needed to view the image: Request and retrieve images, display imagery and various image processing functions, such as window leveling and approximation. This requires PACS to be able to adapt to the individual preferences of the physician, where the ultimate goal is to improve performance and to increase the accuracy of the interpretation of medical images is the diagnostic process of the interpretation of medical images is the diagnostic process.

Essential for PACS evaluation is the ability to add user functionalities based on the use of an API of the system or an internal command scripting language.

1.6. Remote access to PACS resources

As early as the first implementations, it has been found that the installation of PACS can actually be justified economically only when PACS can ensure effective dissemination and use of images throughout the hospital or medical organisation, and not just for the radiology department or other image-generating departments. The distribution of medical imaging within the entire hospital/organisation is significantly different and much more difficult to solve a problem than traditional PACS for radiological wards. Users outside the radiology department may be more unpredictable than radiologists in terms of what images they require, where they should see images, and when they should see them. These users can be even more demanding than radiologists in terms of image transmission performance. This creates a technological challenge.

Since at least 10 years, this challenge has become significantly complicated due to the extension of the remote form of work. This is now a mandatory function of every serious product this group. Most often this is done via Web-server or by specialised PACS customer software installed at remote points. The main problem is the need to use medical information outside the medical center (through the Internet) – currently this restricts data security, patient confidentiality (encryption is mandatory), speed (limited bandwidth), image quality problems (the display quality and possible deterioration due to loss compression) and medical legal consequences of telemedicine.

III. Structure of Regional PACS and Hospital PACS

In the framework of the activities of the National Scientific Program “e-Health in Bulgaria” two structural developments were made:

- structure of hospital PACS for hospital, which did not have its own system;
- regional PACS structure, based on developments under this scientific programme.

A principle scheme of the connection of regional PACS to a hospital systems is shown in Figure 2.

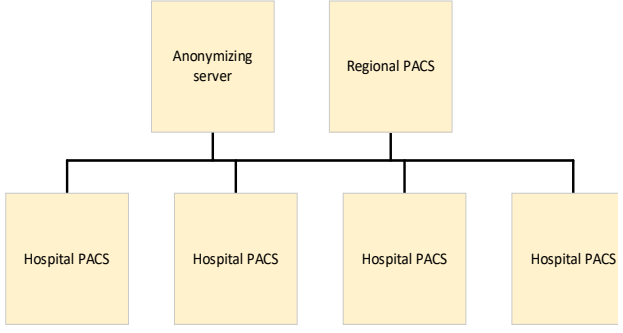

Fig. 2. Network architecture for Hospital-Regional PACS interconnection

This scheme gives only a primary idea of the overall structure to be maintained. It is basis for the development of the principle scheme of how to access patient’s data from several different hospitals connected to the regional PACS. This scheme is shown in Fig. 3.

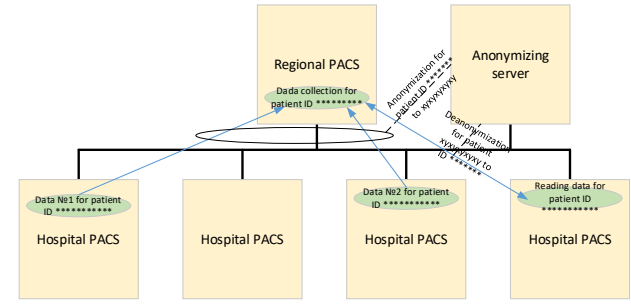

Fig. 3. Structure of realization of data records for the same patient from different places and reading from another place in / from regional PACS

These initial schemes do not present the structure of the systems in terms of general protection, expansion, internal and external access to locales and regional PACS.

Fig. 4 shows the scheme of the PACS installed in USBALE “Acad. Ivan Penchev”. At the time of installation, the hospital did not have its own PACS or its own sources of medical images.

This structure in Fig. 4 enables PACS itself to be isolated from access to its resources from external sources. The main point is the separation of external access from internal access. The problem that had to be resolved is the following. The DICOM protocol requires static connection of image modalities and view stations.

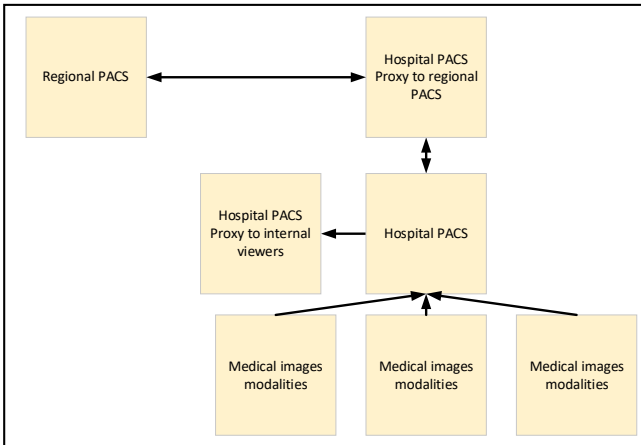

Fig. 4. Detailed PACS structure implemented in USBALE “Acad. Ivan Penchev”

This excludes the use of DICOM customers (viewers) connected through dynamic network addresses. Due to increased capacity and medical diagnostic capabilities, DICOM clients are installed in the hospital at static addresses, which are connected to PACS through DICOM protocol. In order to eliminate the possibility of modifying the database (deleting records), all DICOM clients have only reading access to PACS. Diagnostics, metrics and other invasive imaging activities are performed only on local copies of investigated image.

In relation to the need for external (outside of the hospital infrastructure) access to PACS, hospital staff have access to PACS through DICOM WEB Browser, part of the installed PACS. This is possible because this system provides API for HTTP access to DICOM resources (the REST API). Access is protected by personal accounts and passwords. In the same way as with internal access to images, the user has read access to PACS, but works with local image copies. The original content cannot be modified.

The detailed structure of the regional PACS is shown in Fig. 5.

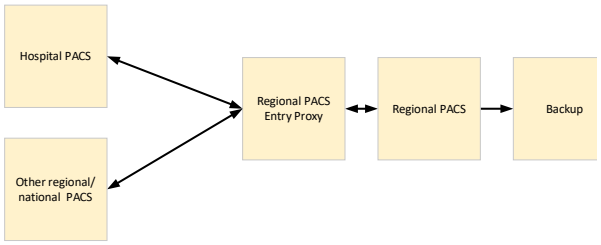

Fig. 5. Detailed structure of regional PACS

Currently installed regional PACS covers two hospitals and regional PACS systems. Its structure is shown on Fig. 6.

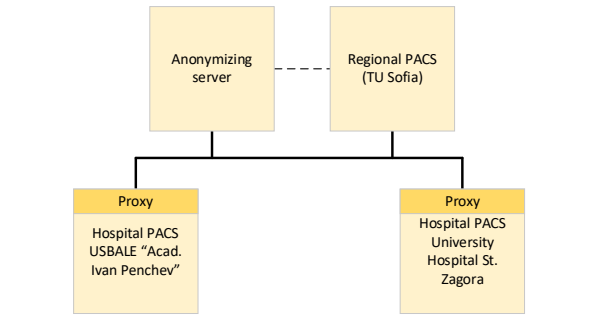

Fig. 6. Current structure of Bulgarian Regional PACS

IV. Initial Structure of Protection of Hospital and Regional PACS

Like all complex systems, PACS is predisposed to technical problems and operational disadvantages. Problems may arise due to incorrect or incomplete installation or configuration, where they exceed the initially intended resources and tasks, or by adding new image generating devices or displaying images. The specific problems for hospital and interhospital networks are the requirements of the DICOM protocol. Multiple communication devices do not support all types of protocols required by DICOM. The protection of local and regional PACS comes down to several basic requirements:

- Complete protection of the main database. This requires a one-way operation of the exchange (only to the database).
- Prohibit any form of HTTP exchange with the main PACS. There remains only DICOM exchange protected by accounts, passwords, certificates and total identification of each subscriber.
- Anonymization/deanonymisation is provided by a separate server and local customers.
- Only anonymized data are transported from each proxy server to and from the regional PACS.
- All DICOM viewers that are not WEB browsers are identified by their static address, personal identifier (and passwords if they support this option).
- The exported DICOM viewers shall be connected only by VPN, configured and providing the same representativeness as locally based ones.
- HTTP exchange is only allowed to proxy servers that do not contain irrecoverable information.

V. Conclusion

Within the activities carried out by the National Scientific Program "e-Health in Bulgaria", PACS was selected and an installation of local hospital PACS and regional PACS was made.

The regional PACS is installed on the territory of TU Sofia and performs according to Figure 5.

In "Acad. Ivan Penchev" Hospital is installed local PACS, which is in regular hospital mode1 operation in the COVID department of the hospital and works with real data.

The technical installation of a local PACS in Stara Zagora University Hospital as a proxy of the existing hospital PACS for connection with the regional PACS, located in the Technical University of Sofia, is also done.

References

[1] H. K. Huang, PACS: Picture Archiving and Communication Systems in Biomedical Imaging, VCH, 1996, ISBN: 978-1560816850

[2] H. K. Huang, PACS-Based Multimedia Imaging Informatics: Basic Principles and Applications, 3rd Edition, Wiley-Blackwell, 2019, ISBN: 978-1118795736, https://doi.org/10.1002/9781118795552

[3] A. Peck, Clark's Essential PACS, RIS and Imaging Informatics, CRC Press, 2019, ISBN: 978-1498763233

[4] E. Samei at al., "AAPM/RSNA tutorial on equipment selection: PACS equipment overview: general guidelines for purchasing and acceptance testing of PACS equipment" in Radiographics, Jan-Feb 2004; 24(1), pp. 313-334, https://doi.org/10.1148/rg.241035137.

[5] H. K. Huang, DSc, PACS and Imaging Informatics: Basic Principles and Applications, Hoboken, NJ: Wiley, 2004 ISBN 0-471-25123-2, https://doi.org/10.1002/0471654787

[6] DICOM 3.0 Standard. [Online]. Available: http://www.nema.org/stds/2007-DICOMFULLSET.cfm

[7] Dreyer D. K., Hirschorn J. S., Thrall A., Mehta H., PACS A Guide to the Digital Revolution, 2006, Springer Science +Business Media, Inc., USA, ISBN 978-0387-26010-5, https://doi.org/10.1007/0-387-31070-3