UDC 004.771, DOI: 10.2298/CSIS0901185D

Architectures of DICOM based PACS for JPEG2000 Medical Image Streaming

Dinu Dragan[1] and Dragan Ivetić[1]

[1]Faculty of Technical Sciences, Trg D. Obradovića 6,
21000 Novi Sad, Serbia
{dinud, ivetic}@uns.ns.ac.yu

Abstract. Delivering of medical image content to mobile/embedded devices with low storage and processing capabilities and low resolution displays is a challenging, but important task for achieving ubiquitous computing in modern hospital environments. The common approaches in industry and technical literature employ JPEG2000 compression and image streaming. Beside image compression, JPEG2000 facilitates image streaming. Different sized images are extracted from one codestream with minimal spatial distortion within decompressed image. We developed DICOM2000 syntax which enables JPEG2000 streaming over DICOM networks. DICOM2000 brings compression and streaming power of JPEG2000 to DICOM which is the standard for medical image interchange. It enables transmission of best quality medical images suited for client device processing and display capabilities. In this paper communication architectures of DICOM2000 based PACS are compared with the common architectures of DICOM based PACS. For the purpose of the paper, these communication architectures are categorized, named, and described. At the end, the advantages of the DICOM2000 based PACS over standard PACS are pointed up.

Keywords: Picture Archiving and Communication System (PACS), Digital Imaging and Communication in Medicine (DICOM), JPEG2000, medical image streaming.

1. Introduction

Employment of digital medical images reduces medical systems overall cost and increases hospital efficiency. But there are some drawbacks. Digital medical images tend to be large in size and storing/network demanding. The complete annual volume of medical images in modern hospital easily reaches 10 Terabytes [1]. Also, Picture Archive and Communication System (PACS) requires Gigabit/s or 10 Gigabit/s bandwidth network [2, 3]. For example, a typical digital X-ray image can be 2Kx2K grayscale image represented with 12bpp which means that the medical image would be about 50 megabits [4].

Image compression reduces the medical image size, relaxing the storage and network requirements [4]. Nevertheless, modern PACS tend to achieve ubiquitous computing environment which means that they should support and include (mobile and embedded) devices with different power, storage, communication, and display capacities, all served from one source and for various usage [5, 6]. Because of their limitations of processing power, memory capacity, display capability, and because of mobile networks bandwidth limitations, these devices can not process digital medical images in their original size [4, 7]. PACS has a maximum efficiency and minimum requirements when the source is a medical image compressed (losslessly or lossy) with a compression technique which achieves smaller spatial distortion and supports image streaming [8, 9]. The image streaming means that the pixel data needed to represent a part of the image (or the whole image) in a certain resolution and quality are extracted from one stored image codestream and transmitted to the client-side application [10], Fig.1. JPEG2000 compression supports all the listed requirements [11].

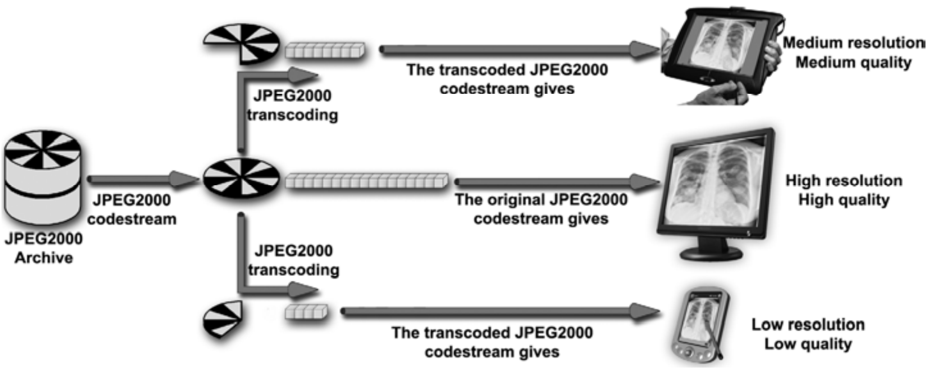

Fig. 1. The illustration of JPEG2000 streaming - extraction of a lower-resolution image from the codestream

For example, all three different types of client devices from Fig. 1 are served from one codestream. Only the data needed to view the image in best quality and resolution are transmitted. It is possible to see a part of the image in original resolution and the best possible quality even on low resolution and low quality displays. It just takes several interactions with JPEG2000 codestream. The low resolution version of the image represents only a preview. User can mark a region of the image which is later extracted from JPEG2000 codestream in higher resolution. The process goes until a region from the image is extracted in original resolution. Although it is not possible to see the entire image in original resolution, it is possible to “slide” through the image (user navigates through connected regions of the image in original resolution) [11].

JPEG2000 is an ISO/IEC standard for still image compression which achieves a more superior compression performance than the other still image compressions with minimal spatial distortion within decompressed image [11, 12, 13]. It offers lossless and lossy compression modes, within the same compression process. JPEG2000 compression supports region of interest coding and image streaming. Different sized images, with minimal spatial distortion, can be extracted in a simple way from one JPEG2000 codestream at server-side and served to different clients, Fig 1. The quality of the extracted images is far better than the quality achieved by the auto-scale function of an image browser but the minimum data set is used. The use of JPEG2000 compression severely reduces the size of PACS medical image archive [14, 15]. JPEG2000 employs image streaming even for losslessly coded images.

There are other still image compression standards employed for medicine, such as JPEG, SPHIT and a variety of proprietary compression techniques [15, 16]. JPEG2000 compression has several advantages over other compression techniques used in medicine [4, 15, 16]. It achieves superior compression performance with minimal spatial distortion within decompressed image, enables high quality image streaming, and it is an industry approved standard accepted by Digital Image and Communication in Medicine (DICOM) standard.

DICOM is communication protocol usually used in PACS [17]. The DICOM standard defines the DICOM message format, the protocol for message interchange and the file structure for biomedical images and image-related information [18, 19, 20, 21]. DICOM message consists of two parts:

– *message header* containing descriptive information about the medical image, patient, medical study etc,
– *image data* containing pixels of the medical image in native DICOM format which is raw and uncompressed.

Beside native DICOM format, the standard defines the mechanism for encapsulation of other compression and image formats. Currently, DICOM standard supports run-length encoding, lossy and lossless JPEG compression, lossless and near lossless JPEG-LS compression, and lossy and lossless JPEG2000 image compression [18]. None of these compression standards, except JPEG2000, supports image streaming.

Although the DICOM standard supports JPEG2000 encoding, it does not support JPEG2000 streaming over DICOM communication protocol [9, 17]. The standard DICOM massage has to be extended to support image streaming [8, 9]. The DICOM standard defines a mechanism for communicating information that was not anticipated by the standard and therefore is not contained in the standard DICOM message [17, 18, 22]. DICOM2000 syntax, the extension of DICOM standard message for JPEG2000 streaming over DICOM communication protocol was introduced in [14]. The proposed extension is transparent for other DICOM implementations, which enables quick, easy and transparent integration of the proposed extension into the existing PACS. The proposed syntax has been implemented and tested in the controlled environment. It achieved good results, enabling fast medical image browsing inside DICOM networks, and presentation of DICOM data and high-quality low-resolution medical images on limited size display devices. The results were reported in [14].

There are several possible architectures of DICOM2000 based PACS [14]. We will describe them and point out their advantages and disadvantages. Also, we will compare them with other solutions proposed in technical literature and with the architectures of PACS based on standard DICOM syntax which support interchange of JPEG2000 medical images. In general, we recognized three broad categories and communication architectures of DICOM based PACS for JPEG2000 medical image interchange: standard DICOM based PACS with JPEG2000 support, proprietary PACS based on DICOM and JPEG2000, and DICOM2000 based PACS. Unique names are assigned to communication architectures to ease up their referencing. The organization of the paper is as follows: the rest of this section gives quick survey of the DICOM2000 syntax; section 2 describes the architectures of DICOM based PACS with JPEG2000 support; section 3 describes the solutions for medical image streaming proposed in the technical literature; section 4 describes the architectures of DICOM2000 based PACS; and section 5 concludes the paper.

1.1. DICOM2000 Syntax

The solutions proposed in technical literature implemented JPEG2000 streaming as a part of an external communication system additional to DICOM communication system [23, 24, 25]. With DICOM2000 syntax, the JPEG2000 streaming is incorporated inside DICOM communication protocol. The query mechanism of DICOM2000 syntax is modeled after JPEG2000 Interchange Protocol (JPIP) [26]. The standard DICOM message is extended to support the JPIP query mechanism in a transparent way.

The JPIP standard is a part of the JPEG2000 family of standards [27, 28]. It enables interaction with JPEG2000 content and it is used for remote JPEG2000 image browsing. The JPIP standard defines the complete set of syntaxes and methods used for remote browsing of JPEG2000 content [26]. It enables JPIP client-side applications to request the resolution, quality and desired region of interest of the JPEG2000 image.

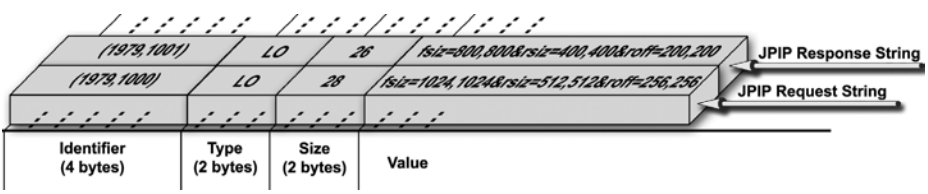

Fig. 2. The example of DICOM2000 attributes structure

DICOM2000 message contains two additional attributes that enable the DICOM2000 client-side applications (DICOM clients that support DICOM2000 syntax) to interact with the JPEG2000 medical images, Fig. 2. The first attribute, named *JPIP Request String*, is DICOM2000 client request formatted as the JPIP request string. The second attribute, named *JPIP Response String*, is DICOM2000 server response for the corresponding JPEG2000 image formatted as the JPIP response.

Each DICOM attribute, and therefore the DICOM2000 attribute, consists of several features defined in the standard. There are four fields containing attribute identifier (4 bytes length), data type (2 bytes length), size (2 bytes length) and value (variable length, where 2^{16} is the maximum byte length). The value field of the DICOM2000 attributes contains the parameter string formatted as JPIP request/response string, Fig. 2. The JPIP request consists of a sequence of markers formed as ***name=value*** pairs. The JPIP markers: ***fsiz***, ***rsiz***, ***roff***, are used to define the resolution, the region size, and the region offset of the requested medical image. DICOM2000 attributes are transparent for all the other DICOM implementations which do not employ DICOM2000 syntax. Although, the unrecognized attributes are not parsed, the rest of the DICOM massage is still readable and it interpretable.

The detailed overview of DICOM2000 syntax can be found in [14].

2. Standard DICOM Based PACS with JPEG2000 Support

The DICOM message encapsulates the entire JPEG2000 codestream as it is described in the first part of JPEG2000 standard [11]. DICOM does not support the encapsulation of the JPEG2000 file formats [23]. Inside DICOM message, the pixel data in uncompressed native DICOM image format are replaced with corresponding JPEG2000 codestream. All the attributes in DICOM message describing image pixels represent the actual values of the compressed medical image.

The encapsulation of JPEG2000 codestream enables the JPEG2000 image transmission together with a DICOM message, Fig. 3. Communicating DICOM applications have to agree whether they will support the transmission of lossless or lossy JPEG2000 medical images [18, 23].

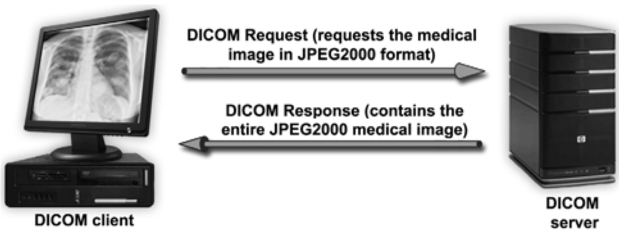

Fig. 3. Standard DICOM communication for JPEG2000 interchanges

The standard DICOM communication for JPEG2000 interchange can be implemented in several ways [14]. The main difference between these implementations is whether DICOM server-side application supports JPEG2000 compression or not. The Standard DICOM JPEG2000 Double

Repository architecture described in Fig. 4 does not support JPEG2000 compression. Therefore, it has to store medical images in native DICOM image format and in JPEG2000 format. This is necessary, because all DICOM applications have to support transmission of medical images in native DICOM image format [18, 23]. Depending on the DICOM client request, DICOM server will either serve the version of medical image in native DICOM image format or in JPEG2000 format. Also, the client-side applications have to provide both versions of the medical image when storing new images on the server. This approach only increases the medical image archive instead of reducing it, it increases the complexity of client-side applications and it is highly unlikely to be implemented. Another drawback of the Standard DICOM JPEG2000 Double Repository architecture is that old images in DICOM native format can not be served to DICOM client requesting JPEG2000 medical images.

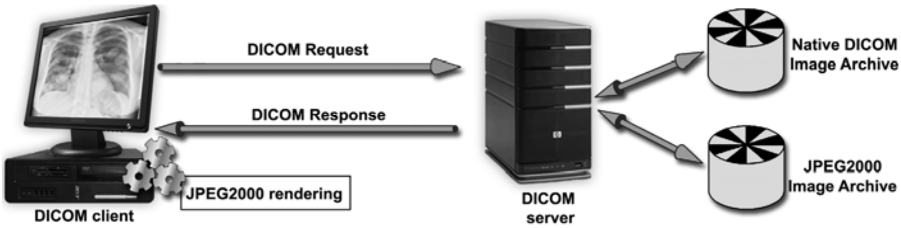

Fig. 4. Standard DICOM JPEG2000 Double Repository Architecture – the DICOM based PACS with JPEG2000 support which contains two separated medical image repositories: for images in native DICOM format and for images in JPEG2000 format

If DICOM server-side application supports JPEG2000 compression, it should store medical images only in JPEG2000 format, therefore reducing the medical image archive. The Standard DICOM JPEG2000 Single Repository architecture is described in Fig. 5. When DICOM client-side application requests the medical image in native DICOM image format, JPEG2000 image is decompressed, transcoded into native DICOM format, and sent to DICOM client. If DICOM client requests the medical image in JPEG2000 format, it is encapsulated inside DICOM message and sent to client.

JPEG2000 medical images could be stored inside ordinary database management system, or on JPIP server, (as described also at the bottom-right part of the Fig. 9). The implementation of PACS based on JPIP server supports additional ways for JPEG2000 medical image interchange described latter in this section. It is necessary to transcode the DICOM images from old archives into JPEG2000 images for the Standard DICOM JPEG2000 Single Repository architecture. This would enable DICOM clients to request old medical images in JPEG2000 format.

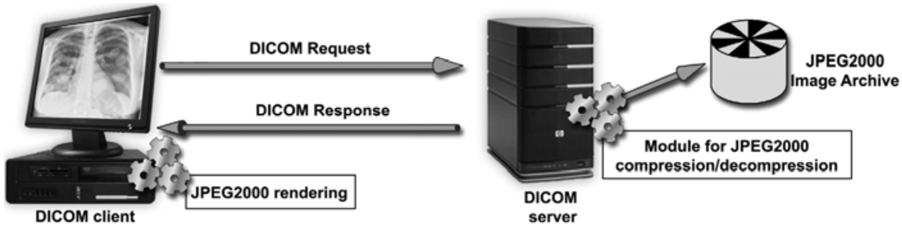

Fig. 5. Standard DICOM JPEG2000 Single Repository Architecture – the PACS architecture for DICOM JPEG2000 Transfer Syntax which contains one medical image archive for images in JPEG2000 format and module for JPEG200 compression

Although, the encapsulation of JPEG2000 medical images reduces the storage and network band-with requirements compared to the native DICOM image format, it does not enable the JPEG2000 streaming. It is still necessary to send the entire JPEG2000 codestream, even if the client-side device can not support it. The medical image resolution may be too large for client-device display resolution, or the client-device may not have enough memory to process it. Only the PC based DICOM client-devices can support the efficient complete image processing and rendering [14]. Therefore, the Standard DICOM JPEG2000 Single Repository architecture requests powerful client-side devices.

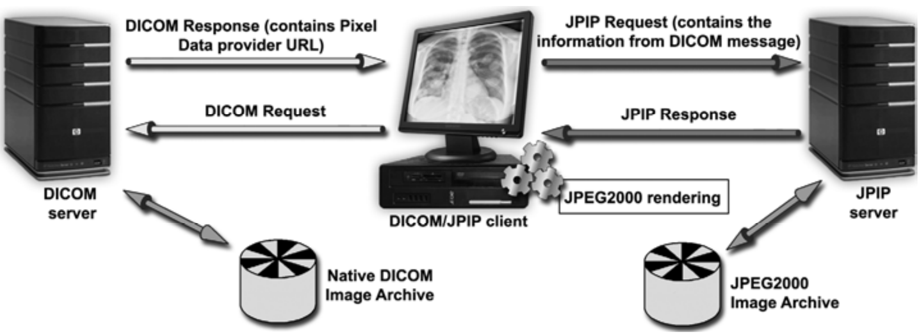

Fig. 6. DICOM standard JPIP Pixel Data Provider service

Although the DICOM standard does not support it directly, it recognizes the importance of medical image streaming. The standard defines the *Pixel Data Provider* service which enables pixel data transmission using a network protocol that is defined outside the DICOM standard [9, 18, 23]. Currently, the only service supported is the *JPIP Pixel Data Provider* which represents a mechanism for supporting the use of JPIP network protocol. JPIP Pixel Data Provider architecture is described in Fig. 6. When this mechanism is used, pixel data contained in DICOM massage are replaced with a single DICOM attribute containing the URL string that represents the JPIP request, including the specific target information.

DICOM client-side application in DICOM standard JPIP Pixel Data Provider service has to implement the JPIP protocol and to assume the role of JPIP client. DICOM client requests DICOM image over *JPIP Pixel Data Provider* service, the left hand side of the Fig. 6. The DICOM response message contains all the corresponding information associated with the medical image other than pixel data. It also contains the network address of the JPIP server and the name of the target image. Over the second communication channel (JPIP network), the DICOM client-side application, now in the role of a JPIP client, requests the targeted image which is served by the JPIP server, the right hand side of Fig. 6. Because of the use of JPIP protocol, the whole range of the JPEG2000 streaming capabilities is on disposal. Client-side application can request parts of the medical image in precise resolution and quality. Also, old medical images in DICOM format have to be transcoded into JPEG2000 format and stored at JPIP server side. In this way even the old images are available over *JPIP Pixel Data Provider* service.

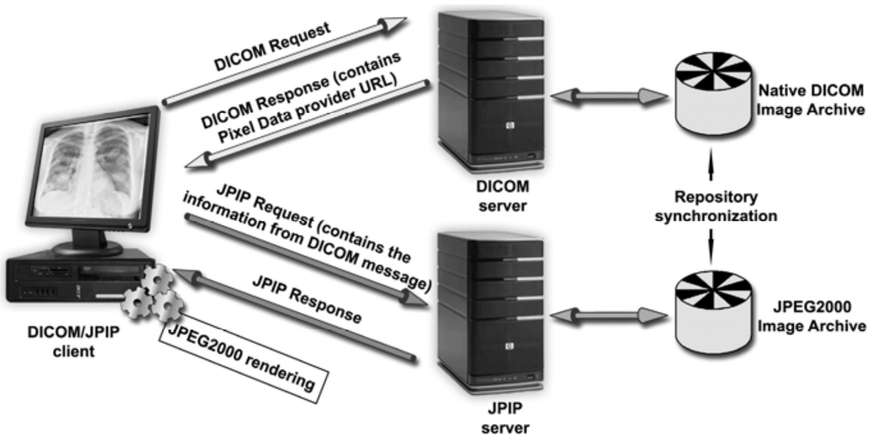

Fig. 7. Standard DICOM JPIP Provider Double Repository Architecture – the DICOM standard JPIP Pixel Data Provider service when DICOM and JPIP server-side applications do not share medical image archives

DICOM standard JPIP Pixel Data Provider service can be implemented in three ways. The first way is Standard DICOM JPIP Provider Double Repository architecture, Fig. 7. DICOM server-side application has to have access to medical images in native DICOM image format, because it has to support the transmission of medical images in native DICOM format. The semantics of *JPIP Pixel Data Provider* service treats JPIP server-side application as completely independent from DICOM server-side application [23]. That means that these server-side applications do not share medical image archives. This is a drawback because JPIP server-side and DICOM server-side medical image repositories have to be synchronized. The Server Content Management becomes an issue and a way of data synchronization has to be implemented, but it is not defined by DICOM standard [23]. Also, the DICOM server-side application has no control over the pixel data transmission. As far as DICOM server-side is concern, the entire DICOM image is served. If, for some reason, image does not exist at JPIP server-side, or image can not be served, the DICOM image has to be transmitted from the beginning. This time, the medical image has to be transmitted in its full size and completely over DICOM network protocol. Therefore, the JPEG2000 streaming can not be guaranteed.

The synchronization between DICOM and JPIP server-side can be avoided if these servers share the medical image archive, although it is not in the manner of DICOM standard [23]. Shared medical image archive imposes some limitations. JPIP server manipulates only JPEG2000 images. Therefore, medical images should be stored in JPEG2000 format. Because DICOM server supports transmission of native DICOM images, it has to support JPEG2000 compression. The DICOM standard does not support image storing operation using the *JPIP Pixel Data Provider* service. Therefore, image storing operation has to be blocked on JPIP server-side.

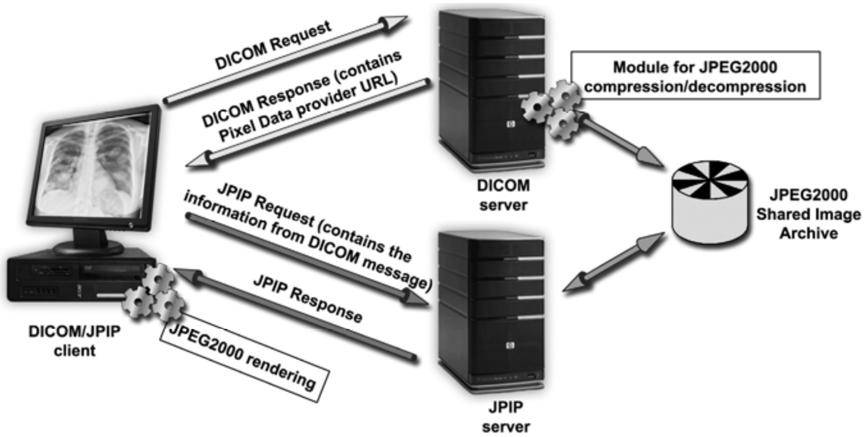

Fig. 8. Standard DICOM JPIP Provider JPEG2000 Repository Architecture – the DICOM JPIP Pixel Data Provider service when DICOM and JPIP server-side applications share one medical image archive

The second way for implementation of the DICOM standard JPIP Pixel Data Provider service is the Standard DICOM JPIP Provider JPEG2000 Repository architecture, Fig. 8. The JPEG2000 medical images are stored in shared image archive. In this case the question is whether to store images in native DICOM image format, in JPEG2000 image format or in both. The last option is out of the question for the same reasons explained for the Standard DICOM JPEG2000 Double Repository architecture. The other two options may increase processing time during image format transcoding, but that is unavoidable.

The third way to implement the DICOM standard JPIP Pixel Data Provider service is the Standard DICOM JPIP Provider JPIP Repository architecture,

Fig. 9. Medical images are stored on JPIP server side JPEG2000 image archive. In this case, the DICOM server has to support JPIP communication protocol. The Standard DICOM JPIP Provider JPIP Repository architecture supports DICOM transmission of JPEG2000 medical images and DICOM *JPIP Pixel Data Provider* service. Also, JPIP server-side application should support image storing operation initiated from DICOM server-side application, and block all the others [23].

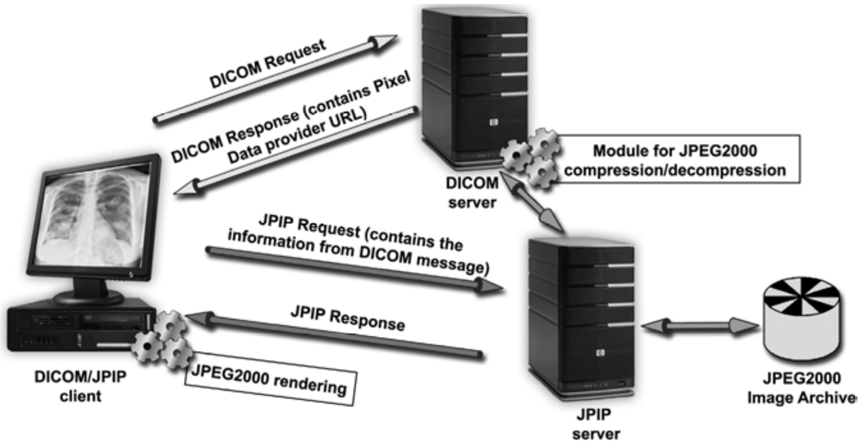

Fig. 9. Standard DICOM JPIP Provider JPIP Repository Architecture – the DICOM JPIP Pixel Data Provider service where all the images are stored at JPIP server-side application; DICOM server stores and requests images from JPIP server

Because DICOM does not support medical image storing operation using the *JPIP Pixel Data Provider* service, it is impossible to update the changes made to medical images received over *JPIP Pixel Data Provider* service, and it is impossible to add comments and observations to them. The DICOM client-side applications have to store images on the DICOM server-side using other DICOM services. Basically, the processed and/or commented medical images are stored as new instances, or as it is in many cases, they are simply discarded and lost [18].

3. Proprietary PACS Based on DICOM and JPEG2000

To our knowledge, several solutions have been proposed for medical image streaming over PACS based on DICOM [14, 23, 24, 25]. The solutions are mainly based on JPEG2000 family of standards and/or on non-standard compression techniques similar to JPEG2000. There are two main approaches [14]. In the first approach, new network protocols are developed based on DICOM message format. A peer-to-peer system for medical image sharing has been developed by Blanquer et al [29]. Proposed system uses

JPEG2000 medical images encapsulated in DICOM messages. Images are shared between various parts of the system over ordinary network protocol – neither DICOM nor JPIP protocols are used. The DICOM header is sent first. The medical image pixel data is sent layer by layer to the destination peer. This system enables only quality scalability. There is no mechanism that will allow resolution scalability.

Quality scalability of DICOM medical images has been implemented by Ramakrishnan and Sriraan [30]. This implementation is based on Set Partitioning In Hierarchical Trees compression (SPIHT) which is very similar to the JPEG2000 compression [30]. The data transmission is based on HTTP network protocol. The DICOM header is sent first followed by medical image pixel data. The pixel data is sent progressively. Therefore the client-side application can stop transmission when certain quality is achieved. Similar to Blanquer's solution, this system enables only quality scalability.

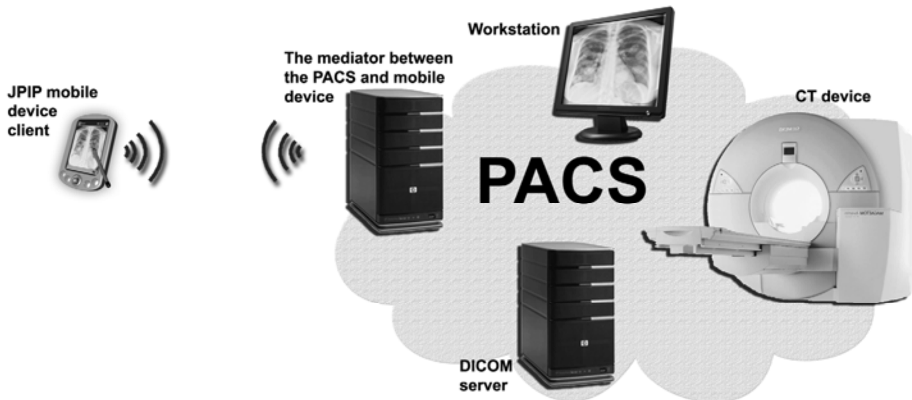

Fig. 10. Two Layer Proprietary Architecture – the application mediator streams medical images to mobile devices and achieves communication between mobile device and the PACS

The solution based on new network protocols is limited because it can not be used within default, industry approved PACS systems. Also, it does not enable transparent integration of the proposed systems in the existing PACS. Usually, it is necessary to provide two communication channels and some kind of mediator between the two systems. In both proposals, the authors suggested that new PACS should be implemented completely based on the proposed network protocols.

The second approach for DICOM medical image streaming implies the development of two layer communication architecture. One layer is used for communication within DICOM based PACS, the right hand side of Fig. 10. The second layer is used to stream images to the client-side devices, the left hand side of Fig. 10. The second layer of the communication is usually based on the JPIP communication protocol.

The example of this approach can be found in works by Tian et al [24, 25]. In this proposal, the medical image archive is based on the native DICOM image format. The image streaming and compression are not combined. Therefore, the storage requirement remains high. As in JPIP pixel data provider mechanism, there has to be at least two communication protocols. The client-side application has to request the medical image over JPIP protocol. The mediator translates the JPIP request into the DICOM request and conveys the request to the DICOM server-side application. The received medical image is further processed at mediator side and then sent back to the client-side application. If the DICOM message does not contain JPEG2000 medical image, then the image has to be compressed first. Therefore, additional processing takes place and the overall serving time grows significantly.

4. DICOM2000 Based PACS

The DICOM2000 syntax extends standard DICOM query mechanism. Beside, information about patient, study, medical image meta-data, DICOM2000 client-side application can define the resolution, quality, and the region of interest of the requested JPEG2000 medical image.

The communication based on DICOM2000 syntax is described in Fig. 11. There are two types of clients: DICOM2000 clients and standard DICOM clients. The DICOM2000 syntax is completely transparent for other DICOM applications which do not support it. Therefore, DICOM2000 server-side application communicates with standard DICOM clients. This is in compliancy with DICOM standard.

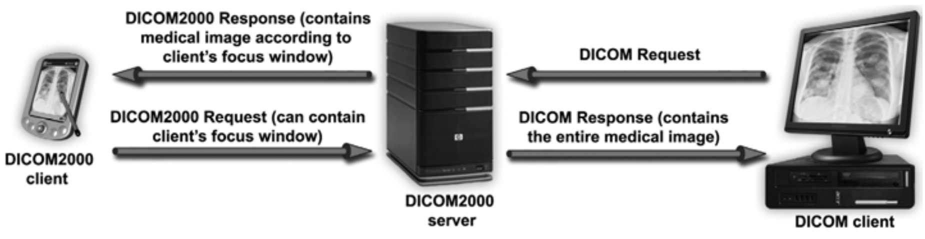

Fig. 11. DICOM2000 Communication – DICOM2000 clients can define their "focus window"; the DICOM2000 system still has the ability to communicate with other DICOM applications

After DICOM2000 server-side application receives DICOM2000 request, target JPEG2000 medical image is processed and transcoded according to the client request, the left-hand side of the Fig. 11. The resulting JPEG2000 pixel data (suited to DICOM2000 client-device processing and display capabilities) is encapsulated inside DICOM2000 message alongside the corresponding information and sent over the DICOM2000 communication channel. The encapsulated JPEG2000 pixel data are extracted, decompressed, and rendered on the client-side application display device.

If DICOM2000 server receives DICOM request, the entire JPEG2000 image is decompressed into native DICOM format and sent to DICOM client. The DICOM2000 server-side application has the ability to decompress and transcode JPEG2000 medical images into the native DICOM image format. Also, if DICOM client has the JPEG2000 display capabilities the entire JPEG2000 image is encapsulated inside DICOM message and transmitted. If the client request does not contain *JPIP Request String* attribute, DICOM2000 server treats it as DICOM request.

It is easy to integrate DICOM2000 based applications into preexisting DICOM based PACS, because of DICOM2000 syntax transparency. This is truly an advantage over PACS based on new network protocols for medical image streaming. Applications that do not support DICOM2000 syntax will simply ignore added attributes.

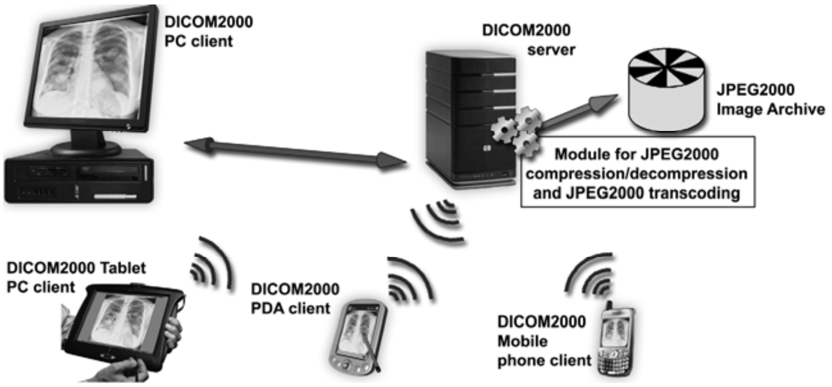

Fig. 12. DICOM2000 Single Server Architecture – all the functionalities are placed at DICOM2000 server-side application

DICOM2000 syntax achieves all the benefits of DICOM JPEG2000 transfer syntaxes and *JPIP Pixel Data Provider* service combined in one. The size of PACS medical image archive is smaller when JPEG2000 compression is used. Streaming of medical images is achieved through DICOM communication channel. Image archive contains only one copy of each image which is used to serve all client devices no matter of their capacities. Different sized images are extracted in a simple way from one JPEG2000 codestream with minimal spatial distortion (maximum quality). As opposed to the other proposed solutions for DICOM medical image streaming, the DICOM2000 supports medical image storing operation even for mobile devices. Therefore, it is possible to update and store medical images processed on mobile devices [8].

The DICOM2000 communication can be implemented in two ways. The first way is the DICOM2000 Single Server architecture, Fig.12. All the functionalities are placed at DICOM2000 server-side. Beside JPEG2000 compression, server-side application has to support JPEG2000 transcoding. This enables DICOM2000 server to transcode JPEG2000 images according to client-side request. When DICOM2000 client-side application requests JPEG2000 medical images, the *JPIP Request String* is parsed and the JPEG2000 medical image is transcoded according to client request.

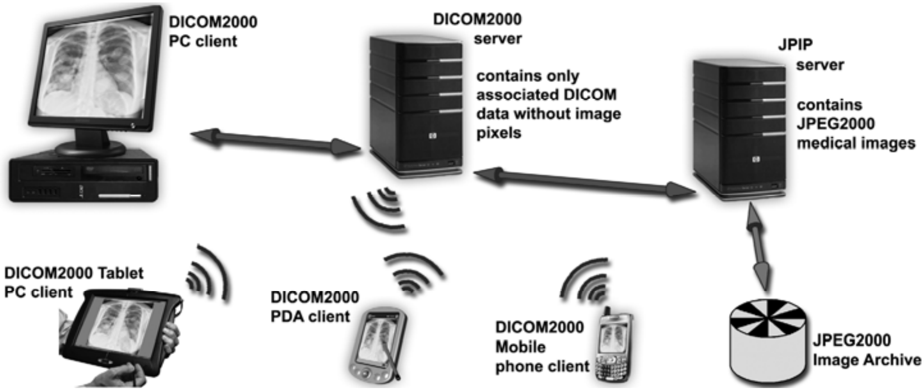

Fig. 13. DICOM2000 Two Server Architecture – the functionalities are divided between the DICOM2000 and JPIP server-side applications; JPEG2000 medical images are stored at JPIP server-side application which is in charge for JPEG2000 transcoding

The second way for implementation of the DICOM2000 Communication is DICOM2000 Two Server architecture, Fig. 13. All the functionalities are divided between the DICOM2000 and JPIP server-side applications. The JPEG2000 transcoding functionality is shifted to JPIP server-side. Also, the JPEG2000 medical images are stored at JPIP server-side. Only the information corresponding to the medical image is stored at the DICOM2000 server side. DICOM2000 server controls all the communication. Client-side application can approach medical images only through DICOM2000 server. Medical image storing operation commits through DICOM2000 server. Client-side applications upload new medical images on DICOM2000 server which stores them on JPIP server-side application. Uploaded native DICOM images are first compressed in JPEG2000 format.

When DICOM2000 client-side application requests JPEG2000 medical images, the *JPIP Request String* is extracted from the DICOM2000 message, integrated into JPIP request alongside the name of the targeted JPEG2000 medical image, and sent to the JPIP server-side application. In communication with JPIP server, the DICOM2000 server acts like JPIP client-side application. The JPIP server transcodes the requested JPEG2000 stream and only the JPEG2000 pixel data serving the DICOM2000 client request are streamed back to the DICOM2000 server-side application. The DICOM2000 server-side encapsulates the received JPEG2000 pixel data alongside with the corresponding information inside DICOM2000 message and sends them back to DICOM2000 client-side application.

The DICOM2000 Two Server architecture has been implemented and tested in controlled environment [14]. It achieved very good results [14]. The size of PACS image archive has decreased more than 10 times. Low resolution and low quality JPEG2000 images have been extracted from JPEG2000 codestreams and sent to mobile phones where they were successfully viewed in best possible quality for given resolution [8]. The received images are treated only as preview. Region of interest is afterwards selected and requested in higher resolution. The process continues until the region of the image is viewed at the same resolution as the original image. The viewer is able to navigate through the mage sliding region after region of the image in original resolution.

5. Conclusion

Modern day PACS have to include mobile devices to achieve ubiquities computing environment for medical work. Therefore, DICOM standard, as the standard for communicating medical images, should support image streaming. Up to date solutions for image streaming are based on JPEG2000 standard in general. This standard combines image compression with data streaming. Different sized images, with minimal spatial distortion, are being extracted in a simple way from one (lossless or lossy) JPEG2000 codestream at server side and served to different clients. To our knowledge, there are no solutions for PACS which implement JPEG2000 streaming over DICOM networks. We proposed and developed DICOM2000 syntax which implements precisely that, streaming of JPEG2000 medical images over DICOM. The DICOM2000 brings the compression and streaming power of JPEG2000 to DICOM

In the paper we presented PACS architectures which allow interchange of JPEG2000 medical images. Architectures of DICOM2000 based PACS are compared with PACS architectures based on standard DICOM syntax and solutions proposed in technical literature. DICOM2000 based PACS have notable advantages over other DICOM based PACS which implement JPEG2000 medical image interchange. Listed in short, these advantages are:

– Size of PACS image archive is more than ten times smaller.
– Image compression is combined with image streaming. This means that any client could be served with best quality image suited for its capabilities.
– Extracted medical images are with minimal spatial distortion. They are of far better quality than auto-scaled images of the same size.
– All client requests linked to one medical image are served from single image codestream.
– Network traffic is reduced since there is no unnecessary data. It enables fast medical image viewing even in low-band networks.
– The entire communication is achieved over DICOM communication protocol. DICOM server has the control over the pixel data transmission.

– DICOM2000 based PACS can be easily coupled with other PACS which support standard DICOM communication. DICOM2000 applications can be easily and transparently integrated into the existing DICOM based PACS.
– It does not exclude the other PACS architectures for JPEG2000 medical image interchange. For example, it is possible to combine *JPIP Pixel Data Provider* service with DICOM2000.
– Medical image storage operation is supported even for mobile devices.
– DICOM2000 based PACS can easily be integrated with old DICOM archives which contain images in the native DICOM image format. The background process can translate old DICOM medical images into the JPEG2000 format and store them into the new medical images archive.

There are two possible architectures of DICOM2000 based PACS. DICOM2000 Single Server architecture puts all the functionalities at DICOM2000 server-side application. DICOM2000 Two Server architecture divides all the functionalities between DICOM2000 and JPIP server-side applications. Although the DICOM2000 Two Server architecture seams more complicated and more time consuming, it offers some extra benefits – a possibility to integrate standard DICOM services for JPEG2000 medical image interchange with DICOM2000 syntax functionalities.

We have implemented the DICOM2000 Two Server architecture. The system achieved good results. Different sized medical images have been extracted from original JPEG2000 codestream and transmitted to DICOM2000 clients. The size and quality of the images have been suited to client devices processing and display capabilities.

The current implementation of DICOM2000 system is not complete, because it does not support the viewing of the image ROI. This would enable DICOM2000 client-side applications to request desired part of the medical image in original resolution. The entire medical image could be viewed region by region.

DICOM2000 based PACS shifts medical computing environment toward the ubiquitous computing.

6. Acknowledgments

The work presented in the paper was developed within the: project “E-roentgenology of Special hospital for lung disease,” No. 6233B [31] and IT Project “WEB portals for data analysis and consulting,” No. 13013, supported by the government of Republic of Serbia, 2006. – 2010.

7. References

1. Choong, M.K., Logeswaran, R., Bister, M.: Cost-effective handling of digital medical images in the telemedicine environment. International Journal of Medical Informatics, Vol. 76, No. 9, 646-654. (2007)

2. Huang, H. K.: Enterprise PACS and image distribution. Computerized Medical Imaging and Graphics, Vol. 27, No.2-3, 241-253. (2003)
3. Sneha, S. and Dulipovici, A.: Strategies for Working with Digital Medical Images. In Proceedings of the 39th Annual Hawaii international Conference on System Sciences, HICSS, Vol. 05, Kauai, HI, USA. IEEE Computer Society, Washington, DC, 100.1. (2006)
4. Skodras, A. N.: The JPEG2000 Image Compression Standard in Mobile Health. M-Health: Emerging Mobile Health Systems, SpringerLink, 313-327. (2006)
5. Bardram, J.E.: Hospitals of the future – ubiquitous computing support for medical work in hospitals. The 2nd international workshop on ubiquitous computing for pervasive healthcare applications - UbiHealth 2003, Seattle, Washington, USA. (2003)
6. Atkinson, C., Kaplan, B., Larson, K., Martins, H.M.G, Lundell, J., Harris, M.: Ubiquitous Computing for Health and Medicine. Designing Ubiquitous Information Environments: Socio-technical Issues and Challenges, eds. C. Sørenson, Y. Yoo, K. Lyytinen, and J.I. DeGross, London: Kluwer Academic Publishers, 355-358. (2005)
7. Dragan, D. and Ivetic, D.: An Approach to DICOM Extension for Medical Image Streaming. In Proceedings of the 19th DAAAM International Symposium, "Intelligent Manufacturing & Automation", Trnava, Slovakia. (2008)
8. Mirkovic, J., Ivetic, D., Dragan, D.: Presentation of Medical Images Extracted From DICOM Objects on Mobile Devices. In Proceedings of the 9th International Symposium of Interdisciplinary Regional Research "ISIRR 2007" Hungary – Serbia – Romania, Novi Sad, Serbia. (2007)
9. Dragan, D. and Ivetic, D.: An Implementation of DICOM/JPEG2000 Client/Server Architecture. In Proceedings of the 9th International Symposium of Interdisciplinary Regional Research "ISIRR 2007" Hungary – Serbia – Romania, Novi Sad, Serbia. (2007)
10. Eyadat, M. and Muhi, I.: Compression Standards Roles in Image Processing: Case Study. The Proceedings of the International Conference on Information Technology: Coding and Computing – ITCC'05, 135-140. (2005)
11. Information technology – JPEG2000 image coding system: Core coding system. ISO/IEC 15444-1, 2000 | ITU-T Recommendation T.800. (2002)
12. Taubman, D. and Marcellin, M.: JPEG2000: Image compression fundamentals, standards and practice. Kluwer Academic Publishers, Boston, USA. (2001)
13. Tinku, A., and Ping-Sing, T.: JPEG2000 Standard for Image Compression – Concepts, Algorithms and VLSI Architecture. Wiley-Interscience publication. (2005)
14. Dragan D.: Encapsulation of JPEG2000 Compression by DICOM standard message [master thesis]. University of Novi Sad, Faculty of Technical Science, Department for Computing and Control, Novi Sad, Serbia. (2008)
15. Przelaskowski, A.: Compression of mammograms for medical practice. In Proceedings of the 2004 ACM Symposium on Applied Computing – SAC '04, 249-253. (2004)
16. Clunie D.A.: Lossless Compression of Grayscale Medical Images - Effectiveness of Traditional and State of the Art Approaches. Proceedings of SPIE, 74-84. (2000)
17. American College of Radiology, National Electrical Manufacturers Association: Digital imaging and communication in medicine (DICOM): version 3. Draft Standard, ACR-NEMA Committee, Working Group VI, Washington DC. (1993)
18. Dragan, D., and Ivetić, D.: DICOM overview. The VII International Symposium "Young People and Multidisciplinary Research", Resita, Romania. (2005)

19. Dragan, D., Ivetić, D., and Popović, M.: DICOM Communication and Mapping on TCP/IP Protocol. In Proceedings of the Symposium INFOTEH-JAHORINA 2006 [CD-ROM], Vol. 5, Ref. E-II-15, 384-388, Jahorina, Bosnia and Hercegovina. (2006)
20. Bidgood, W. D. Jr., Horii, S. C., Prior, F. W., and Van Syckle, D. E.: Understanding and using DICOM, the data interchange standard for biomedical imaging. Journal of American Medical Information Association Vol. 4, No. 3, 199-212. (1997)
21. Oosterwijk, H.: DICOM Basics. OTech Inc/Cap Gemini Ernst and Young. (2002)
22. Seok-Hwan, J. and Whoi-Yul, K.: Defining a New Annotation Object for DICOM Image: a Practical Approach. Computerized Medical Imaging and Graphics, Vol. 28, No. 2-3, 371-375. (2003)
23. American College of Radiology, National Electrical Manufacturers Association: Digital imaging and communication in medicine (DICOM): revision PS 3.1-2006 ~ PS 3.15-2006. Draft Standard, ACR-NEMA Committee, Rosslyn, VA. (2006)
24. Tian, Y., and Zhang, J.G.: JPIP-based Wireless Transmission and Display of High Resolution DICOM Medical Images. Chinese Journal of Medical Instrumentation (Zhongguo Yi Liao Qi Xie Za Zhi), Vol. 30, No. 4, 299-301. (2006)
25. Tian, Y., Cai, W., Sun, J., and Zhang, J.: Accessing medical image databases on the go. SPIE Newsroom, Electronic Imaging & Signal Processing [Online]. Available at: http://spie.org/x19505.xml. (cited 2008 Feb)
26. Information technology – JPEG2000 image coding system: Interactivity tools, APIs and protocols. ISO/IEC 15444-9, 2005 | ITU-T Recommendation T.808. (2005)
27. Taubman, D., and Prandolini, R.: Architecture, Philosophy and Performance of JPIP: Internet Protocol Standard for JPEG2000. In Proceedings of the International Symposium on Visual Communications and Image Processing (VCIP2003), Lugano, Italy. SPIE Vol. 5150, No. 3, 791-805. (2003)
28. Moshfeghi, M. and Ta, J.: Efficient Image Browsing with JPEG2000 Internet Protocol. Medical Imaging 2004: PACS and Imaging Informatics, Proceedings of SPIE, Vol. 5371, 31-42. (2004)
29. Blanquer, I., Hernández, V., and Mas, F.: A Peer-to-Peer Environment to Share Medical Images and Diagnoses Providing Context-Based Searching. In Proceedings of the 13th Euromicro Conference on Parallel, Distributed and Network-Based Processing (Euromicro-PDP'05), Lugano, Switzerland. IEEE Computer Society, Washington, DC, 42-48. (2005)
30. Ramakrishnan, B., and Sriraam, N.: Internet Transmission of DICOM Images with Effective Low Bandwidth Utilization. Digital Signal Processing, Vol. 16, No. 6, 825-831. (2006)
31. Ivetić, D., Berković I., and Dragan, D.: Technological Aspects of E-Rentgenology Systems. In proceedings of the Symposium INFOTEH-JAHORINA 2006 [CD-ROM], Jahorina, Bosnia and Hercegovina. Vol. 5, Ref. E-II-10, 373-375. (2006)

Dragan Dinu was born in Zrenjanin and received the Dipl. Ing. degree in technical engineering in 2003, and M.Sc. in technical science in 2008, from the Faculty of Technical Science, University of Novi Sad. He works as research and teaching assistant at Department for Computing and Automatics, Faculty of Technical Sciences, University of Novi Sad. His research interests include still image compression, medical imaging and communication, HCI, and multimedia. Mr. Dragan is currently a student member of IEEE and member of DAAAM International.

Ivetić Dragan was born in Subotica and received the Dipl. Ing. degree in technical engineering in 1990, and the M.Sc. and Sc.D. degrees in technical science, in 1994 and 1999 respectively, from the Faculty of Technical Science, University of Novi Sad. Since 2000 he has been Professor of Computer Science at the Department for Computing and Automatics, Faculty of Technical Sciences, University of Novi Sad. His research interests include HCI, multimedia, and software engineering. Profesor Ivetic received DAAD scholarship in 1997 and ACM scholarship in 1998.

Received: October 15, 2008; Accepted: February 06, 2009.