# Is there still a place for peer-to-peer in the DICOM world?

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*Abstract* - **Digital radiology imaging systems, based on DICOM standard, are generating more and more images annually. Access to the images is possible through DIMSE network language or DICOM web methods. Peer-to-peer networks, on the other hand, have gained some interest in the DICOM community, but most have been surpassed by cloud computing methods. WebRTC seems like a potential technology for helping DICOM standard to gain P2P connectivity, which could help both business and scientific community easier access to the images repositories. In this paper, we examine all present technologies.**

***Keywords*** **- DICOM; peer-to-peer; web; WebRTC**

## I. INTRODUCTION

Digital radiology departments are those who have digital methods of storing, transmitting and displaying radiological images. Digitization is primarily related to the introduction of digital image radiological devices and information systems for storing, transmitting and displaying radiological images, such as RIS/PACS (Radiological Information System / Picture Archiving and Communication System). Digitalization is standardized by DICOM (Digital Imaging and Communication in Medicine). DICOM defines storage, transfer, and display of DICOM objects. Digitization brings numerous benefits to patients such as radiation dose reduction, due to unnecessary repetition of recording (in some cases), the ability for other specialists to inspect images and share them across the network. It can improve education and interpretation. By eliminating harmful chemicals (dark room processing) digitalization is also environment-friendly.

### A. DICOM files

The DICOM file is a set of DICOM data. DICOM data can be a text or binary sequence of bytes, which describes some clinical data (e.g. patient name, device type, image pixels, PDF report). The DICOM file can start with several metadata, followed by a sequence of bits of different DICOM data, and ends with the image data (pixels), audio waveform (WAV) or document data (PDF).

The digitized radiological image is a two-dimensional array of positive integer values $f(x, y)$ where $1<x<M$ and $1<y<N$, in which $M$ and $N$ are positive integers representing the number of columns and rows. Pixel or gray tones (gray level) are most often used in four categories: 0 to 255 (8 bits), 0 to 1023 (10 bits), 0 to 4095 (12 bits), or 0 to 65535 (16 bits), depending on the digitization process. Gray tones represent the physical or chemical properties of anatomical structures in the object. For example, in images obtained by digitizing an x-ray film or a phosphor plate, pixel values represent the optical density of small square film surfaces or phosphorous plate values. Using a CT (Computed Tomography) device, the pixel value represents the relative linear absorbance of the tissue coefficient, on the MR (Magnetic Resonance) device, the pixel value corresponds to the magnetic resonance imaging of the tissue, and ultrasound signal ultrasound passes through the tissue and is recorded as an image ultrasonic device.

### B. DICOM Message Service Elements

One of the most significant advantages of digitization is access to image archives through a DICOM network protocol based on TCP/IP protocol. For the purpose of communication, the DICOM standard uses its network language, which consists of DIMSE (DICOM Message Service Elements) elements. More DIMSE elements make one DICOM network service, Table 1. The main purpose of DICOM communication is that two DICOM communicating devices are exchanging data in a precisely defined format and order [1]. The DICOM data exchange model is based on service delivery. A DICOM device requiring service from another device is designated as a Service Class User (SCU), and the service provider is designated as a Service Class Provider (SCP). All DICOM services are performed at DICOM level of service class. Server classes connect DICOM data with data transfer and processing functions. DICOM devices send each other messages by requesting or providing the appropriate information.

TABLE I
DIMSE NETWORK SERVICES

| Service | Description |
|---|---|
| C-ECHO | Connection check |
| C-STORE | Store DICOM object |
| C-FIND | Search for DICOM objects |
| C-GET | Retrieve DICOM object where receiver initiates connection |
| C-MOVE | Retrieve DICOM object where sender initiates connection |

### C. *DICOM associations*

DICOM associations define protocol and rules of the lower level for DICOM network connections. DIMSE services of higher level are based on DICOM associations. The main purpose of DICOM associations is to enable DICOM devices compatibility and data transfer in well-defined format and order. The basis of any DICOM association is PC (Presentation Context) concept. PC is defined by two parts: DICOM Abstract Syntax (information about DICOM device) and DICOM Transfer Syntax (information about data format) [1].

### D. *Protocol Data Unit*

PDU (Protocol Data Unit) is core and the lowest level of DICOM communication. PDU packet contains control information and user data. PDU is formed by mandatory data followed by variable fields which contain one or more objects and sub-objects. There are seven PDU types [1], Table 2. P-Data-TF is different from all PDU types; it is the only one PDU responsible for transferring real DICOM data.

TABLE 2.
PDU DATA TYPES

| Type | Description |
|---|---|
| A-Associate-RQ PDU | Request for association |
| A-Associate-AC PDU | Accept association (response to A-Associate-RQ PDU) |
| A-Associate-RJ PDU | Reject association (response to A-Associate-RQ PDU) |
| P-Data-TF PDU | User DICOM data; DICOM command, pixels or audio elements |
| A-Release-RQ PDU | Request to release association |
| A-Release-RP PDU | Response to A-Release-RQ PDU |
| A-Abort PDU | Abort any association |

P-Data-TF contains DICOM objects, divided into PDV (Protocol Data Value) fragments. The software detects PDVs in P-DATA-TF PDU and process fragment by fragment. Received PDVs can define DICOM command or DICOM file. When last PDV fragment is received, the software saves DICOM file or executes DICOM command, such as C-Move (e.g. "send all patient XYZ images to another DICOM device").

### E. *DICOM Web*

DICOM also describes web access to DICOM devices, called WADO (Web Access to DICOM Objects). WADO allows access to DICOM objects on a DICOM server via HTTP/S (Hypertext Transfer Protocol / Secure) protocol. The data may contain a presentation format (JPEG, BMP or GIF) or a native DICOM format. WADO RESTful Services (WADO-RS) is an addition to the DICOM standard that defines Representational State Transfer (REST) services for accessing DICOM devices [2]. QIDO-RS (Query based on ID for DICOM Objects by RESTful Services) defines the web-method for searching DICOM objects through defined search parameters. STOW-RS (Store over the Web RESTful Service) enables the storage of DICOM objects through POST method to the DICOM server. The UPS-RS Worklist Service defines the RESTful interface for the UPS SOP class, which allows you to search, retrieve, or modify worksheets. DICOM RS Capabilities Service defines the detection of supported DICOM web services on a particular DICOM web-node.

## II. PEER-TO-PEER NETWORKS

P2P (Peer-to-Peer) networks are "decentralized distributed systems that enable computers to share and integrate their computing resources, data, and services" [3]. Another definition adds that such systems "are able to self-organize into network topologies with the purpose of sharing resources capable of adapting to failures and accommodating transient populations of nodes while maintaining acceptable connectivity and performance, without requiring the intermediation or support of a global centralized server or authority" [4]. P2P applications include VoIP, file-sharing, messaging, media streaming, searching etc. Such are BitTorrent, Gnutella, Freenet, Blockchain and Skype with millions of users. P2P file-sharing networks degree of network centralization can be divided into 3 types: centralized, decentralized, and hybrid P2P networks [3].

Centralized P2P Networks use a central server to keep meta-information about shared content, such as Napster. Decentralized P2P Networks address some problems of centralized P2P networks like scalability and central point of failure, where nodes take over routing and searching functionalities. Hybrid P2P Networks provide trade-off solutions with a hierarchical architecture where some nodes act as a super-nodes or servers [3]. One interesting example is JXTA (not maintained anymore), open source P2P platform developed by Sun Micro-Systems, where so-called "rendezvous" peers provide query services by using the local cache.

P2P networks can be divided according to the resource discovery [3]. Structured P2P systems have a dedicated network structure which relates stored content and the IP address of a node. In the structured P2P systems Distributed Hash Tables (DHTs) are usually used for resource discovery. In DHT-based P2P systems, each file is associated with a key generated by hashing the file name or content - key-value pair. Each node in these systems stores a certain range of keys and each peer node only needs a small amount of "routing" information about other nodes [3].

Unstructured P2P Systems do not maintain network structure, where address and content stored on a given peer node are unrelated, where nodes randomly connect to each other. In order to search for the content, queries must be flooded through the network and can cause a high amount of traffic [3]. Most popular content will be easier to find, while rare content will be hard to find.

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## III. DICOM AND P2P RELATED WORK

We will give a short overview of P2P efforts in building DICOM systems. Unfortunately, this area is not well researched and by the introduction of cloud and grid computing, P2P systems in DICOM/PACS domain have been neglect. During last 20 years, some authors have proposed medical data sharing and searching in P2P networks, mostly based on proprietary developed applications or grid architectures [5]. For example, Blanquer et al. [6] present a P2P platform for sharing digital medical information within a radiological virtual community, providing radiologists with new data searching possibilities for a huge distributed dataset of images and diagnoses. Maglogiannis et al. [7-8], presents user-friendly, medical collaboration platform, which uses RTP (Real Time Protocol) protocol for audio and video communication.

Important P2P project in medical image domain was Dicoogle project [5], a networking P2P platform that allows the medical and academic community to access, share and discover clinical medical image. The system uses JGROUPs [9] library that enabled the development of the Dicoogle P2P layer, including query, retrieve and data transfer. Dicoogle provides also a network discovery mechanism in order to find all the available resources in the entire group.

Dicoogle discussed "connectivity potential of P2P networks to support DICOM standard" and possibilities to "turn large volumes of clinical information and analytical tools, currently hidden in clinical units, into shared repositories for education and research" [5]. Authors conclude that "P2P architectures appear as natural off-the-shelf solutions to the increasing dynamics of DICOM nodes" [5].

## IV. WEB AND P2P

Internet was originally imagined as a distributed network of independent nodes, where each node can directly communicate with another node [10]. Nowadays, the Internet is mainly a global client-server network where nodes communicate over the servers (not directly).

One of the main services of the Internet is WWW (World Wide Web or just "web") - a global hyperlinked information space identified by URLs (Uniform Resource Locator), based on client-server architecture and consumed by a tool called web browser. The web is the most popular Internet service. Protocol of web is HTTP (Hypertext Transfer Protocol). HTTP transfers documents based on URL address from the server. Therefore, web browsers became the most used applications in the world. The web is also consumed by other application that utilizes HTTP protocol - so-called web clients.

One of the most important aspects of Internet and access to the web is that Internet user needs to have installed a web browser. It brings us to the situation where every Internet user in the world has the same application, that is, let's presume, maintained and updated regularly. What if web browser can act as a P2P application that can act as a "decentralized distributed systems and enable computers to share and integrate their computing resources, data, and services" [3]? It seems it can!

### A. *WebRTC*

The WebRTC (Web Real-Time Communications) is a set of technologies that enable devices on the Internet to communicate in a real-time manner through a simple API [11]. WebRTC is standardized by W3C and IETF. It is coming from VoIP and video-conferencing background, partly developed by GIPS company, which was bought by Google and the WebRTC code was open sourced [12].

The most common users of WebRTC technology are web browsers and mobile applications in smartphone devices. WebRTC in practice allows the P2P exchange of the data between clients, without the need for a web server as a data broker. It is most commonly used for streaming video and audio communications and P2P data exchange (files, chat rooms, etc.). However, WebRTC technologies cannot work in practice without servers that allow users to discover services. We will give a short overview of the WebRTC technology stack, figure 1.

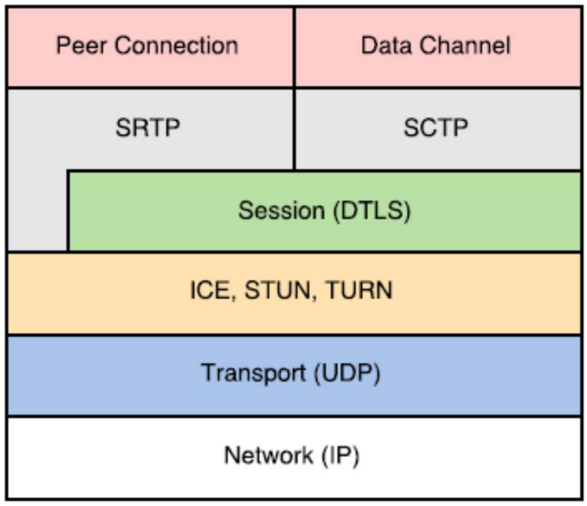


Figure 1. WebRTC technology stack [13]

For transport layer, WebRTC uses UDP (User Datagram Protocol). UDP can pass through the most NAT (Network Address Translator) by using a technique called UDP Hole Punching [13]. UDP is also a good choice for the real-time audio and video communication. To traverse NATs WebRTC uses ICE (Interactive Connectivity Establishment) protocol which uses STUN (The Session Traversal Utilities for NAT) and TURN (Traversal Using Relays around NAT) protocol. STUN helps peer to discover its public IP address when located behind NAT. Therefore, it requires a publicly available server. When it is not possible to establish direct P2P communication, data are relayed through TURN servers.

WebRTC uses RTP (Real-time Transport Protocol) and it secure profile SRTP (Secure RTP) network protocol for delivering audio and video over the network.

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In order to make UDP secure, WebRTC uses The Datagram Transport Layer Security (DTLS) protocol, which is a derivation of the TLS protocol which provides the same security services for unreliable protocols [13].

The Stream Control Transmission Protocol (SCTP) is application protocol that provides reliable, message-oriented, flow and congestion control, multi-homing, and other features to improve connection reliability and stability. It is used for classical phone calls over the Internet and for data transfer in WebRTC by Data Channel API. DTLS is used to encrypt SCTP packets [13].

WebRTC API is not only bound to the JavaScript and the web browsers. It is available as a native APIs [14] for C++, Java, Android and IOS applications. It is also available by 3rd party libraries on Node.js platform [15]. WebRTC reach is more than having 2 web browsers exchange date, and by broadening the reach, WebRTC can give much more than video conferencing and simple file-sharing.

### B. *WebRTC development*

WebRTC is envisioned to simplify application development. WebRTC API is simple and abstracts a huge and complex set of different protocols and technologies. There are three main API components: *getUserMedia* – responsible for accessing audio and video devices such as camera and microphone; *RTCPeerConnection* – which enables audio and video communication between peers, by performing signal processing, codec handling, P2P communication, security and bandwidth control; *RTCDataChannel* allows bidirectional communication of arbitrary data between peers via simple WebSocket like API and low latency.

In the time of writing this article, WebRTC is supported by main web browsers (Chrome, Firefox, and Safari) on both desktop and mobile devices (Android and IOS).

### C. *WebRTC examples*

Applications such as Facebook Messenger, Amazon Chime, Google Meet uses WebRTC extensively for the audio-video meeting, chats, and conferences. They measure usage in billions of minutes [16] or in 400 million users monthly [17]. Another interesting product is Peer5: "a peer-to-peer Content Delivery Network (P2P CDN) for massively-scaled, high-quality streaming" [18]. WebTorrent [19] is a streaming torrent client for Node.js and the browser. In the browser, WebTorrent uses WebRTC (data channels) for P2P transport. WebRTC is also used in healthcare domain by providing video and audio collaboration between physicians, patients, and vendors.

## V. Discussion

By standardizing WebRTC, P2P concepts have become part of the largest client-server architecture in the world - the web. Web browser - the ubiquitous applications - have become P2P nodes, capable of making direct connections with other peers, both on the desktop and mobile devices. Mobile devices have surpassed desktop clients in accessing the Internet, which means that next generation of P2P networks will have to deal with mobile devices too. WebRTC comes as a potential problem solver for all platforms.

The problems of today's DICOM archives is unavailability for secondary use - research and analysis [20]. Image archives are "silos" filled with various clinical information about patients, their clinical history, and their findings. Especially today, there is a need to find a better way to collect, label and reuse medical images [21] due to advanced computer learning and the building of intelligent systems based on computer intelligence.

We see potential in P2P technologies and DICOM protocol to communicate together. Can WebRTC help in "increasing dynamics of DICOM nodes" [4]? DICOM image volumes and production are growing every year, some researchers estimate 800 billion images are generated every year [22].

## VI. Conclusion

We gave the overview of the medical imaging standard DICOM and a short overview of P2P networks. By introducing and standardizing WebRTC in the world of the web, P2P communication has become easier to organize, maintain and develop. We also see potential in medical imaging domain, where WebRTC can help to build modern P2P DICOM networks.

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