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Online Availability Check of Teleradiology Components

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For a region-wide teleradiology network in Germany a vendor-independent Uptime-server concept was defined. The Uptime-server was realized for the availability check and prospective error-detection of the emergency teleradiology servers and clients based on encrypted digital imaging and communication in medicine (DICOM)-e-mail transfers. The concept and the experiences of 2 years of use with more than 30 clients and servers in 15 hospitals and in nine other regional partners are shown. The Uptime-server does provide automated availability checks for all servers and clients, automated checks of the download speed of the Internet lines, and a graphical user interface for the clinical user and the system administrator. A clinical user can display the availability information from all clients and servers in the network (see http://www.teleradiologie-rnd.de). In case of malfunctions during an emergency transfer, immediate reactions are possible, often without the need for help of a hotline or a system administrator. The chosen Uptime-server concept proofed to be reliable; it worked with products from nine different manufacturers without problems. Its statistical output can be used to fulfill the legal requirements of regular availability checks for teleradiology lines.

KEY WORDS: Teleradiology, DICOM, e-mail, availability

BACKGROUND

The availability of information and communication technology equipment is particularly important for components used in medicine. Failure of a component during a medical procedure can be fatal for a patient. Therefore, a reliable system design, suitable maintenance contracts, and quality assurance procedures are essential. In many installations, standard information and communication technology components are used additionally and in conjunction with the medical products. These components often represent single points of failure for communication-based procedures. Because of the high costs for 24-h maintenance contracts, many information technology components in smaller hospitals and private practices are not controlled during the night and on weekends.

Teleradiology applications are in use worldwide for exchanging medical images and—in many cases—additional clinical data. Teleradiology plays an important role in smaller hospitals and in rural areas where not enough radiologists are available to ensure 24-h on-call service, eg, for computed tomography. Diagnostic centers, for example, in the University Hospitals, can provide emergency teleradiology services for these participating institutions.

Some of the teleradiology installations at smaller hospitals are only set up for emergency teleradiology during the night and on weekends. The frequency of use of these installations is quite low. Therefore, the components are not in daily

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use and malfunctions may not be detected until an emergency transmission fails.

For a region-wide teleradiology project[1] with a large number of participating centers in Germany, a cost-effective method was needed for an availability check of all installed teleradiology clients and servers. Because of the varying security policies in the participating hospitals and the multivendor structure of the teleradiology clients (DICOM-e-mail network) standard maintenance tools could not be used.

This article describes a method for a vendor-independent online availability check of teleradiology servers and clients based on OpenSource components. It demonstrates the concept and the results of 2 years of use with more than 30 components from eight different manufacturers in 15 hospitals and in nine other regional participants. The software is in the public domain[2].

MATERIALS AND METHODS

DICOM E-mail

The teleradiology protocol was described in detail in a recent publication[3]. It is based on the DICOM standard and conforms to German teleradiology standards (see Fig. 1). Furthermore, it operates by standard e-mail exchange with additional encryption according to the OpenPGP standard[4,5]. DICOM images are attached according to the DICOM Supplement 54[6]; other attachments (text and graphic formats such as pdf, jpg, rtf) are allowed as long as they represent a valid MIME type. Additionally, the built-in zip compression option of the OpenPGP standard is used. E-mails are exchanged using the secure variants of the standard e-mail server protocols S/POP3, S/IMAP4, and S/SMTP via the Internet.

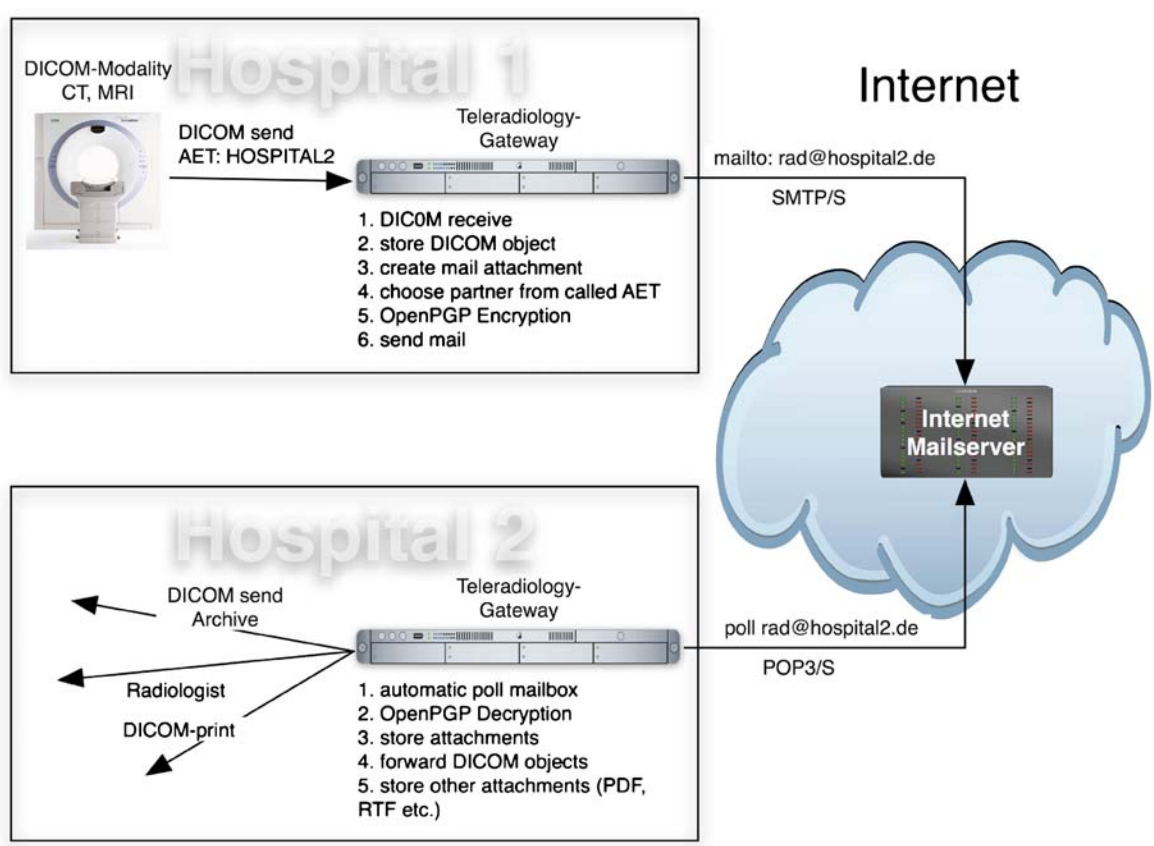

Fig 1. Encrypted DICOM e-mail protocol. An example for the automated sending of an image series from an imaging modality to a participating hospital is shown. The automated DICOM to e-mail and vice versa conversion is carried out by teleradiology work stations or gateways inside the hospital networks. The networks are protected against Internet attacks by firewalls (not shown).

Network

The DICOM e-mail network in the Rhein-Neckar Area of Germany comprises over 20 hospitals, including four "Level one" trauma centers and 17 district and city hospitals[2]. It also includes more than 40 other private radiology practices, offices for quality assurance, and installations for radiologists working at home in three German states. The network is used for a variety of teleradiology applications such as emergency teleradiology services (e.g., neurosurgery and neurology consultation), image and report distribution, scientific cooperations, and on-call services at home). Only the installations designed for emergency teleradiology were included in the availability check.

Installed Teleradiology Components

A total of 35 servers and clients are used for emergency teleradiology services in 24 institutions (five mailservers and 30 teleradiology clients). These installations employ different Internet connections, ranging from ADSL lines in small hospitals and private radiology practices to broadband connections of up to 1 GBit at the trauma centers.

Uptime Server: Set-up

The Uptime server is located in a high-availability area of a major Internet service provider. Each registered teleradiology client or server has a mailbox, which can be polled via POP3 or IMAP 4 protocol. In addition, it provides a webserver, which can display detailed information for the end-user and administrator[7]. The Uptime server software is based on scripts running on SUSE Linux 8.2 and using the Qpopper mailserver version 4.0.5, MySQL Ver 11.18 Distrib 3.23.55, Webmin 1.190, and Tomcat 4.0 for the user interface. The software was developed for the teleradiology project Rhein-Neckar-Dreieck. It is available in the public domain[2].

RESULTS

The following requirements for the Uptime-server concept were defined by the project group (central project leader and 12 local project leaders):

- Automated procedure without manual interaction
- Use of standard DICOM e-mail clients
- No other software should need to be installed on the client computers, if possible
- Network communication via standard e-mail protocols (S/POP3, S/IMAP4, and S/SMTP)
- Display of the current connectivity status of all regional clients and servers accessible by all users
- Calculation of availability scores of all clients and servers for any time period, accessible by the system administrators
- Automated check of line quality
- Messaging system for system administrators with malfunction alerts

The DICOM e-mail protocol uses automated mailbox checks for receiving images. With this functionality automated availability checks can easily be extended simply by defining an additional mailbox on an Uptime-Server to be checked for surveillance of the polling part of the teleradiology system. As the automated and timed sending of images is not possible without additional special software this function is not established in any of the available work stations.

To establish whether checking the receiving direction only is sufficient for clinical use of the Uptime-server concept, the sending and receiving processes had to be analyzed.

Analysis of the Teleradiology Components Used for Encrypted DICOM E-mail

The software and hardware components in the hospital and at the site of the Internet service provider (ISP) needed for sending and receiving patient data from one center to another are listed in the following:

- Teleradiology client/gateway (teleradiology software with both sending and receiving options, work station hardware) hospital
- Internal network components (Switches, cables) hospital
- Firewall hospital
- Components for Internet connection (DSL modem, router, line) hospital
- Internet connection
- Components for Internet connection (DSL modem, router, line) ISP
- Internal network components ISP
- Mailserver software and hardware ISP

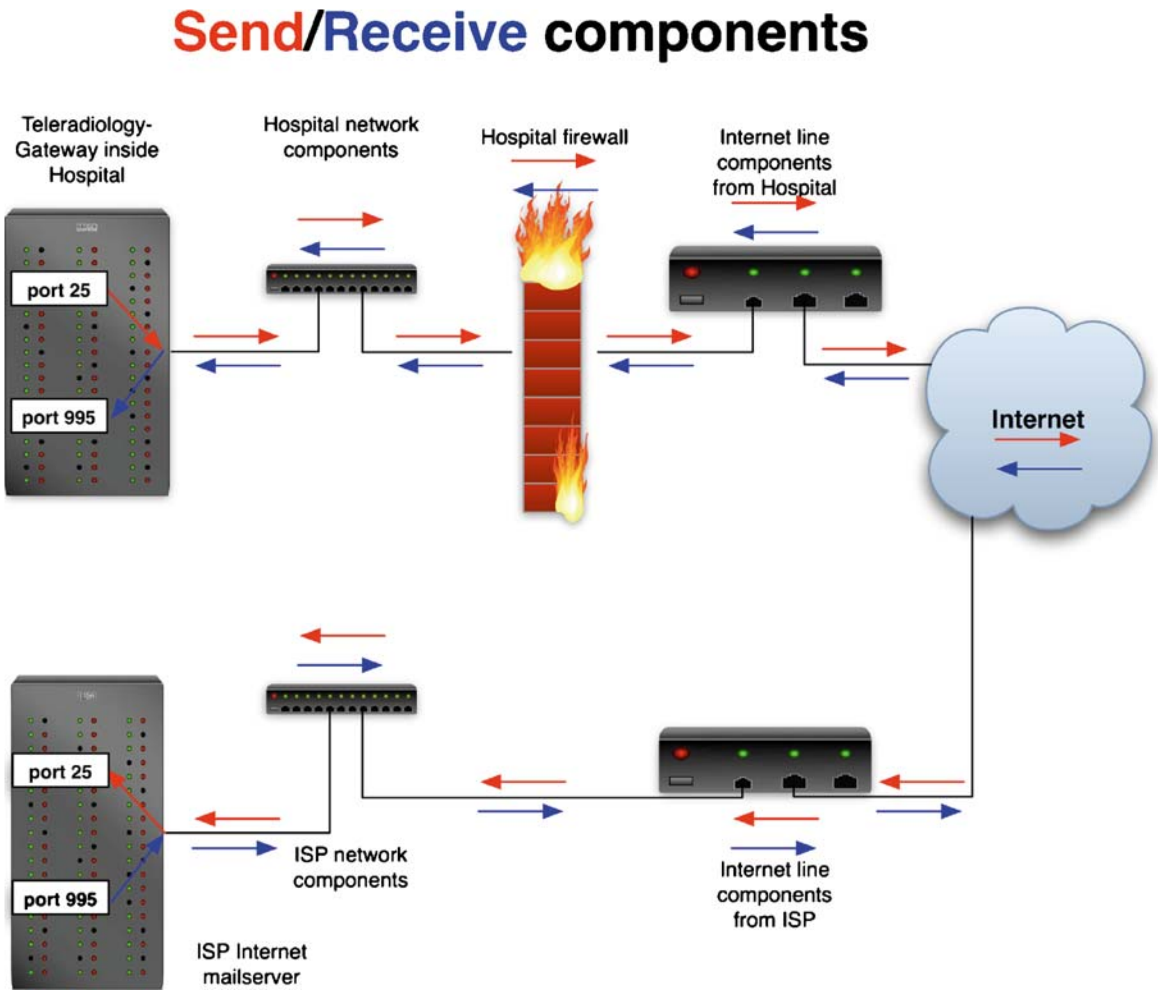

Fig 2. Software and hardware structure needed within the hospital and the Internet service provider (ISP) for sending and receiving DICOM e-mails, which is monitored.

Figure 2 shows that the hardware components needed to send and receive images are identical. The software components inside the teleradiology client and the mailserver are different for the two directions. Therefore, an availability check that only addresses the receiving direction includes all hardware components and the majority of the software components within the transfer process. Nevertheless, the characteristics of the components can be different for the sending and receiving direction. The line to the ISP can be asymmetrical, e.g., with ADSL connections, or concurrent users can share the same ISP, which affects only one direction of the line speed (e.g., other users with download rates without tampering with the upload rates).

Definition of the Connectivity Status

A standard DICOM e-mail teleradiology client in our network checks its mailboxes (at least three different mailservers) periodically. The time between two checks is set to values of between 1 and 5 min by the system administrator, depending on the quality of the Internet connection and the clinical applications.

For prospective error detection it was defined that, in addition to its regular mailboxes, each client also checks its Uptime-server mailbox. This additional mailbox check can be carried out by all 11 available software clients according to the encrypted DICOM e-mail standard[8]. On the Uptime-server a specific time period is configured for each client mailbox during the initial set-up. The Uptime-server registers each mailbox check and creates a database entry, including a time stamp. The current status of the client is set according to the time difference to the last mailbox check (example with a specific time period of 5 min):

- Status online (green): the time difference was less than 10 min
- Status warning (yellow): the time difference was between 10 and 15 min
- Status offline (red): the time difference was more than 15 min

Automated Check of the Line Quality

To measure the line quality, a test image is added regularly to the Uptime-server mailboxes. This is done daily for regular client mailboxes and hourly for client mailboxes with suspected line problems. The standard SMPTE test pattern with 512*512 resolution (516 kB in size) is used as a test image and encrypted mails using the corresponding public keys for the clients are generated. The POP3 server reports the size of the e-mail and the time needed for the mailbox check. This information, together with a time stamp, is registered in the Uptime-server database. Therefore, the line speed for each mailbox check and client can be calculated and displayed to the administrator in the graphic user interface.

Graphic User Interface

Every user can view the current connectivity status, which is displayed in a map (Fig. 3).

The mouse over message for each component shows the corresponding hospital name and department. A mouse click on each component shows the last 10 checks (Fig. 4).

Administrator Support, Statistics

If any of the teleradiology components is set to the status "offline", a message is sent via e-mail to the corresponding system administrator. A maximum of five subsequent mails for a longer period of the "offline" status is generated; a single status "online" resets this counter.

The button "Statistics" in the webpage (see Fig. 2) takes you to a secure login procedure. After logging in, the corresponding teleradiology components are presented in a drop-down list. For each component, the availability can be calculated for a specified time period. The availability is calculated from the number of green, yellow, and red statuses:

$$Availability = \frac{green + yellow}{green + yellow + red} * 100 \quad [\%]$$

The database entries can be exported for further statistical analysis or graphic display.

Statistical Results of Availability

The Uptime-server proved to be 100% stable in 2005, as measured within the high-availability Internet service provider center. Analysis of the registered database entries showed a lower availability of the Uptime-server area as a whole of 99%. This was a result of two events during 2005 from a malfunctioning and ultimately nonfunctional central Ethernet switch. This resulted in a registration failure of the Uptime-server messages as well as a failure in the automated sending of the error messages. This one point of failure within the architecture of the provider center was corrected.

The Uptime-server was able to perform the availability tests without further problems during the 24 months of routine service (January 2004 to December 2005). The project started with three clients in 2004 and increased to more than 35 in 2005. More than 2 million database entries were generated.

The availability for the different clients ranged from 48% to 100% in 2005. The poor results for three clients resulted mainly from the unnecessary user-driven shutdowns of the components inside the smaller hospitals.

An example of a detailed availability survey for a central teleradiology component inside a university hospital is shown in Figure 5. The 16 registered events (downtime ranging from 15 to 65 h, mean 8.3 h, median 1.0 h) resulted in an overall availability of only 98.6% in 2005. A detailed analysis of the events revealed that the actual availability was higher than reported. The event in March 2005 was recorded with a downtime of 65 h. This was a result of a hardware crash of the RAID component in the central gateway. The gateway

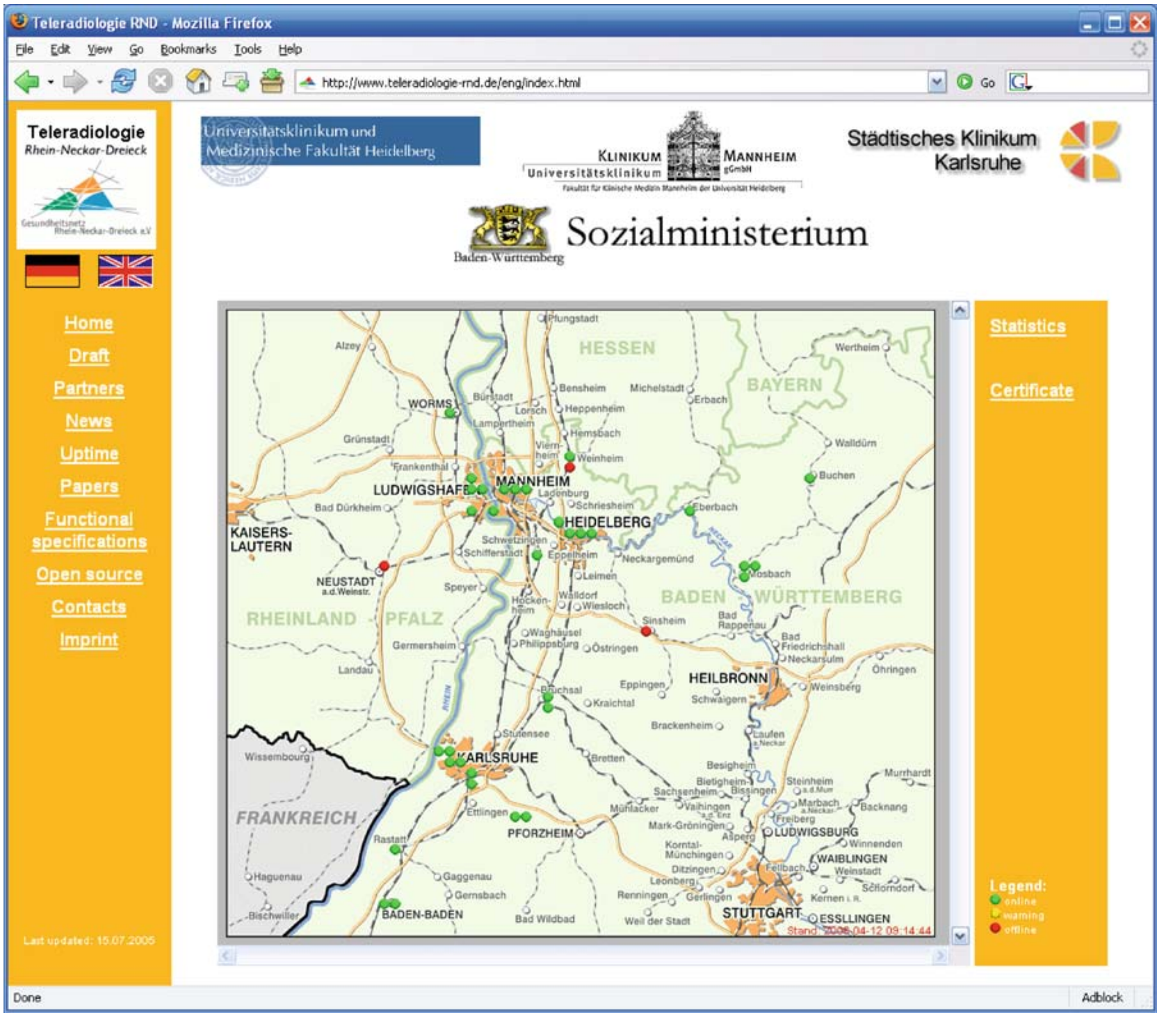

Fig 3. Uptime-server connectivity status of the teleradiology network in the Rhein-Neckar-triangle, Germany. Each teleradiology client is drawn as a dot, representing the current status for that component.

was replaced by an intermediate server within 6 h and was working again within 8 h. Unfortunately, the corresponding Uptime-server mailbox was not configured within this intermediate server; therefore, the Uptime-server showed an offline status until the original gateway was repaired and running, which took 65 h. Taking this correction into account, the availability of the central gateway was 99.2% in 2005.

Results of Line Speed

Initially measuring the download speed revealed a limitation of the software being used: the time stamps are limited to the hh:mm:ss format, and subsecond resolution was not possible with any of the software components tested. In addition, the time to register at the mailserver proved to be between 3 and 4 s even with empty

Zugriff	User	IP	DNS
2006-01-23 11:19:55	hd_ukl_wb1	129.206.90.254	129.206.90.254
2006-01-23 11:14:55	hd_ukl_wb1	129.206.90.254	129.206.90.254
2006-01-23 11:09:54	hd_ukl_wb1	129.206.90.254	129.206.90.254
2006-01-23 11:04:54	hd_ukl_wb1	129.206.90.254	129.206.90.254
2006-01-23 10:59:55	hd_ukl_wb1	129.206.90.254	129.206.90.254
2006-01-23 10:54:53	hd_ukl_wb1	129.206.90.254	129.206.90.254
2006-01-23 10:49:55	hd_ukl_wb1	129.206.90.254	129.206.90.254
2006-01-23 10:44:53	hd_ukl_wb1	129.206.90.254	129.206.90.254
2006-01-23 10:39:54	hd_ukl_wb1	129.206.90.254	129.206.90.254
2006-01-23 10:34:55	hd_ukl_wb1	129.206.90.254	129.206.90.254

Fig 4. Display of the last 10 mailbox checks, shown after clicking on one of the clients in the map. This action is allowed for all users and all clients.

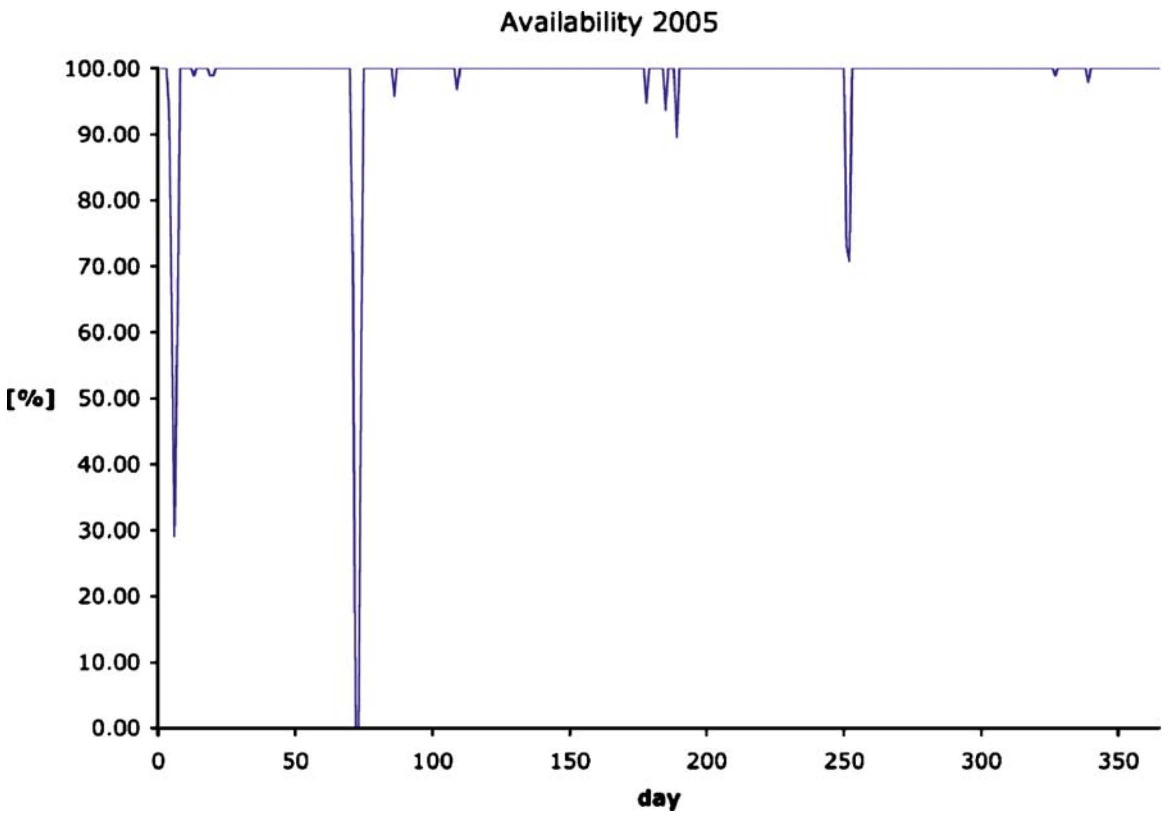

Fig 5. Example for the availability chart: central teleradiology gateway inside the University Hospital Mannheim, Germany, in 2005 (100 MBit Internet line). Daily availability calculated from the status messages from the Uptime-server. Sixteen events were registered.

mailboxes. Therefore, the line check with a single test image of 500 kB size was not useful with fast Internet lines (⩾10 MBit), as the difference in the time stamps was also in the range of 3 to 4 s. The clients with fast internet connections were therefore tested with a test image series of 10 images, resulting in differences in the time stamps of between 6 and 8 s. The limited time resolution results in a stepwise characteristic of the speed graph (see Fig. 6).

DISCUSSION

The set-up of the Uptime-server and the technical concept for the availability check of the teleradiology components proved to be adequate in over 2 years of use and with more than 35 components from eight different manufacturers.

The present system provides, in particular, features previously not described for teleradiology systems:

- vendor-independent, prospective detection of malfunction
- display of availability of all regional teleradiology clients and servers accessible by the end-user (physician, technician)
- continuous automated measurement and statistical evaluation of availability and speed of teleradiology systems

Prospective-Detection of Malfunction and Limitations

This Uptime-server concept provides automated, prospective vendor-independent malfunction detection for DICOM e-mail teleradiology installations. Despite the fact that the Uptime-server only detects system failures, this can be termed prospective because malfunctions are identified before the systems begin a teleradiology transfer. The automated procedure can only be used to receive images since vendor-specific, local software add-ons would be required to automate the sending process within a teleradiology client. Nevertheless, the majority of the components for the sending and receiving

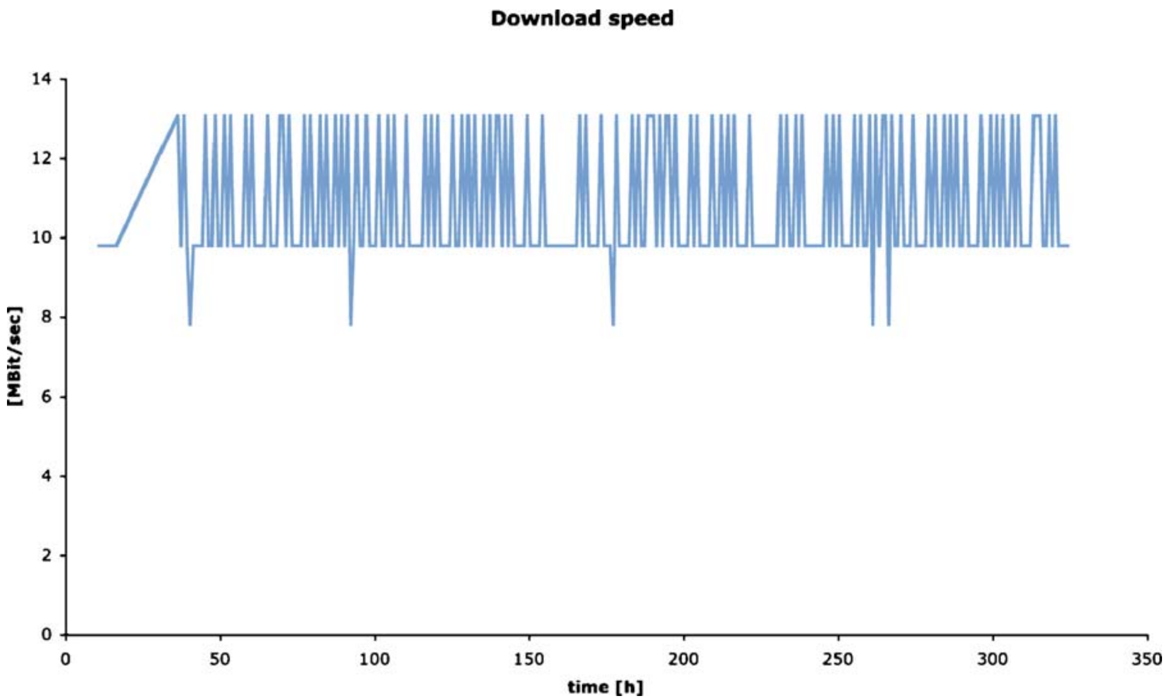

Fig 6. Example for the line check: teleradiology client inside a "Level one" trauma center with 100 MBit Internet line. Line check with automated hourly download of 10 DICOM files, dataset size 4.8 Mb. Reduced download speed is due to performance restrictions of the Hospital firewall.

processes are identical; hence, the vast majority of malfunctions can be detected using this method. Especially for users with asymmetric Internet lines (e.g., ADSL), additional regular manual tests of the send direction are mandatory to complete the stability checks of the lines.

The Uptime-server checks the availability of the teleradiology clients inside a hospital, too. However, if additional in-house components are required for the teleradiology system, such as a PACS, to display the received images, then malfunctions of these components cannot be detected. In addition, only failure of the SMTP service (image send not possible) of a teleradiology work station with a working POP3 service (image receive possible) on the same work station would not generate an error on the Uptime-server. If desired, the control of single services and other parameters such as available hard disk space are possible with network tools, for example, the Nagios systems[9].

In addition to system management tools such as the latter, other systems have also been described for teleradiology management[10]. Some of these systems can provide more detailed information on hard disk capacity, CPU load, and other parameters. They are always vendor-dependent and/or require locally installed software and/or changes in the local firewall settings. Because of the large number of participants in the regional network, the varying local systems, and the different firewall policies the Uptime-server concept is highly preferred because it can be easily administered and integrated without the need for local network changes or software installations.

End-user and Workflow Support

The end-user can check possible reasons for a teleradiology system failure at his own and at the other participating hospitals without the help of a local system administrator or an external hotline. This is especially helpful in case of failure of an emergency transfer. Even with a 24-h maintenance contract, response times for such hotlines are usually up to 2 h. With the user interface, physicians can identify common sources of errors in less than 2 min. Using the information provided to all systems in the regional network, he can decide whether it is possible and useful to send the images again, for example using a different mailserver or to a different partner. Since all major hospitals in the region (three neurosurgery units, three cardiac surgery units, four central stroke units, and six regional stroke units) are present in the network, a second partner can almost always be reached when the selected reference center is currently not available.

Emergency Teleradiology

The underlying communication protocol in the network (encrypted DICOM e-mail) is an asynchronous protocol, which other authors consider inappropriate for emergency consultations[11]; these authors prefer real-time systems[12]. We agree that additional measures are needed to ensure the necessary transfer and presentation speed, reliability, and quality of emergency consultations if asynchronous communication is used. The Uptime-server presented here is one of the measures used, together with a mandatory direct communication between the physicians via telephone and organizational regulations. This set-up allows fast, reliable, and flexible emergency consultations for a variety of specialties in the regional network.

Limitations

The method of the Uptime-server presented here is currently limited to e-mail-based teleradiology systems. Nevertheless, its general set-up can be configured to support any server-based protocol and can therefore be used for any asynchronous teleradiology system.

The automated line check can currently only be used for the receiving direction in a standardized form since automated sending of images is only possible with modified client software.

The new version 1.5 of the DICOM e-mail recommendation[13] specifies the mechanism of automated answers to notification requests. Using this mechanism, the automated test of the sending direction would be possible. Since the current clients do not support this new mechanism yet, this will be a feature of an upcoming version of the Uptime-server.

CONCLUSION

This Uptime-server concept proved to be reliable and useful in more than 2 years of use with 35 clients. It worked with products from eight different manufacturers without problems. It can be used by the administrators for prospective error detection of all connected teleradiology clients. Its statistical output can be used to fulfill the legal requirements of regular availability checks for teleradiology lines.

The built-in graphic user interface represents a unique approach for the display of relevant availability information to the clinical users of teleradiology installations. It allows fast responses to system malfunctions and avoids cost-intensive and relatively slow hotlines.

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