The Enhanced Workflow and Efficiency of the Wireless Local Area Network (WLAN)-Based Direct Digital Radiography (DDR) Portable Radiography

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Published online: 6 January 2015
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Abstract With the implementation of the PACS in the hospital, there is an increasing demand from the clinicians for immediate access and display of radiological images. Recently, our hospital has installed the first wireless local area network (WLAN)-based direct digital radiography (DDR) portable radiography system. The DDR portable radiography system allows wireless retrieval of modality worklist and wireless transmission of portable X-ray image on the console to the Picture Archiving and Communication System (PACS), via WLAN connection of wireless fidelity (Wi-Fi). The aim of this study was to analyze the workflow and performance between the WLAN-based DDR portable radiography system and the old practice using conventional portable X-ray machine with computed radiography (CR) system. A total of 190 portable chest X-ray examinations were evaluated and timed, using the conventional portable X-ray machine with CR from March to April of 2012 and using the new DDR portable radiography system on December of 2012 ($n=97$ for old system and $n=93$ for DDR portable system). The time interval of image becoming available to the PACS using the WLAN-based DDR portable radiography system was significantly shorter than that of the old practice using the conventional portable X-ray machine with CR (6.8 ± 2.6 min for DDR portable system; 23 ± 10.2 min for old system; $p < 0.0001$), with the efficiency improved by 70 %. The implementation of the WLAN-based DDR portable radiography system can enhance the workflow of portable radiography by reduction of procedural steps.

Keywords Workflow re-engineering · Direct digital radiography (DDR) · Portable radiography · Computed radiography (CR) · PACS · Wi-Fi · Wireless local area network (WLAN) · Local area network (LAN) · Image distribution · Image processing · Information storage and retrieval · Productivity

Background

With the implementation of the Picture Archiving and Communication System (PACS) in a digital environment hospital, there is an increasing demand from the health care providers for immediate access and display of radiological images with no time and location restriction from either on workstations inside the radiology department or on web-based clients outside radiology department [1, 2]. Nowadays, wireless local area network (WLAN) has been widely implemented in hospitals as the medical data transmission medium [3, 4]; therefore, the need for the interface between the wireless network and the PACS for communication of medical image data has increased. Theoretically, using wireless network in transferring images to PACS from a WLAN-based portable imaging modality, including portable radiography system and portable ultrasonography, can shorten the time interval for image transmission [1].

Portable radiography is for providing portable X-ray services for the critically ill or bedridden patients in the hospital. In the past decade, portable radiography was performed in our hospital using the conventional portable X-ray machine in conjunction with the computed radiography (CR) system. Undoubtedly, the workflow bottleneck was the need for off-

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site processing of the X-ray-exposed CR cassette and transferring X-ray images to the PACS via wired Ethernet LAN in the radiology department.

With the advent of direct digital radiography (DDR) and wireless portable imaging modalities, our hospital has newly installed the first WLAN-based DDR portable radiography system. The WLAN-based DDR portable radiography system allows wireless retrieval of modality worklist, and the digital X-ray image acquired is immediately available on the console for wireless transmission to the PACS, via WLAN connection of wireless fidelity (Wi-Fi). The aim of this study was to analyze the workflow and performance of the WLAN-based DDR portable radiography system, and the efficacy of the interface between WLAN network and PACS. We hypothesized that there would be a workflow enhancement and quantifiable improvement in efficiency of portable radiography using the DDR portable radiography system, as compared with the old practice using the conventional portable X-ray machine with CR system.

Methodology

Materials

In this study, the WLAN-based DDR portable radiography system used for performing portable radiography was the DRX-Revolution (Carestream Health, Rochester, NY, USA), while the conventional portable X-ray machine used for this study was the Mobilett portable X-ray units (Siemens, Erlangen, Germany), together with the CR cassettes and the DirectView CR 850 solo cassette reader (Eastman Kodak Health Imaging, Rochester, NY, USA) for capturing X-rays and processing X-ray images, respectively. Both portable radiography systems are integrated fully with the Centricity PACS version 3.2 (General Electric Healthcare, Milwaukee, WI, USA), and the Centricity Radiological Information System (RIS) version 4.2i (General Electric Healthcare, Burlington, VT, USA).

Setup of Intra-hospital WLAN

Before deployment of the DDR portable radiography system for portable radiography service, the WLAN network of Wi-Fi had to be set up and configured to connect and interface with the wired Ethernet LAN of the PACS network. The wireless connection enables the DDR portable radiography system to wirelessly retrieve modality worklist from broker after making registration in the RIS, and to wirelessly transmit the images in Digital Imaging and Communications in Medicine (DICOM) 3.0 standard with patient and examination information to the PACS or other destinations, like DICOM printer.

The Wi-Fi protocol used in our hospital was the Institute of Electrical and Electronic Engineers (IEEE) 802.11g standard, which operates in 2.4-GHz frequency and allows maximum data bit rate of 54 Mbps [5]. WLAN access points were built to support the linking between the wireless DDR portable radiography system and the wired PACS network using Wi-Fi. The setup of WLAN access points involved the installation of multiple antennas throughout the hospital building for maximizing the area of coverage. The wireless DDR portable radiography system was configured to automatically scan and connect the WLAN network with the strongest Wi-Fi signal in the course of conducting portable radiography.

Security of patient data transmission over the WLAN of Wi-Fi was accomplished by adopting the Wi-Fi Protected Access 2 (WPA2) as the latest wireless network security protocol in our hospital. WPA2 can provide the authentication for verification of the DDR portable radiography system and allow a powerful encryption technology of Advanced Encryption Standard (AES) for data encryption. More importantly, the Specific Service Set Identifier (SSID) broadcasting from the WLAN access points was only identified and recognized by the DDR portable system. This configuration was not only for security reason, but it also prevented any adverse impact or slowing down of the functionality of other wireless medical systems, such as telemetry [4], during the time of DICOM image data transfer. In case of failure of the WLAN connection, connection to the PACS network using physical cable was the contingency plan for data communication. As the DDR portable radiography system supports both wireless and wired connection to the PACS network with different destinations, such as PACS server, RIS, and printer, those destinations were registered with two static IP addresses for wireless and wired connections, respectively, to a single Application Entity (AE) title of the DDR portable radiography system.

Wi-Fi Signal Strength Test and Transmission Time Measurement

Wi-Fi signal strength was tested on every floor in our hospital building using the DDR portable radiography system before studying its performance. The test period was done on early December of 2012. The Wi-Fi signal strength was observed based on the Wi-Fi indicator showing four levels of signal strength, including “excellent,” “good,” “weak,” and “no” signal, on the console of the DDR portable radiography system. The weak and no signal found on specific floor and location was then followed up and strengthened in an attempt to achieve strong signal in most areas of wards before commencing the study.

In this study, besides demonstrating the interface between WLAN network and PACS using the new DDR system, we quantitatively measured the time for wireless transmission of a

digital chest radiograph from the DDR portable radiography system to the PACS during the study. The measurement was the time between triggering image transfer and finishing delivery of image to PACS.

Evaluation of WLAN-Based DDR Portable Radiography System

In this study, we analyzed the performance and the workflow of portable radiography using the wireless DDR portable radiography system and the non-wireless conventional portable X-ray machine with the CR system, respectively. For the performance analysis, we quantitatively measured the time interval of image becoming available to PACS. The measurement was defined as the time the radiographer started the examination in ward subtracted from the time that the digital portable X-ray image was finished delivery to PACS. This measurement was used for monitoring the time required for digital portable X-ray image becoming available in the PACS to be accessed by the radiologists and clinicians after the portable X-ray examination was performed.

In data collection process, the workflow steps of starting the examination and finishing the image transmission to the PACS were timed respectively for calculating the time interval

of image availability to PACS. Two periods of data collection were conducted in our hospital during office hours from 0800 to 1700, using the conventional portable machine with CR from March to April of 2012 and using the DDR portable radiography system on December of 2012. A total of 190 portable chest X-ray examinations were evaluated and timed ($n=97$ for old system and $n=93$ for new DDR system). In order to minimize the inter-operator variability in data collection, only two radiographers with 4–5 years of clinical experience were involved. The two radiographers were adequately trained with the operation of the new DDR portable system prior to the data collection process. As the performance of portable radiography was the primary focus of this study, no patient data were collected in the data collection process.

The calculated mean time intervals were compared between the DDR portable radiography system and the conventional machine with CR system using the unpaired t test to calculate the two-tailed p value. The statistical analyses were performed by using SPSS for Windows (SPSS, Chicago, IL, USA). A significance level of $p<.05$ was considered statistically significant. Besides, the efficiency improvement of DDR portable radiography system was calculated by the measured mean time interval of image becoming available to PACS:

$$\% \text{ of Efficiency Improvement} = [\text{mean time (old system)} - \text{new DDR system}] / \text{mean time (old system)} \times 100 \%$$

Results

Time of Image Available to PACS and Efficiency

The result of the time interval of image availability in PACS is shown in Table 1 and Fig. 1. The time for image becoming available to the PACS of the WLAN-based DDR portable radiography system was found to be shorter than that of the old practice using the conventional portable machine with CR system, with the mean measured time as 6.8 ± 2.6 min for the DDR portable system and 23 ± 10.2 min for the old system. More importantly, the shortest time interval for image availability to PACS using DDR portable radiography system was only 2 min, as compared with the old system with 9 min. The mean time differences between the new and old portable radiography systems were found to be statistically significant ($p<0.0001$). Moreover, the efficiency of the DDR portable radiography system was remarkably improved by 70 % over the old system.

Owing to off-site processing of CR cassette being required in the old practice of portable radiography, many hospitals install their CR reader in specific wards or levels to save transportation time of the exposed CR cassette. Therefore, the

mean time interval of lift utilization for returning to the radiology department was extracted for references only (see Table 1). Depending on the need of transportation of the CR cassettes for image processing, the measurements of the time interval of image availability to PACS using the old system can be fit to the hospitals universally for the performance of portable radiography, by voluntarily deducting the referencing lift utilization time shown in Table 1.

Table 1 Results of the time interval of the image becoming available to the PACS, using the new DDR portable radiography system and conventional portable machine with CR system (Old system)

	New DDR system	Old system
Mean $\pm$ 1 SD (min)	6.8 $\pm$ 2.6	23.0 $\pm$ 10.2
Range (min)	2–13	9–54
Time difference (min)	16.2	
p value	<0.0001	
Efficiency	+70 % for DDR	
Lift utilization time (min)	N/A	3.8

Lift utilization time is for references only

1 SD 1 standard deviation, N/A not applicable for using DDR portable radiography system, DDR direct digital radiography

Fig. 1 Graphical results of the mean time of image becoming available to the PACS for the new DDR portable radiography system and the conventional portable machine with CR system (*Old system*). The time differences between the new DDR system and the old system are found to be statistically significant. *Error bars* represent 1 standard error

Workflow Changes

The comparison of workflow between the old practice of conventional portable machine with CR system and the new DDR portable radiography system is shown in Fig. 2. For the old practice, a certain number of CR cassettes had to be brought along with the conventional portable X-ray unit to perform portable radiography. After taking X-ray in ward, the exposed CR cassettes had to be transported to our radiology department for retrieving patient and examination data from worklist and for processing by the CR reader. Image assessment and manipulation steps were done prior to transmitting the processed digital portable X-ray image to the PACS and DICOM laser printer via the wired Ethernet LAN. The off-site processing of exposed CR cassette with the need of transportation was identified to be the workflow bottleneck and time-consuming step for conducting portable radiography in our old practice.

At present, the new DDR portable radiography system allows immediate availability of digital image and connection to the wired Ethernet LAN PACS network without location restriction via WLAN or Wi-Fi (see Fig. 3). Therefore, all the image post-acquisition processing steps, including quality assessment of X-ray images and wirelessly sending digital X-ray images to the PACS and DICOM laser printer, can be done within the ward. Our findings showed that using the DDR portable radiography system could reduce the workflow steps for portable radiography, when compared with the old practice using the conventional portable machine with CR system (see Fig. 2). Thus, the workflow of DDR portable radiography system could be greatly enhanced.

Fig. 2 The comparison between the old and new portable radiography workflow using the conventional portable machine with CR system and the new DDR portable radiography system, respectively. The workflow steps of the new practice for completing image transmission to PACS are three steps shorter than that of the old practice

Wireless Transmission Time of DDR Portable Radiography System

The mean measured time for wireless transmission of a digital chest radiograph from the DDR portable radiography system to the PACS was found to be 2.2 ± 1.1 s.

Discussion

Performance Analysis of DDR Portable Radiography System

Our findings demonstrated that the time interval of image availability to PACS was significantly shortened with

Fig. 3 Schematic diagram of workflow using the WLAN-based DDR portable radiography system. The DDR portable system can connect to the wired PACS network via WLAN of Wi-Fi, for modality worklist retrieval from broker interfacing the RIS and DICOM image transmission to PACS archive and other destinations

improved efficiency by 70 %, by using the WLAN-based DDR portable radiography system (Table 1 and Fig. 1). The reason is that with the advent of the DDR portable radiography system with immediate display of X-ray image on the system's monitor for quality assessment following an exposure, it is able to connect to the PACS network wirelessly through WLAN technology of Wi-Fi for image transmission. Therefore, using the WLAN-based DDR portable radiography system can accomplish the demand for immediate access of radiological images from the PACS by the radiologists and clinicians.

Moreover, literature supported that fast access to the radiological images digitally could significantly improve the clinicians' workflow [6]. The significantly short time for image availability in PACS using the DDR portable radiography system is therefore beneficial to the radiologists and clinicians for making early diagnosis and medical decision, and ultimately, the patients, especially in the intensive care unit and emergency room, can receive treatment without delay.

The long time interval of image availability to PACS of the old practice is due to the fact that the exposed CR cassettes were required to be transported to our radiology department for image processing and for transferring digital images through wired network connection. Thus, a delay of image availability to PACS was inevitably resulted [1].

Workflow Analysis of DDR Portable Radiography System

As shown in the results, the DDR portable radiography system allows wireless connection to the wired PACS network without time and location limitations (Fig. 3). As a result, the workflow steps for performing portable radiographic examination using the DDR portable radiography system are

reduced (Fig. 2). The detailed workflow analysis of the WLAN-based DDR portable radiography system is described as below.

Our PACS is fully interfaced with the RIS of the same vendor. Patient and examination information showing on the request form is registered and ordered in the RIS. The information is then sent to the broker and the PACS database server in Health Level 7 (HL7) standard [5]. The integration of the imaging modality, RIS and PACS, contributes to workflow improvement [7]. Prior to the image acquisition procedures, the WLAN-based DDR portable radiography system allows wireless retrieval of DICOM modality worklist (MWL), which provides patient's demographic data and examination information, from the modality worklist provider (i.e., the broker linking with the RIS). Literature revealed that the most frequent error in practicing portable X-rays was to mistakenly X-ray a wrong patient by the radiographers [8]. In order to minimize the error and secure data consistency, bedside double checking of the patient name is done first. Subsequently, the radiographer selects the appropriate patient name from the worklist displaying on the touch-screen interface panel, or directly scans the 1D barcode of the examination's accession number showing on the PACS label on the portable X-ray request form.

After making the X-ray exposure to the patient, the portable X-ray image can be immediately displayed on the console of the DDR portable radiography system. With the Wi-Fi connection ability, the X-ray images can be promptly transferred to the Ethernet LAN of PACS network in DICOM 3.0 standard. The image is then available in the PACS for review by the radiologist inside our radiology department. The shortened and reduced workflow steps of portable radiography are therefore achieved.

In order to allow the portable radiological images to be reviewed through the Hospital Information System (HIS) on the web-based computers by the clinicians after completing image transmission to the PACS, the examination status needs to be triggered from “arrive” into “complete”/“exam.” It is theoretically done by the DICOM service class of the Modality Performed Procedure Step Service (MPPS) after finishing the imaging procedure. MPPS enables the DDR portable radiography system to pass an N-SET DICOM Message Service Element (DIMSE) message to the RIS for notification of completing an examination [9]. Then, a message is passed from RIS to HIS in HL7 standard for setting the status into “complete.” However, the MPPS was found to not technically support the communication between the DDR portable radiography system and our vendor of RIS in our study.

Alternatively, we used the web browser based Virtual Network Computing (VNC) viewer (UltraVNC) installed in the DDR system’s console to remotely access one of the RIS computers located in our radiology department, via the Wi-Fi

connection. By this means, the radiographer can manually change the portable examination status to “exam” in the RIS after completing each portable examination (see Fig. 4). Following that, a message is automatically sent to HIS in HL7 standard for setting the status into “complete.” And now, the clinician can review the portable X-ray images on the web-based computers through the HIS immediately after the portable radiography examination has been performed. Besides, the VNC remotely accessing the RIS can allow the radiographer to check the integrity of images sent to the PACS on the Enterprise Web Application. Furthermore, the radiographer can make an examination order by doing registration on the remotely accessed RIS at the moment of requesting urgent portable examination. In addition, the connection to the RIS computer through VNC viewer is protected with a passcode for the sake of security.

By utilizing the WLAN-based DDR portable radiography system, the workflow of portable radiography can not only be enhanced, the radiographer can also improve the efficiency of

Fig. 4 Image capture of the VNC viewer in the DDR portable radiography system for wirelessly and remotely connecting the RIS computer. The examination status has to manually change from “start”

into “exam” (arrow) to indicate the end of examination for images reviewing on the HIS by clinicians

portable radiography by speedy delivery of digital radiological images and information to the clinicians for making timely diagnosis and treatment to the patients.

WLAN Interfacing with Wired PACS Network

In our study, we have successfully demonstrated the interface between the WLAN of Wi-Fi and the wired Ethernet LAN of PACS network of the radiology department, using the DDR portable radiography system. With multiple access points linked to a wired PACS network throughout an entire hospital building, it is undoubted that the WLAN-based DDR portable radiography system provides flexibility and mobility for radiological images and medical data communication.

Data transmission speed using Wi-Fi for wireless data communication is one of the main concerns of our study. Owing to

the limited network bandwidth and limited network stability, WLAN of Wi-Fi communication speed is inevitably slower than physically cabled network technology. For the DDR portable radiography system, the IEEE 802.11g standard was the protocol of our Wi-Fi connection, which operates in short wavelength of 2.4-GHz frequency for effective distant penetration power and allows maximum data bit rate of 54 Mbps [5]. In the course of the study, we measured the time for wireless transmission of a digital chest radiograph from the DDR portable radiography system to the PACS. The mean measured time was found to be 2.2 ± 1.1 s, which is a satisfactory result for wireless image transmission in perspectives of the radiographers and clinicians. Comparison was then made between the measured transmission time and theoretical time. The theoretical time can be calculated by

$$\{[(\text{spatial resolution of DDR chest radiograph}) \times \text{bit depth}] / \text{Data bit rate of Wi-Fi}\}$$

The theoretical transmission time of a digital chest radiograph was found to be 1.32 s ($2500 \times 2500 \times 12$ bits/54 Mbps) and was slightly faster than the mean measured time of 2.2 ± 1.1 s. Although we had already tested that the Wi-Fi connectivity and signal strength were strong in most areas before the study, the slight discrepancy of the measured transmission time can be attributed to the Wi-Fi using radiofrequency technology for data transmission. The Wi-Fi radiofrequency can be limited by its propagating and penetrating ability through the thick concrete walls and can be intermittently interrupted by many electronic devices, Bluetooth devices, cell phones, and microwave oven used in staff lounges, with emission of 2.4-GHz radiofrequency inside the hospital. The future direction to increase the Wi-Fi transmission speed is to use the IEEE 802.11n protocol with significant improvement in link distance range and speed with up to 600 Mbps [5].

Conclusion

The implementation of the WLAN-based DDR portable radiography system can provide enhancement in the workflow of portable radiography by reducing the procedural steps. Using the DDR portable radiography system, the time of digital image becoming available in the PACS was significantly shortened with improved efficiency by 70 %. Furthermore, we have successfully demonstrated the communication of patient, examination, and image data between the WLAN network of Wi-Fi and the wired Ethernet LAN of PACS network using

the WLAN-based DDR portable radiography system in this study.

Acknowledgments The authors acknowledge with thanks the wireless network support from the Information Technology Department of the Hong Kong Sanatorium & Hospital.

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