A Study in Traffic Characteristic Analysis of Picture Archiving and Communication System (PACS) in the Hospital Network

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Summary
Computer Network is much more important for data communication in healthcare and medical informatics field. Designing in hospital network is not simplified because Information Technology is sharply developed. Traffic analysis is one of major's factors for the network design. In recently, characteristic of HTTP, FTP, SMTP, VoIP and other Internet applications are widely studied. However, a characteristic of PACS traffic that is a popular medical imaging is rarely studied. Therefore, this paper presents PACS traffic analysis in an intra-domain network. The traditional traffic analyst often represents results in terms of bandwidth such as bandwidth utilization. In contrast, PACS traffic analysis in this paper is based on a term of delay since a constraint of PACS communication is defined as the desirability that one-way direction of each picture should be displayed on a viewing workstations screen within 5 seconds. From some experiments, a relationship between a duration time and packet arrival rate (pps) is presented. In addition, relationships among the bandwidth connection, the duration time of PACS flow, and the packet arrival rate (pps). PACS image size and ping delay time are also presented.

Key words:
Picture Archiving and Communication System (PACS), Traffic Measurement, Traffic Characteristics, Hospital network

1. Introduction

Over the past several years, Picture Archiving and Communication System (PACS) architecture has changed from radiographic film to digital imaging, called filmless system [1-8]. PACS is an electronic computer and filmless information system, which is used to capture, store, distribute and display images with Digital Imaging and Communications in Medicine (DICOM) standard [9]. It has been implemented in Siriraj Hospital since 2001 with a single server and 1.8 Terabytes IDE hard disks for image storages. Today, its storage is extent to 30 terabytes on a Storage Area Network (SAN).

Recently, there have been many researches about traffic analysis of HTTP, Telnet, VoIP, FTP and other applications in terms of bandwidth usage, a packet length (size) distribution (byte) and a packet arriving rate (pps) [10-14]. The packet arriving rate is normally measured in a unit of packet per second (pps). In [10], the packet length distribution and packet interval time of WAN, LAN and Intranet traffic were presented. The highest percentage of IP packet length is 46, 144, and 46 bytes on WAN, LAN, and Intranet traffic, respectively. In 2005, The Packet length and the packet arriving rate (pps) of VoIP, Telnet, DNS, SMTP, HTTP and FTP on Local Area Network (LAN) in terms of mean packet length are 66.8, 104, 128, 446, 504, 752 bytes, orderly [11]. In [12], Internet Traffic Stream was analyzed in terms of bandwidth usage in units of byte. There are three types of traffic: Web TCP, Non-Web TCP and UDP. It is found that Web TCP traffic is of the highest volume and UDP traffic is of the lowest volume for both university networks. In 1997, WAN Traffic Patterns and Characteristics were represented in terms of traffic measurements taken from two locations on an internet MCI's commercial backbone. International and domestic traffic was separated for measuring traffic [13].In 1991, the packet length and the packet arrival time for each application e.g. FTP, HTTP etc., on LAN traffic were reported in terms of packet arrival time (pps) by time of day [14].

Traffic patterns and characteristics are important for network design. Additionally, a QoS routing which relates to a constraint of delay-sensitive applications is necessary. A constraint of VoIP is that time-delay in one-way direction of VoIP packet should be less than 150 msec [15-16]. Telnet's constraint is that teletyping in Telnet should be below 150 msec [11], [15]. A display of each webpage on browser (e.g. IE) should be less than 5 sec [17]. A constraint of displaying each image of PACS on viewing workstations is that it should be below 5 sec [6]. Up to now, Traffic Analysis on PACS has been rarely studied.

In addition, the most of traffic analysis is based on terms of bandwidth usage. However, the PAC constraint is in terms of the time-delay. Therefore, this paper presents characteristic patterns of PACS based on the time-delay. The packet length, the packet per second (pps), and flow volume are demonstrated. PACS packet length distribution is presented in terms of histogram. Furthermore, PACS packet arrival time is presented in terms of probability density function (PDF). From experiment results, it is found that when the bandwidth is large, the duration time

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will be short but the packet arriving rate (pps) is high. The duration time is defined as an amount of time for one flow (session). On the other hand, when the bandwidth is small, the duration time will be long but the packet arriving rate (pps) is low. Additionally, it is found that when the duration time per one Hospital Number (HN) flow is long, packet arriving rate (pps) will decrease. In contrast, when the duration time is short, the packet arriving rate (pps) will increase. This information is useful for the network design and QoS routing in the hospital computer network. This paper is extended experiments from the previous work [21] that presented a nature of PACS traffic in an intra-domain network. In this paper, a measurement of PRTG is extended to one month as well as an effect of variable PACS flows (6 flows) on duration time (sec), packet arriving rate (pps), PACS image size (MB), and ping delay (msec) are investigated.

The rest of this paper is organized as follows. In section 2, background is stated. In section 3, experiment setup is explained. Section 4 provides the experiment result. Section 5 gives conclusions and planned future work.

2. Background

This section consists of two sections as follows: PACS history and Traffic Analysis for Internet Applications

2.1 PACS History

The Picture Archiving and Communication System (PACS)'s concept was introduced as early as 1982 after more than 20 years of research, development and implementation [20]. The PACS is a system for receiving, storing and distributing the medical images using applications or web technologies in the computer network [18], [20-21]. The PACS servers store the database containing the images. Clients (viewing workstations) can access to PACS server via the network. The most common format for image storages is DICOM (Digital imaging and Communications in Medicine) [19]. Basically, the PACS components are (1) Interfacing to Hospital Information System (HIS) and Radiology Information System (RIS), (2) Imaging Modalities, (3) DICOM Gateway, (4) PACS Controller and Archive, (5) Viewing Workstations [21] as shown in Figure 1.

In [18], grid technology for communication and accessing is used for providing the best resource selection, disaster recovery and cost optimization. The experimental results show that it provides better performance comparing with common PACS system as 29.70%, 45%, 416.02 Kbps and 132.81 Kbps for average CPU load, memory utilization average and average in-outgoing traffic, respectively.

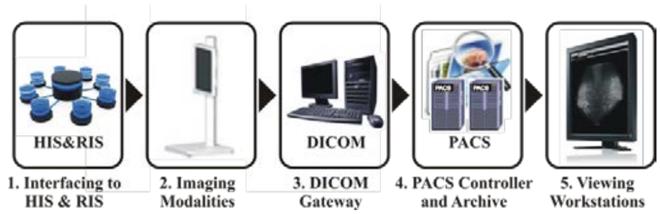


Fig.1shows the PACS Components

Rogier van de Wetering et al, proposed the PACS maturity model (PMM) for 5 levels follows: (1) PACS Infrastructure, (2) PACS Process, (3) Clinical Process Capability, (4) Integrated managed innovation (5) Optimized PACS Enterprise Chain [20].

2.2 Traffic Analysis for Internet Applications

A general form of traffic analysis is based on terms of packet arrival time and packet length (bytes) [10] - [14]. Henry J. Fowler et al, studied traffic characteristics of congestion on local area networks with connectionless service. This analysis was presented in terms of packet arrival time by time of day in order to understand congestion management [14]. Kevin Thompson et al, reported traffic characteristics that were measured from WAN traffics in terms of traffic volume, flow volume, flow duration and packet size. Additionally, traffic composition in terms of IP protocols, TCP and UDP applications is presented [13]. In [10], there are three traffic models measured as follows: LAN, WAN and Intranet. This focuses on the relationship of IP packets length in bytes and frequency as percentage. In [12], TCP Web, non TCP Web, UDP are analyzed in terms of bandwidth usage in units of percentage and packet size distributions in units of bytes.

Up to now, a research of PACS traffic analysis in term of traffic volume and packet delay has not yet been analyzed properly.

3. Experimental Setup

This section consists of two subsections. One is network configurations and the other is experimental configurations.

3.1 Network configuration

Siriraj Hospital Management Information System (SiHMIS) Network as shown in Figure 2 is a main part of Faculty of Medicine Siriraj Hospital, Mahidol University Thailand. A network diagram in a figure 2 can be divided into three zones: PACS server zone, Medical Equipment zone, and Workstation zone.

In the first zone, main servers are Web, Database, Synapse, and Radiology Information System (RIS) including Storage Area Network (SAN). All interfaces of PACS servers connected via a core switch, i.e. are Gigabit Ethernet links. In the second zone, Medical Equipment is connected to access switches e.g. Cisco Catalyst 4948, and access switches are connected to a distributed switch e.g. Cisco Catalyst 2960; all interfaces of the distributed switches connected to the core switch are Gigabits. In the third zone, there are many viewing workstations, which can access the PACS server via the access switch, distributed switch, Firewall, and Core switch, (in that order).

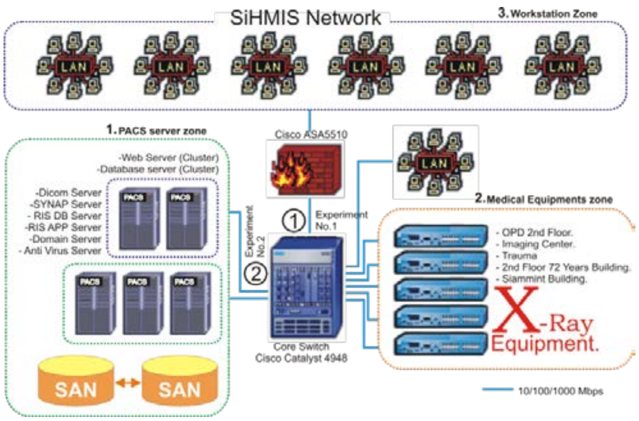


Fig. 2 show a major part of Siriraj Hospital Network divided into three parts. Note that Siriraj is the biggest hospital in Thailand which there are 2,368 beds for serving patients.

The Siriraj PACS (SiPACS) contains PACS server and Medical Equipment zone as shown in figure 2. SiPACS is separated from SiHMIS network by Firewall for security. All access switches in SiHMIS zone are connected to all workstations with 10/100/1000 Mbps.

A firewall shown in figure 2-3 is Cisco ASA 5510 Firewall. Figure 3 shows a diagram of the PACS server farm.

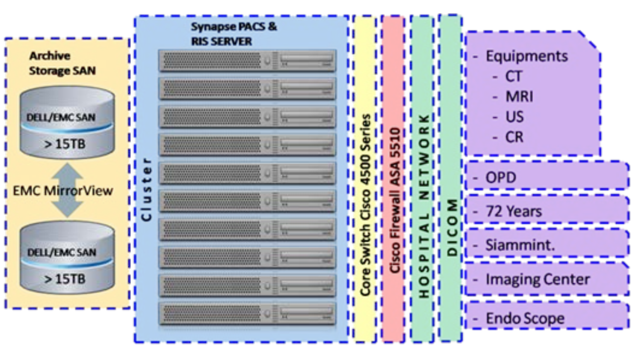


Fig. 3 shows PACS server farm called as Siriraj PACS (SiPACS) which is located at Siriraj Hospital, Bangkok, Thailand.

3.2 Experiment configuration

Network and experiment configurations in this paper were implemented on an actual network of Siriraj hospital, Faculty of Medicine Siriraj Hospital, Mahidol University, Thailand. There are five experiments as follows:

(i) Experiment 1: A nature of PACS traffic was measured during April 4-5 and May 18, 2010 using PRTG Traffic Grapher for reporting the nature of PACS Traffic. PRTG (Paessler Router Traffic Grapher) was used from measuring at an interface of the core switch connected to the firewall marked as ①② which is displayed in the figure 2.

(ii) Experiment 2: 22 PACS flows were sent from servers in PACS servers' zone to a sniffer computer in a workstations Zone on July 29, 2010 as show in a figure 4. Packet interval time is represented in a form of Probability Density Function (PDF)

(iii) Experiment 3: The relationship among bandwidth connection, duration time and packet arriving rate were observed. 10 PACS flows sent from PACS server to the sniffer computer on July 27, 2010 during 11:30 to 11:56. In addition, LAN card of sniffer computer was changed for varying bandwidth connection in order to observe the outcome. Therefore, there are five sub experiments as follows: 10 Mbps Half Duplex (HDx), 10 Mbps Full Duplex (FDx), 100 Mbps Half Duplex (HDx), 100 Mbps Full Duplex (FDx), 1000 Mbps Full Duplex (FDx).

(iv) Experiment 4: An objective of this experiment is to study an effect of hospital network congestion in different time period on the same day. 10 PACS flows were sent to the sniffer computer with different time periods. There are three time periods as follows: 09:00 to 09:30 AM, 12:00 to 12:30 PM, and 04:00 to 04:30 PM.

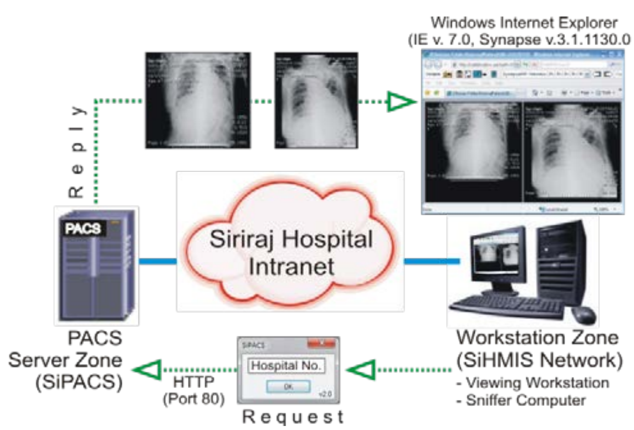


Fig. 4 displays the network connection between PACS servers and a sniffer computer that is a viewing workstation for experiment 2 to 6.

(v) Experiment 5: The packet size distribution was investigated in unit of bytes. It was analysed using a Sniffer Pro version 4.70.04 on August 18, 2010. These sniffed packets included 80 thousands packets during one hour. All interfaces of the core switch, which is shown in the figure 2, are configured to mirror all traffic to one port of the core switch. And a sniffer pro computer is connected to this mirror port.

(vi) Experiment 6: an effect of variable about PACS flows (6 flows) on duration time (sec), packet arriving rate (pps), and ping delay (msec) are analysed using Wireshark network protocol analyser version 1.6.1 on September 18, 2011.

4. Experimental result

4.1. Result of experiment1

PACS traffic measurement during 7 days on August 2 to 9, 2010 is presented using the PRTG network monitor tool as shown in a figure 5.

PACS traffic on August 4, 2010 06:00 AM to 12:00AM is shown in figure 6 and during 12:00 PM to 06:00PM is displayed in figure 7.

Figure 5 shows a graph of delay time on PACS server during a week. It is found that traffic congestion is not near seasonality.

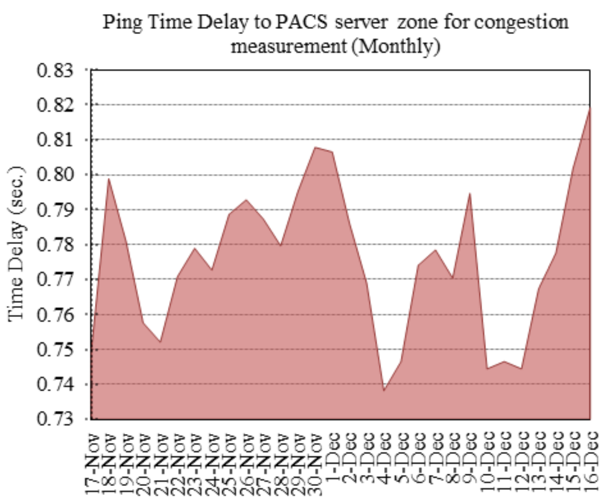


Fig.5 demonstrates a graph of delay time on PACS Sever (Weekly)

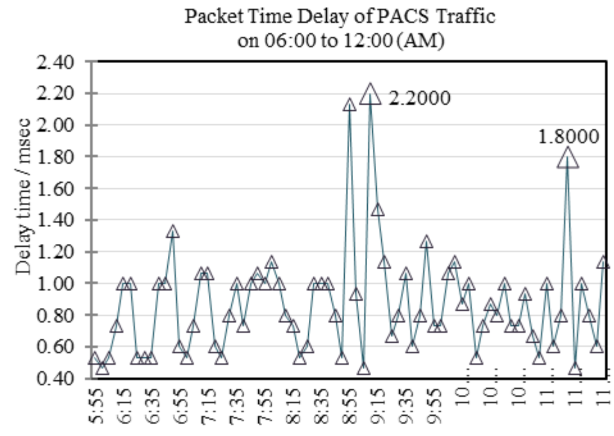


Fig. 6 shows a graph of Delay time of SiPACS on 06:00AM to 12:00AM

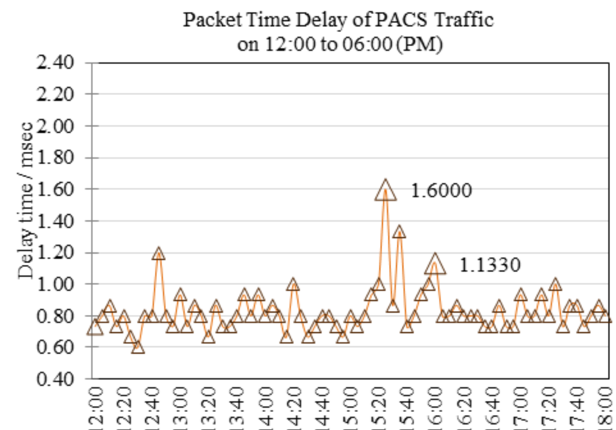


Fig. 7 displays a graph of Delay time of SiPACS on 12:00PM to 06:00PM

In figure 6 and 7, it is shown that a graph of delay time of PACS server on 06:00AM to 12:00AM is heavier than during 12:00PM to 06:00PM.

4.2. Result of experiment 2

Figure 8 looking overall at the big picture, it can been seen that when the capture duration time per one Hospital Number (HN) flow is long, the packet arriving rate (pps) will decrease. In contrast, when the capture duration time is short, the packet arriving rate (pps) will increase.

The most significant point is that the packet arriving rate (pps) of HN no.16 is high, but its duration time in unit of msec is short. At HN no.19, its packet arriving rate (pps) is low but its duration time is long. Then, the packet arriving rate (pps) of HN no.20 is lower but its duration time is longer. Next, the packet volume (pps) of HN no.21 is higher but its duration time is shorter.

Another important point is that total number of HNs in this experiment is equal to 22 flows. However, the numbers of HN whose duration time exceeded 5 sec are equal to 19 flows, which is equal to 86.36 %. From Siriraj's Key Performance Indicators (KPI), the constraint of displaying each image of PACS on terminal is that it should be below 5 sec [6]. This means that only 13.64% of HN that meet the Siriraj's KPI as shown in the figure 8. It should be noted that the duration time is defined as the amount of time for one flow (session).

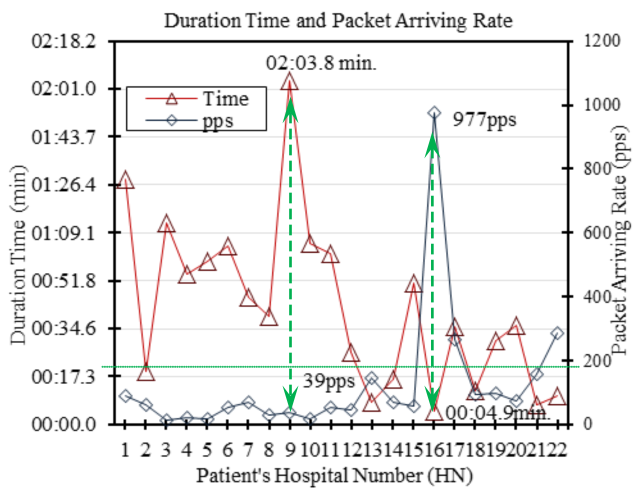


Fig. 8 shows Duration time and Packet arriving rate with 22 HNs. It should be noted that HN is a patent's hospital number and KPI is a key performance indicators

Figure 9 shows the packet interval time during 1 to 999 msec of about 60,000 PACS packets in the form of Probability Density Function (PDF). Figure 10 displays the packet interval time during 1,000 to 98,633 msec. Table 1 lists the packet size and packet interval time in term of mean, mean deviation, Standard Deviation.

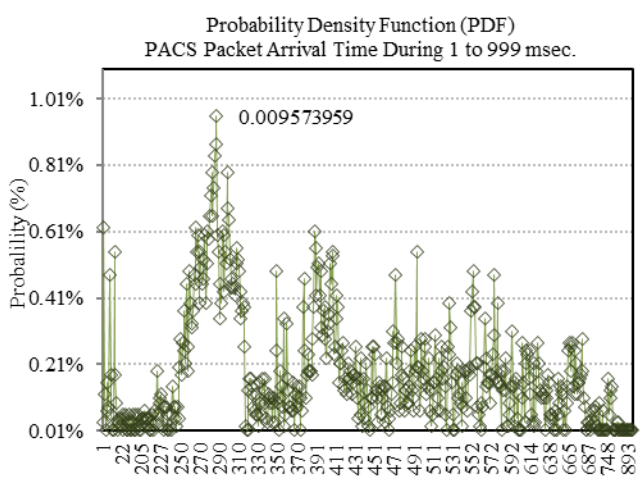


Fig. 9 shows PACS Packet Interval Time during 1 to 999 msec.

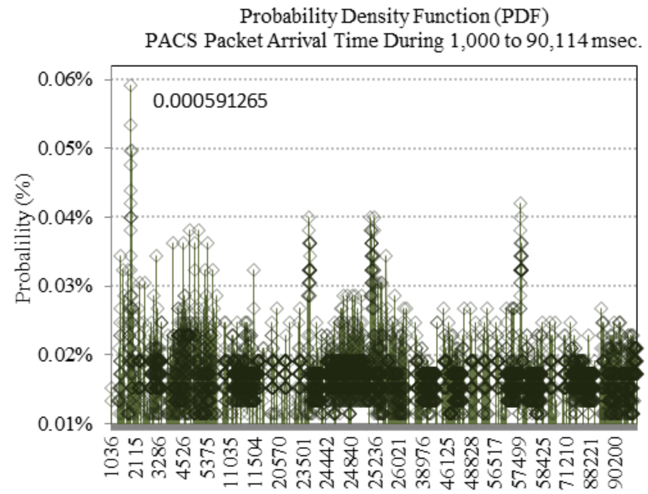


Fig. 10 PACS Packet Interval Time during 1,000 to 98,633 msec.

TABLE 1 Mean, Mean Deviation, and standard deviation for packet size and packet interval time

	Packet Size (byte)	Interval Time (msec.)
Mean	885.86	31,611.00
Mean Deviation	71.04	24,905.80
Standard Deviation	73.35	29,939.82

4.3. Result of experiment 3

Figure 11 displays the relationship of three factors: bandwidth connection (Mbps), duration time (msec), and packet arriving rate (pps). Table 2 represents the same result as figure 11 and Table 2, it is found that when the bandwidth is large, the duration time will be short but the packet arriving rate (pps) is high. On the other hand, when the bandwidth is small, duration time will be long but the packet arriving rate (pps) is low.

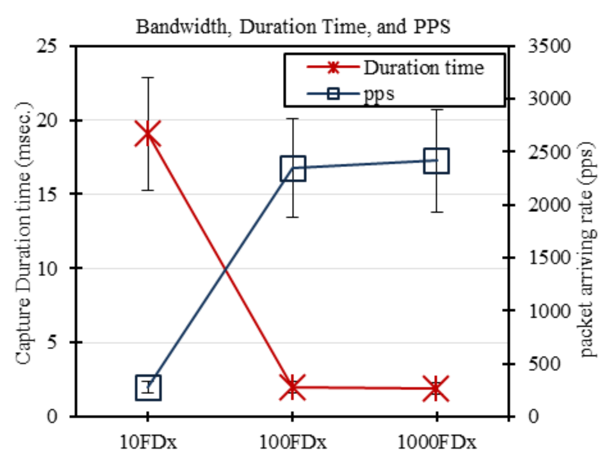


Fig. 11 shows bandwidth connection, Duration time, and packet per second (pps)

TABLE 2 Effect of variable bandwidth connection (mbps) on duration time and packet arriving rate.

No.of HNs / BW. Speed		Hospital Number (HN) of CHEST						Mean	Mean Std
		1	2	3	4	5	6		
10FDx	Time	33.00	20.40	14.20	19.65	13.30	13.80	18.94	6.48
	pps	151	220	326	261	348	329	274.99	75.76
100FDx	Time	2.00	1.70	2.30	1.61	2.10	2.00	2.02	0.18
	pps	2326	2453	1943	3023	2134	2194	2210.08	175.64
1000FDx	Time	1.90	1.70	1.90	2.01	1.70	2.00	1.84	0.10
	pps	2728	2483	2198	2448	2552	2099	2412.07	149.81

In HN.4 at column No.6, it is found that the link bandwidth 100 Full-Duplex introduces a better performance in both duration time and packet arriving rate than the link 1,000 Full-Duplex.

This because during HN.4 of PACS flow was transferred, hospital traffic is light immediately. This means that traffic in hospital was fluctuated in that time period.

4.4. Result of experiment 4

Figure 12 and 13 demonstrate an effect of the network congestion on duration time and packet arriving rate, orderly. During 09:00 to 9:30AM, the traffic is peak. This results in the lowest packet arriving rate and the longest duration time. Between 12:00 to 12:30AM, the traffic is a low volume. This leads to the highest packet arriving rate and the shortest duration time. During 04:00 to 04:30PM, the traffic is at a normal volume. This introduces a high packet arriving rate and a short duration time.

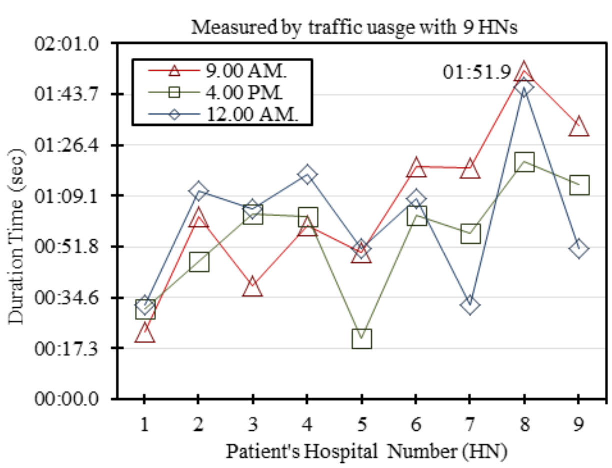


Fig. 12 shows the duration time of HN.1 to HN.9. Blue colour line was done on August 19, 2010 during 09:00 to 09:30AM. Red colour line was done on 12:00 to 12:30AM. And green colour line was done on 04:00 to 04:30PM.

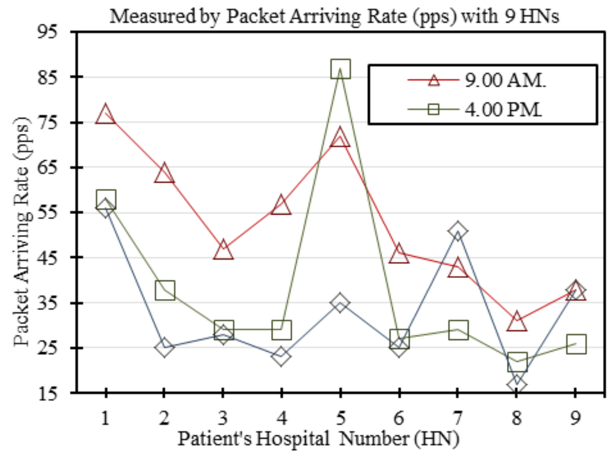


Fig.13 displays the packet arriving rate of HN.1 to HN.9. Blue colour line was done on August 19, 2010 during 09:00 to 09:30AM. Red colour line was done on 12:00 to 12:30AM. And green colour line was done on 04:00 to 04:30PM.

4.5. Result of experiment 5

Figure 14 demonstrates the packet length distribution (bytes) of all traffic of both PACS zone and Medical equipment zone. Figure 15 lists all information about these capture packets.

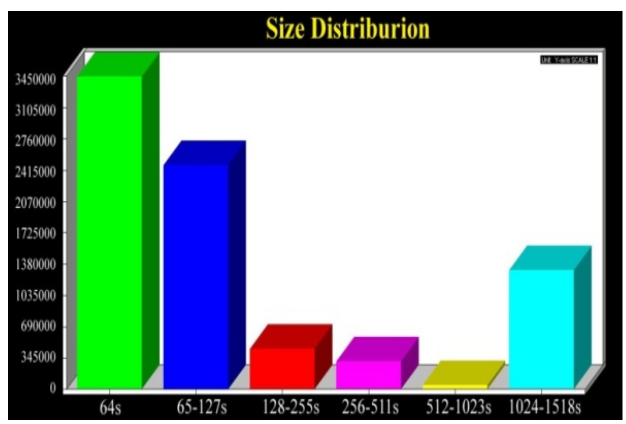


Fig. 14 shows the packet length distribution of experiment 5 by using Sniffer Pro

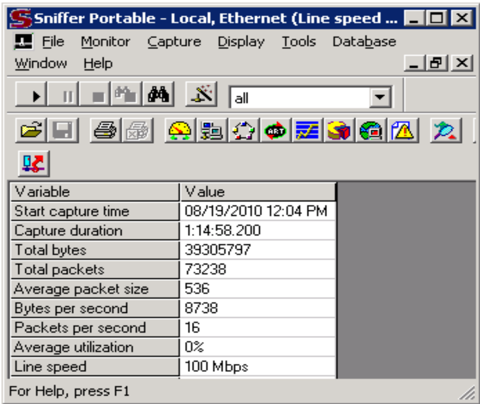


Fig. 15lists detail of statistic by Sniffer Pro

4.6. Result of experiment 6

Figure 16-17 demonstrates relationship among the mean of PACS duration time (sec), the packet arriving rate (pps) , and PACS image size with variable from 1 flow to 6 flows. Figure 18 and Table 3 display all information about relationship between the PACS image size and duration time.

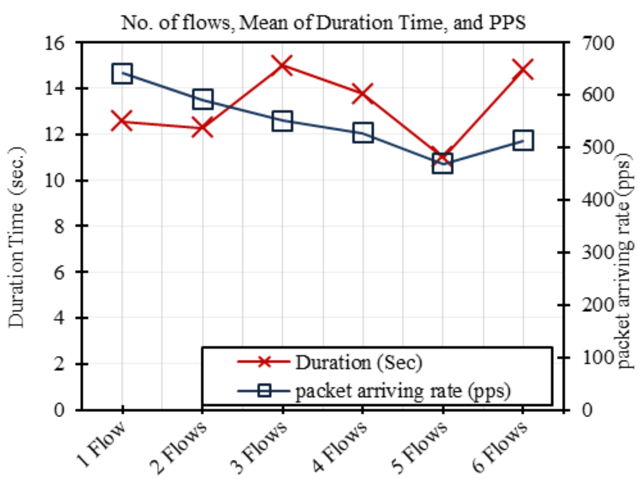


Fig.16 displays the relationship between the average of PACS duration time (Red colour line) and packet arriving rate (Blue colour line).

Figure 16 shows that when a number of PACS flows are linearly increased from 1 flow to 6 flows, a trend of the duration time is also increased. Except at flow No. 5, the usage of PACS system may be lightened during on that period. When the duration time is short, the packet arriving rate (pps) is high. On the other hand, the duration time is long when the packet arriving rate (pps) is low.

In Figure 17, it is found that when PACS flows are on linearly increasing from 0 (no PACS traffic) to 6 flows, a trend of average of ping delay is also enlarged.

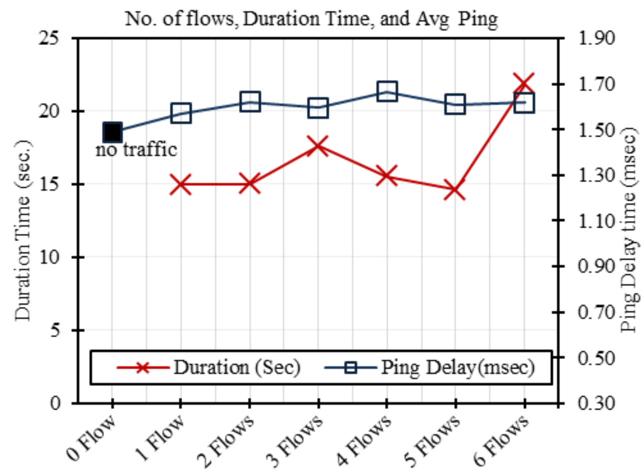
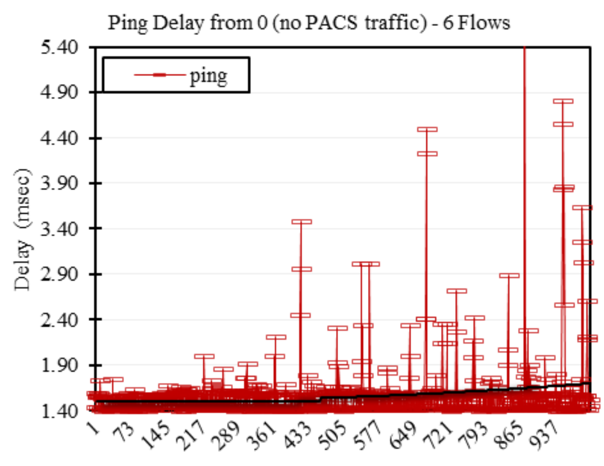


Fig.17 displays the relationship between PACS duration time (Red colour line) and ping delay time (Blue colour line).

TABLE 3 lists of Ping traffic packet from 0 flow to 6 flows

	0 Flow	1 Flow	2 Flows	3 Flows
No. of ping packet	1-145	146-288	289-432	433-567
	4 Flows	5 Flows	6 Flows	
No. of ping packet	577-720	721-864	865-1009	

Table 3 lists a mapping between the number of ping packets and the number of PACS flows. It displays that the numbers of ping packet 1 to 145 are done when there is no PACS flow. Next columns, the numbers of ping packet 146 to 288 are taken place when there is one PACS flow. End of Column, the number of ping packet 865 to 1009 are processed when 6 PACS flows are sent simultaneously. This Table is used for explanation of the figure 18.



0Flow | 1Flow | 2Flows | 3Flows | 4Flows | 5 Flows | 6Flows

Fig.18 displays the traffic ping delay time from 0 (no PACS traffic), 1 flow, 2 flows, 3 flows, 4 flows, 5 flows, and 6 flows (Red colour line). Black colour line displays the average of ping packet delay.

This paper makes an additional experiment for explaining an effect ping packet delay on generated increase of PACS flows. As shown in Figure 18 and Table 3, it is found that when the numbers of PACS flows are enlarged, the average of ping packet delay is also increased.

In figure 19, it is found that when the PACS image size is large, the duration time is also high in the same direction except at HN.2 and HN.3. This is because the network congestion during HN.2 and HN.3 transferred is lightened.

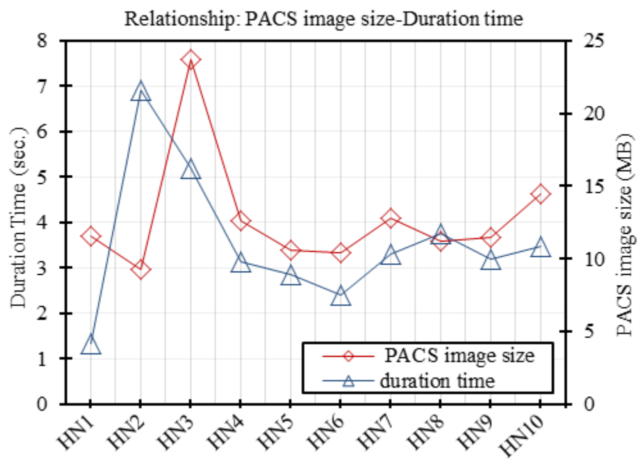


Fig.19 displays the relationship between PACS duration time (Blue colour line) and PACS image size (Red colour line).

5. Conclusion

This paper analyses traffic characteristic of PACS application in the hospital network. From experiment, it is found that a relationship exists among the bandwidth (Mbps), the duration time (sec), the packet arriving rate (pps) and the PACS image size. The bandwidth and the packet arriving rate increase or decrease in the same direction but the duration time is in the opposite direction. Additionally, there is only 13.64% of HN that passes the criterion of Siriraj's KPI. Therefore, there is a need to design a network for PACS with respect to PACS traffic pattern, its relationship of several parameters, and its constraints in order to enable PACS services quality to be above the KPI that is the PACS constraint.

In future work, some relationship among above factors appeared in this paper will be represented in mathematic. This is helpfully for simulation and design.

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