Performance Evaluation and Comparison of Facsimile Transmission in IP and PSTN Networks

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Abstract. In this paper, we describe the performance evaluation and comparison of facsimile transmission in Internet Protocol (IP) and Public Switched Telephone Network (PSTN) networks. Facsimile continues to be a communication method for transmitting legal documents. Traditional method uses PSTN network for communication. The evolution of IP networks has led to the transmission of facsimile also through the IP networks. The metrics Facsimile Satisfactory Rate (FSR) was used for the evaluation of image quality of the facsimile transmission using different technologies. Empirical observations proved that store-and-forward facsimile transmission using IP network resulted in a better image quality.

Keywords: Facsimile transmission, Fax, FSR, T.37, T.38, FoIP

1. Introduction

Facsimile is still one of the popular methods for official document exchange. Traditional facsimile transmission uses the PSTN for communication. The facsimile device scans the document, converts it into bitmap and then transmits it as electrical signals through the telephone system (PSTN). The receiving facsimile device converts the coded image back to its normal form and produces a hard copy [4]. Currently most of the facsimile devices are designed according to the G3 (Group 3) standard [8]. G3 facsimile supports one dimensional image compression of black and white images. The   evolution of IP networks has led to the transmission of facsimile through the IP network. There are two methods for facsimile transmission using IP networks. This has been given by the International Telecommunication Union (ITU) recommendations. Store-and-forward fax over IP method uses T.37 protocol which encapsulates facsimile images in e-mails and transports it to the recipient at the destination. The recipient can be another facsimile device or an e-mail inbox [5]. The real time fax over IP uses T.38 protocol for facsimile transmission across IP network in real time [6]. The IP network (packet based network) is very much different from the PSTN. The fax protocol T.30 was designed in particular for the PSTN. PSTN offers steady latency and strict timing. Packet based networks lacks these features. Jitter and packet loss in the packet based networks heavily affects the facsimile communication. T.38 protocol was designed to mitigate these factors and improve the reliability of facsimile transmission using the packet based network. One of the key objectives of facsimile transmission is that the transmitted image should be of good quality. The goal of this research is to study and compare the performance of facsimile transmission using different methods under various traffic conditions.

2. Background and Related Work

The PSTN consists of switched Time Division Multiplexing (TDM) circuits. They are either single lines or trunks. A line is used to connect a single telephony device to a switch. A trunk is used to connect a switch to another switch. Traditional facsimile transmission requires a dedicated fax machine or a computer with

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fax modem to send and receive faxes as shown in figure 1. The data is send to another fax machine using the telephone line in the form of digital bits. The sending fax machine uses a scanner to convert the image into digital bits. A microprocessor chip called digital signal processor is used to reduce the number of bits. A modem is used to convert the bits into analog signal for transmission over analog telephone line. The recipient fax machine or a computer that has fax modem converts the bits back to images or prints the image on paper. This method requires at least one telephone line on the sending and receiving device. Only one fax can be sent or received at a time using this method.
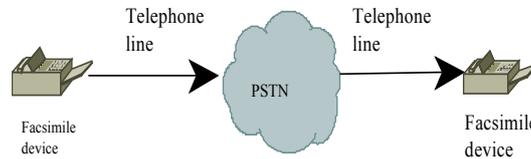
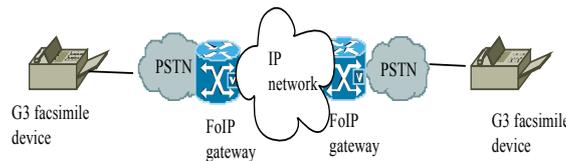Fig.1: Traditional facsimile transmission

Fig. 2: Real-time facsimile transmission

In a packet based network or IP network data is transmitted as packets. In real-time facsimile transmission the facsimile documents are send from one facsimile device to another in real-time over the IP network using the FoIP (Fax over IP) gateways [11]. The sending device segments the data into individual packets. Each packet is independent and has unique identifier. The packets may use different routes to reach the destination. So the individual packets that are part of the same transmission may experience varying level of delay in propagation (latency). The packets may not be reaching the destination in same order as it was send. T.38 protocol is used to prevent the excessive delays and improve the reliability of faxing across the Internet. In the case of real-time facsimile transmission, the traditional fax machine is connected using the PSTN to the FoIP gateway which connects it to the IP network as shown in figure 2. The T.38 protocol provides error recovery mechanism by transmitting redundant information along with each packet. The receiving FoIP gateway can reassemble missing packets using this redundant information. T.38 can be used along with TCP or UDP as the transport layer protocol. We used UDP as the transport layer protocol.

T.37 protocol is used to send facsimile over the Internet to an e-mail client [9]. In this method the facsimile transmission process is divided into sending and receiving phases. If required the faxes can be stored between the sending and receiving phases and hence the name store-and-forward facsimile transmission. As per figure 3 the store-and-forward gateway transforms the faxes send by G3 fax machines to e-mail messages and sends them across the IP network. This gateway is known as the on-ramp gateway. Another gateway at the destination converts the e-mail message back into a fax message and delivers it to the G3 fax machine. This gateway is referred to as off-ramp gateway. Store-and-forward faxing is especially useful when a single fax needs to be sent to multiple fax machines. Store-and-forward faxing can be used to receive faxes that are to be delivered as e-mail attachments or to send and receive faxes to and from G3 facsimile devices or to create and send e-mail messages as faxes to G3 facsimile devices.
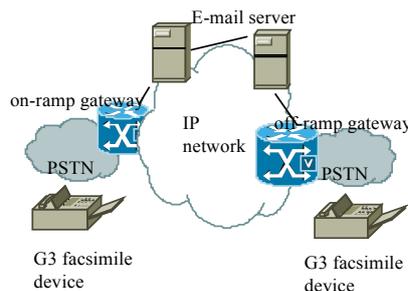
Fig.3: Store-and-forward facsimile transmission

The on-ramp gateway takes fax from a G3 facsimile device and converts it into a TIFF (Tagged Image file Format) file attachment. The gateway creates a MIME (Multipurpose Internet Mail Extension) e-mail message and attaches the TIFF file to the e-mail [12]. The gateway then forwards the e-mail and the attachment to the concerned SMTP (Simple Mail Transfer Protocol) server of the messaging infrastructure [13]. The messaging infrastructure does the routing, storage and transport of the message. The SMTP server can deliver the mail in two ways: as e-mail message with attachment or as fax to a G3 fax machine. In the second case, the SMTP server delivers the fax to the off-ramp gateway, which transforms the TIFF file to a standard fax format and then it is send to a standard PSTN based G3 fax machine. The off-ramp gateway also generates delivery status notifications (DSNs) and message disposition notifications (MDNs) as required.

Only limited work has been reported in the field of performance evaluation of facsimile transmission. [14] Reported the performance evaluation of facsimile in a packet based network under varying network conditions such as delay, jitter and packet loss. The research work [1] provides a basic framework for internet fax transmission. The paper [10] has studied the utilization of SIP (Session Initiation Protocol) in conjunction with SDP (Session Description Protocol) as companion protocol to SIP to exchange real-time fax. [15] Studied the use of T.38 facsimile in conjunction with SIP for transmission of fax traffic over IP networks. [16] Proposed an architecture and development efforts in constructing a real-time implementation of multicasting in fax over Internet.

3. Performance Evaluation

A detailed analysis of facsimile transmission using the following methods was carried out: Using traditional PSTN network with standard G3 facsimile devices, real-time facsimile transmission using standard G3 facsimile devices and store-and-forward facsimile transmission using standard G3 facsimile devices. The test environment was created using the regular facsimile devices and the public IP network and PSTN. It also used a regular SMTP server and thus made a real-life environment for the testing purpose. The experiment was conducted during peak hours and off-peak hours of network traffic to study about the image quality under varying traffic conditions.

3.1. Test Setting

The test environment as shown in figure 1 was set up for the experiment using traditional PSTN network with standard G3 facsimile devices. The test environment as shown in figure 2 was set up for experimenting real-time facsimile transmission. The test environment as shown in figure 3 was set up for experimenting store-and-forward facsimile transmission. The test setting used the PSTN service, IP network and the gateway provided by the same service provider which is the best service provider in the country. Group 3 facsimile device (Samsung SF-650) and standard SMTP server (Exchange Server 2007) which are popular in the market was used for the study. The experiments were conducted at peak hours and off peak hours as defined by the service provider [2].

3.2. Test Methodology

The study was conducted to evaluate the efficiency of facsimile transmission using traditional PSTN network with standard G3 facsimile devices, real-time facsimile transmission using standard G3 facsimile devices and store-and-forward facsimile transmission using standard G3 facsimile devices by analyzing various parameters of image transmission, like image quality, transmission speed, and transmission success rate under varying network traffic conditions. The metrics Facsimile Satisfactory Rate (FSR) was used for the evaluation [14]. The study was conducted between 9 am and 11 am on working days (Saturday to Wednesday) to evaluate the efficiency during peak hour and between 9 pm and 11 pm on working days to evaluate the efficiency during off peak hour.

3.3. Image Quality Analysis

The test image used for the experiment is as shown in figure 4 was chosen as per [14]. It is a standardized, digitized image set with high density and patterns that offer enough observation points for the analysis of image quality as given in [7]. The quality of a transmitted image (FIQ) evaluation was done as demonstrated [14]. Ten observation points were defined. These 10 observation points were assigned 2 points

if all the details of the observation point were clear, 1 point if some were clear and some were blurred, and 0 if most of the observation points were not clear.

3.4. Normalized Transmission Time and Transmission Success Rate

The quality of a transmitted image (FIQ) evaluation was done as demonstrated [14]. Ten observation points were defined. These 10 observation points were assigned 2 points if all the details of the observation point were clear, 1 point if some were clear and some were blurred, and 0 if most of the observation points were not clear. Each facsimile transmitted image were given to 100 subjects, to evaluate the Facsimile image quality FIQ. As demonstrated [14], normalized transmission time and transmission success rate were also used to analyze the efficiency of facsimile transmission in PSTN and IP networks.
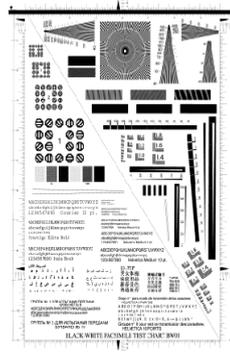

Fig. 4: Test image

Average transmission time (FTT) is the difference between the start time of the facsimile transmission (tstart) and the end time of the successful transmission at the receiving facsimile device (tend):

$$F_{TT} = t_{end} - t_{start}$$

The values tend and tstart were obtained from the facsimile transmission report on the fax device. The Normalized Transmission Time (FNTT) is the ratio of FTT and FTTO parameters:

$$F_{NTT} = \frac{F_{TT}}{F_{TTO}}$$

where FTTO was defined as the average measured transmission time in the case of ideal network condition, when there is no traffic congestion. The FSR parameter was defined as the ratio of number of successful transmission (nok) to the total number of facsimile documents sent (nfax):

$$F_{SR} = \frac{n_{ok}}{n_{fax}}$$

3.5. Overall Efficiency Evaluation of the Facsimile Transmission

Facsimile Satisfactory Rate parameter (FSR) is given by:

$$FSR = \frac{F_{SR} \times F_{IQ}}{F_{NTT}}$$

3.6. Acceptable Level of FSR

Eighty subjects, who are familiar with the facsimile communication, were interviewed to conclude whether they agree with the minimum value 16.88 points for FIQ, 0.8 for FSR and 1.1 for FNTT as given in [14]. As all the interviewees agreed to the above value for each parameter, the acceptable value of FSR is 12.27.

3.7. Network Parameters

When the network (IP and PSTN) traffic increases the subscribers will face difficulty to subscribe the services. To study the effect of traffic volume on the quality of facsimile image transmission, the experiments were conducted during off-peak hours and peak hours of network traffic. As per the service provider the traffic during off-peak hours was only one fourth of that during the peak hours. Each transmission was repeated five times in order to increase the confidence level of the experimental result.

4. Results

The experimental results are organized in sections, where each section contains results of the respective method. Each experiment was repeated five times each during off-peak hours and peak hours of network traffic.

4.1. Facsimile Transmission Using Traditional PSTN

As shown in the figure 5, the FIQ parameter revealed that the image quality was within the acceptable range (17.9 to 18.6) during off-peak hours and peak hours of network traffic. No significant image quality degradation was revealed. The FIQ parameter was almost comparable for the off-peak hours and peak hours except in one case. The normalized transmission time FNTT parameter varied between 1 and 1.05 as shown in figure 6 for the traditional facsimile transmission using PSTN during off-peak hours and peak hours. FNTT parameter was same during most of the experiments.
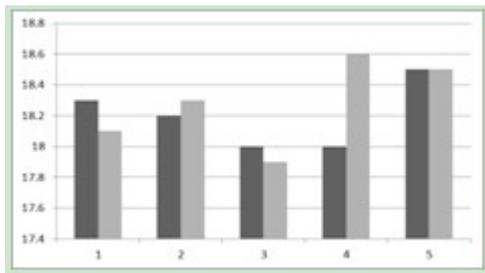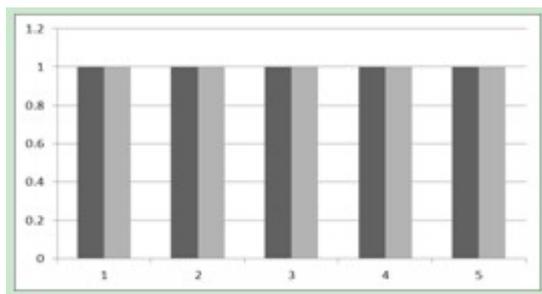
F_{IQ} off peak hours, $\square$ F_{IQ} peak hours
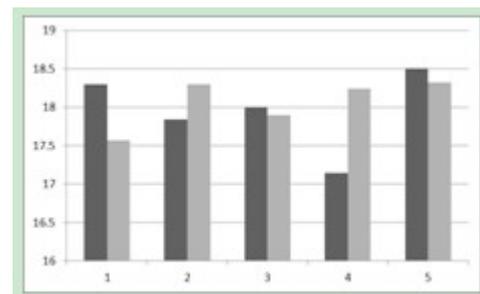Fig. 5: FIQ for traditional facsimile using PSTN
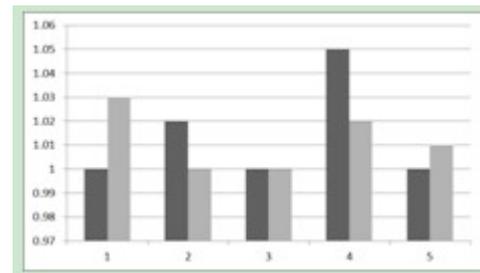
F_{NTT} off peak hours, $\square$ F_{NTT} peak hours
Fig. 6: FNTT for traditional facsimile using PSTN

F_{SR} off peak hours, $\square$ F_{SR} peak hours
Fig. 7: FSR for traditional facsimile using PSTN

FSR off peak hours, $\square$ FSR peak hours
Fig. 8: FSR for traditional facsimile using PSTN

The FSR parameter as shown in figure 7 revealed that there were no unsuccessful transmissions during the off-peak hours and peak hours for the facsimile transmission using traditional PSTN. The FSR parameter was within an acceptable range (17.14 to 18.5) during the off-peak hours as shown in figure 8. It was within the tolerable range (17.57 to 18.3) also for the peak-hour facsimile transmission using traditional PSTN. All the parameters were within the tolerable range for the facsimile transmissions during the off-peak hours and peak hours using traditional PSTN. The experiments revealed that the facsimile transmission using traditional PSTN has good image quality and that it was reliable.

4.2. Real Time Facsimile Transmission

As shown in the figure 9, the FIQ parameter revealed that the image quality was within the acceptable range (above 16.88) during off-peak hours and peak hours of network traffic. No significant image quality degradation was revealed. The FIQ parameter was almost comparable for the off-peak hours and peak hours except in two cases. The normalized transmission time FNTT parameter varied between 1 and 1.03 as shown in figure 10 for the real-time facsimile transmission during off-peak hours and peak hours. FNTT parameter was same during most of the experiments. The FSR parameter as shown in figure 11 revealed that there were no unsuccessful transmissions during the off-peak hours and peak hours for the real-time facsimile transmission. The FSR parameter was within an acceptable range (18.32 to 18.9) during the off-peak hours as shown in figure 12. It was within the tolerable range (18.16 to 18.6) also for the peak-hour real-time facsimile transmission. All the parameters were within the tolerable range for the real-time facsimile

transmissions during the off-peak hours and peak hours. The experiments revealed that the real-time facsimile transmission has good image quality and that it was reliable.
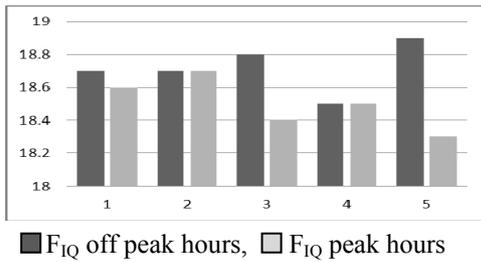

F_{IQ} off peak hours, ☐ F_{IQ} peak hours

Fig. 9: FIQ for real-time facsimile transmission

F_{NTT} off peak hours, ☐ F_{NTT} peak hours
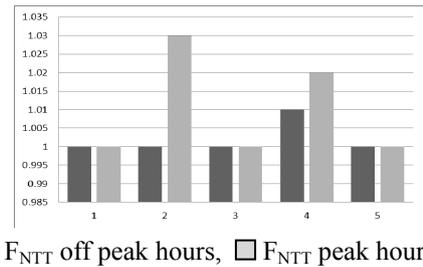
Fig. 10: FNTT for real-time facsimile transmission

F_{SR} off peak hours, ☐ F_{SR} peak hours

Fig. 11: FSR for real-time facsimile transmission

F_{SR} off peak hours, ☐ F_{SR} peak hours
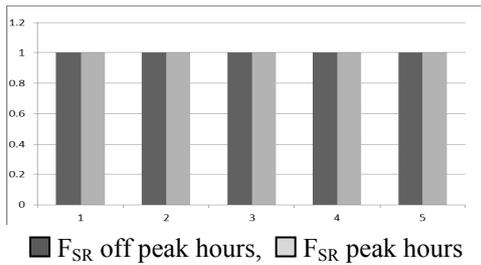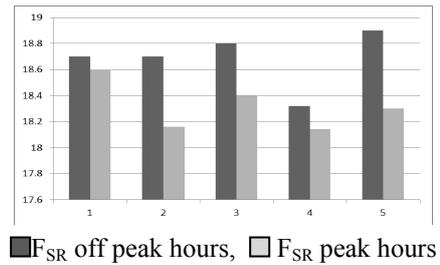
Fig. 12: FSR for real-time facsimile transmission

4.3. Store-and-forward Facsimile Transmission

As shown in the figure 13, the FIQ parameter revealed that the image quality was within the acceptable range (above 16.88) during off-peak hours and peak hours of network traffic. No significant image quality degradation was revealed. The normalized transmission time FNTT parameter varied between 1 and 1.03 as shown in figure 14 for the store-and-forward facsimile transmission during off-peak hours and peak hours. FNTT parameter was same during most of the experiments. The FSR parameter as shown in figure 15 revealed that there were no unsuccessful transmissions during the off-peak hours and peak hours for the store-and-forward facsimile transmission. The FSR parameter was within an acceptable range (18.5 to 18.8) during the off-peak hours as shown in figure 16. It was within the tolerable range (18.4 to 18.86) also for the peak-hour store-and-forward facsimile transmission. All the parameters were within the tolerable range for the store-and-forward facsimile transmissions during the off-peak hours and peak hours. The experiments revealed that all the methods real-time facsimile transmission, store-and-forward facsimile transmission and facsimile transmission using traditional PSTN has good image quality and that it was reliable.
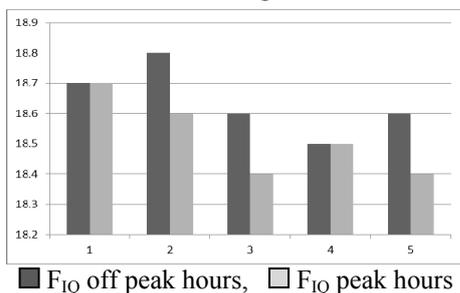
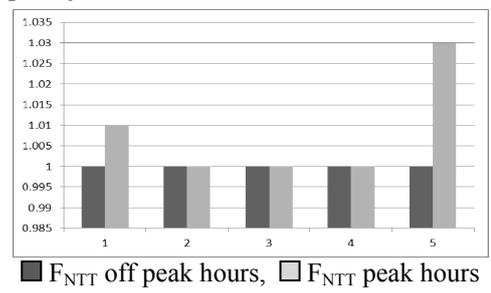
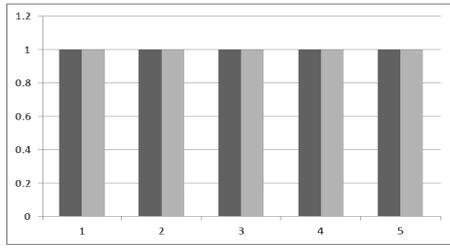
F_{IQ} off peak hours, ☐ F_{IQ} peak hours
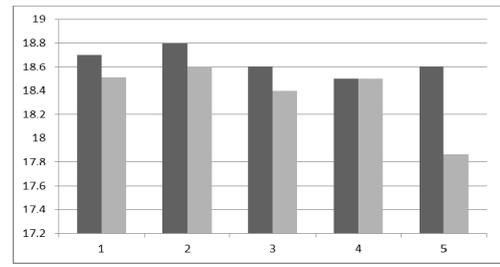
Fig. 13: FIQ for store and forward facsimile transmission

F_{NTT} off peak hours, ☐ F_{NTT} peak hours

Fig.14: FNTT for store and forward facsimile transmission

| Fig. 15: FSR for store and forward facsimile transmission | Fig.16: FSR for store and forward facsimile transmission |

5. Experimental Analysis

Analysis of variance and t-test were conducted to determine which of the three methods i.e. real-time facsimile transmission, store-and-forward facsimile transmission or facsimile transmission using traditional PSTN is better or whether the performance of all the methods were same. The hypothesis for the variance analysis and t-test is defined as 'there is no difference in performance of facsimile transmission using the three methods'. The average of the FSR values for peak hours and off-peak hours of each method was used for the variance analysis. The F value obtained was 9.38 which were higher than FCrit which was 3.89. Hence the hypothesis is false. So the different methods differed in performance. Further the t-test was conducted. Test 1 was conducted to compare the real-time facsimile transmission with store-and-forward facsimile transmission. Test 2 was conducted to compare the real-time facsimile transmission with traditional PSTN-based facsimile transmission. Test 3 was conducted to compare the store-and-forward facsimile transmission with traditional PSTN-based facsimile transmission. The results are shown in table 1. The tcrit is 10% more than the respective P value in all the three tests. So the hypothesis is rejected.

Table 1 t-test results

	Test 1	Test 2	Test 3
P value	0.965	0.008	0.007
t Critical value	2.3	2.3	2.3

The mean value for the three different methods of facsimile transmission is given in table 2. The mean for store-and-forward facsimile is more than that of real-time facsimile and traditional facsimile using PSTN. This means that store-and-forward facsimile yields better performance than the other two methods. Store-and-forward facsimile transmission is more reliable and has better performance than the real-time facsimile transmission and traditional PSTN-based facsimile transmission.

Table 2 Mean values

	Real-time facsimile	Store-and-forward facsimile	Traditional facsimile using PSTN
Mean	18.502	18.507	18.011

6. Result Discussion

Various characteristics of the packet-based communication such as delay, jitter and packet loss [14] affects the performance degradation of facsimile transmission in an IP network. Although the image quality of facsimile transmission using real-time and store-and-forward methods were comparable to some degree, store-and-forward transmission had better image quality. This was due to the fact that IP network impediments create several timing issues while using T.38 for facsimile transmission [17].

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8. References

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