Facsimile Communication over IP Networks

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by
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Certificate

This is to certify that the work contained in the thesis entitled "*Facsimile Communication over IP Networks*", by *B.V.S. Girish*, has been carried out under my supervision and that this work has not been submitted elsewhere for a degree.

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Abstract

Communication over the packet-switched networks such as IP networks is far more efficient and cost-effective than the circuit-switched networks such as PSTN. It is therefore desirable to use IP network as transport for circuit-switched applications such as voice and facsimile. However, voice transport over IP network is common. In this work, we have designed and implemented a facsimile gateway for the transmission of facsimile documents between two standard terminal devices connected to a telephone network using the IP network for part of the communication path and between a terminal device connected to a telephone network and an electronic mail service accesible via an IP network. Our design is based on the store-and-forward mode of transmission in which the facsimile document does not reach the destination before the sending terminal device terminates the facsimile call. So the sending terminal device will receive the confirmation of delivery to the recipient in a separate fax transmission.

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Chapter 1

Introduction

1.1 Traditional Fax

Facsimile (Fax) is an application for sending a document from one terminal device to another. Traditionally, the fax transmission occurs over telephone network. In traditional facsimile (which refers to implementations of T.30 protocol [ITU96a]), communication over the telephone network is accomplished using modems (Section 2.4). The transmission of data from one end to the other is preceded by negotiation of capabilities of the sender and the receiver (to ensure that the receiver can decode and render the received document) and followed by confirmation of delivery. Over time, there have been many extensions to the basic image model, to allow for additional compression methods and for representation of images with grey-scale and color. Other delivery extensions have included sub-addressing (additional signals after the call is established to facilitate automated routing of faxes to desk-tops or mailboxes).

Typically, the terminal device consists of a paper input device (scanner), a paper output device (printer), and (a limited amount of) processing power. Traditional facsimile has a simple user operational model. The sender

1. inserts paper into a device,
2. dials a number corresponding to the destination,
3. presses the 'start' button on the device,

4. the sending device connects to the receiving device using the telephone network,
5. the sending device scans the paper and transmits the image of the paper,
6. the remote device receives the transmitted image and prints it on paper, and
7. upon completion of transmission and successful processing by the recipient, the sender is notified of success.

The operation (5) of transmission consists of:

5a. *Negotiation:* The capabilities of the sender and recipient the are exchanged, and suitable mutually acceptable parameters for the communication are selected.

5b. *Scanning:* Digitized images of pages of a document are created.

5c. *Compression:* The image data is encoded using a data compression method.

5d. *Transmission:* Data is sent from one terminal to the other.

In addition, after the image data is sent, the operations consists of:

i. *completed delivery:* the sending device indicates the completion of transmission to the recipient

ii. *completed receipt:* the recipient receives the indication of message completion from the sending device,

iii. *processing and disposition:* the recipient processes the message and generates a signal to indicate to the sending device whether the document was received properly.

1.2 Internet Fax

Internet Fax refers to a document transmission mechanism where at least part of the communication path is an IP Network. Communication might be between:

- Two fax terminals, both connected to a telephone network with an IP network in between. This requires use of a PSTN to IP (onramp) gateway and an IP to PSTN (offramp) gateway. For example, in Figure 1.1, the communication path would be:

```
fax terminal F1 -> onramp gateway G1 -> offramp gateway G2 -> fax terminal
```

- A fax terminal and an Internet node such as email server or fax aware server. The initial part of the communication is over telephone network and the later part is over IP network. This requires an onramp gateway. For example, in Figure 1.1, the fax terminal F1 transmits the document to the onramp gateway and based on the recipient information provided by the sender at F1, the onramp gateway transmits the document to the mail box of the recipient on host H1.

```
fax terminal F1 -> onramp gateway G1 -> Mail box on host H1
```

- An Internet node and a fax terminal. In this case, the initial part of the communication is over an IP network and the later part is over PSTN. This requires an offramp gateway. For example, in Figure 1.1, email service on host H1 sends a document to the offramp gateway G2 along with the destination fax number. The offramp gateway dials the destination fax number and transmits the document to the recipient fax terminal F2.

```
Email service on host H1 -> offramp gateway G2 -> fax terminal F2
```

Operation (2) of the user operational model of fax could now be as follows:

2a. Sender dials the number corresponding to the fax onramp gateway.

2b. Onramp gateway answers the call and asks for the destination fax number.

2c. Sender dials the destination fax number.

2d. The onramp gateway determines the IP address of the server corresponding to the fax number. It also determines whether the fax can be sent to an email box instead of a fax terminal (Section 3.4).

2e. If the fax can be sent to an email box (e.g. to mail box on host H1 or G2 in Figure 1.1), the onramp gateway asks for the user-id. The sender can enter the user-id, if known. The onramp gateway determines the email address (Section 3.4.2) based on the information provided by the sender (fax number and user-id).

2f. The onramp gateway now has specific information about the destination. If the destination is a fax terminal or an email box, it asks the sender to proceed with the fax transmission. If the destination cannot be reached (invalid fax number or user-id), it terminates the connection.

1.2.1 Modes of Internet Fax

Unlike in traditional fax where there is a single mode of operation, fax over the Internet can occur in several modes [Mas97].

- Real-Time Internet fax: This allows for two facsimile terminals conforming to T.30 protocol to engage in a document transmission in a way that all of the T.30 communication protocol is preserved, i.e., all the signals corresponding to the T.30 protocol (for example, session establishment) are exchanged between the two end terminals [Sil97].

- Store-and-forward Internet fax: This entails a process of storing the entire document at an Internet host called a staging point (for example, an onramp or an offramp gateway), prior to transmitting it to the next staging point. Transfer can be directly between sender and recipient or there can be a series of intermediary staging points. In Figure 1.1, the fax terminal F1 establishes a fax session and transmits the document to the onramp gateway G1. F1 gets a notification that the transmission to G1 was (un)successful. When G1 receives the complete document, it transmits the document to the offramp gateway G2. Upon complete reception of the document, G2 transmits it to the fax terminal F2.

- Session Internet fax: In this mode of fax, the delivery notification is provided to the transmitting terminal prior to disconnection. Unlike *store-and-forward*, there is an expectation that direct communication, negotiation, and retransmission can take place between the two endpoints. But it is not necessary that the

T.30 protocol be preserved end-to-end as in the case of real-time fax. In Figure 1.1, the fax terminal F1 establishes a connection with the onramp gateway G1 and G1 simultaneously establishes a connection with offramp gateway G2 which in turn establishes a connection with the fax terminal F2. The T.30 protocol signals need not necessarily be transmitted between the end terminals F1 and F2 unlike in real-time mode of fax. Prior to disconnection, F1 gets a notification that the transmission to F2 was (un)successful.

1.3 Need for Internet Fax

Traditional facsimile has proved to be a reliable application and is in widespread use. However, with the help of Internet, enhanced services can be provided at economical costs.

- Traditional facsimile document transmission is very expensive especially over international long distances. The same document when transmitted over the Internet would cost very less.
- Another example of enhanced service is that, the sender can send documents to multiple recipients in a single transmission (using IP multicast). The recipients can be Internet servers or traditional fax terminals.
- With traditional fax, a Group 3 fax terminal (Section 2.1.1) cannot communicate with a Group 4 fax terminal. However, with Internet fax, this would be possible by building gateways.

The work in this direction has only started a few years back. A related area of interest is Internet Telephony which refers to the voice communication over the IP network. Internet Telephony has been a topic of research for quite some time and many commercial products are available which provide real-time voice communication over the Internet.

But Internet Telephony per se will not solve the Internet fax problems. The reason being that, telephony requires protocols for the establishment and release of connections. Once the connection is established, the end users can carry out the conversation for an unspecified amount of time. Any delay in the propagation of signals would only hamper the quality of the service. Since facsimile is basically a telephony application, it involves the usual connection establishment and release common to the telephony. But the additional task will be to exchange the documents based on a standard protocol and this involves strict protocol timings. Internet does not provide real-time guarantees. This creates a bottleneck for having a real-time facsimile communication over the Internet. Any delay in the propagation of signals would mean that the session would be abruptly terminated.

1.4 Existing Fax Software

There are many fax softwares based on client-server architecture which can send faxes over the PSTN network. Typically, the server receives documents from the clients over the IP network for transmission to the fax terminal. Many email to fax gateways exist which transmit an email message received over the Internet to a fax terminal over the PSTN. Some fax softwares also route an incoming facsimile document from a fax terminal to an email box of the recipient in a limited environment (e.g. in the receiving host or a domain). We briefly describe one of the existing fax softwares.

1.4.1 HylaFax

HylaFAX is a facsimile system for UNIX systems. It supports:

- sending facsimile,
- receiving facsimile,
- polled retrieval of facsimile, etc.

Incoming facsimile are stored in a receiving area as TIFF (Section 2.2.2) files and may be automatically delivered by mail and/or printed. A fax server status program can be used to monitor the send and receive queues, as well as the state of facsimile servers.

The software is structured around a client-server architecture. Fax modems may reside on a single machine on a network and clients can submit an outbound job from any machine that can communicate with the machine on which the modems reside. Clients and server communicate over a protocol which is similar to FTP. One can also use standard FTP to communicate to the server directly. An access control mechanism is included to control which users on which machines may submit jobs.

Multiple modems on a single server machine are effectively scheduled for high throughput. Support is provided for scheduling jobs during off-peak hours based on the destination phone numbers (e.g. long distance calls may be scheduled for off-peak phone rates). An access control mechanism can be used to restrict the class of phone numbers called.

1.5 Scope of the Work

In this thesis, we have designed and implemented the Onramp and the Offramp fax gateways for store-and-forward mode of fax. The design provides for a Group 3 fax terminal to transmit documents to another Group 3 fax terminal any where in the world. A Group 3 fax terminal can also transmit documents to an email box of one or more recipients (Figure 1.1) using onramp gateway. For example, in Figure 1.1, the sender at fax terminal F1 will first transmit the document to the onramp gateway (G1) after providing the recipient information. Based on this information (like fax number or user-id), the G1 determines whether the recipient is a fax terminal or an email box. G1 then transmits the document to the offramp gateway G2 for further transmission to F2 or to the host H1 for delivering to the mail box. The sender will get the Delivery Status Notification indicating failure or success in a separate fax transmission.

We have implemented the design on the *Linux* Operating System. In the implementation, we have assumed that the onramp fax gateway has the information about all the offramp fax gateways for IP Address determination (Section 3.4.1). We have also assumed that the sender can transmit to only a single email recipient.

1.6 Organization of the Thesis

In Chapter 2, we discuss related technologies. Traditional fax transmission is discussed which includes a description of different signals and the encoding scheme. Next, we discuss the mail transport over IP networks. Starting with the Simple Mail

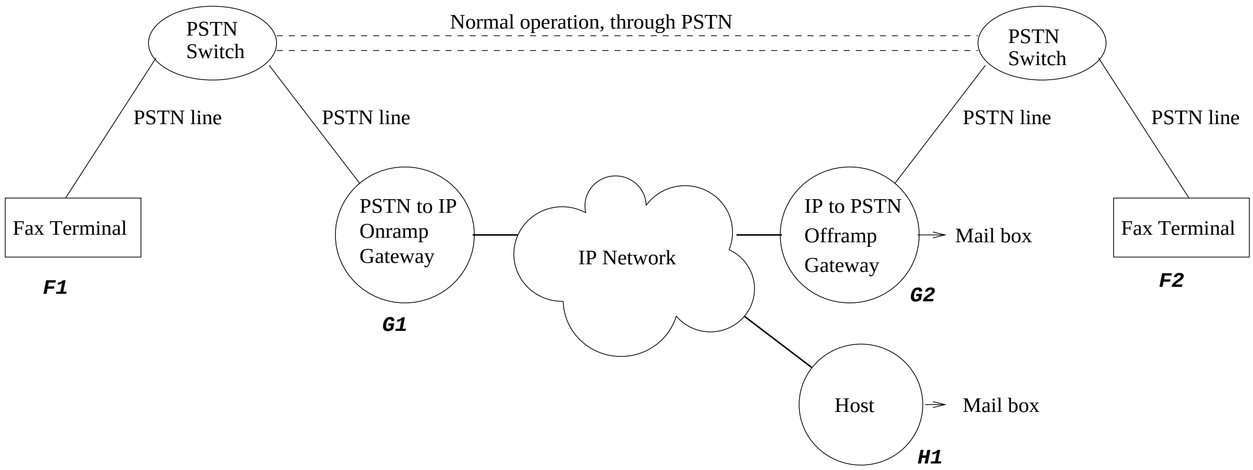

Figure 1.1: Facsimile Transmission over IP

Transport Protocol (SMTP) [Pos82], we proceed to describe the extended version of SMTP which is required for delivery notifications and Multipurpose Internet Mail Extensions (MIME) [FB96a] which is required for encoding and sending the document image as an attachment.

In Chapter 3, we present the design of the fax gateway that we have developed. We describe the design of various interfaces. Then we discuss a scheme for address determination. Finally, we describe the delivery notification method that we have employed.

In Chapter 4, we discuss implementation of our design. We describe each of the modules and their interaction with each other.

In Chapter 5, we present the conclusions and suggest future work.

Chapter 2

Background

2.1 Fax Transmission over PSTN

2.1.1 Fax Standards - Group 1, 2, 3, and 4

Fax standards have emerged from analog transmission units (Group 1,2) in the late sixties and early seventies to the digital transmission units (Group 3,4) in the eighties. The Group 3 facsimile standard however, has been in wide use for two decades now. The salient points about these standards are summarized below.

- Group 1
  - Became a standard in 1968 for analog facsimile devices to communicate over analog telephone lines.
  - Unreliable, six minutes per page, poor resolution.
  - The characteristics and operation of the facsimile devices conforms to the ITU-T Recommendation T.2.
- Group 2
  - Became a standard in 1976 for analog facsimile devices to communicate over analog telephone lines.
  - Worldwide compatibility.

  - Three minutes per page.
  - The characteristics and operation of the facsimile devices conforms to the ITU-T Recommendations T.30 and T.3.

- Group 3
  - Became a standard in 1980 for digital facsimile devices to communicate over analog telephone lines.
  - Provides flexibility to add innovative features without compromising basic compatibility with standard Group 3 machines.
  - 6 to 30 seconds per page, plus about 15 seconds for the first page initial handshake.
  - The characteristics and operation of the facsimile devices conforms to the ITU-T Recommendations T.30 and T.4 [ITU96b].
  - It is the current standard.

- Group 4
  - Became a standard in 1984 for digital facsimile devices to communicate over digital telephone lines.
  - Designed for ISDN 64 kbps.
  - The characteristics and operation of the facsimile devices conforms to the ITU-T Recommendations T.563, T.503, T.521, T.6, T.62, T.70, T.72, T.411 to T.417.
  - Incompatible with Group 3.

2.1.2 Fax Transmission Protocol - T.30

The T.30 Recommendation defines the procedures which are necessary for document transmission between two facsimile terminals in the public switched telephone network.

These procedures essentially comprise the following five separate and consecutive phases as shown in Figure 2.1:

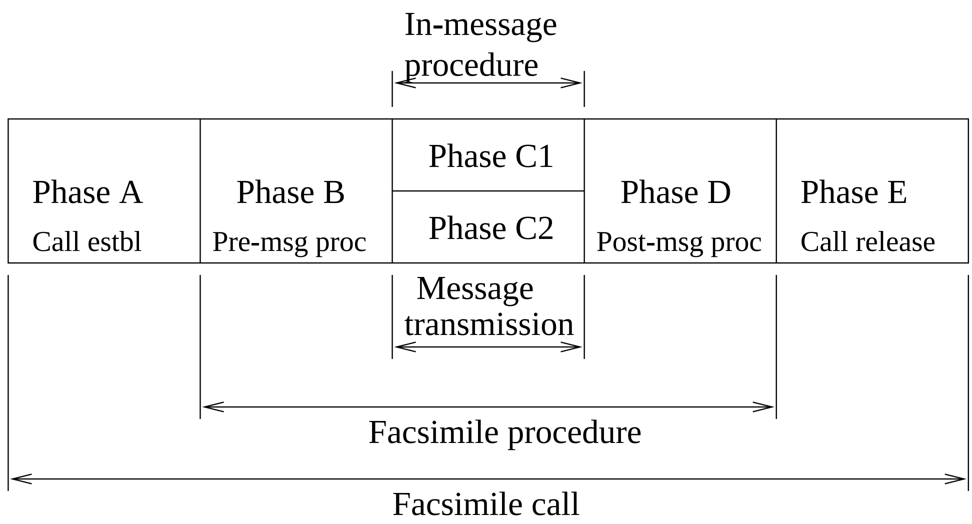

Figure 2.1: Time sequence of a facsimile call

Phase A - Call establishment

Call establishment consists of establishing a connection between the calling and called terminals and exchanging the fax tones. It can be realized manually and/or automatically.

In manual operation at the calling terminal, the operator dials the number and hears the ringing tone. When the called terminal answers the call, the calling terminal operator hears the fax tone immediately or can have a verbal exchange depending on whether the called terminal answering is automatic or manual. The calling facsimile terminal is then switched to line which transmits the fax tone to the called terminal.

In manual operation at the called terminal, the operator answers the call when the ring is heard. Depending on whether the calling terminal call establishment is manual or automatic, the operator can have a verbal exchange or hears the calling fax tone. The operator then has to switch the facsimile terminal to line.

In automatic operation at the calling terminal, the terminal detects the dial tone and dials the desired number. When the called terminal answers the call, the calling terminal immediately transmits a fax calling tone.

In automatic operation at the called terminal, the terminal answers the call when there is an incoming ring and transmits the fax called tone immediately.

▮ *Phase B - Pre-message procedure*

The pre-message procedure consists of the identification of capabilities and the commanding of the chosen conditions as well as confirmation of acceptable conditions.

Identification section

This consists of:

- capabilities identification. The called terminal sends this information to the calling terminal. e.g. bit rate, page length and width, data compression format, scan time per line etc.
- confirmation for reception. The called terminal sends this message to the calling terminal.
- terminal identification (option). e.g. telephone number, name of the organization etc.
- non-standard facilities identification (option). e.g. for enhanced security.

Command section

This consists of:

- capabilities command for specifying the chosen (negotiated) capabilities based on the identified capabilities.
- training which involves sending a series of 0s, to give an indication of the acceptability of the channel for the chosen data rate.
- synchronization of the calling and called terminal.

▮ *Phase C1 - In-message procedure*

The in-message procedure takes place at the same time as message transmission and controls the complete signalling for in-message procedure. i.e. the control signals required for the transfer of the message are sent along with the message. e.g. in-message synchronization, error detection and correction and line supervision.

▮ *Phase C2 - Message transmission*

The message transmission procedure is discussed in Recommendation T.4 which includes coding scheme (Section 2.2.1), modulation and demodulation, etc.

▮ *Phase D - Post-message procedure*

The post-message procedure includes information regarding:

- end-of-message signalling: This is sent by the calling terminal to indicate to the called terminal that all the pages in the document have been transmitted and to return to phase B for reception of another document.
- multi-page signalling: This is sent by the calling terminal to indicate to the called terminal that a page of the document has been completely transmitted and to return to phase C for reception of the next page in the same document.
- end-of-facsimile procedure signalling: This is sent by the calling terminal to the called terminal to indicate that all the pages in the document have been completely transmitted and that no further documents are forthcoming and to proceed to phase E.
- confirmation signalling: This is sent by the called terminal to confirm the receipt of the message in response to any of the above information sent by the calling terminal.

▮ *Phase E - Call release*

The calling terminal transmits a disconnect signal to the called terminal for the release of the call. No response is expected.

▮ *Signalling*

The signalling between the terminals uses the binary coded signalling system which is based on a High Level Data Link Control (HDLC) format developed for data transmission procedures. The basic HDLC structure consists of a number of frames,

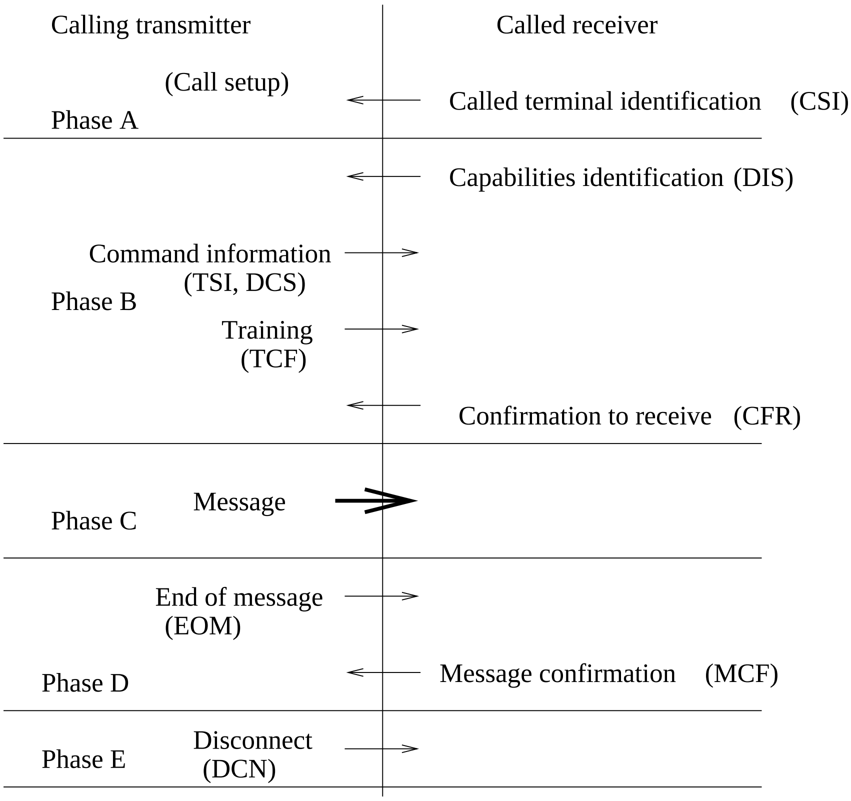

Figure 2.2: Signal sequence

each of which is subdivided into a number of fields. It provides for frame labelling, error checking and confirmation of correctly received information.

T.30 recommendation provides for the called terminal to either transmit or receive. Figure 2.2 shows the signal sequence when the called terminal is transmitting. We briefly describe some of the important message exchanged between the calling and called terminals.

Initial Identification

The following messages are sent from the called to the calling terminal.

1. Digital Identification Signal (DIS) - This is the capabilities identification signal transmitted by the called terminal to the calling terminal in phase B. This information helps the calling terminal to know the characteristics of the called terminal and decide the capabilities parameters to be employed for the session.

2. Called Subscriber Identification (CSI) - This optional signal may be used to provide the specific identity of the called subscriber by its international telephone number. This signal is sent by the called terminal in phase A.

Command to receive

These messages are sent from the transmitter to the receiver.

1. Digital Command Signal (DCS) - This signal is in response to the DIS signal sent by the called terminal. This indicates the capabilities used in the session.
2. Transmitting Subscriber Identification (TSI) - This optional signal indicates the identification of the transmitting terminal. It may be used to provide additional security to the facsimile procedures.
3. Sub-address (SUB) - This optional signal indicates that the information contained in this is a sub-address in the called subscribers domain. It may be used to provide additional routing information in the facsimile procedure.
4. Password (PWD) - This optional signal indicates that the information contained in this is a password for transmission.
5. Training Check (TCF) - This is a training signal which is sent by the calling terminal to give an indication of the acceptability of the channel for the chosen data rate. Its format is a series of 0s for 1.5 seconds. No HDLC frame is required for this command.

Pre-message response signals

These signals are sent from the receiver to the transmitter.

1. Confirmation To Receive (CFR) - This is in response to the training signal (TCF) from the called terminal confirming that the entire pre-message procedure has been completed and the message transmissions may commence in phase C.
2. Failure To Train (FTT) - This is in response to the training signal (TCF) rejecting the training signal and requesting a retrain.

Post-message commands

These signals are sent from the transmitter to the receiver.

1. End Of Message (EOM) - To indicate the end of a complete page of facsimile information and to return to the beginning of phase B.
2. MultiPage Signal (MPS) - To indicate the end of a complete page of facsimile information and to return to the beginning of phase C.
3. End Of Procedures (EOP) - To indicate the end of a complete page of facsimile information and to further indicate that no further documents are forthcoming and to proceed to phase E.

Post-message responses

These signals are sent from the receiver to the transmitter.

1. Message Confirmation (MCF) - To indicate that a complete message has been satisfactorily received and that additional messages may follow. (This is a positive response to MPS, EOM, EOP.)
2. Retrain Positive (RTP) - To indicate that a complete message has been received and that additional messages may follow after retransmission of training and confirmation to receive (CFR).
3. Retrain Negative (RTN) - To indicate that the previous message has not been satisfactorily received. However, further receptions may be possible, provided training is retransmitted.

Other line control signals

These signals are sent for the purpose of handling errors and controlling the state of the line.

1. Disconnect (DCN) - This command which is typically sent by the transmitter for terminating the facsimile session, indicates the initiation of phase E (call release). This command requires no response.

2. Command Repeat (CRP) - This optional response sent by the receiver indicates that the previous command was received in error and should be repeated in its entirety. This is used only in the case of a pre-message (phase B) command being received in error.

2.2 Image File Formats

2.2.1 File Format for Group 3 Terminals - T.4

T.4 recommendation defines the characteristics of Group 3 facsimile terminals which enable documents to be transmitted on the public switched telephone network. These terminals enable black and white documents to be transmitted and also colour documents if the terminal conforms to the optional colour mode of the recommendation. The characteristics defined in this recommendation include dimensions (resolution, size of documents etc.) that the terminals should support, transmission time per total coded scan line (the sum of data bits, fill bits and end-of-line bits constitute a total coded scan line), coding scheme, modulation and demodulation among others. We briefly describe the coding scheme below.

■ *Coding Scheme*

T.4 recommendation describes many coding schemes. We briefly describe the coding scheme which is recommended for Group 3 terminals.

One-dimensional Coding Scheme

- *Data:* A line of data is composed of a series of variable length code words. Each code word represents a run-length of either all white or all black. White runs and black runs alternate. A total of 1728 picture elements represent one horizontal scan line of 215mm length.

  In order to ensure that the receiver maintains colour synchronization, all data lines will begin with a white run length code word. If the actual scan line begins with a black run, a white run length of zero will be sent. Black and white run lengths, up to a maximum length of one scan line are defined by the code words which are of two types - the terminating code words and the make-up code words. Each code word is a unique sequence of bits. There is a terminating code word for each run length in the range of 0 to 63 pels (picture elements). However, a make-up code word is there for run lengths which are a multiple of 64 up to a maximum run length of 1728 pels. Each run length is represented by either one terminating code word or one make-up code word followed by a terminating code word.

Run lengths in the range of 0 to 63 pels are encoded with their appropriate terminating code word (code words are different for black and white run lengths).

Run lengths in the range 64 to 1728 pels are encoded first by the make-up code word representing the run length which is equal to or shorter than that required. This is then followed by the terminating code word representing the difference between the required run length and the run length represented by the make-up code.

- *End-of-line (EOL):* This code word follows each line of data. It is a unique code word that can never be found within a valid line of data. Therefore, resynchronization after an error burst is possible. In addition, this signal will occur prior to the first data line of a page.

- *Fill:* A pause may be placed in the message flow by transmitting *Fill*. Fill may be inserted between a line of Data and an EOL, but never within a line of Data. Fill must be added to ensure that the transmission time of Data, Fill and EOL is not less than the minimum transmission time of the total coded scan line established in the pre-message control procedure. The maximum transmission time of Fill bits is less than 5 seconds.

- *Return To Control (RTC):* The end of a document transmission is indicated by sending six consecutive EOLs. Following the RTC signal, the transmitter will send the post page message commands in the framed format and the data signalling rate of the control signals defined Recommendation T.30.

2.2.2 File Format for Internet Fax - TIFF

The Tag Image File Format (TIFF) [MZB+98] is used to represent the data content and structure generated by the current suite of ITU-T Recommendations for Group 3 facsimile.

The TIFF-based file format enables standardized messaging-based fax over the Internet. TIFF has historically been used for handling fax image files in applications such as store-and-forward messaging.

TIFF provides a means for describing, storing and interchanging raster image data. A primary goal of TIFF is to provide a rich environment within which applications can exchange image data.

2.3 Mail Transport over IP Networks

2.3.1 SMTP

The Simple Mail Transfer Protocol (SMTP) [Pos82] is designed to provide a mail transport service which is reliable and efficient. SMTP generally uses the TCP/IP protocol suite which provides reliable communication, for transmission of e-mails.

■ *The SMTP Model*

The SMTP design is based on the following model of communication: as result of a user mail request, the sender-SMTP establishes a two-way transmission channel to a receiver-SMTP. The receiver-SMTP may be either the ultimate destination or an intermediate node. SMTP commands are generated by the sender-SMTP and sent to the receiver-SMTP. SMTP replies are sent from the receiver-SMTP to the sender-SMTP in response to the commands. The dialog is purposely lock-step, one-at-a-time.

The SMTP provides mechanisms for the transmission of e-mail; directly from the sending user's host to the receiving user's host when the two host are connected to the same transport service (IP network), or via one or more relay SMTP-servers when the source and destination hosts are not connected to the same transport service.

To be able to provide the relay capability the SMTP-server must be supplied with the name of the ultimate destination host as well as the destination mailbox name.

When the same message is sent to multiple recipients the SMTP encourages the transmission of only one copy of the data for all the recipients at the same destination host.

Commands are not case sensitive. But this is not true of mailbox user names. For some hosts the user name is case sensitive, and SMTP implementations must take care to preserve the case of user names as they appear in mailbox arguments. Host names are not case sensitive.

The SMTP Procedures

The basic procedure used in SMTP is described below.

Mail transactions

There are three steps to SMTP mail transactions. Once the transmission channel is established, the transaction is started with a MAIL command which provides sender identification. One or more RCPT commands follow which provides the receiver information. Then a DATA command gives the mail data. And finally, the end of mail data indicator confirms the transaction.

The first step in the procedure is the MAIL command. The <reverse-path> contains the source mailbox.

```
MAIL FROM:<reverse-path> <CRLF>
```

This command tells the SMTP-receiver that a new mail transaction is starting and to reset all its state tables and buffers of any previous transaction in the session, including any recipients or mail data. It gives the reverse-path which can be used to report errors. If accepted, the receiver-SMTP returns an OK reply.

The <reverse-path> can contain more than just a mailbox. The <reverse-path> can be a reverse source routing list of hosts and source mailbox. The first host in the <reverse-path> should be the host sending this command.

The second step in the procedure is the RCPT command.

```
RCPT TO:<forward-path> <CRLF>
```

This command gives a forward-path identifying one recipient. If accepted, the receiver-SMTP returns an OK reply, and stores the forward-path. If the recipient is unknown, the receiver-SMTP returns a Failure reply. This step can be repeated any number of times.

The <forward-path> can contain more than just a mailbox. The <forward-path> is a source routing list of hosts and the destination mailbox. The first host in the <forward-path> should be the host receiving this command (receiver-SMTP).

The third step in the procedure is the DATA command.

```
DATA <CRLF>
```

If accepted, the receiver-SMTP returns an Intermediate reply and considers all succeeding lines to be the message text. When the end of text is received and stored the SMTP-receiver sends an OK reply.

Since the mail data is sent on the transmission channel, the end of the mail data must be indicated so that the command and reply dialog can be resumed. SMTP indicates the end of the mail data by sending a line containing only a period. The mail data includes the memo header items such as Date, Subject, To, Cc, From.

The end of mail data indicator also confirms the mail transaction and tells the receiver-SMTP to now process the stored recipients and mail data. If accepted, the receiver-SMTP returns an OK reply. The DATA command should fail only if the mail transaction was incomplete (for example, no recipients), or if resources are not available.

Opening and Closing

At the time the transmission channel is opened there is an exchange to ensure that the hosts are communicating with the hosts they think they are.

The following two commands are used in transmission channel opening and closing:

```
HELO <domain> <CRLF>
QUIT <CRLF>
```

In the HELO command the host sending the command identifies itself.

2.3.2 ESMTP

SMTP has provided a stable and effective method of mail transport. Nevertheless, the need for a number of protocol extensions has become evident. Rather than describing these extensions as separate and haphazard entities, the Extended SMTP (ESMTP) [KFR+94] in a straightforward fashion provides a framework in which all future extensions can be built in a consistent way.

Given this environment, the framework for the extensions consists of

1. A new SMTP command
2. A registry of SMTP service extensions
3. Additional parameters to the SMTP, MAIL FROM and RCPT TO commands

The EHLO command

A client SMTP supporting SMTP service extensions should start an SMTP session by issuing the EHLO command instead of the HELO command. If the SMTP server supports the SMTP service extensions it will give a successful response. If the SMTP server does not support any SMTP service extensions it will generate an error response.

▪ *DSN*

The SMTP protocol requires that an SMTP server provide notification of delivery failure, if it determines that a message cannot be delivered to one or more recipients. These notification messages are often insufficient to diagnose problems, or even to determine at which host or for which recipients a problem occurred. Moreover, there is no notification for the successful delivery. So there is a strong need for delivery status notification (DSN) [Moo96] service for Internet mail.

Such a service is provided by an extension to the SMTP protocol called the Delivery Status Notification. Using this mechanism, an SMTP client may request that an SMTP server issue or not issue a delivery status notification (DSN) under certain conditions.

An SMTP client wishing to request a DSN for a message may issue the EHLO command to start an SMTP session, to determine if the server supports any of several service extensions. If the server gives a successful response, and the response includes the EHLO keyword DSN, then the Delivery Status Notification extension is supported.

Ordinarily, when an SMTP server returns a successful response to the RCPT command, it agrees to accept responsibility for either delivering the message to the named recipient, or sending a notification to the sender of the message indicating that delivery has failed. However, an extended SMTP (*ESMTP*) server which implements this service extension will accept an extended RCPT command (described below) which alters the conditions for generation of delivery status notifications. The ESMTP client may also request whether the entire contents of the original message should be returned (as opposed to just the headers of that message), along with the DSN.

In general, an ESMTP server which implements this service extension will propagate delivery status notification requests when relaying mail to other SMTP-based Mail Transport Agents (MTA) which also support this extension, and makes a *best effort* to ensure that such requests are honored when messages are passed into other environments.

Additional parameters for RCPT and MAIL commands

The extended RCPT and MAIL commands are issued by a client when it wishes to request a DSN from the server, for a particular recipient. The extended RCPT and MAIL commands are identical to the RCPT and MAIL commands of SMTP, except that one or more of the following parameters appear after the sender or recipient address, respectively.

The NOTIFY parameter of the ESMTP RCPT command

A RCPT command issued by a client may contain the optional esmtp- keyword *NOTIFY*, to specify the conditions under which the SMTP server should generate DSNs for that recipient. The value of this parameter can be *NEVER*, *SUCCESS*, *FAILURE*, *DELAY*.

The meaning of the NOTIFY parameter values is generally as follows:

- A NOTIFY parameter value of *NEVER* requests that a DSN not be returned to the sender under any conditions.

- A NOTIFY parameter value containing the *SUCCESS* or *FAILURE* keywords requests that a DSN be issued on successful delivery or delivery failure, respectively.

- A NOTIFY parameter value containing the keyword *DELAY* indicates the sender's willingness to receive *delayed* DSNs. Delayed DSNs may be issued by the MTA (at which the message is delayed) if delivery of a message has been delayed for an unusual amount of time (as determined by the MTA). But the MTA still attempts for a particular amount of time to deliver the message. The absence of the DELAY keyword in a NOTIFY parameter requests that a delayed DSN not be issued under any conditions.

The RET parameter of the ESMTP MAIL command

The RET esmtp-keyword on the extended MAIL command specifies whether or not the message should be included in any failed DSN issued for this message transmission. If the RET esmtp-keyword is used, it must have an associated esmtp-value, which is one of the following keywords:

- FULL requests that the entire message be returned in any *failed* delivery status notification issued for this recipient.

- HDRS requests that only the headers of the message be returned.

If no RET parameter is supplied, the MTA may return either the headers of the message or the entire message for any DSN containing indication of failed deliveries.

The ENVID parameter to the ESMTP MAIL command

The ENVID esmtp-keyword of the SMTP MAIL command is used to specify an *envelope identifier* to be transmitted along with the message and included in any DSNs issued for any of the recipients named in this SMTP transaction. The purpose of the envelope identifier is to allow the sender of a message to identify the transaction for which the DSN was issued.

The ENVID esmtp-keyword must have an associated esmtp-value. No meaning is assigned by the mail system to the presence or absence of this parameter or to any esmtp-value associated with this parameter; the information is used only by the sender or his user agent.

2.3.3 MIME

One of the notable limitations of RFC 821/822 based mail systems is the fact that they limit the length of the text lines to 1000 characters of 7bit US-ASCII. This forces users to convert any non-textual data that they may wish to send into seven-bit bytes representable as printable US-ASCII characters before invoking a local mail UA (User Agent, a program with which human users send and receive mail). Examples of such encodings currently used in the Internet include pure hexadecimal, uuencode, the 3-in-4 base 64 scheme specified in RFC 1421, and many others. Another limitation is that, RFC 822 does not specify a format for non-text messages such as audio or images. It also does not support the use of character sets richer than US-ASCII. So additional specifications are needed.

The Multipurpose Internet Mail Extensions (MIME) [FB96a, FB96b] describes several mechanisms that combine to solve most of these problems without introducing any serious incompatibilities with the existing mail standards. In particular, it describes:

1. A MIME-Version header field, which uses a version number to declare a message to be conformant with MIME and allows mail processing agents to distinguish between such messages and those generated by older or non-conformant software, which are presumed to lack such a field. For example,

   ```
   MIME-Version: 1.0
   ```

2. A Content-Type header field, generalized from RFC 1049, which can be used to specify the media type and subtype of data in the body of a message and to fully specify the native representation (canonical form) of such data. For example,

   ```
   Content-type: text/plain; charset="us-ascii"
   ```

3. A Content-Transfer-Encoding header field, which can be used to specify both the encoding transformation that was applied to the body and the domain of the result. Encoding transformations other than the identity transformation are usually applied to data in order to allow it to pass through mail transport mechanisms which may have data or character set limitations. For example,

   ```
   Content-transfer-encoding: base64
   ```

4. Two additional header fields that can be used to further describe the data in a body, the Content-ID and Content-Description header fields.

2.4 Modems

A modem is a device that modulates data from digital signals to analog signals and vice-versa (e.g. modem used with PCs for dial-up connections). Since fax machines also need to transmit and receive digital data over the analog PSTN, there are dedicated modems inside fax machines called fax modems. Data/Fax modems are typically used with personal computers and can handle both data and fax information. The data is modulated in a standard format on an voice band carrier for transmission over the telephone network. The analog signals are then converted back into digital data by the receiving modem (demodulation). Different standards are used for fax and data.

2.4.1 Modem Fax Classes

A modem typically has one or more classes of operation. A class 0 modem (or modem configured to class 0) behaves as a data modem. Class 1 and class 2 modems support fax. With a class 1 fax modem, the software running on the host should handle all of the T.4 fax image and T.30 session protocol information and timing. Thus, the ability to communicate properly is a function of the software. With a Class 2 fax modem, the host software should generate a T.4 fax page image and send it to the fax modem a page at a time. The fax modem then handles the T.30 session protocol information and timing. This relieves the computer's CPU from some work. The ability to communicate is more a function of the fax modem than the software. It is to be noted that the T.30 protocol is also implemented partially on the host.

2.4.2 Host - Modem Communication

The communication between the host and the modem is achieved through the use of a set of commands known as 'AT' (attention) commands [Cir95]. The host sends these AT commands to the modem and the modem provides status information to the host in the form of response codes. The modem contains several storage locations called S-registers. The contents of the S-registers can be modified by using the AT commands. The behaviour of the modem is directed by the contents of the S-registers as well as directly by the AT commands.

All the commands sent to the modem must be preceded by an 'AT' and terminated by a carriage return <CR> (contents of S-register S3). The AT commands used for class 2 modem and the response codes are listed in Appendix A. After sending an AT command string to the modem, the host must wait for a response code from the modem before sending a new AT command string to the modem. For example,

- *ATDT597646<CR>* directs the modem to dial the number 597646 in *tone* mode. Here, *D* is the command to dial and *T* is the dial modifier to dial in tone mode.
- *ATS1?<CR>* is the command to read the contents of the S-register S1. The modem responds by providing the value contained in this register and the OK response code.
- *ATS0=3<CR>* is the command to modify the contents of the S-register S0 to the value 3. The modem responds with an OK response code. The contents of this register, n, directs the modem to answer the call automatically after n rings.

Chapter 3

Design of the Fax Gateway

A fax gateway is a service which acts as an interface to transfer facsimile documents between PSTN and IP networks. This gateway is connected on one side to PSTN and on the other side to an IP network. For a particular session of fax transmission, based on the function that a gateway performs, it can be classified as

- *Onramp fax gateway:* This is a service that can accept an incoming facsimile call from PSTN and forward the facsimile document via the Internet to any Internet service or node (including the fax offramp gateway).
- *Offramp fax gateway:* This is a service that can accept a facsimile document or a document intended for a fax terminal from the Internet and forward it to a traditional fax terminal over the PSTN.

Our design of the fax gateway consists of an interface to the PSTN network and two interfaces to the IP network, one of them is the mail transport system (*SMTP Sender*) for routing the fax document to an email box of the intended recipient and the other is the interface to communicate with the peer gateway (*Onramp/Offramp IP Interfaces*) for routing the fax document to the destination fax terminal.

3.1 PSTN Interface

The primary function of this interface is to send and receive the fax documents from a fax terminal over a PSTN connection. The other necessary functions are:

- Determining the IP address and Email address (optionally) based on the destination fax number and user-id if given by the sender. The actual task of determination is done by a different service (Section 3.4.1), but this module will send a request and wait for a successful response before proceeding with the fax transmission session with the sending fax terminal. In case no response is obtained or a negative response arrives, the fax session is aborted and a message to this effect is given to the sender prior to disconnection. This is applicable to the onramp gateway.

- Sending a Delivery Status Notification (Section 3.5) to the sender to indicate whether the delivery to the destination fax terminal was successful or not. This is applicable to the offramp gateway.

This module is designed for communicating with a Fax Class 2 modem. Since the T.30 protocol is primarily handled by the modem and partially by the host, the states, phases A through E in the host state diagrams (Figures 3.2 and 3.2) do not correspond to the T.30 phases.

3.1.1 State Diagram for Receiving

To begin with, the host waits in the IDLE state for the modem to give an indication of RING when there is an incoming facsimile call (Figure 3.1). When there is a RING indication, the host commands the modem to answer the call in the voice mode (#VLN=1). After the call is answered, host enters the ANSWERED state and the sender has to be given a voice message for dialing the fax number of the destination fax terminal. This fax number is used for IP address determination of the offramp gateway or of the server for determining the Email address. If required, the sender can be given another voice message for dialing the user-id if the facsimile document has to be routed to an email box. When the required details for transmitting the document to the recipient have been obtained, the sender is signalled to enter into facsimile mode (e.g. a message can instruct the sender to press the 'Start' button on the fax terminal). In case the sender fails to give the required information or if the given information is insufficient or invalid, then the host should instruct the modem to hang up and should go to the IDLE state.

Once the required information has been obtained, the host issues the Fax Answer command (ATA) to the modem and enters the PHASE_A state. Upon receipt of an Answer command from the host, the modem answers and generates the called fax (CED) tone. The modem then generates a DIS frame (Section 2.1.2) to send the receiver (modem) capabilities to the sender and hunts for the first T.30 negotiation frames. Upon detection of the first Phase B preamble, it reports the *fax connection response* (+FCON) message to the host. The host then enters the PHASE_B state. In this state, the host should receive the transmit station id (via the +FTSI:<id> response) and the current session results i.e. the capabilities that will be used for the session (via the +FDCS:<val> response) from the modem when it receives the T.30 TSI and DCS frames respectively from the sender.

When this is followed by OK response from the modem, the host issues the *Data Receive* (+FDR) command to the modem and enters PHASE_C state to receive the data. The modem indicates the confirmation to receive (+FCFR) and when it is ready to commence the data transfer, it issues a CONNECT message. When the host is ready to accept data, it signals the modem to start sending the received data to the host by issuing a <DC2> character (022) to the modem. The data received by the modem might contain special characters (e.g. control characters such as CANCEL <CAN>). For every occurrence of these characters, the modem prefixes an escape character (ASCII DLE character). When the host receives the data, it should destuff these escape characters. When the modem delivers the last byte of a page, it sends a character pair (<DLE><ETX>) to indicate the end of data stream and reports the Page Transfer Status (via the +FPTS:<ppr> response) which is actually the post page response (ppr) message generated by the modem. The *ppr* value indicates the quality of the received page. This is followed by a post page message from the remote facsimile station (via the +FET:<ppm> response) which signals the intentions of the remote station. The host now enters the PHASE_D state.

If the post page message (ppm) value indicates there are more pages in the same document, the host issues *Data Receive* (+FDR) command and enters PHASE_C data receive state. If the indication is that there are more documents, it enters PHASE_B state. If there are no more pages or documents, then the host issues a *Data Receive* (+FDR) command and enters PHASE_E state.

The modem holds the post page response message (ppr) to the remote facsimile station (MCF signal) (represented in the +FPTS parameter) until the next *Data Receive* (+FDR) command. The host may modify the *pprm* (+FPTS parameter) before issuing the *Data Receive* command which releases that message. So the host must issue a *Data Receive* command to release Post Page Response Messages irrespective of the post page message value.

In the PHASE_E state, the host issues a *Session Termination* (+FK) command to the modem to terminate the session. In particular, the modem will send a *Disconnect* (T.30 DCN signal) message at the next opportunity and returns an OK message. The host should then issue a *Hangup* command and the modem will respond with an OK message. The host now enters the IDLE state and waits for another RING.

Whenever there is an irrecoverable error or if the modem indicates an ERROR message, then the host should enter PHASE_E state for an orderly termination of the session.

- *Escape from Data Reception*

From the reception of <DC2> character from the host until the end of Phase C Data, the modem is in a data transfer state, and will not respond to host command characters. The modem will respond to three ASCII control characters: <DC1> (017) and <DC3> (019) flow control characters, and cancel <CAN> (024) character.

Upon receipt of the <CAN> character from the host, the modem will terminate the reporting of received data by sending trailing end of data stream (<DLE><ETX>) characters to the host, and will then execute an implied *Session Termination* (+FK) command in order to conduct an orderly disconnection. The host goes to the IDLE state.

3.1.2 State Diagram for Sending

When a facsimile document has to be transmitted to a fax terminal, the host in the IDLE state should give a dial command (ATD) immedialtely followed by the fax number to the modem (Figure 3.2). It should then enter the PHASE_A state. If this command is unsuccessful, the modem reports an appropriate failure or error type response such as NO CARRIER, NO DIALTONE, or BUSY. If this call is successful, the modem detects the call progress, and generates the calling (CNG) tone. It then waits for a DIS frame which indicates the receiver capabilities. On detection of the first Phase B preamble, it reports the *fax connection response* (+FCON) message to

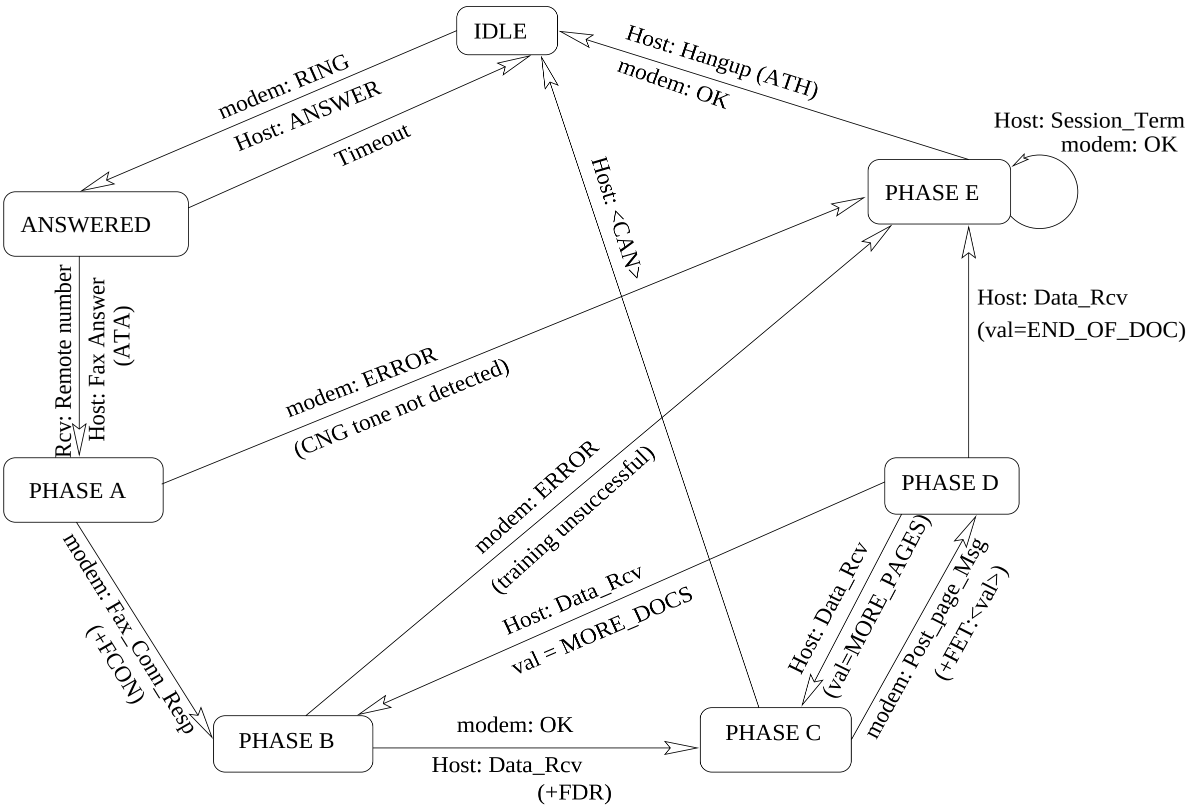

Figure 3.1: State Diagram for Receiving

the host. The host then changes the state to PHASE_B.

The modem reports the called station id (via +FCSI:) and the called station capabilities (via +FDIS:) and this is followed by the OK message. The modem generates a DCS frame which indicates the session capabilities, based on the received DIS frame and on the previously set capabilities (set via +FDCC:<capabilities string> during modem initialization) parameter. The host should issue a *Data Transmit* (+FDT) command which releases the modem to transmit that DCS frame. The modem reports the negotiated capabilities (DCS) to the host and gives a CONNECT message. The host now changes over to the PHASE_C data transmission state.

When the modem is ready to accept the data, it signal the host to start sending the data by sending a <DC1> character (021) to the host and waits for the data. The host sends the data in the stream mode and should terminate the data with an end of data stream (<DLE><ETX>) character pair. If any special characters occur in the data, the host should prefix it with the escape character (ASCII DLE character).

The modem will acknowledge the end of the data by returning the OK message to the host. The host should then issue a *post page message* (+FET=<ppm>) command to the modem and enter PHASE_D.

The *post page message* (ppm) command indicates that the current page is complete and no more data will be appended to it. The *ppm* value indicates whether there are any additional pages that are to be sent and, if so, whether there is a change in any of the document parameters. The remote facsimile station should respond to the post page message with a post page response. The modem reports this (via the +FPTS:<ppr> response) followed by an OK message. If there are more pages to be sent in the current document, the host should issue a *Data Transmit* (+FDT) command and when the modem responds with a CONNECT message, it should change the state to PHASE_C data transmission. If a new document has to be sent with re-negotiation of capabilities, the host should enter the PHASE_B state. If there are no more pages or documents, then the host should enter the PHASE_E state for session termination.

In the PHASE_E state, the host issues the *Session Termination* (+FK) command for an orderly termination of the session. When the modem responds with an OK message, the host should give the *Hang up* (ATH) command and go to the IDLE state.

Whenever there is an irrecoverable error or if the modem indicates an ERROR message, then the host should enter PHASE_E state for an orderly termination of the session.

▮ *Escape from Transmission*

The modem may request the host to halt Phase C transmission, by sending a cancel <CAN> character (024) to the host. In this case, the host should terminate Phase C transmission, issue <CAN>, and wait for the OK response from the modem. The host should then go to the IDLE state.

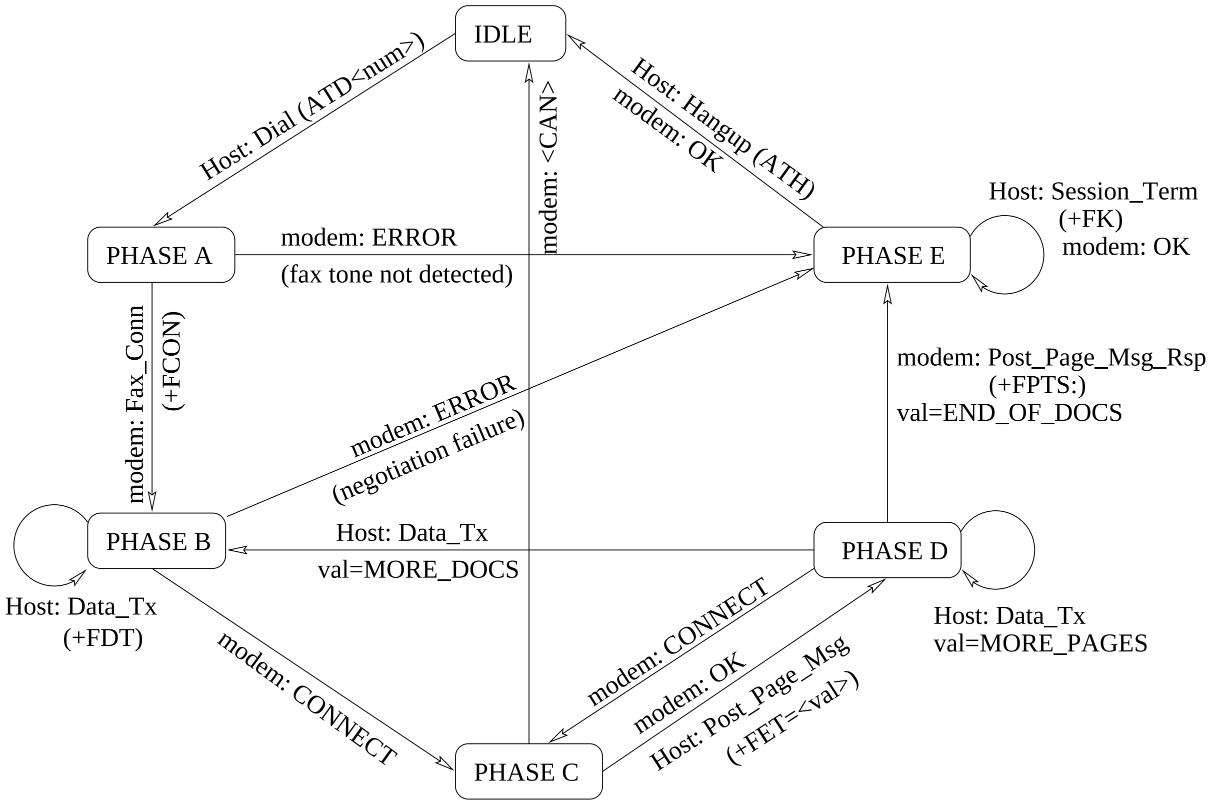

Figure 3.2: State Diagram for Sending

3.2 SMTP Sender

This module starts the SMTP session in the IDLE state by initiating a TCP connection to the the SMTP receiver (Figure 3.3). Once the connection is successfully established, the sender enters the CONNECTION_ESTABLISHED state. The sender then identifies by issuing an EHLO command. If the receiver indicates an error (the receiver might not be an extended SMTP server), the sender should issue a HELO command. The sender should then issue the MAIL command and the arguments to this command should be email address of the fax gateway. If the EHLO command was successful and the response includes DSN option, then the second argument for the MAIL command should be the envelope-id for identification of the delivery status notification received for this message. The envelope-id must contain the sender's fax number and optionally any other information with a suitable delimiter. When this command is successful, the SMTP sender enters the TRANSACTION_STARTED state.

In this state the sender can send the recipient information via the RCPT command. The first argument to this command should be the recipient's email address. If the EHLO command was successful and the receiver SMTP supports DSN, then the second argument should be the NOTIFY parameter with values set to both SUCCESS and FAILURE. The RCPT command should be issued individually for all the recipients. When atleast one of the recipient information is accepted, the sender should issue the DATA command. If none of the recipient information is accepted or if the DATA command fails, then the sender should issue a QUIT command to terminate the session, close the TCP connection and should enter the IDLE state. If the DATA command is successful, then the sender enters the DATA_TRANSFER state.

In this state, the sender should first send the header information including the MIME headers for sending the image as an attachment. It should then send the body of the message. Each page of the facsimile document should be converted to TIFF and encoded using the Base64 encoding method. Each of these encoded pages should appear as an attachment in a single email message. When all the data has been sent, the sender should indicate the end of data and enter the CONNECTION_ESTABLISHED state.

The sender can now choose to start another transaction with the same SMTP receiver or can close the session by issuing a QUIT command and closing the TCP connection. The sender now goes back to the IDLE state.

3.3 Onramp-Offramp Communication

The communication protocol between onramp and offramp gateways utilizes the TCP/IP protocol suite. The use of TCP is suitable because there is no real-time requirements for the document transfer. The Onramp service should provide for re-attempts for the transmission of the document.

3.3.1 Message Format and Description

The message format consists of 4 octets of header and a variable length data as shown in the Figure 3.4.

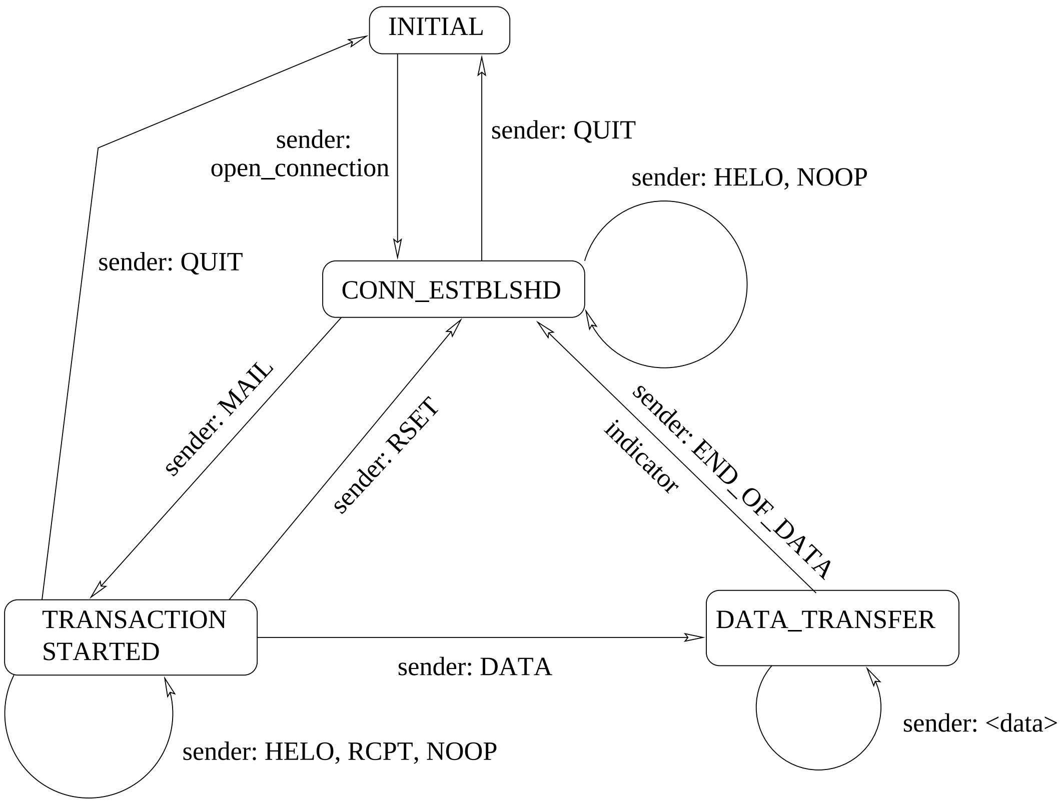

Figure 3.3: State Diagram for SMTP Sender

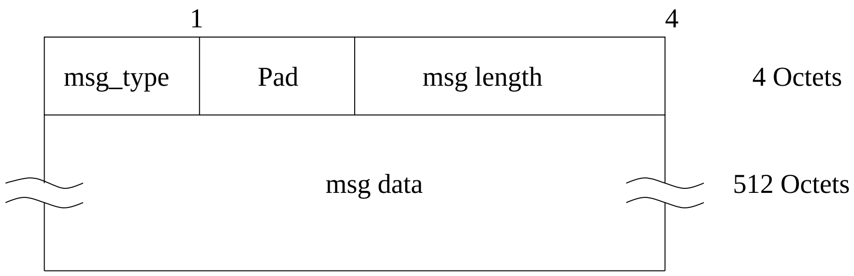

Figure 3.4: Message Format

Message Types

For the state transitions described in the following messages, please refer to the Figures 3.12 and 3.13 for onramp and offramp gateways respectively.

- *CONN_REQ:* This message is sent by the onramp gateway when it is in the IDLE state to the offramp gateway for establishing the connection on top of the TCP connection. The onramp gateway should then enter the CONNECTION_PENDING state. The format of this message is shown in Figure 3.5.

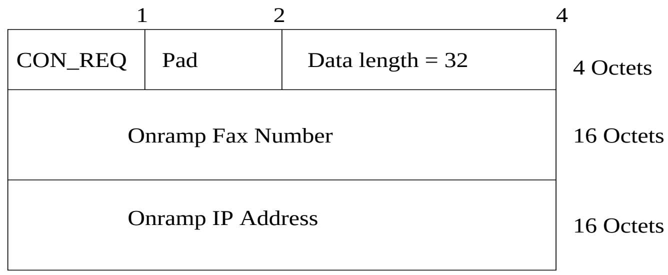

Figure 3.5: Format of Connection Request

- *CONN_RESP:* When the offramp gateway receives the CONN_REQ from the onramp gateway, it should check the resource availability and if it can accept the connection, it should send the CONN_RESP message to the onramp gateway. The offramp gateway should then go to the CONNECTION_ESTABLISHED state and wait for further messages from the onramp gateway. The offramp gateway should be concurrent to support multiple sessions with different onramp gateways at the same time. When the onramp gateway receives the CONN_RESP from the offramp gateway while in CONNECTION_PENDING state, it should enter the CONNECTION_ESTABLISHED state. The format of this message is shown in Figure 3.6.

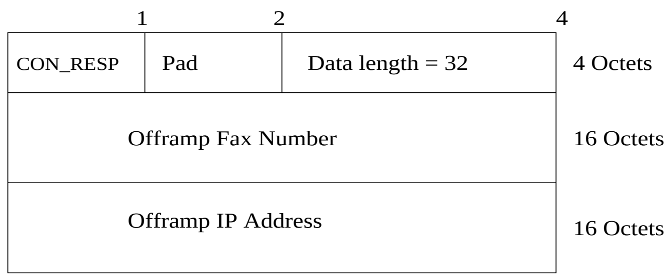

Figure 3.6: Format of Connection Response

- *INFO:* In the CONNECTION_ESTABLISHED state, the onramp gateway should send the information related to the session using this message. It then enters the INFO_SENT state. Figure 3.7 shows the format of this message.

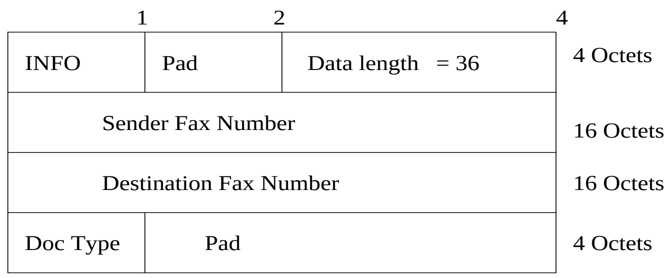

Figure 3.7: Format of Information message

- *ACCEPT/REJECT:* Upon receipt of the INFO message, the offramp gateway should determine whether the destination fax number comes within its service area and is permitted to transfer the document to the destination over the telephone network. If it can, it should send an ACCEPT message to the onramp gateway and enter the DATA_RECV state and wait for the data transfer. If it cannot handle the request, it should send a REJECT message and wait for further messages from the onramp gateway in the CONNECTION_ESTABLISHED state. When the onramp gateway receives the REJECT message, if there are other documents to be sent, then it can enter the CONNECTION_ESTABLISHED state otherwise, it should send a CONN_RELEASE message and enter the RELEASE_PENDING state.

- *DATA:* When the onramp gateway receives the ACCEPT message from the offramp gateway, it should enter the DATA_TRANSFER state. It can now start the data transfer. The data should be sent in this message. Since the default MSS (maximum segment size) value of TCP is 536 octets [Ste96], the data length in each message can be chosen to be 512 octets. Figure 3.8 shows the format of this message.

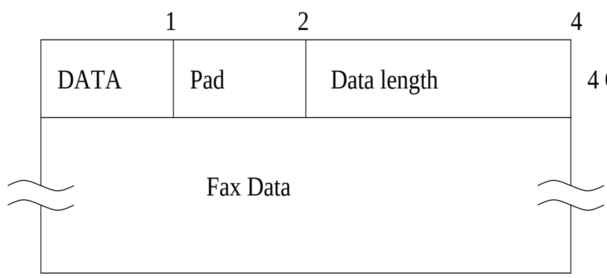

Figure 3.8: Format of Data Message

- *EOP:* When the onramp gateway has completed transmitting a page, it should send a EOP (End Of Page) message to the offramp gateway. This message contains the length of the page that was transmitted. The format of this message is shown in Figure 3.9.

1	2	4	
EOP	Pad	Data length = 4	4 Octets
Page length sent			4 Octets

Figure 3.9: Format of End of Page Message

- *EOP_ACK:* This message is sent by the offramp gateway when it receives an EOP message. The offramp gateway should check the page length value in the EOP message with its own received length and report an EOP_ACK message to the onramp gateway.

- *EOD:* When the onramp gateway has completed the document transmission, it should send EOD (End of Document) message to the offramp gateway. The length field should be set to the total length of the document sent. The format of this message is shown in Figure 3.10.

1	2	4	
EOD	Pad	Data length = 4	4 Octets
Document length sent			4 Octets

Figure 3.10: Format of End of Document Message

- *EOD_ACK:* When the offramp gateway receives the EOD message, it should check the total length of the document received with the value in the EOD message. It should send the this message to acknowledge the end of document and an indication about the document status. The offramp gateway should now enter the DOC_RECVD state.

- *CONN_RELEASE:* When the onramp gateway receives the EOD_ACK message, it can send the CONN_RELEASE message and enter the RELEASE_PENDING state. It can also start another transaction by sending the INFO message and entering the INFO_SENT state. The format of this message is shown in Figure 3.11.

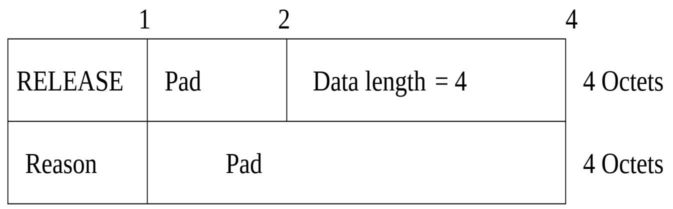

Figure 3.11: Format of Connection Release Message

- *CONN_RELEASE_COM:* Upon receipt of the CONN_RELEASE message, the offramp or the onramp gateway should send a CONN_RELEASE_COM message and go to the IDLE state.

The state transitions which occurs upon the receipt or sending of a message is summarized in the following state diagrams.

3.3.2 Onramp State Diagram

The onramp state diagram is shown in Figure 3.12. In any state other than IDLE, if the onramp gateway receives a CONN_RELEASE_COM message, it should go to the IDLE state.

Whenever any message other than DATA is sent by the onramp gateway, it should start a timer whose value is MESSAGE_RESPONSE_TIMOUT. Upon the expiry of this timer, it should send a CONN_RELEASE_COM to abort the session and go to the IDLE state.

3.3.3 Offramp State Diagram

The offramp state diagram is shown in Figure 3.13. The offramp gateway can also initiate the session termination by sending a CONN_RELEASE message while in DOC_RECVD state, if it cannot accept further transactions or in any other state other than IDLE and RELEASE_PENDING states in exceptional cases.

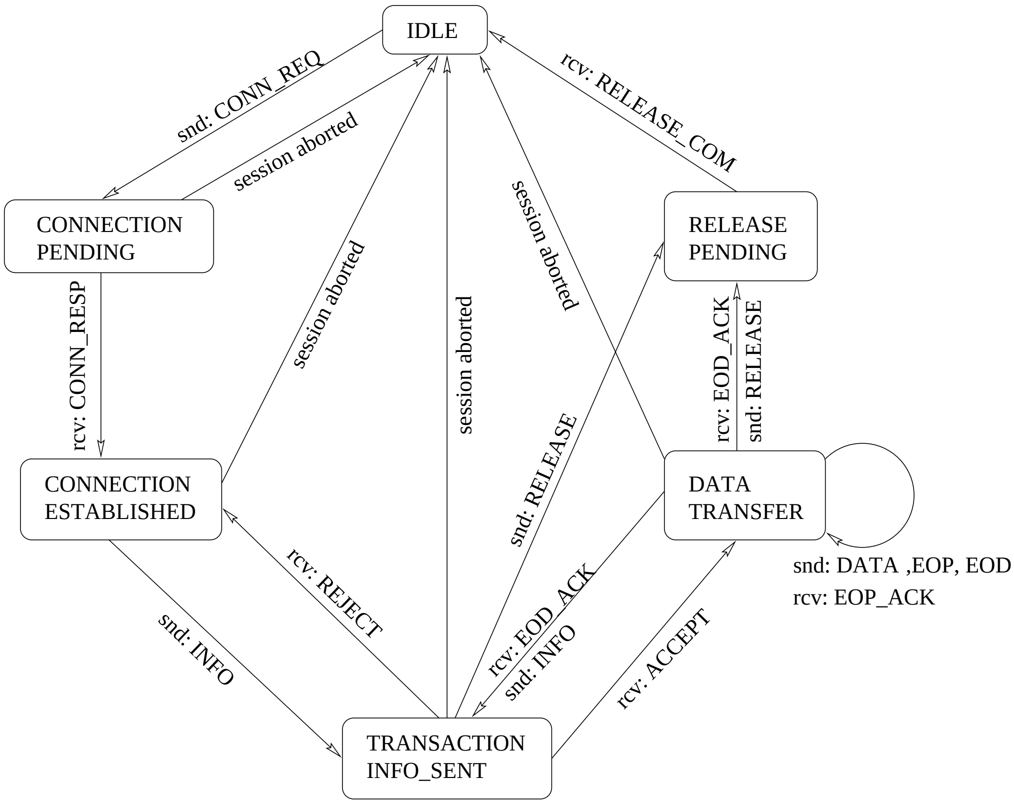

Figure 3.12: State Diagram for Onramp

Whenever the offramp gateway starts waiting for the data from the onramp gateway, it should start a timer whose value is READ_MESSAGE_TIMER. Upon the expiry of this timer, it should send a CONN_RELEASE_COM to abort the session and go to the IDLE state.

3.3.4 Timing Diagram

The time-line of a document transfer between the onramp and offramp gateways in a normal case is shown in Figure 3.14. The document contains two pages. The states corresponding to the onramp and the offramp gateways is shown on the respective sides.

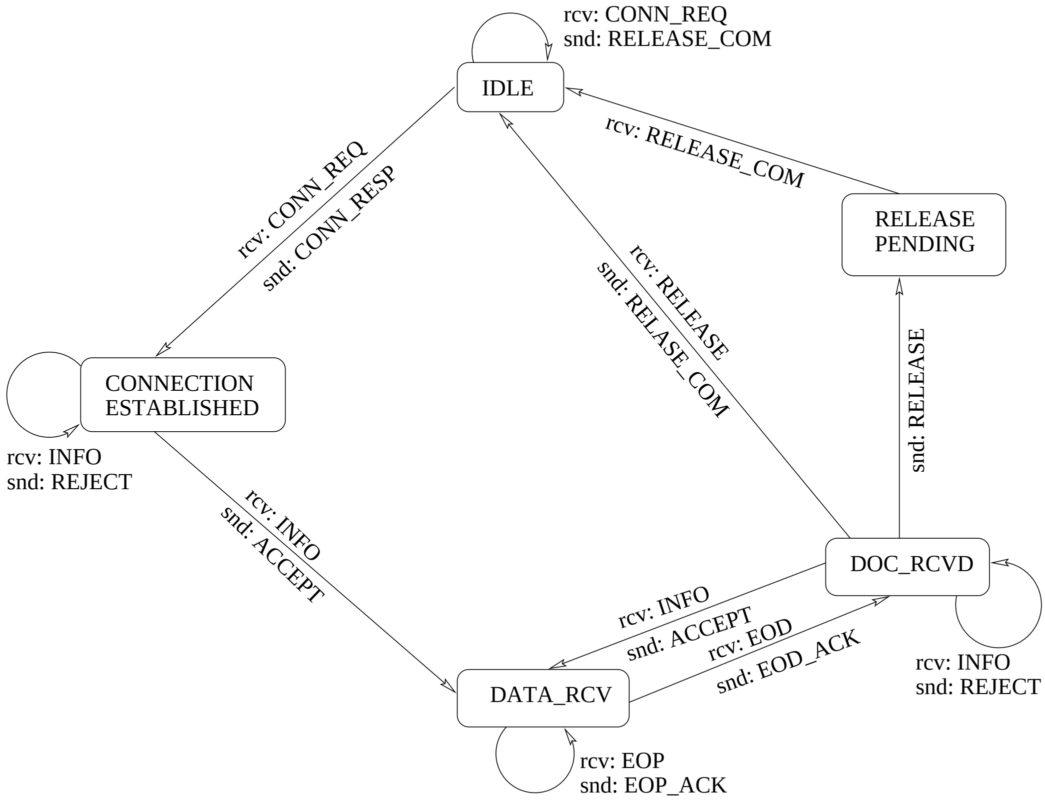

Figure 3.13: State Diagram for Offramp

3.4 Address Determination

The incoming facsimile document can be routed to another group 3 fax terminal or to an email box of the recipient.

The fax has to be routed to the fax terminal through an offramp gateway. However, to route the document to an email box, the minimum service that is necessary is a database service to lookup the email address of the recipient with an user-id or a fax number as the key. This service can be a part of the offramp gateway or can be stand-alone. The onramp gateway determines the IP address based on the fax number. The IP address thus obtained corresponds to the host on which the offramp gateway or the email address lookup service (or both) is available. If the document has to be routed to an email box, the onramp gateway determines the email address from the email address lookup service. The user-id or the fax number used for the email address lookup should be unique on the host or the domain for which the lookup service is running.

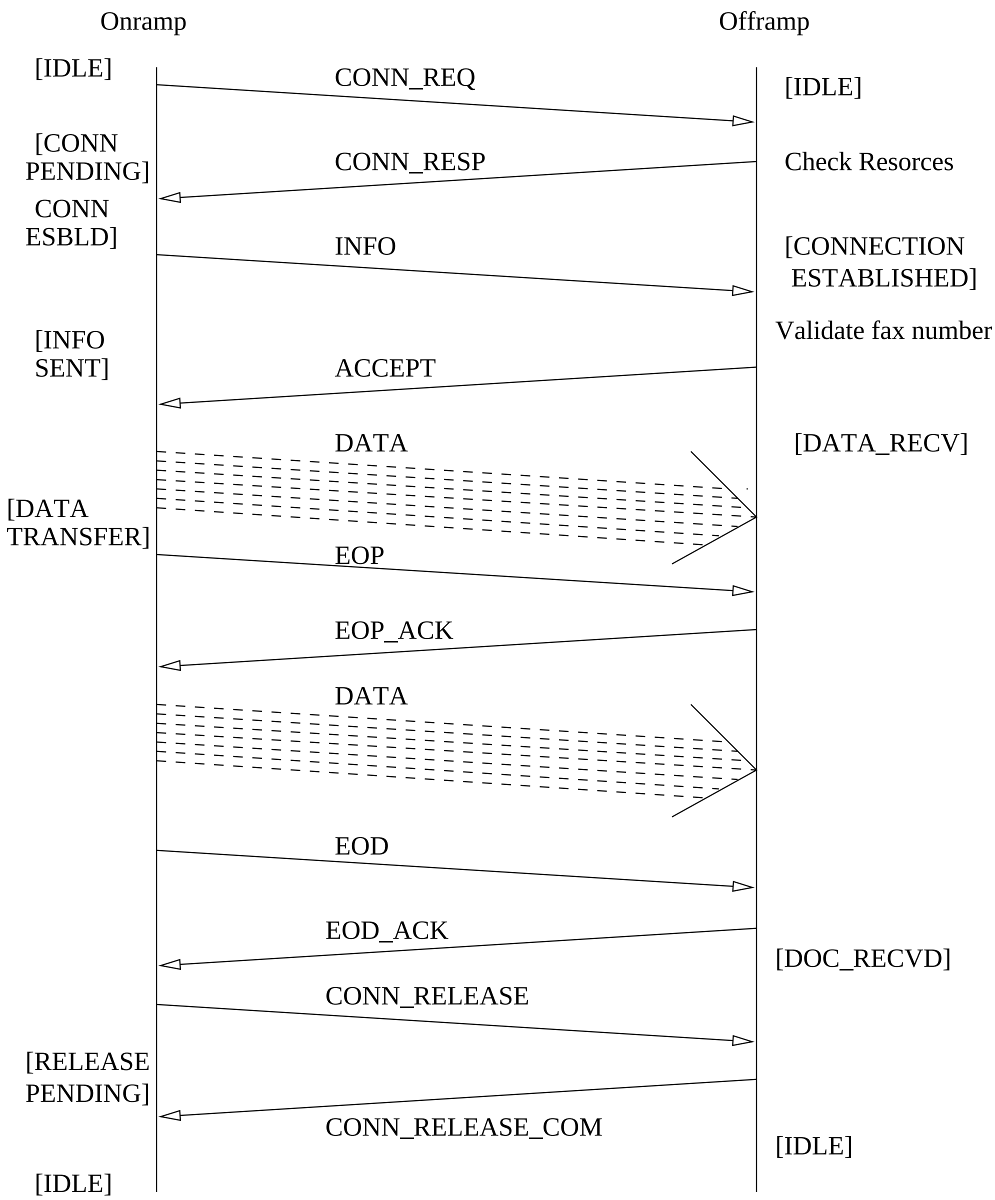

Figure 3.14: Timing Diagram

The following are some of the scenarios that are possible for the recipient.

- The recipient may have just a Group 3 fax terminal with no Internet connection in which case he would have subscribed to a gateway service. The fax has to be delivered in this case to the recipient's fax terminal over the PSTN.
- The recipient may have both a fax terminal and a dialup Internet access to an account provided by an ISP. In this case, recipient may prefer to receive

the incoming fax document to his email box. Since the recipient has a PSTN address associated with the fax terminal, the same can be used for the email address lookup avoiding the use of a separate user-id.

- The recipient may just have an Internet access, but not connected to PSTN (e.g. on a LAN in a workplace). In this case, the fax document has to be routed to the email box, and the recipient must have a separate user-id for the email address lookup. The fax number for the IP address lookup will correspond to a PSTN address (e.g. a fax/telephone number of the organization) which is shared among many people.

- The recipient may have an Internet access, and also a telephone connection but no fax terminal to receive faxes over PSTN. In this case, the fax document has to be routed to the email box. The recipient's PSTN address (i.e. the telephone number) can be used as a key for the email address lookup.

3.4.1 IP Address Determination

From the scenarios that we described above, it is required that, given a PSTN address (fax number or a telephone number) of the recipient, the IP address corresponding to the offramp gateway or the email address lookup server be determined. Further, it is required to know whether the service corresponding to this IP address is only an offramp gateway, only an email address lookup service, or both. If it supports email address lookup, then it is also necessary to know whether a separate user-id is required to determine the email address or the fax number is sufficient. The following are the fields in the IP address lookup table.

- *Fax number Substring:* A fax server typically offers services to a locality in its vicinity. The first few digits in the PSTN number for all the PSTN connections in this locality would fall into a set of common prefix. The set of common prefix includes the international dialing code, the area code, the first couple of digits in the local PSTN number and a combination of these which are valid. So the entire fax number may not be required for determining the IP address. The longest fax number substring in the table which matches the destination PSTN number represents the fax server closest to the destination PSTN number. e.g. if the destination fax number is 597214 and if the lookup table contains two substrings 597 and 5972, then the IP address corresponding to the longest substring i.e. 5972, is the fax server for this destination.

- *IP address:* This is the IP address of the server which offers offramp fax gateway service and/or email address lookup service.

- *Server type:* This specifies what the IP address corresponds to, as mentioned above. The following symbols are used in the table.

  - F: This server supports only the offramp service.
  - D: This server supports only the email address lookup service.
  - B: This server supports both offramp and email address lookup services.

- *UID option:* This specifies whether a separate user-id (UID) is required, optional, or not required for the email address determination. The following symbols are used in the table.

  - R (Required): The email address lookup uses only the user-id as the key. So it is an error if the user doesn't provide the user-id.
  - O (Optional): The email address lookup uses both the user-id and the fax number as the key. If the user provides an user-id, it will be used for the email address lookup, otherwise, the fax number will be used.
  - N (Not Required): The fax number will be used for the email address lookup.
  - I (Ignored): The entry corresponds to an offramp only service.

- *Host name:* This is the name of the host corresponding to the IP address.

As an example, the IP address lookup table is shown below.

Fax substring	IP address	Server type	UID option	Host name
59671	144.16.162.90	F	I	pc090.cse.iitk.ernet.in
55567	144.16.162.110	F	I	pc0110.cse.iitk.ernet.in
60	144.16.162.81	D	R	pc081.cse.iitk.ernet.in
597	144.16.162.167	B	O	pc67.cse.iitk.ernet.in
5972	144.16.162.100	B	N	pc0100.cse.iitk.ernet.in

The IP address lookup service should be provided in an hierarchical manner similar to the Domain Name Service (DNS). For example, there might be one top level fax number server (fns.com), fax number servers for each country (country_code.fns.com), fax number servers for each city (area_code.country_code.fns.com) etc. When the onramp gateway gets the destination fax number, it can decode it to obtain the country code, area code and the local number and directly contact the relevant servers (after obtaining the IP address of these servers) or in a recursive manner from the top level server. Alternatively, a new Resource Record type can be added to the DNS and the library functions can be modified to obtain this record.

3.4.2 Email Address Determination

Based on the information obtained from the IP address lookup, if the remote server supports the email address lookup service and if the user-id is required or optional, then the PSTN interface of the onramp gateway should try to obtain the user-id from the sender. If the sender does not provide the user-id and if the remote Database server requires this information, the onramp gateway should terminate the session but if the user-id is optional, then the onramp gateway should send the the fax number to the database server. If the user-id is provided, then both the fax number and the user-id should be sent to the database server.

The email address lookup service should have a database containing the following fields.

- *Key Type:* This indicates whether the key in the record is an user-id or a fax number. 'U' indicates user-id and 'F' indicates Fax Number.
- *Key:* This is either the user-id or the fax number.
- *User:* This is the login name.
- *Domain:* This should be a valid domain name to which the mails can be routed over the Internet.
- *User Name:* The complete name of the user.

Key type	Key	User id	Domain	User name
U	9318	girish	cse.iitk.ac.in	B.V.S.Girish
F	597077	dheeraj	cse.iitk.ac.in	Dr.Dheeraj_Sanghi

If the lookup is successful, the onramp gateway proceeds with the fax session. It accepts the facsimile document from the sending fax terminal, converts it into TIFF format and sends it to the email box of the recipient. If the lookup is unsuccessful and if the remote server supports offramp service (server type 'B' in the IP address lookup table) then the onramp gateway should proceed with the fax session with the sending terminal and transmit the document to the offramp gateway and if the remote server doesn't support offramp service the the onramp gateway should terminate the fax session with the sending fax terminal.

3.5 Delivery Status Notification

The delivery status notification has to be sent to the sender of the facsimile document both when the facsimile document is successfully transmitted to the recipient and when the transmission was unsuccessful either because the recipient was unreachable or due to some unrecoverable error. If there is a failure in sending the DSN, then it should be re-attempted as in the case of a fax document. However, after successful delivery or after maximum failed attempts, it should be silently discarded and no DSN should be sent for a DSN.

3.5.1 Fax to Fax

There are three different transmissions with storage points at two locations in this case. The sending fax terminal transmits the document to the onramp gateway for further transmission to the offramp gateway and the offramp gateway transmits it to the receiving fax terminal. The notification of a successful delivery is provided by the offramp gateway (the PSTN interface of the offramp). The notification of failure will be provided by the offramp gateway (PSTN interface) when the final transmission to the receiving fax terminal fails or the onramp gateway (IP interface) when the transmission to the offramp gateway fails.

When the onramp or the offramp gateway fails to transmit the document and if the failure is because of a recoverable error, then it should re-attempt the transmission at a later time and when the number of re-attempts for a particular document reaches a certain maximum, then it should send a DSN message to the fax sender and discard the job. If the failure is because of an unrecoverable error, then it should immediately send the DSN message indicating this and discard the job.

3.5.2 Fax to Email

There are two stages of transmission for sending the facsimile document to an email box. The sending terminal transmits to the onramp gateway which in turn transmits to the recipient's email box through one or more MTAs.

If there is an error while transmitting the document to the MTA, then the onramp gateway should send the DSN indicating the failure (after re-attempts, if applicable). If the document is successfully transmitted to the recipient's email box, then a DSN indicating success has to be sent (by the MTA) if the document reaches the recipient's mail box or a DSN indicating failure if there is some error in the mail transport/delivery. For the remote or one of the intermediate MTAs to send the DSN, the MTA should conform to the extended SMTP (ESMTP) and the onramp gateway should request the DSN as explained in Section 2.3.2.

When the MTA sends the DSN, it arrives as an email message to the onramp gateway. A relay at the onramp gateway should interpret this email message and forward the relevant contents to the fax sender.

Chapter 4

Implementation

In the implementation of the fax gateway, we have several modules, each of which runs as a separate process. The modules interact with each other with the help of Shared Memory, Semaphores and Signals. The modules which transmit and receive over the PSTN or the IP network maintain a queue. A document to be sent will be queued as one job in the appropriate Send Queue. When the document is successfully transmitted, the job will be removed from the queue. If there is an error during the transmission, then the job will be put at the end of the queue for trying again at a later time. A timer will be associated with such a failed job so that the re-attempt occurs only after a period of time.

The various modules, their association with each other, the interaction of the onramp and the offramp gateways, and the interaction between the onramp gateway and the MTA is shown in the Figure 4.1. In this implementation, the IP address determination is done using the lookup table available locally.

4.1 Message Switch

This module takes a job from the receive queue of the PSTN Interface module and converts the received facsimile document to an appropriate format (TIFF for email) after destuffing the escape characters (as explained in Section 3.1.1) and reversing the byte order. It puts the resulting document to either the Send queue of the SMTP Sender or the Onramp IP Interface.

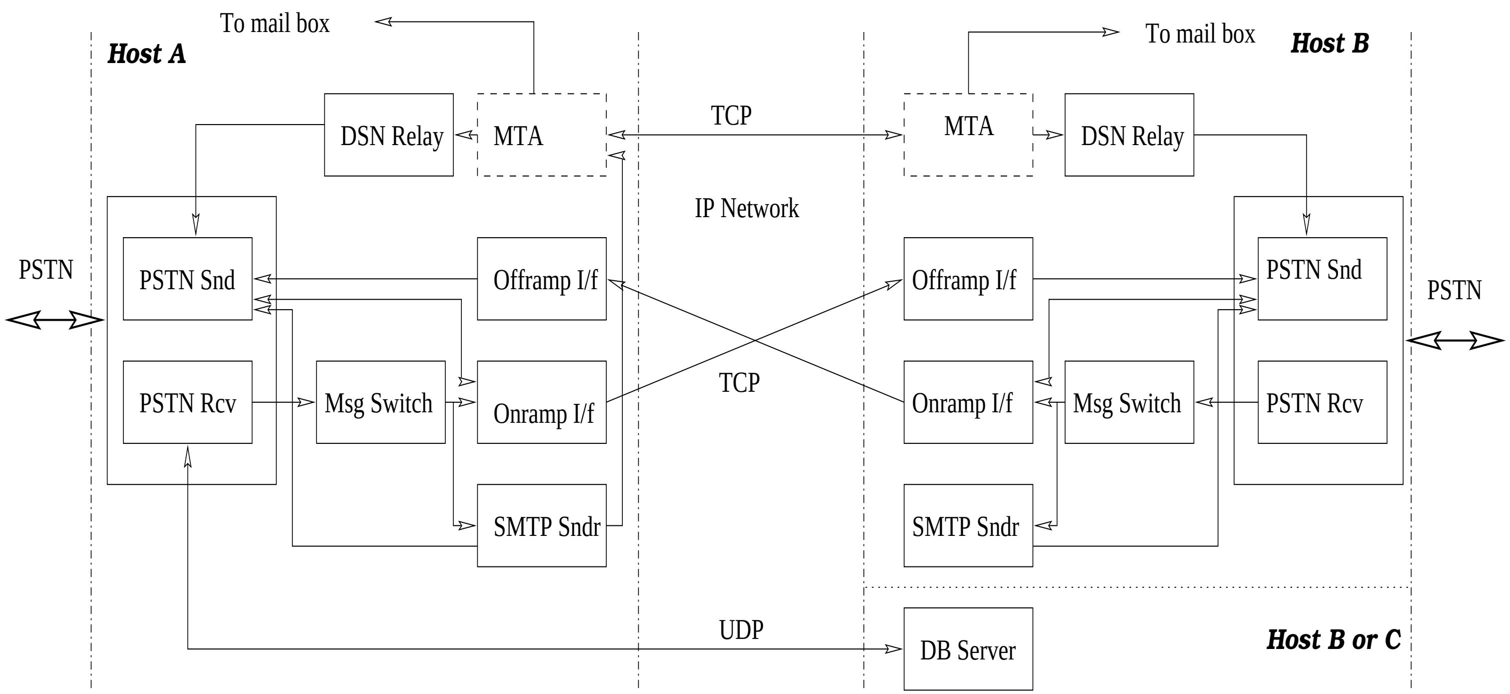

Figure 4.1: Interaction between the modules

The send and receive queues are maintained as shared memory. This module creates the shared memory segments and the semaphores associated with these shared memory segments. When there is no job in the receive queue of the PSTN interface, the process waits on a semaphore. When a new job arrives, the PSTN interface wakes up this process.

4.2 PSTN Interface

The sub modules for sending and receiving the faxes over the PSTN runs as a single process. If there are jobs in the Send queue of this module, then after sending one document, the process waits for a certain time for the incoming facsimile call. If no call arrives, it services the next job. If there are no jobs in the send queue, then the process blocks, waiting for the incoming facsimile call. If a new job now arrives on the send queue, then the process will be signalled to service this job.

The receive queue has the following data structures. This queue is shared by the the Message Switch. The PSTN receive sub-module adds jobs and the Message switch removes jobs from this queue. The Message Switch puts the job in the Send queue of the SMTP sender or the offramp IP Interface based on the serviceType.

```
typedef struct
  {
    char fileName[MAX_FILE_NAME_LEN];
    int noOfPages;           /* filename.pageno gives the complete filename */
    char serviceType;        /* EMAIL or FAX */
    char remoteFaxNo[MAX_FAX_NUM_LEN];
    char senderFaxNo[MAX_FAX_NUM_LEN];
    EmailAddrType emailAddrs[MAX_EMAIL_ADDRESSES];
                                       /* allow for multiple recipients */
    char ipAddr[MAX_IP_ADDR_LEN];      /* offramp IP addres */
  } PstnRcvQType;

typedef struct
  {
```

```
    int qFront;
    int qRear;
    PstnRcvQType pstnRcvQ[MAX_RECV_Q_LEN];
  } PstnShmType;
```

The send queue has the following data structures. This queue is shared by the offramp IP interface which puts jobs in this queue. The PSTN Send sub-module removes jobs from the queue after either a successful send or maximum failed attempts. The jobs are also added to the queue by the Onramp IP Interface and the SMTP Sender to send the Delivery Notification for failed transmissions and by the DSN Relay for relaying the DSN received from the MTA.

```
typedef struct
  {
    char fileName[MAX_FILE_NAME_LEN];
    int noOfPages;        /* pages in the document */
    int attempts;         /* number of failed attempts */
    long time;            /* time when the last attempt was made */
    unsigned char type;  /* whether the document is a Fax Msg or a DSN */
    char remoteFaxNo[MAX_FAX_NUM_LEN];
    char senderFaxNo[MAX_FAX_NUM_LEN];
    char onrampIpAddr[MAX_IP_ADDR_LEN]; /* for delivery notification */
  } IpPstnSendQType;

typedef struct
  {
    int signalEnabled;
    int qFront;
    int qRear;
    IpPstnSendQType ipPstnSendQ[MAX_SEND_Q_LEN];
  } IpPstnShmType;
```

The *signalEnabled* variable is used by the Offramp IP Interface so that appropriate signals can be sent when the PSTN module has blocked, waiting for an incoming fax call.

4.3 SMTP Sender

The recipient's email address is represented using the following structures. The valid email-id is obtained by concatenating the UserId, '@' symbol, and the domainName.

```
typedef struct
  {
    char userId[MAX_USER_LEN];
    char userName[MAX_USER_NAME_LEN];
    char domainName[MAX_DOMAIN_LEN];
  } EmailAddrType;
```

The Send queue of the SMTP Sender has the following fields.

```
typedef struct
  {
    char fileName[MAX_FILE_NAME_LEN];
    int noOfPages;                    /* pages in the document */
    int attempts;                     /* number of failed attempts */
    long time;                        /* time when the last attempt was made */
    int numRcpts;                     /* number of recipients */
    EmailAddrType emailAddrs[MAX_EMAIL_ADDRESSES];
    char senderFaxNo[MAX_FAX_NUM_LEN];
  } SmtpSendQType;

typedef struct
  {
    int signalEnabled;
    int qFront;
    int qRear;
    SmtpSendQType smtpSendQ[MAX_SEND_Q_LEN];
```

```
  } SmtpShmType;
```

The Message Switch adds jobs and the SMTP Sender removes jobs from this queue. This module can transmit the document to multiple recipients. However, since the email address lookup returns at most a single email address, the message will be sent to a single recipient in this implementation. The *signalEnabled* flag indicates whether the process is waiting for a new job (waiting on a semaphore) or is busy servicing jobs in a queue. This information is used by the Message Switch to wake up this process if it is waiting.

4.4 Onramp and Offramp IP Interfaces

The onramp Send queue has the following data structures. The Message Switch puts the jobs in this queue. Jobs to this queue are also added by the PSTN Send sub-module of the PSTN Interface to send the delivery notifications indicating success or failure. The jobs in the queue are removed by the Onramp IP Interface.

```
typedef struct
  {
    char fileName[MAX_FILE_NAME_LEN];
    int noOfPages;                  /* pages in the document */
    int attempts;                   /* number of failed attempts */
    long time;                      /* time when the last attempt was made */
    unsigned char type;             /* Fax Msg or DSN */
    char remoteFaxNo[MAX_FAX_NUM_LEN];
    char senderFaxNo[MAX_FAX_NUM_LEN];
    char offrampIpAddr[MAX_IP_ADDR_LEN];
  } PeerSendQType;

    /* this structure used by onramp and pstnrcv */
typedef struct
  {
    int signalEnabled;
```

```
    int qFront;
    int qRear;
    PeerSendQType peerSendQ[64];
  } PeerShmType;
```

When the Offramp Interface receives documents from the remote Onramp Interface, it directly adds it in the PSTN Send queue (Section 4.2).

The data structures for the onramp-offramp communication is shown below.

```
typedef struct
  {
    char onrampFaxNum[MAX_FAX_NUM_LEN]; /* for information purpose */
    char onrampIpAddr[MAX_IP_ADDR_LEN]; /* used for delivery notification */
  }ConReqType;                          /* used for CONN_REQ */

typedef struct
  {
    char offrampFaxNum[MAX_FAX_NUM_LEN]; /* for information, no other use */
    char offrampIpAddr[MAX_IP_ADDR_LEN]; /* for verification purpose */
  }ConRespType;                         /* used for CONN_RESP */

typedef struct
  {
    char destFaxNum[MAX_FAX_NUM_LEN];   /* recipient fax number */
    char senderFaxNum[MAX_FAX_NUM_LEN];
    unsigned char dataType;             /* FAX msg or DSN */
  }InfoDetType;

typedef struct
  {
    unsigned char relReason;  /* Whether release is normal, due to error etc. */
  }ReleaseDetType;
```

```
typedef struct
  {
    unsigned char data[MAX_DATA_LEN];
  }DataType;

typedef struct
  {
    long pageLen;     /* Length of the data page sent */
  }EopType;

typedef struct
  {
    long docLen;     /* Length of the total document sent */
  }EodType;

typedef struct
  {
    unsigned char msgType;  /* Whether CON_REQ, CON_RESP ... etc. */
    unsigned char pad;
    short len;              /* length of the message body used */
    union
      {
        ConReqType conReq;
        ConRespType conResp;
        InfoDetType info;
        ReleaseDetType relDet;
        DataType faxData;
        EopType eop;
        EodType eod;
      } msgDet;
  } FaxgwMsgType;
```

In this implementation, the size of the message will be constant for all the messages. Since the actual valid length of the message body for the DATA message is a variable, the valid length of the facsimile data in the message body should be indicated in the 'len' field. For all other messages, this field can be ignored since the message body length will be known.

4.5 Database Server

The request and reply packets are exchanged between the onramp gateway and the database server using UDP/IP. When a UDP request arrives, if the user-id field is valid (greater than zero), then it uses that as the key. The fax number is used as the key if no matches are found using the user-id or if the user-id is invalid. There might be multiple email addresses corresponding to a key, i.e., an user-id might represent multiple recipients of the email. However, in this implementation, we have assumed a one to one correspondence.

The format of the UDP request and reply messages is shown below.

```
typedef struct
  {
    unsigned char msgType;    /* req or reply */
    unsigned char chain;      /* indicates whether more reply packets */
    short len;                /* length of the message excluding first 4 bytes */
    int uid;                  /* User-id should be set to -1 if not known */
    char faxNumStr[MAX_FAX_NUM_LEN];
    int hits;       /* Number of email address which corresponds to the key */
    EmailAddrType emailAddr[MAX_EMAIL_ADDRESSES];
  } UidEmailMsgType;
```

The chain flag indicates whether there are more reply messages. This would be possible if there are multiple recipients corresponding to the same key and this number exceeds the number of email addresses sent in one message. The hits value in a message represents the number of email addresses in that message.

4.6 DSN Relay

For relaying the DSN received from the MTA, whenever a mail arrives to the fax gateway, the mailer has to be configured to invoke the relay and deliver the message to it. The relay then determines whether the message is a DSN and if so, extracts the sender fax number from the Envelope-Id field in the message body. The relevant parts of the message is converted from text to run-length encoding and is added in the PSTN Send queue for transmission to the sender.

Chapter 5

Conclusions

We have designed a fax gateway which enables a Group 3 fax terminal connected to a telephone network to transmit fax documents to another Group 3 fax terminal also connected to a telephone network utilizing the IP network for part of the communication. The sending fax terminal can also transmit documents to an email account of the recipient. The design also provides a recipient the flexibility to receive the fax documents to an email account or to a Group 3 fax terminal. Delivery status notification is provided to the sender for both successful and failed delivery.

We have implemented the fax gateway using the TCP/IP protocol suite on Linux, with a few simplifications. We have assumed that the fax number to IP address mapping table is available locally rather than distributed in an hierarchical manner. We have also assumed that there is a single document per fax transmission session. Application level reliability is also provided.

5.1 Future Work

A considerable amount of effort is on for standardizing a procedure for real-time fax over IP. Implementation of the real-time fax gateways would be a challenging task since it involves strict conformance to T.30 timers.

Our design of the fax gateway could be extended to provide the following enhancements.

- *Session* Internet fax service so that the sender would get a similar type of service provided by the traditional fax with respect to confirmation of fax delivery.
- Integration with other Internet services.
- Inter-working of different types of fax terminals (ex. Group 3 and Group 4)

Appendix A

Modem AT Commands

The AT commands listed here is the *Generic* Rockwell fax class 2 AT command set. Modem vendors often change, add, and delete commands based on their particular product and feature set. Thus these commands are not necessarily the AT commands used within a particular modem, even if it is based on Rockwell chipset products.

1. Voice Mode Commands

Command	Function
#VCL=N	Voice mode selection
#VLN=N	Relay/Speaker Control

2. Service Class ID

Command	Function
+FCLASS=	Service Class

3. Class 2 Action Commands

Command	Function
D	Originate a Call
A	Answer a Call
+FDT	Data Transmission
+FET=N	Transmit Page Punctuation
+FDR	Begin or Continue Phase C Receive Data
+FK	Session Termination

4. Class 2 Session Parameters

Command	Function
+FMFR?	Identify Manufacturer
+FMDL?	Identify Model
+FREV?	Identify Revision
+FDCC=	DCE Capabilities Parameters
+FDIS=	Current Sessions Parameters
+FDCS=	Current Session Results
+FLID=	Local ID String
+FCR	Capability to Receive
+FPTS=	Page Transfer Status
+FCR=	Capability to Receive
+FAE	Adaptive Answer
+FBUF?	Buffer Size (Read Only)
+FPHCTO	Phase C Time Out
+FAXERR	Fax Error Value
+FBOR	Phase C Data Bit Order

5. Class 2 DCE Responses

Command	Function
+FCON	Facsimile Connection Response
+FDCS:	Report Current Session
+FDIS:	Report Remote Identification
+FCFR	Indicate Confirmation to Receive
+FTSI:	Report the Transmit Station ID
+FCSI:	Report the Called Station ID
+FPTS:	Page Transfer Status
+FET:	Post Page Message Response
+FHNG	Call Termination with Status

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