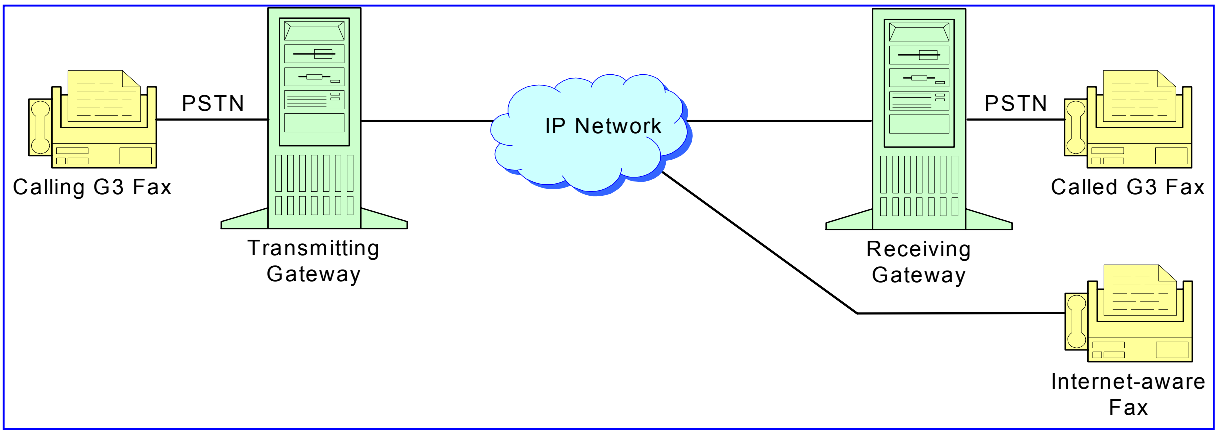
Fax Relay over Packet Networks

Overview, G3 Fax Session, Fax Image Transfer, V.34 Fax Transfer, Network Obstacles, Overcoming Network Delays, Fax Spoofing, T.38 Fax Relay, AudioCodes Fax Relay DSP

Overview

Fax relay service over Packet networks, such as Frame Relay or IP, is a service enabling standard fax machines to communicate over the packet network instead of the PSTN. The most prominent motivation for this service is the cost of long distance charges that could be avoided by bridging the service over a WAN network.

Figure 1: Typical Layout



G3 Fax Call over the PSTN

The ITU-T first published the Group 3 fax protocol in 1980. The protocol is composed of several standards that specify different parts of the fax call. The procedures for session control are described in the ITU T.30 specification. Image transfer procedures are described in ITU T.4 specification. Since these standards are defined at a digital level, and Group 3 fax is specified for the PSTN, modems are involved. The half-duplex V.21 Channel 2 modem at 300 bps (V.21H) is selected as T.30 handshake modem, and for the T.4 image transfer, several options apply.

Session Control Procedures

The T.30 specification divides a fax call into five phases:

- Phase A - Call setup
- Phase B - Pre-message procedure for identifying and selecting the facilities
- Phase C - Image transfer
- Phase D - Post-message procedure including multi-page and end of procedure signals
- Phase E - Call release

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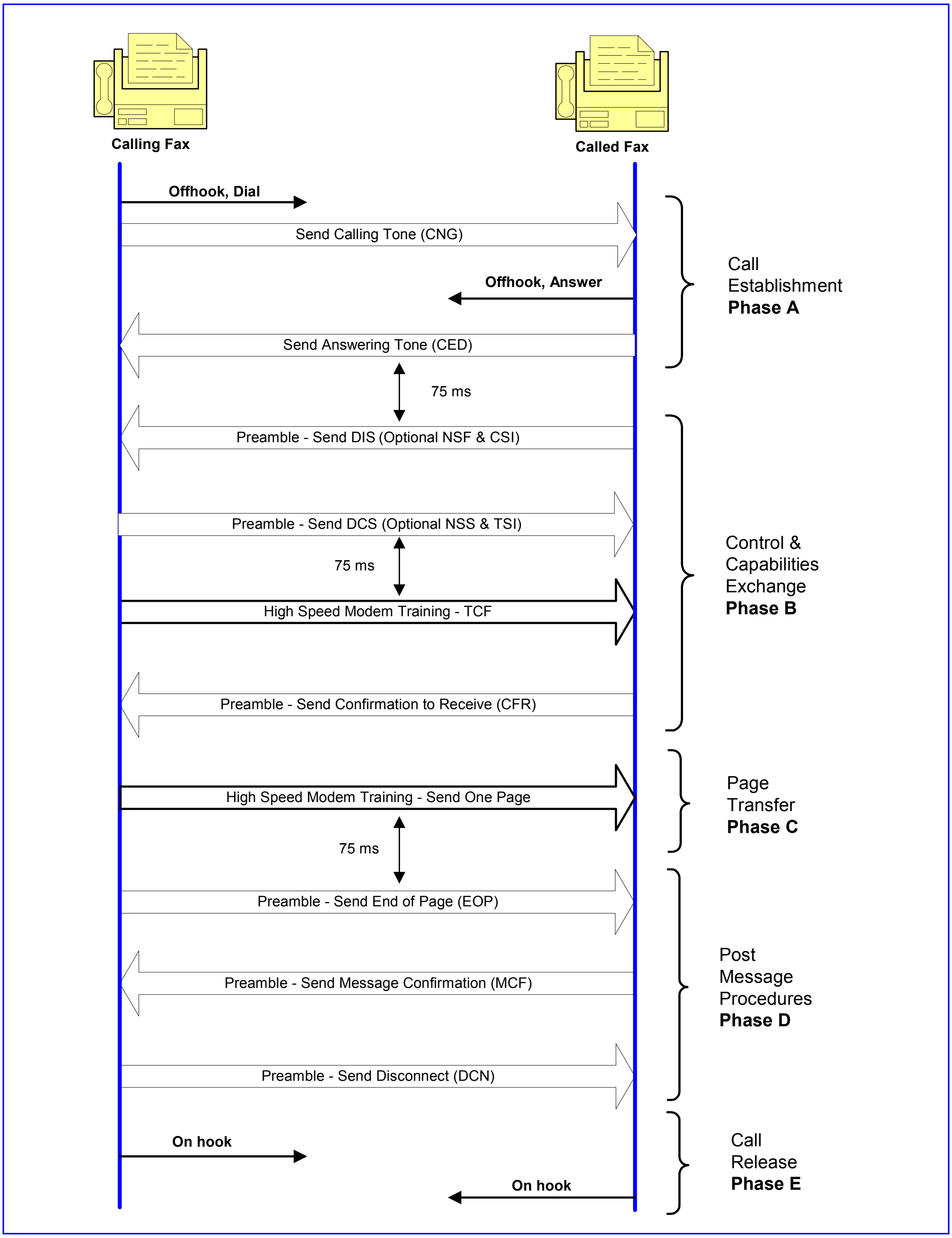
Figure 2: PSTN Fax Call Flow



Phase A – Call Setup

During phase A, the calling fax (CNG) and the called (CED) fax, send tones (CNG, CED) into the line to announce their presence. Any mistakes resulting in a person calling a fax or vice versa can then be detected. The CED tone is used by the calling fax machine to determine if the call was answered. At the end of phase A, both machines transmit to V.21H modem, the called fax transmitting first.

Phase B – Capability Negotiations

During phase B, the fax machines attempt to find a set of capabilities that enable them to transfer the document. The V.21H/T.30 capability is mandatory in all Group 3 compliant fax machines. The called fax transmits the Digital Identification Signal (DIS) describing its capabilities to the calling fax. The calling fax then determines the common denominator for both machines, and responds with a Digital Command Signal (DCS) to inform the called fax of the selected settings. These settings include:

- Data rate
- Image resolution
- Image encoding
- Page size capabilities
- Error-correction mode

When the called station sends the DIS frame, it may optionally send two other frames containing Called Station Identification (CSI) for station identification and Non Standard Facilities (NSF) frame for non-T.30 operation. The calling station optionally sends Transmitting Subscriber Identification (TSI) and Non-Standard facilities Setup (NSS) frames. The DCS signal is followed by high-speed Training Check Frame (TCF) of zeros. When the called station has agreed to the setting and the training check has passed, the called station sends the Confirmation to Receive (CFR) frame ending phase B and enabling phase C.

T.30 Physical and Data Link Control Layers

The framing of the messages carried by V.21H is done by HDLC. Every message is preceded by a one second preamble.
While waiting for the other side to respond to a sent frame, the initiating side maintains a timer (T4) that is defined in T.30 to a value of 3.0 sec ± 15%. When that timer expires, a "no response error" occurs. The initiating terminal may transmit the frame up to three times, and then take appropriate action, like disconnecting.

Phase C – Image Transfer

During phase C, the link makes the transition into high-speed transmission from the sending fax to the receiving fax. The exact rate and modem used depends on the negotiations and training check which were concluded in phase B. Optional modems include:

- V.27*ter* (4800/2400 bps)
- V.29 (9600/7200 bps)
- V.17 (14400/12000/9600/7200 bps)

The formatting of the bit stream is specified in ITU T.4 specification. More information on this subject follows.

Phase D – Post-message Procedures

After the end of the current page transfer by phase C, the link returns to V.21H/T.30 state. The originating fax sends one of several messages that are supported by phase D. These messages include:

- End Of Procedure (EOP) – To finish fax transmission and go to phase E.
- Multi Page Signal (MPS) – To return to phase C and transmit more pages.
- End Of Message (EOM) – Indicate end of page and return to the beginning of phase B.
- Partial Page Signal (PPS) – Used in error correction image transfer to end a block.
- End-of-Fax Signaling – The disconnect command (DCN) is used to terminate the fax session.

More messages are supported for other features.

Phase E – Call Release

- Call Release – Executed automatically (for example, after DCN) or manually (by user going on-hook).

T.4 Image Transfer

The T.4 basic image transfer syntax is based on sending a synchronous bit stream from the sending fax to the receiving fax using a high-speed modem. The information is divided into scanned lines, with a known resolution. Each line picture elements (pels) are encoded by one of several methods. The most simple is one-dimensional, run length, Huffman encoding. A special symbol is reserved for end of line (EOL), and this symbol delineates the line boundary and the end of a page by repeating six times. Other coding methods use vertical correlation of the image to encode the difference from the previous line instead of the actual line data.

The transmission of the encoded pels can't be interrupted until the page has completed the transfer. There are no protocol or timing elements that can break the page into more controllable pieces. If transmission is corrupted in the middle of the page, the receiving fax may be able to detect it, only if it interrupts the EOL framing and corrupts the line.

Error Correction Mode

To address the need for more powerful error control during image transfer, the T.30 (Annex A) defines transfer syntax for a T.4 bit stream which implements the error detection and retransmit request through T.30.

The T.4 bit stream is divided into 64-byte or 256-byte frames. These frames are transmitted as payload inside HDLC frames with Frame Check Sequence (FCS) for error detection. Up to 256 frames constitute a T.4 partial page. At the end of each partial page, the originating fax sends the T.30 PPS message, and waits to get the message confirmation (MCF) from the receiving fax. If a problem has

occurred, the receiving fax can respond with a partial page request (PPR) to seek retransmission of the blocks received with errors.
Another advantage of this syntax is the separation of a page bit stream into more controllable frame-size pieces.

V.34 Fax Transfer

ITU T.30 Recommendation from 04/1999 defines advanced fax transmission using V.34 modulation system. The V.34 fax session starts with Amplitude Modulated (AM) answering tone CED. The originating and called faxes negotiate V.34 capabilities using V.8 protocol and full-duplex modem V.21 at 300 bps. Binary procedural data is exchanged at 1200 or 2400 bps using V.34 full-duplex control channel. Image data and return-to-control command are transferred in Error Correction Mode using half-duplex primary channel V.34 at data rates up to 33.6 kbps.
Due to large differences compared with the previous G3 fax definition from 1980, this type of faxes is frequently called "Super" G3 faxes.
The V.34 fax relay mode is currently under study in ITU. It poses some very heavy technical problems, and also does not save significant bandwidth. For this reason, Super G3 faxes are either forced to fall back to G3 mode, or transferred in transparent (bypass) mode with PCM A-law or μ-law at a sampling rate of 8 kHz. The following sections deal with real-time fax relay mode for regular G3 (not V.34) faxes.

Fax Relay

The most simple approach to transfer fax signals in layout shown in Figure 1 is the bypass mode (PCM at 64kbps) used for V.34 faxes and data modems. But more reliable and preferred method of delivering fax via network in real time is the fax relay.
Communicating gateways demodulate all signals received from fax machine, make packet exchange with network, and transmit modulated network data into fax. Advantages of fax relay are listed in Table 1.

Table 1: Fax Relay Versus PCM Fax Transfer

	PCM Transfer		Fax Relay	
Needed Bit Rate for packet transfer	Phase	Rate	**Phase**	**Rate**
	During all fax transfer	Constant, full-duplex at 64 kbps	**Silence, V.21 preamble flags, training**	**No Packets**
			T.30 Handshake	**300 bps full duplex**
			T.30 Fax image	**≤ 14400 bps half duplex**
Packet Lost Protection	No protection		**Up to 4 redundant packets at highest fax rate**	
Network Jitter Tolerance	Up to 100…150 ms, or else long buffers are required in gateway		**Up to 500 ms, no buffering in gateway host**	
Network Delay Tolerance	Up to 2 sec, round-trip		**Up to 12 sec, round-trip**	

Most of the processing is done by the DSP built in the gateway. The main function of the gateway is a correct packet exchange with the DSP and network.

Fax Relay – Packet Network Challenges

Delay

The first problem presented by the network is delay. It is the end-to-end delay that the packets accumulate over the network. The reason for this delay can come from the need of every node to perform validation and routing functions on incoming packets upon arrival, and from actual transport time spent on low capacity segments that may be part of the route. The longer the route, the more loaded the network or the routers, the more delay is accumulated. In fax relay applications, the more important factor is roundtrip delay. In the T.30 protocol several procedures are defined that incorporate a timeout mechanism. The most notable is the aforementioned timer T4 found in the "*RESPONSE RECEIVED"* procedure of the T.30.

When this timer expires without a response to a sent frame, the initiating fax may disconnect the call. The value of the timer is 3 ± 15% sec, and taking into account processing, transmission, and detection delay, we have a little over 2 sec of roundtrip delay left. If the network presents a delay of that order, it interrupts the operations of the T.30 protocol.

The basic method solving the network delay problem for real-time fax transfer is the fax spoofing, refer to separate section on page 9.

Delay Jitter

In connection with the delay parameter, there exists another factor that presents problems. The factors that cause delay are subject to fast changes over the life span of a single connection. Load surges may occur on a specific segment, a router may need to perform periodic maintenance routines, etc.

This leads to a distribution of the actual delay for specific packets over a considerable range. The distribution function is not easy to estimate, as it comes from multiple sources with unknown Delay characteristics.

During a T.30 dialog, the timing between V.21H signals is at the level of seconds. Within a single message transfer, the jitter presents a greater problem. If the receiving relay function begins the transmission of the V.21H message before it has all the necessary packets, it may stop transmission with aborting the HDLC frame. The fax receiving this signal requests or waits for the frame retransmission or disconnect.

During a T.4 basic image transfer, the situation is worse due to the longer message it contains. The whole page must not be interrupted once started. If the fax modulator in the relay function runs out of fax packets due to the packet arrival jitter, the image is compromised.

The problem of packet arrival jitter can be handled by implementing delay jitter buffers that accumulate enough head start in the beginning of a non-interruptible transmission to make sure it completes without packet under-runs. If we use a longer jitter buffer we minimize the chances of message loss due to jitter buffer under-run, but the same delay is now added to the transmission path, decreasing the overall tolerance to network delay.

Network Packet Loss

The most disruptive aspect of network behavior is packet loss. Packet loss is defined as a packet failing to reach its destination without the transmitter knowledge (i.e., collision detection). When a router buffer for a specific interface becomes too loaded with traffic that can't go out fast enough, and the local memory is exhausted, a packet is dropped

In connection mode protocols, such as TCP, an inordinate amount of care is taken to ensure complete, in-sequence transfer of information by packets. However, these protocols add much delay, processing and memory requirements, which real time fax relay applications may not accept.

If protection is not provided, the results can be loss of packets. The V.21H session is more sensitive in that a lost packet may end the session, or prevent it from ever starting. During image transfer, lost packets can result in corrupted lines and pages. The Error Correction mode (ECM) in T.30/Annex A was designed to cope with transmission errors on the PSTN, but although tackling the same issue, it is not designed for packet networks.

There are two basic ways to deal with network packet loss. The first is detection and retransmission of lost packets (T.38 TCP), and the second is redundant transmission, and error recovery codes (T.38 UDP). For reliable fax communication, T.38 indicators and V.21 data packets should have a redundancy higher than image data packets

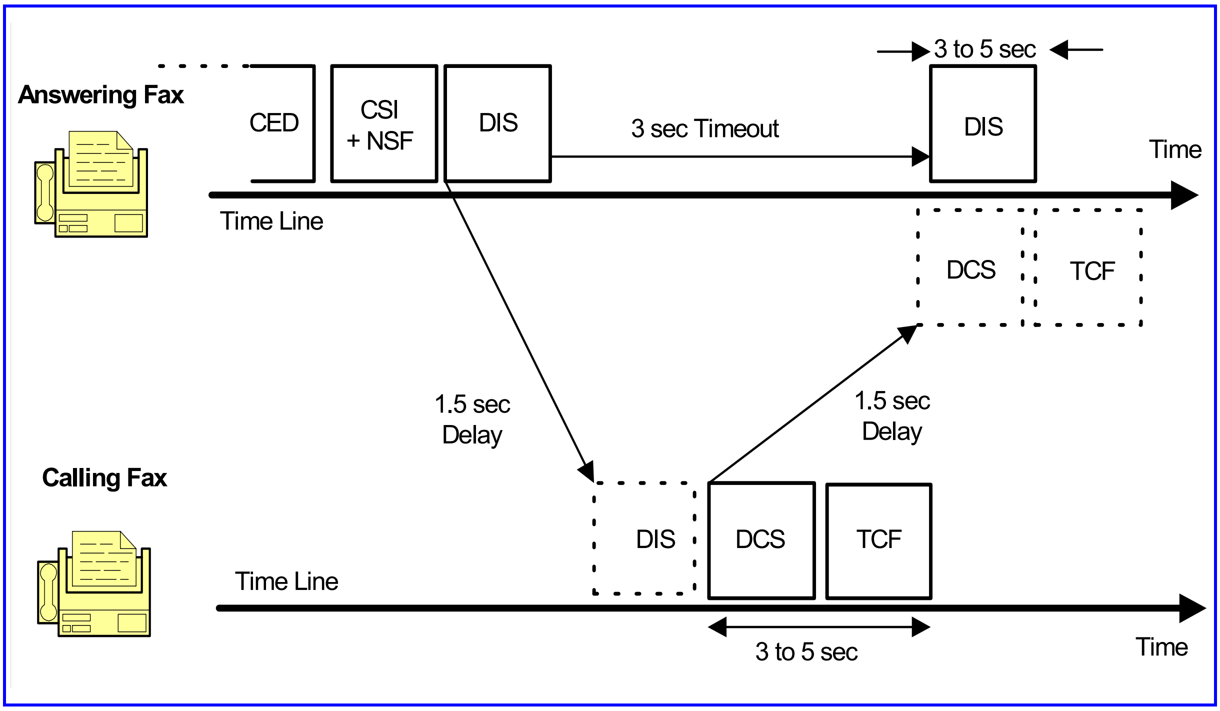
Dealing with Network Delay by Spoofing

Effects of Long Round Trip Delay

If the combined roundtrip delay of the network and the relay function exceeds the T.30 response timeout, a response can be delayed enough for the sender to retry sending the command. Since the fax machine to relay function link is half-duplex, the delayed response can even create a collision with the retried command, and the session can fail.

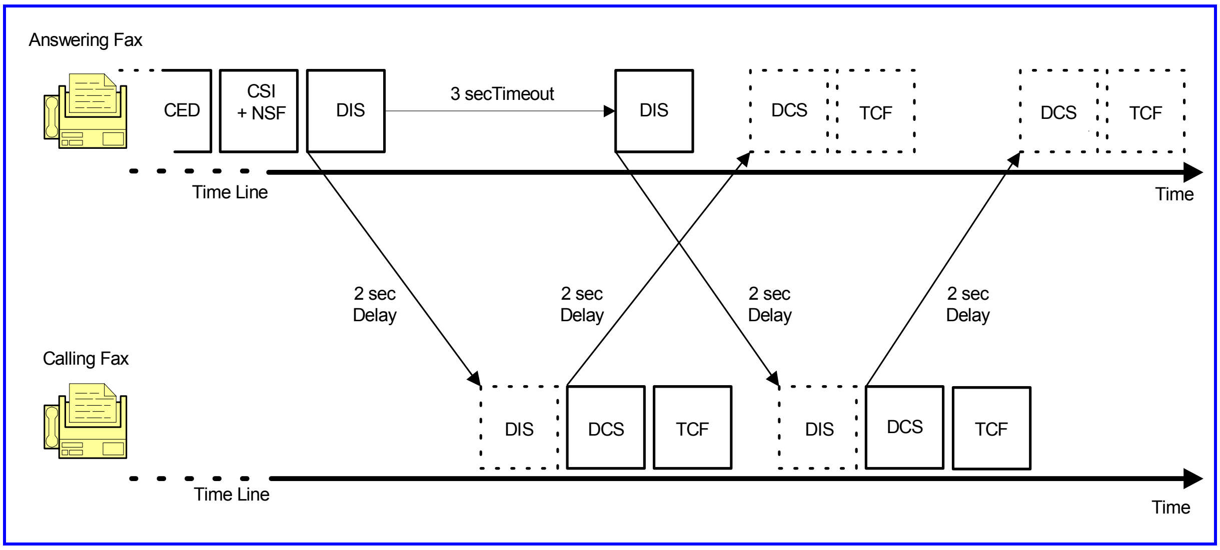
Figure 3 and Figure 4 on page 8, show two examples of round trip delay.

Figure 3: Round Trip Delay ~ 3 sec Collision Between DIS and DCS on Answering Side.



Even if the timing was not disrupted enough to cause collisions, the delay may be long enough to cause multiple copies of the same command and its response. This causes an unnecessary ripple between both sides.

Figure 4: Repeated T.30 Element due to Round Trip Delay - No Collision



If for example, the roundtrip delay is 4 seconds, the DIS from the answering fax is repeated by it when the DCS/TCF from the calling fax is halfway though the network. When the calling fax gets the second DIS, it repeats the DCS/TCF needlessly.

Fax Spoofing

To solve the problem of the possible collisions, a relay node that receives fax traffic from the network while it is engaged with demodulation of fax signals from the local fax machine, buffers the network traffic. After the demodulation has ended, the buffered fax traffic from the network is re-modulated toward the local fax. This simulates a full duplex connection on the half-duplex analog fax section.

If the relay node follows the T.30 state machine, it should be able to filter out or delay certain messages that have been repeated due to large roundtrip delays.

T.38 Real-Time Fax Relay

The ITU T.38 recommendation defines the Internet Fax Protocol (IFP)"

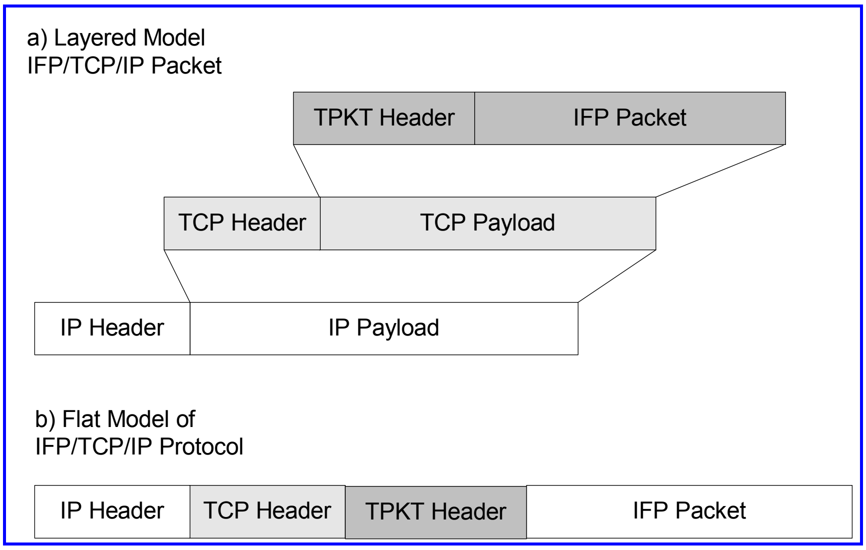
> "to allow Group 3 facsimile transmission between terminals where in addition to the PSTN or ISDN a portion of the transmission path used between terminals includes an IP network, e.g., the Internet."

T.38 TCP

For dealing with network packet loss, it suggests both basic solutions. The first is working with TCP over IP, gaining the reliable transfer of all packets through TCP facilities. The price however is heavy in terms of delay, and required resources. Since TCP handles network packets loss by waiting for positive acknowledge of packet arrival and re-transmission of all missing packets, some packets may arrive with such delay that they are no longer relevant. The buffers maintained by TCP for re-transmission are also costly.

The high-level packet structures are shown in Figure 5 and Figure 6 on page 10.

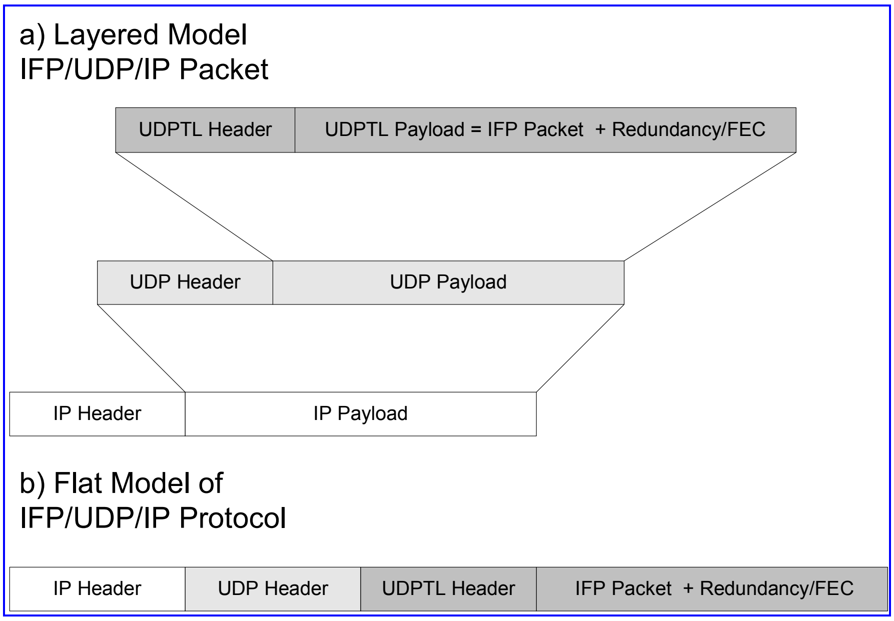
Figure 5: T.38 High-level IFP/TCP Packet Structure (T.38 Recommendation Figure 4)



T.38 UDP

The other option offered by T.38 is the UDPTL extension over the UDP/IP service. The added UDPTL header allows for sequence numbers and redundancy information to be added to the fax payload.

Figure 6: T.38 High-level UDPTL/IP Packet Structure (T.38 Recommendation Figure 5)

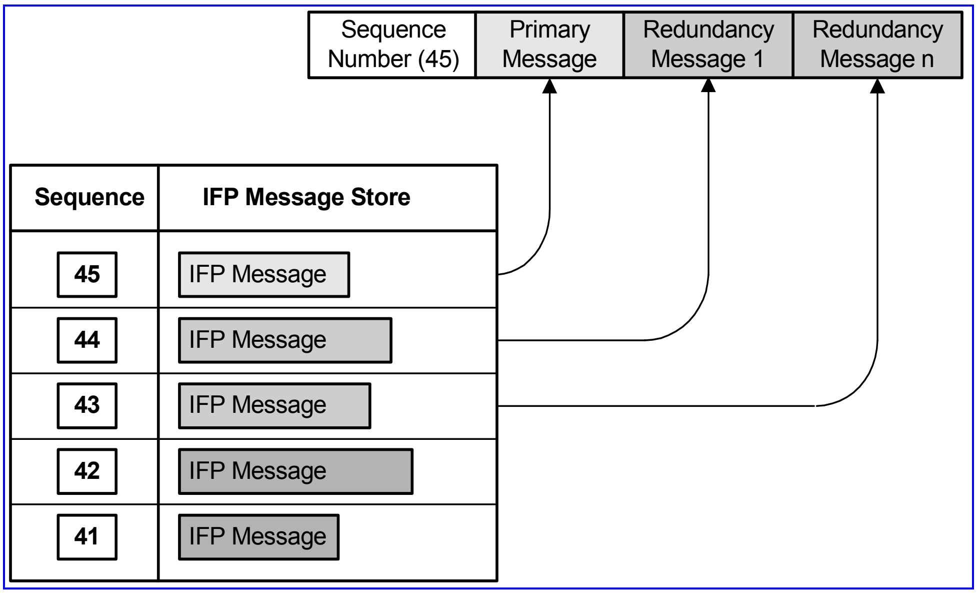


Every fax payload must contain a primary payload corresponding to the sequence number provided in the UDPTL header, and one or two redundant payloads. These payloads are the previous primary payloads.

In addition, UDPTL contains the option to transmit Forward Error Correction (FEC) information protecting the previous N primary payloads against the loss of one of them. For more information refer to ITU T.38 Annex C.

The Payload sequence is shown in Figure 7 on page 11.

Figure 7: Payload Sequence



T.38 IFP Packets

Recommendation T.38 defines two types of IFP packets: T.38 INDICATOR and T.38 DATA.
T.38 INDICATOR defines a type of fax signal and is sent in the beginning of signal.
T.38 DATA packet consists of signal type field, and IFP data element. Generally, the IFP data element is a sequence of sub-packets having data field type and optional size and payload data. T.38 DATA packets are sent during data demodulation of V.21 handshake or T.4 high-speed signals.

T.38 Call Setup

Call setup defined in T.38 is based on Fast Connect Procedure of Recommendation H.323. The setup operates in one of two distinct environments:

1. IP fax only environment.

2. Fax and voice over IP environment.

"The Fast Connect procedure allows the endpoints to establish a basic point-to-point call with as few as one round-trip message exchange, enabling immediate media stream delivery upon call connection."
The gateway starting communication negotiate the **fastStart** element consisting "of a sequence of **OpenLogicalChannel** structures describing media channels which the calling endpoint proposes to send and receive, including all of the parameters necessary to immediately open and begin transferring media on the channels."

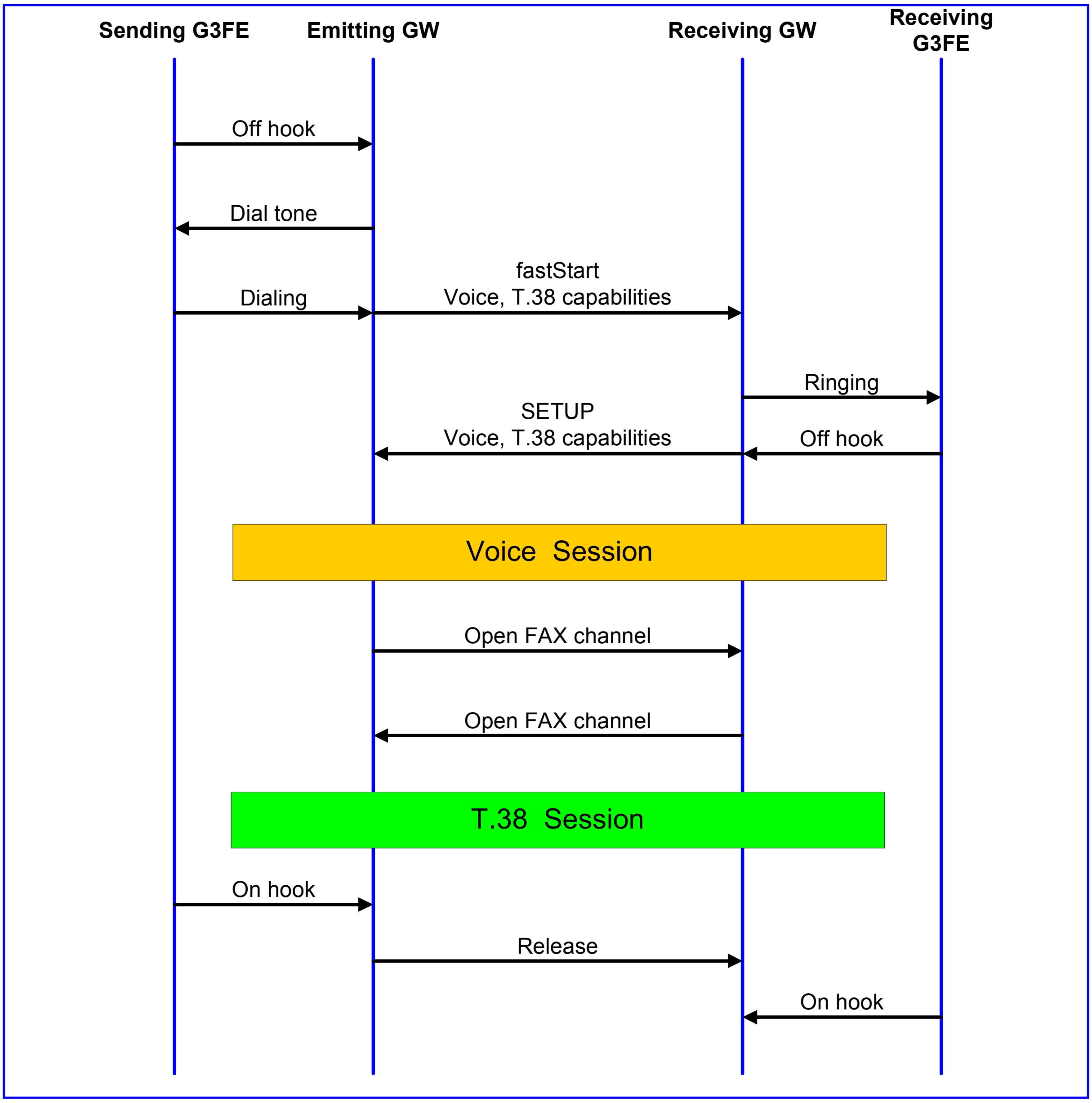
All required ports are established during the initial **fastStart** exchange.
T.38 packets are sent on a TCP/UDP port separately from call signaling port (TCP).
The gateways negotiate also several T.38 capabilities:

- Data rate management method (TCF transfer or local generation)

- Data transport protocol (UDP or TCP)
- Fill bit removal (enable removal and insertion of fill bits for non-ECM image data)
- MMR and JBIG transcoding capabilities
- Maximum input buffer and datagram sizes
- T.38 version

Figure 8 shows a normal T.38 call setup sequence for voice and fax:

Figure 8: Normal Connection and Disconnection Sequence for Voice and Fax Call



The gateway detected fax signals CNG, CED or V.21 preamble flags starts T.38 session first. The gateway going to T.38 session and continuing to receive voice packets from the network mutes the output signal to G3FE.

In case of an IP fax-only call, the connection sequence is the same as Figure 8 excluding "Voice Session". The "Open FAX" procedures are optional for this case.
If both or one of gateways involved to communication do not support the Fast Connect Procedure, some fax signals of Phase A (CNG, CED) or Phase B (DIS) may not be transferred while the gateways negotiate T.38 capabilities and TCP/UDP port number.
The worst case is starting T.38 negotiation on detecting V.21 preamble flags. This may cause the partial or total lost of the first [NSF/]CSI/DIS signal. According to T.30 Recommendation, the answering G3 fax should repeat [NSF/]CSI/DIS several times, so that on completion of T.38 call setup, this signal is finally transferred to the originating G3 fax. However, due to T.30 violations at the fax itself, there is a probability of fax disconnection before sending DCS and TCF. Due to this, opening a T.38 session on detection of CNG or CED is more reliable.

DSP R&D of G3 Fax Relay in AudioCodes

Fax Relay was first used in AudioCodes products in 1994 with its first DSP, supporting rates of up to 9600 bps. Since then it has been developed and gone through major changes, being implemented in the AC480x and AC481x families, which were sold to hundreds of customers around the world and were used as building blocks to AudioCodes' TPM™ Modules and TrunkPack™ Boards. Today, this mature and field proven software is implemented in all AudioCodes' products, from low-end DSPs to high-end carrier class gateways. It has passed numerous interoperability tests and is one of the top Fax Relay implementations in the world for number of installed ports.

Group 3 Fax Relay Features of AudioCodes DSP

- Fax Rates
  - V.27: 4800/2400 bps
  - V.29: 9600/7200 bps
  - V.17: 14400/12000/9600/7200 bps
- Error Correction Mode
- Sub-address and password transfer
- All types of image resolution and size
- All types of image encoding
- Binary file transfer
- Fax polling
- Tolerance to network jitter up to **400 ms**
- Tolerance to network delay up to **12 sec** (round-trip)
- T.38 ASN.1 encoding/decoding

V.34 fax is transferred in bypass mode (PCM A-law/μ-law at 64 kbps).

Fax Relay Verification Tests

Telegra Fax Tests Supported by AudioCodes DSP

All AudioCodes DSPs pass the Telegra Fax Design Verification Test Library. Web-site for Telegra D/M download:

http://onenetworks.comms.agilent.com/telegra/D_MUpdate.asp.

The tests are carried out with network delay 300 msec (one-way) and network jitter 200 msec.

FaxLab Tests Supported by AudioCodes DSP

All AudioCodes DSPs pass the FaxLab Test Library of “Real World” Fax Emulations, see web-site

http://www.qualitylogic.com/genoa_test_tools/fax/devices.html.

The tests are carried out with network delay 300 msec (one-way) and network jitter 200 msec. See Appendix for a full list of "Real World" Fax Emulations.

Note: It is the User’s responsibility to ensure the fax device operates correctly in the User’s application.

More Information

For more information on implementation of AudioCodes' Voice over IP and Fax over IP solutions, please contact support@audiocodes.com.

References

ITU-T Recommendation T.30 (1996), *Procedures for document facsimile transmission in the general switched telephone network.*

ITU-T Recommendation T.4 (1996), *Standardization of Group 3 facsimile terminals for document transmission.*

ITU-T Recommendation T.38 (4/2002), *Procedures for real-time Group 3 facsimile communication over IP networks.*

ITU-T Recommendation H.323 (1998), *Packet-based multimedia communications systems*.

Appendix

Table 1: Fax Emulations of FaxLab 4.0 (continued on pages 16 and 17)

Fax Machine Model	Fax Machine Model
3Com Etherlink III LAN + 33.6 (FaxTalk)	Lumina 2096
AT&T 9015 PF	Megahertz PCMCIA Card (FaxTalk)
AT&T DataPort (Quicklink)	Minolta 3300
AT&T PPF200	Mita LDC-570
Boca MV.34E (FaxTalk)	Mita TC-170
Brother 6650MC	Monroe MX-4020
Brother 7150C	Motorola CELLect 14.4 (FaxTalk)
Brother Fax-190	Motorola Power 14.4 (BitFax)
Brother Intellifax 2500	Motorola Power 14.4 (FaxTalk)
Brother Intellifax 600	Motorola Power 14.4 (FaxWorks)
Brother Intellifax 625	Motorola Power 14.4 (Quicklink)
Brother Intellifax 950M	Motorola Power 14.4 (WinFax)
Brother MFC 4650	Motorola UDS 14.4 (FaxTalk)
Brother MFC 4550	Muratec F-56
Canon B70	Muratec F-90
Canon Fax 750	Muratec Imagemate CX
Canon Fax B340	Muratec M-820
Canon Fax TF-301	NEC Nefax 480
Canon L777	NEC Silent Writer 95
Canon Multi-Pass C2500	New Media 14.4 PCMCIA (FaxTalk)
Cardinal (FaxTalk)	Okidata OKIFax 1000
Compaq 9600 PCMCIA (FaxTalk)	Okidata OKIFax 2200
Eiger 14.4 PCMCIA (FaxTalk)	Olivetti OFX-1000
Fujitsu dex 740	Olivetti OFX 3100
Fujitsu dex 85	Lumina 2096
Gammalink Fax Modem (GammaFax)	Megahertz PCMCIA Card (FaxTalk)
Global Village teleport Bronze II (Global Fax)	Minolta 3300
Hayes JetFax (Hayes)	Mita LDC-570
Hayes Optima 14.4 (FaxTalk)	Mita TC-170
Hewlett Packard Fax-200	Monroe MX-4020
Hewlett Packard OfficeJet	Motorola CELLect 14.4 (FaxTalk)
Hewlett Packard OfficeJet 350	Motorola Power 14.4 (BitFax)
Intel SatisFAXtion /400e (Quicklink)	Motorola Power 14.4 (FaxTalk)
Konica 7310	Motorola Power 14.4 (FaxWorks)

Table 1: Fax Emulations of FaxLab 4.0 (continued on pages 16 and 17)

Fax Machine Model	Fax Machine Model
Motorola Power 14.4 (Quicklink)	Sharp FO-145
Motorola Power 14.4 (WinFax)	Sharp FO-235
Motorola UDS 14.4 (FaxTalk)	Sharp FO-445
Muratec F-56	Sharp FO-5400
Muratec F-90	Sharp UX-104
Muratec Imagemate CX	Sharp UX-108
Muratec M-820	Sharp UX-117
NEC Nefax 480	Sharp UX-1400
NEC Silent Writer 95	Sharp UX-256
New Media 14.4 PCMCIA (FaxTalk)	Sharp UX-3600M
Okidata OKIFax 1000	Supra 28.8 MacIntosh (Supra)
Okidata OKIFax 2200	Supra FAX Modem V.32bis (FaxTalk)
Olivetti OFX-1000	Supra FAX Modem V.32bis (WinTalk)
Olivetti OFX 3100	Telecom AM-11
Panasonic KXF500	Telecom NP-80
Panasonic KXF580	Toshiba TF-231
Panasonic KXF1600	Toshiba TF-421
Panasonic KXF3000	Toshiba TF-501
Panasonic KXFP270	US Robotics Sportster (Quicklink)
Panasonic PX-1500	US Robotics Sportster 14.4 Internal (FaxTalk)
Panasonic PX-350	US Robotics Sportster 28.8 MacIntosh (MacComm)
Panasonic PX-5	US Robotics Worldport PCMCIA (FaxTalk)
Panasonic UF-V60	US Robotics 33.6 Mdl 1172 (FaxTalk)
Pitney Bowes 8050	US Robotics 33.6 Mdl 1172 (Microsoft Fax)
Practical Peripherals V.32bis (FaxTalk)	US Robotics 33.6 Mdl 1172 WinFax Pro V7.5)
Ricoh 180	Viva 14.4 Fax Modem (FaxTalk)
Ricoh 3500L	Xerox 3004
Ricoh Fax 240	Xerox 7021
Ricoh Fax-3000L	Xerox 7024
Ricoh RF-05	Xerox 7033
Samsung FX-1502	Xerox WorkCenter 250
Samsung FX-40	Zoom Telephonics 14.4 Internal (FaxTalk)
Sanyo SFX 11	Zoom Telephonics 9600 Internal (FaxTalk)
Sanyo SPF-301	Zoom Telephonics V.32bis Internal (FaxTalk)
Scout 14.4 PCMCIA (FaxTalk)	ZyXEL Omni 288S (FaxTalk)
	ZyXEL U-1496E (FaxTalk)

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