FAX OVER IP

By

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ABSTRACT

The purpose of this thesis report is to give developers of facsimile applications a review of fax standards and to provide some in-depth knowledge of how a complete fax over the Internet Protocol (FOIP) system (consisting of both hardware and software) can operate. ITU-T, IETF and other organizations have released a number of documents each of which provides a part of the fax standards existing today. There are in fact so many standards that it is very hard to distinguish the important from the not so important. The fax standards are continuously updated with new revisions regularly. The fax standards related to FOIP are presently not finished in terms of documenting a practical working system! This thesis starts with the standards related to fax machines connected to analog telephone lines and leaves off where the FOIP standards end in 1999.

This thesis will provide an insight into the most important FOIP standards in order to help companies decide exactly what they want when buying facsimile standards and developing a fax solution for the Internet Protocol.

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1 INTRODUCTION

Group 3 Facsimile Equipment (G3FE) designed for the PSTN (Public Switched Telephone Network) are the most common fax devices on the market today. The market has continually grown since G3FE were introduced in 1980. Earlier fax machines running the facsimile Group 1 and facsimile Group 2 standards are obsolete and are not currently in use. A new Group 4 fax standard was released by CCITT in 1984 that would allow facsimile devices to be connected to the ISDN (Integrated Services Digital Network) with a new coding scheme called T.6, or Modified Modified Read (MMR) coding. The fact remains that fax modems do not work with ISDN and there are only a few ISDN facsimile devices out in the market, so the standard is seldom used. The facsimile Group 4 MMR coding standard was incorporated as an option in the CCITT/ITU-T Group 3 standard in 1992.

A small to medium sized company can have fairly significant fax costs. Interfacing G3FE devices to special hardware can however, reduce these costs. A facsimile message can then be transferred over an IP-Network. The economical savings for a company using the IP-Network as a facsimile transmitter instead of the PSTN network can be enormous, depending on the size of the company and its market segment. The ITU-T (International Telecommunication Union) has, in conjunction with the telephony manufacturers (ITU-T sector and development members), developed different standards for telecommunication to achieve a standardized market. ITU-T is a specific sub-sector of ITU (formerly known as CCITT) that deals with wire-based telecommunication.

Different companies can now develop their products according to the recommendations, so their products can be interfaced to other systems.

The standards are still in the development stages, and not all problems have been addressed or solved yet. Companies typically have a lot of patents, so not all information is publicly accessible. There are many ambiguities in the standards so there are many different ways of implementing a design. Depending on the choice of system, it is hard to find the correct standards and exactly which implementation to use.

This thesis will provide insight into the recommendations from ITU-T that governs Fax over IP related standards. It will give more information into how a Group 3 facsimile device can be incorporated to work on the Internet. All new standards and recommendations from ITU-T will be examined further and explanations will be given as to where they belong in a Fax over IP system.

2 TRADITIONAL FACSIMILE DEVICES

2.1 GENERAL INTRODUCTION

A traditional facsimile device (G3FE) is a fax machine that is designed to be connected to analog telephone lines. Group 3 facsimile devices are the most common standard fax machines today, and will probably stay in the market for many years to come.

This chapter describes those ITU-T protocols that are commonly used in G3FE. This gives a platform to work with in discussions connecting a Group 3 device to the Internet.

2.2 GROUP 3 FAX OVERVIEW

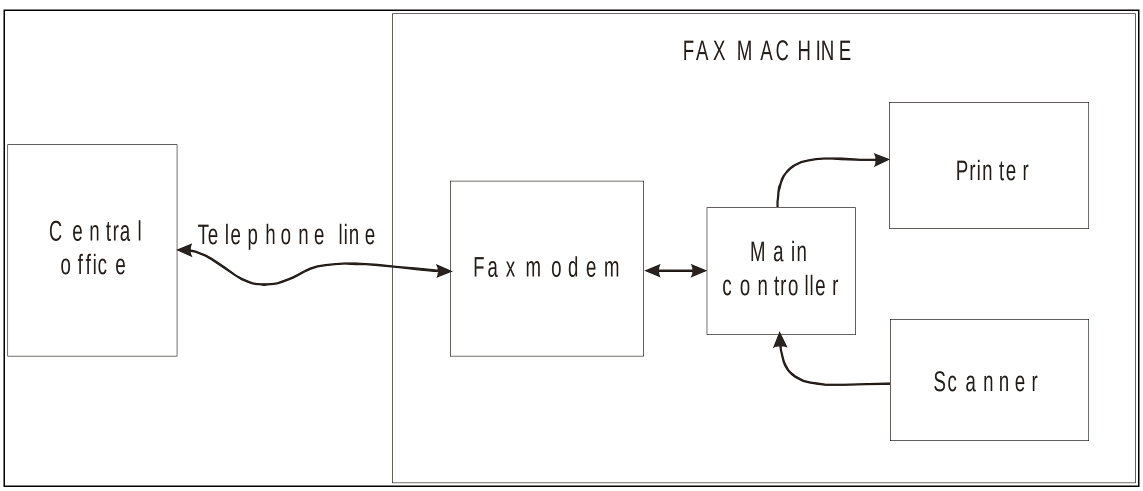

Figure 1 The main modules of a G3FE connected to a central office

Figure 1 shows the basic building blocks of a G3FE device. The fax modem is connected to the phone line (PSTN) and goes to a central office (CO). The CO is where the analog telephone line ends up at the telephone provider. The fax modem incorporates several transmission standards that can communicate with the central office. Its job is basically to convert data from analog to digital when receiving information from the phone line and to convert data from digital to analog when sending information out on the phone line via different transmission protocols. The main controller transmits and distributes signals and data to the other components of the fax machine. This is basically the brain. The printer module is a printer that prints facsimile images. The scanner is able to scan in pictures and send that information to the fax modem. All this exchange involves hardware and software control, protocols and standards. This part of the document describes how the software protocols from CCITT/ITU-T work within a G3FE device.

2.3 INTRODUCTION TO THE CCITT/ITU-T PROTOCOLS

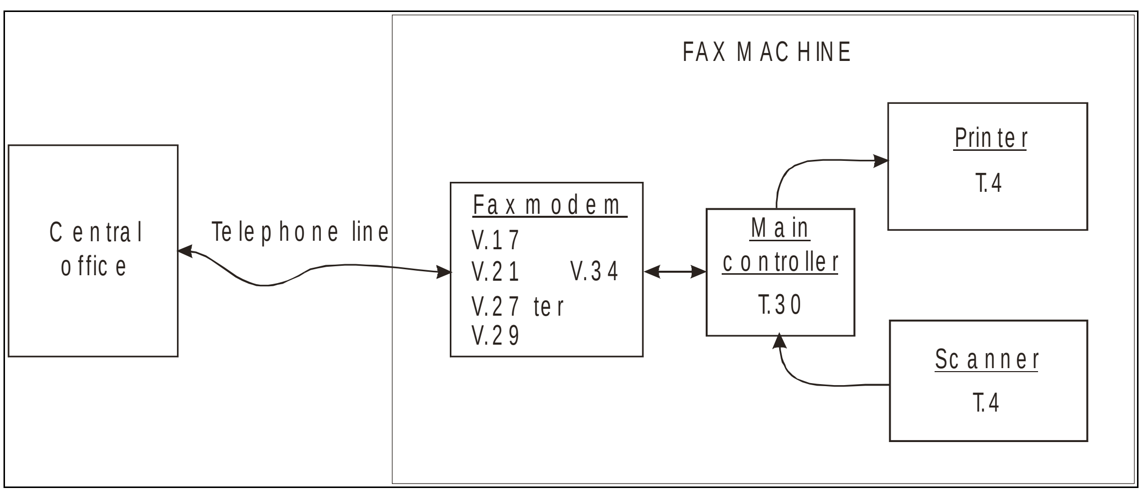

Figure 2 Software modules of a G3FE.

Figure 2 shows a block diagram of the most common CCITT/ITU-T standards for a fax machine. The ITU-T standards V.17, V.21, V.27ter and V.29 are the most common protocols used to transmit and receive data in a fax machine. V. 17 is the fastest and can handle up to 14.4kbits per second. Newer fax machines incorporate the 33.6kbits per second V.34. V.17 is normally the fastest protocol that is used in practice. These protocols are the so-called modulation types that the fax modem can handle.

The T.30 protocol mainly consists of a large state machine that controls all the information flow inside a fax machine, both to the components inside and to the outside world. This protocol is often referred to as the facsimile state machine. The T.30 has been modified and upgraded 3 times since its original ITU-T launch in 1996. The T.30 was known as X.30 when CCITT originally launched it.

The T.4 recommendation controls the image description and interfaces the information required to scan and print fax pages. It also contains the image size, resolution, and the compression/decompression routines (T.4 contains several ways of compressing and decompressing a fax image).

2.4 FAX MODEM MODULATION PROTOCOLS

The reason why so many fax modulation types exist is the ever-increasing demand for speed and new technology. The first fax standard for G3FE was the V.21 which can transmit/receive 300 bits per second. Today a normal fax machine uses speeds of 14400bps (the V.17 protocol). Like most other standards most of these will, in all probability, become either obsolete or updated with backward compatibility in a few years. V.34 is the protocol that will set the new standards of speeds. The different modulation standards incorporate different ways of communication and these will be explored further in the next sub-chapters.

2.4.1 ITU-T Recommendation V.21

V.21 is capable of transmitting/receiving 300 bits per second from the PSTN at full duplex communication (sending and receiving data at the same time). V.21 was the first Group 3 modulation scheme. All G3FE devices must incorporate this standard. V.21 is used for exchanging initial capabilities of two fax machines. After the optimal capabilities of the two fax machines have been determined, they will switch to another form of modulation. V.21 is not used for sending the fax image data itself since it is too slow.

V.21 uses a modulation type that is called FSK (Frequency Shift Keying). This means that it uses different frequencies to represent data. One frequency is used for a logic “1” and another frequency is used for logic “0”. Typical modems that use full duplex communication use 4 different frequencies when transmitting/receiving data. Two of the frequencies are called channel 1 and the other two are called channel 2. Channel 1 is used for the modem that originally made the call while channel 2 is used by the modem that received the call (full duplex communication). Since fax machines only communicate in one direction at a time, the full duplex communication mode is not used. Fax machines only use half-duplex communication and channel 2. This means that when a fax machine transmits or receives information, a frequency of 1850Hz means a logical “0” while a frequency of 1650Hz means a logical “1”. Both of the fax machines use those two frequencies.

2.4.2 ITU-T Recommendation V.27ter

V.27ter is a 4800/2400 bits per second modem standard for use in the PSTN. V.27ter uses a modulation type that is called DPSK (Differential Phase-Shift Keying). This method uses phase difference to encode bit transitions rather than the frequency. The simplest form of DPSK is called DPSK-2. This method involves sending a sinusoidal waveform with 0° phase shift or with 180° phase shift. This provides two states and therefore it is called DPSK-2. The frequency is the same in each case. V.27ter incorporates 2 different DPSK modulation schemes. These are DPSK-8 and DPSK-4. The baud rate of a V.27ter 4800bps is 1600 symbols/second.

Figure 3 shows, the phase shifts that are used in the V.27ter 4800bps standard. There are eight different phases. This means that 8 different states (or 2^3 bits) can be sent per baud.

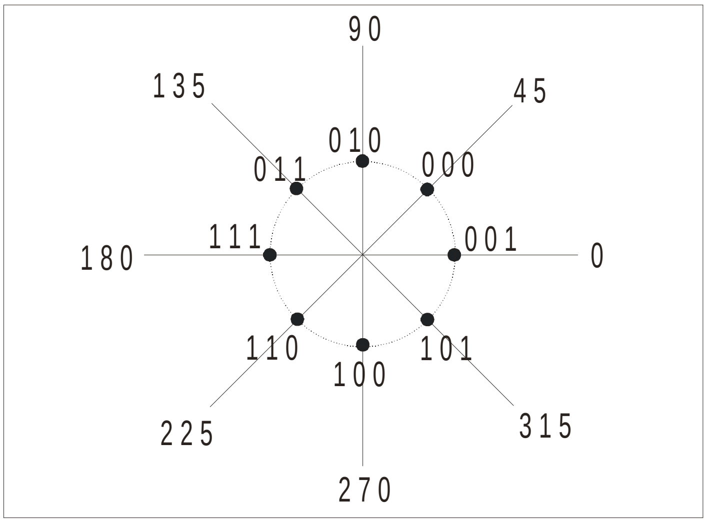

Figure 3 V.27terDPSK-8, 4800bps modulation scheme

Table 1 shows the bit combinations that are sent per phase. 3 bits *1600 baud = 4800 bps.

Tribit values			Phase change
0	0	0	0°
0	0	1	45°
0	1	0	90°
0	1	1	135°
1	0	0	180°
1	0	1	225°
1	1	0	270°
1	1	1	315°

Table 1 V.27ter DPSK-8 table

Table 2 shows the bit combinations for the fallback (fallback schemes are invoked if the higher data rates lead to too many errors) DPSK-4. Figure 4 shows how the DPSK-4 uses the phases. This modulation scheme has 2 bits * 1200 baud = 2400bps.

Dibit values		Phase change
0	0	0°
0	1	90°
1	1	180°
1	0	270°

Table 2 V.27ter DPSK-4 table

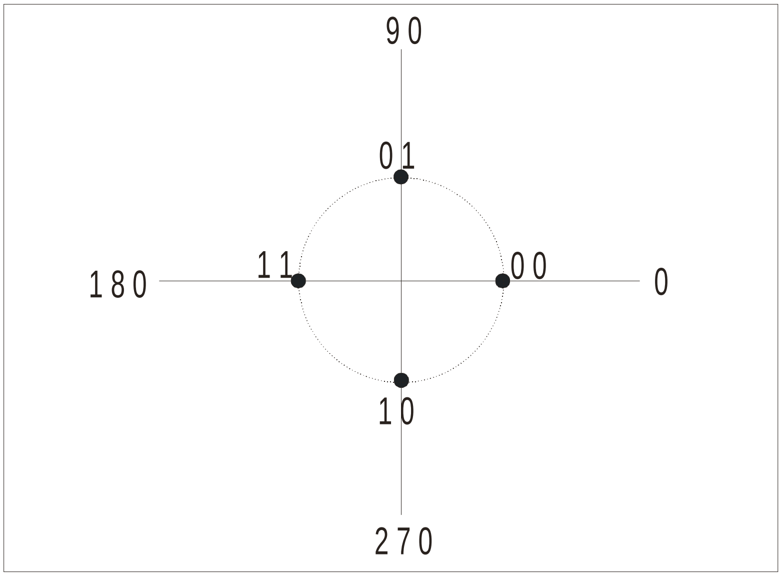

Figure 4 V.27ter DPSK-4, 2400bps modulation scheme

2.4.3 ITU-T Recommendation V.29

The V.29 is the most common modulation scheme used for transmitting image data. It can transmit up to 9600bps with fallback of 7200bps. The original idea behind V.29 was to incorporate frequency shifts at the same time as having phase shifts. This was not feasible because of the number of errors induced by the PSTN. Therefore, the V.29 incorporates amplitude modulation with phase shifts. This modulation type is known as QAM (Quadrature Amplitude Modulation). The diagrams that explain these phase-amplitude relationships are called constellations. Figure 5 shows the constellation of the V.29 9600bps modulation scheme. Notice that there are actually 4 amplitudes in the constellation. There are two amplitudes per phase but no neighboring phases (45° phase change) use the same two amplitudes.

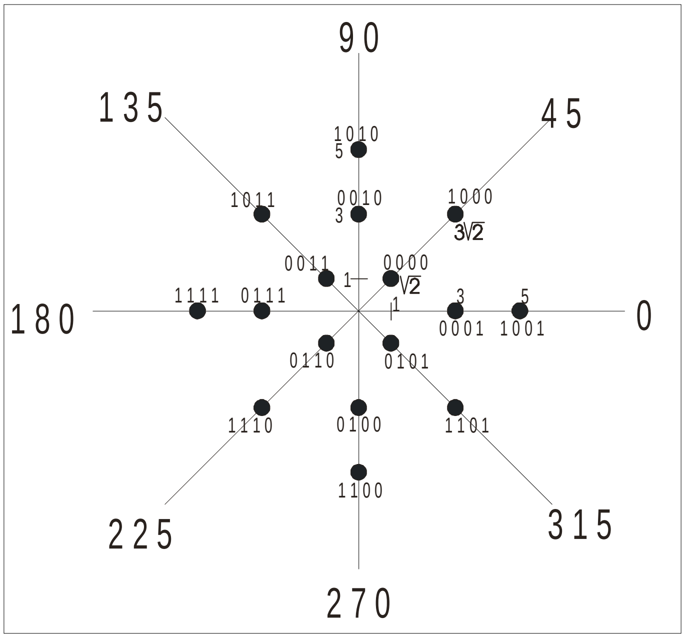

Figure 5 V.29 4 bit, 9600bps QAM constellation modulation scheme

There are 2 amplitudes per phase shift giving a total of 16 states or 2^4 bits. The baud rate of V.29 9600 is 2400. So therefore it has 2400baud*4bits = 9600bps. The fallback speed of 7200bps still contains 2400baud, but it drops one of the amplitudes per phase so that there are only 2^3 bits. 2400baud*3bits=7200bps. Figure 6 shows the 7200bps fallback constellation [8].

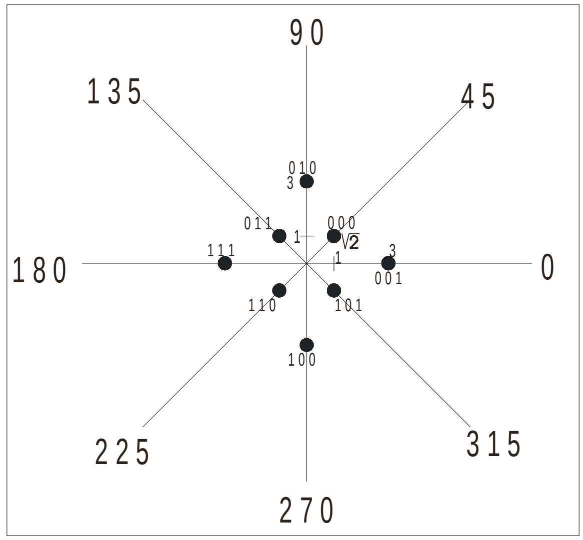

Figure 6 V.29 fallback 3 bit, 7200bps QAM constellation modulation scheme

2.4.4 ITU-T Recommendation V.17

V.17 is the most common modulation standard for G3FE devices when transferring images (high speed data). V.17 supports rates up to 14400 bps, but also has fallback rates of 12000bps, 9600bps and 7200bps. V.17 uses a special form of QAM called TCM (Trellis Coding Modulation).

While V.29 uses a whole 90° phase shift before using the same amplitudes, thus losing a whole bit of a baud, the Trellis coding scheme uses these extra amplitudes to check the validity of the information. Figure 7 shows the V.17 9600bps TCM constellation. The symbols identified by squares are the trellis coding bits. Since V.17 uses 2400baud and one bit is used for trellis, then the maximum number of bits per second is 2400baud*4bits = 9600bps. This is exactly the same as V.29 9600bps, but it is a far more reliable modulation scheme, because of the redundant bits.

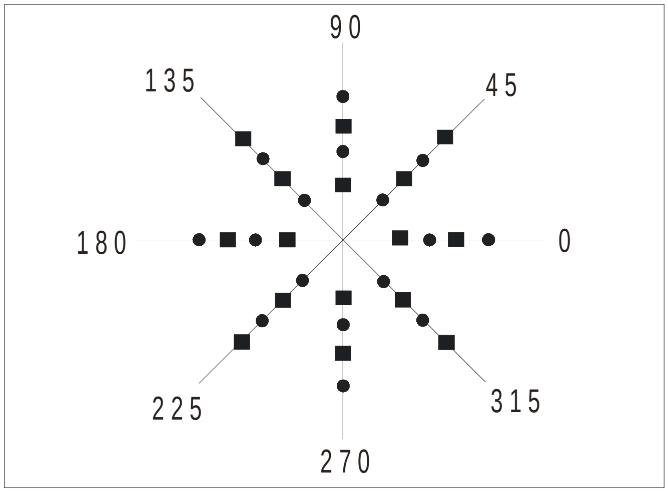

Figure 7 V.17 9600bps TCM constellation

The trellis coding leads not only to more reliable transmission, but it also helps the V.17 modulation scheme to achieve even higher speeds. Figure 8 shows the V.17 14400bps constellation. It has 128 different states. 64 of those are the trellis coding, so there are 64 usable states for data or 2^6 bits. Since the baud rate is still 2400, then the bits per second becomes 2400baud*6bits = 14400bps

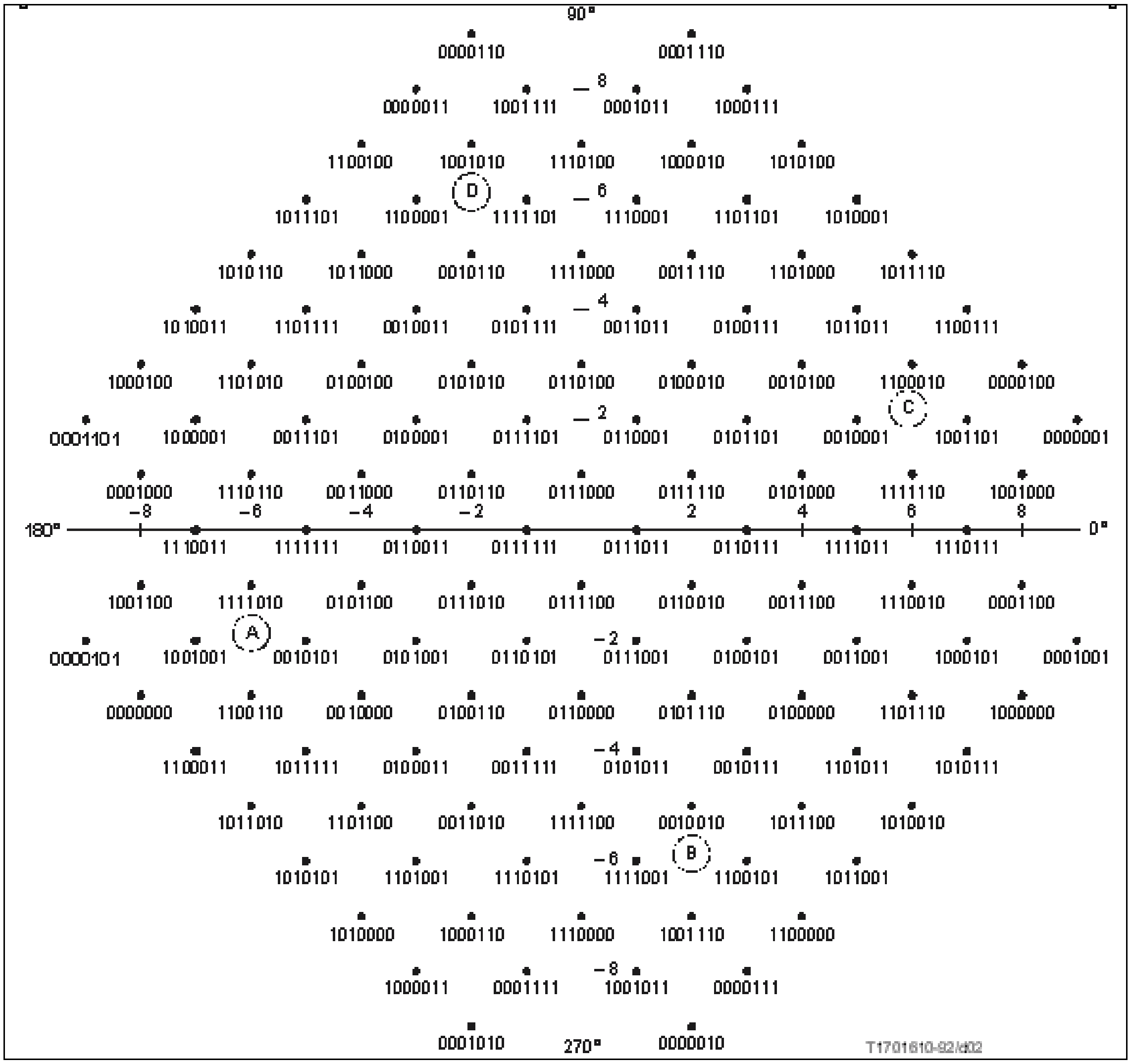

Figure 8 V.17 14400bps TCM constellation

2.4.5 ITU-T Recommendation V. 34

V.34 is the most recent modulation standard for facsimile devices that supports signaling rates up to 33600bps. Like V.17, V.34 also uses TCM constellations. An important difference is that V.34 utilizes echo canceling and some special adaptive schemes like line probing to reach the 33600bps continuous transfer rate. Significant work has been put into the V.34 standard, but some major parts of it related to the IP networks are still under development. V.34 will most likely not be used for Fax over IP in the next 2-3 years.

2.5 ITU-T RECOMMENDATION T.4

The T.4 protocol was introduced by CCITT in 1980 as the facsimile Group 3 standard. In 1984 the protocol had been revised several times and expanded. It was then decided to split the document into two parts. One part was the X.30 (later known as T.30) and the other was named T.4.

ITU-T Recommendation T.4 defines the properties of image characteristics of Group 3 facsimile terminals. T.4 enables image data to be transmitted on the general switched telephone network, international leased circuits, and the ISDN. This recommendation enables documents to be transmitted both as black and white documents and as color documents. T.4 is highly integrated with the ITU recommendation T.30. Together they form the platform for document transmission for G3FE.

T.4 contains all image information and the encoding/decoding routines that are required for a Group 3 facsimile device. T.4 and T.30 complement each other in a Group 3 facsimile device. The main parts of T.4 are the run-length coding/decoding schemes, the bi-level compression schemes, and the color/gray-scale compression techniques. It is beyond the scope of this document to explain in detail these coding schemes, so the reader is referred to ITU-T Recommendation T.4 [1]. The encoder/decoder schemes will be briefly explained in this chapter.

2.5.1 1-D coding (Modified Huffman)

Modified Huffman (MH, also known as 1-dimensional-coding) is the most common run-length scheme used in a Group 3 facsimile device. If a fax machine has MH encoding, then it can receive a fax. MH is the most common black and white encoding scheme, the lowest common denominator (the simplest decoder/encoder that all G3FE devices incorporate), and the easiest encoder to understand.

MH coding uses two different look-up tables of codes called terminating codes and make-up codes. These, in conjunction with black run-lengths and white run-lengths, describe how a facsimile image can be compressed. The terminating codes and make-up codes for black and white run-length are described in the T.4 recommendation. A MH coded line always starts with a white run-length. It can either be a make-up code or a termination code. If it is a terminating code, then the next run-length will be black. If it is a make-up, then the next run length will be white. A new line is ended with an EOL (end of line) code, and the end of the facsimile page is marked with six consecutive EOL codes. The pattern of six consecutive codes is also called RTC (return to command). This encoding scheme compresses a typical facsimile black and white image 6-10 times. The longer the run-lengths of black and white, the better the compression becomes. This coding scheme is explained further in Appendix A.

2.5.2 Two-dimensional coding scheme (MR)

The two-dimensional coding scheme is an optional extension of the one-dimensional coding scheme specified in 2.5.1. This is a line-by-line coding method in which the position of each changing picture element on the current, or coding, line is coded with respect to the position of a corresponding reference element situated on either the coding line or the reference line which lies immediately above the coding line. After a line has been coded, it becomes the reference line for the next coding line. Two-dimensional coding alternates using two-dimensional coding and one-dimensional coding. There are three coding modes specified in the T.4 protocol: pass mode, horizontal mode and vertical mode. This coding/decoding algorithm is quite advanced and is nicely explained in the ITU-T Recommendation T.4 [1].

2.5.3 Extended two-dimensional coding scheme (MMR)

The basic facsimile-coding scheme specified in ITU-T Recommendation T.6 [10] may be used as an option in Group 3 facsimile terminals. This is also known as Modified Modified Read encoding. This coding technique requires error free transmission. It uses the same basic technique for compression as Modified Read, but it reaches an even higher compression level by not using EOL codes or 1-D compressed lines.

2.5.4 Progressive bi-level image compression

The usage of the progressive bi-level image compression scheme defined in recommendation T.82 for Group 3 facsimile terminals should be in accordance with the application rules described in the corresponding sections of Recommendation T.85 [16].

2.5.5 Continuous-tone color and gray scale modes

Continuous-tone color and gray-scale modes are optional features of Group 3, which enable transmission of color or gray-scale images. Color and gray scale modes are incorporated by introducing JPEG (Joint Photographics Expert Group) image compression routines. This is further explored in the CCITT Recommendation T.81 [14].

2.6 ITU-T RECOMMENDATION T.30

T.30 is intended for document facsimile terminals covered by Recommendation T.4. It describes the procedures and signals to be used where G3FE terminals are operated over PSTN (or optionally ISDN). T.30 contains a large state machine that controls the phase and position a facsimile device is located during facsimile transmission. There are basically 5 different phases in a facsimile transmission. The phases are Phase A through Phase E, described below.

- Phase A: *Call set-up*

  This phase includes the call establishment, when the transmitting and receiving units connect over the telephone line and recognize one another as fax machines. This is the start of the handshaking procedure.

- Phase B: *Pre-message procedure for identifying and selecting the required facilities*

  This is the pre-message procedure where the answering machine identifies itself and describes its capabilities in a burst of digital information packed in frames conforming to the HDLC (High-level Data Link Control) standard.

- Phase C: *Message transmission*

  This is the fax transmission portion of the operation. This step consists of two parts

"C1" and "C2", which take place simultaneously. Phase C1 deals with synchronization, line monitoring, and problem detection. Phase C2 includes data transmission (ITU-T Recommendation T.4 controls this).

- Phase D: *Post-message procedure*

  This phase begins once a page has been transmitted. Both the sender and receiver revert to using HDLC packets as during Phase B. If the sender has further pages to transmit, it sends an MPS (Multi Page Signal) frame, and the receiver replies with an MCF (Message Con-Firmed). Phase C recommences for the following page.

- Phase E: *Call release*

  The call release portion. The side that transmitted last sends a DCN frame (a hang-up frame) and hangs up without awaiting a response.

ITU Recommendation T.30 has been revised and updated 3 times. Altogether, the T.30 now contains 336 pages. More information can be acquired from the ITU-T recommendation T.30 [2].

2.7 ITU-T RECOMMENDATION T.6

ITU-T Recommendation T.6 [10] is a protocol for facsimile images developed to work on the ISDN. It would have the same function for ISDN as T.4 has for the PSTN. T.6 incorporated a new compression codec called MMR. ISDN has error correction built in, so the compression algorithm does not use any of its own. This compression algorithm was later included as an optional coding technique in the T.4. T.6 is a very small document and is basically not used at all, due to the lack of ISDN fax machines in the market.

2.8 STRUCTURE OF G3FE OPERATION

The standards in the former chapters form a platform where two G3FE devices can communicate and exchange data. The calling/receiving procedure and where the different recommendations apply will be explained in this chapter.

Whenever information is sent back and forth between two Group 3 facsimile devices, the physical signal is modulated with one of the modulation schemes V.21, V.17, V27ter, V.29 or very seldom V.34 . Figure 9 shows how the interchange between two fax machines works. The T.30 state machines controls all flow. The calling fax machine first dials the number to a receiving fax machine. As soon as the calling fax machine hears the ringing tone it sends a frequency of 1100 Hz called CNG. The called fax machine picks up this signal, recognizing the CNG signal. It then sends a 2100Hz tone back called CED. The calling fax machine detects this tone and that concludes Phase A or the call establishment part of the T.30 state machine.

Figure 9 PSTN fax control flow from recommendation T.30.

The T.30 state machines of both fax machines then enter Phase B. Phase B starts with information sent from the called fax machine. All exchange of control signals happens at 300 baud (the V.21 modulation scheme). Phase B consist almost entirely of an exchange of HDLC frames. The called fax machine first sends a preamble (preamble is used for synchronizing the fax machines) then a digital identification signal (DIS) message which states the capabilities of the fax machine (such as the highest supported modulation speed). After this, it can also optionally send a NSF (non-standard facilities) frame and/or a CSI (called subscriber information). NSF is built as an extension so new features from the different fax manufacturers can be incorporated. NSF can, for instance, incorporate more detailed documents than normal, higher speeds, better security, or other manufacturer specific information that would give them an edge over the competition. The CSI frame consists basically of a 20 byte wide field conveying the identity of the fax machine by sending its telephone number as ASCII characters.

The calling fax machine now sends a DCS (digital command signal) frame. A DCS frame is basically the same as a DIS frame, except that a DCS frame specifies exactly which feature is going to be used for a specific purpose, while the same bits in a DIS tell all features one can use for the same purpose. The reason for this is that a DIS frame sent from the called fax machine tells about the capabilities, but it does not choose which one to use. The calling fax machine compares the DIS frame from the called fax machine with its own capabilities and then chooses the best capabilities that they have in common. The calling fax machine can then optionally (and it usually does) send a TSI (transmitting subscriber information) frame. A TSI frame contains the phone number of the calling fax machine.

The capabilities that the fax machines are going to use have now been determined, so they are ready to test if the chosen speed actually works. This is done by the calling fax machine sending a TCF (training check frame) at high speed (V.17 14400bps for instance). This is not a HDLC frame, since it only consists of a series of 01111110 bits sent for 1.5seconds ±10%. The called fax machine decides if the data is good or bad. It then switches to V.21 and sends back either a CFR (confirmation to receive frame) which means that this was successful or a FTT (failure to train frame). If a CFR frame was sent, then it enters Phase C, the image transmission phase, at high speed. If an FTT was sent, then the calling fax machine will compose a new DCS frame with less speed or hang up. The new DCS speed is trained and if it works then we enter Phase C.

Phase C involves transmitting the image at high speed. The information sent conforms to the compression schemes from ITU-T Recommendation T.4 [1]. At the end of the transmission a RTC (return to control) frame is sent indicating that all images have been sent. RTC consists of 6 EOL codes specified in the T.4 protocol (see Appendix A). The fax machines then proceed to Phase D.

Phase D starts with a frame sent from the calling fax machine. It usually (there are other choices too) sends an EOP (end of procedure) frame telling that the picture is transmitted , and then hangs up the line. If there are more pages to be sent, it sends a MPS (multi page signal) frame telling that it wants to send more images. If the called fax machine receives a MPS frame from the calling fax machine, it responds with a MCF (message confirmation) frame telling that the page was transmitted successfully and that it is ready to receive more pages. When the EOP is sent from the transmitting fax machine, then the fax machines enters Phase E.

Phase E consists basically of the calling fax machine sending a DCN (disconnect) message and then hanging up the line. The fax transmission is then over.

This concludes the chapter discussing how facsimile devices are able to interchange information over the public switched telephone network. The next chapter tells how this process can be applied to networks using the Internet Protocol.

3 FACSIMILE TRANSMISSION OVER IP

3.1 GENERAL INTRODUCTION

The biggest telecommunication companies have recently started incorporating ITU-T recommendations and standards for transferring voice, data, and fax over the IP network. Earlier, all telephony companies made their own internal standards that were incompatible with the equipment of other manufacturers products. This has started to change with IETF and ITU-T protocols that have been released the last decade. This chapter will discuss some of the standards that are important in Fax over IP.

3.2 FAX OVER IP MODULE OVERVIEW

Figure 10 shows an outline of how FOIP is implemented. The phones and fax machines in a company branch are connected to a PBX (private branch exchange) unit. The PBX converts the signals from analog to digital and combines the digital signals to E1/T1 trunks (a T1 trunk contains 24 ISDN B channels, while an E1 trunk contains 30 ISDN B channels). This signal is then connected to a workstation or PC that contains an IP gateway card. Since the card is connected to a PC or workstation, all the information from the PBX can be transferred, modified, or treated with different protocols. This information can then be sent using the Internet to other places in the world that receive the information and act accordingly.

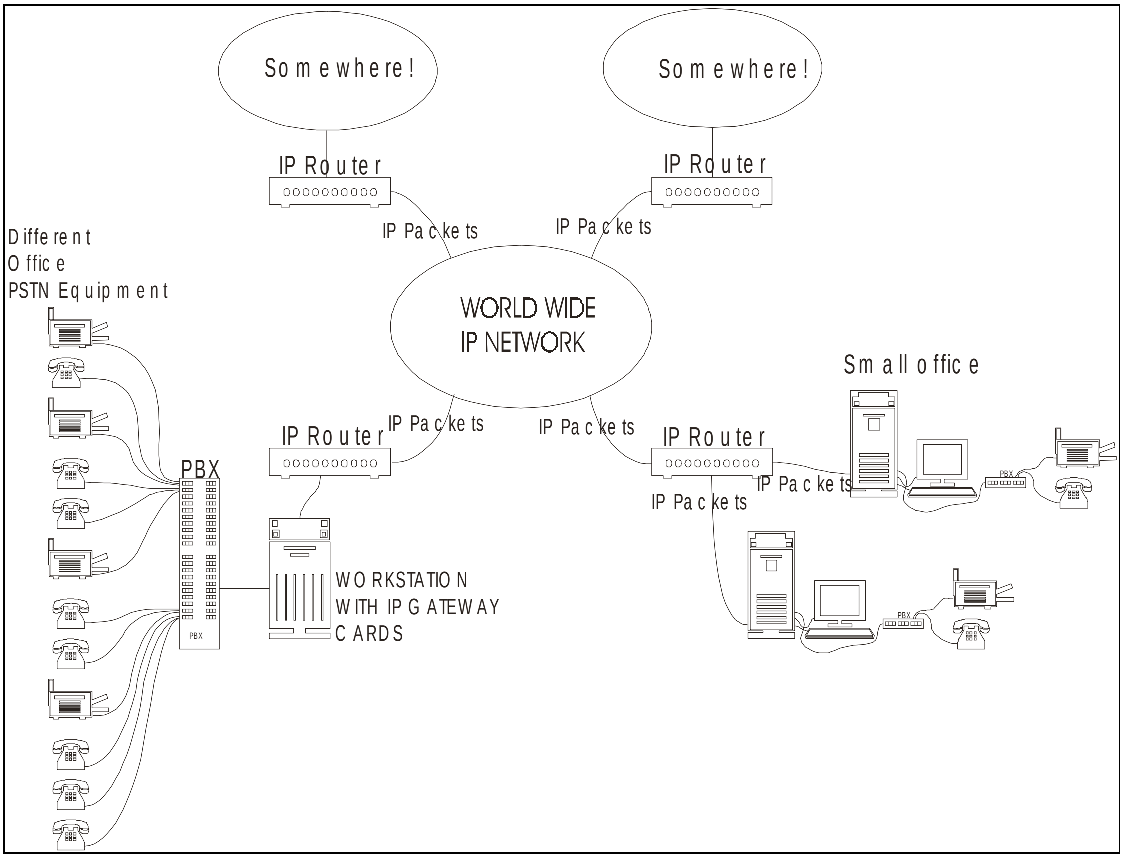

Figure 10 Fax over IP overview

For a fax transmission, this means that the fax machine can call the IP Gateway card, which conveys the information to another IP Gateway another place in the world. The receiving card can then communicate with its own fax machine that will receive the fax information.

This chapter goes into more depth about the standards under development from ITU-T and which standards are important to the telephony companies. The software protocols on the IP Gateway cards are especially interesting in this respect. All protocols in this chapter are being developed further and all of them have chapters still studied by ITU-T that are not released to the public.

3.3 H.323 MULTIMEDIA

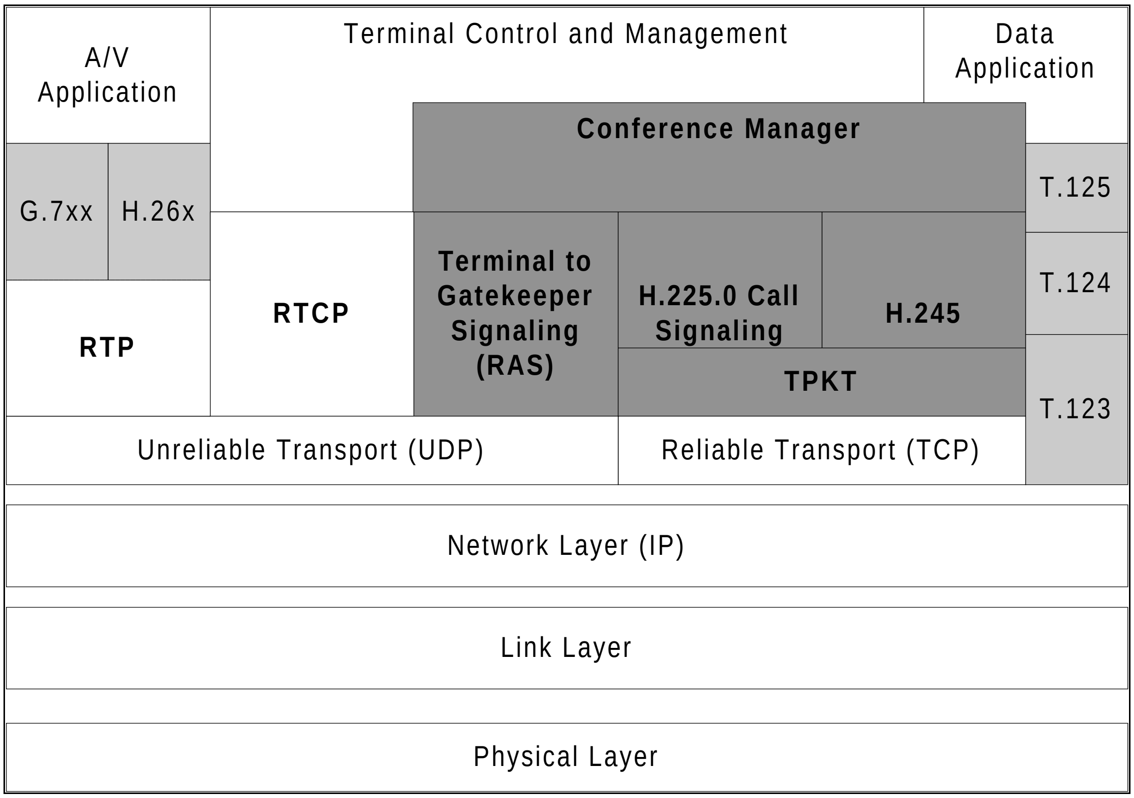

Figure 11 The H.323 stack

H.323 is an umbrella recommendation from ITU-T that specifies how real-time multimedia communications over IP compliant networks should work. H.323 is made with the purpose of defining a layer in which different voice, fax and data codecs can ideally be easy to be interfaced. H.323 supports several voice and multimedia codecs and ITU-T recommendation T.38 [12] real-time fax is the chosen protocol for facsimile devices. The interface standards between T.38 and H.323 are still under development from the ITU-T, but are expected to emerge in the near future.

Figure 11 shows the layer in an IP network where the H.323 is located. The lowest level is the physical layer, such as the physical copper/optical lines. Then the linking to the physical layers, before reaching the network layers or the Internet Protocol. Layer number four has the two different Internet Protocol messaging systems TCP (transport control protocol) and UDP (user datagram protocol). TCP is a protocol that makes sure that no data packets contain faulty data. In this case the packet will be sent again. UDP involves sending the packet without any error checking. T.38 can utilize both of these protocols; however, even though TCP is slower then UDP it is much more fault tolerant and would therefore be a good protocol to choose. Layer 5 is where the H.323 stack is located.

The H.323 is a very ambitious standard that takes care of the technical requirements for all real-time communications over IP networks. Description of the H.323 standard itself is out of the scope of this report, and there are several excellent books in the market that explain the standard [26 and 27]. H.323 is not a necessary protocol for FOIP, it just provides a unified messaging system where data, voice and fax are all integrated in the same manner.

The most important standards that are incorporated with the H.323 standard are:

- H.225.0, which uses:
    - RAS for registration, admission, status,
    - Q.931 for call signaling (setup, teardown, disengage),
    - RTP/RTCP for media stream packetization and synchronization,
- H.245 for call control (capabilities, master/slave, logical channels),

- H.450 for supplementary services,
- H.235 for security,
- H.261 and H.263 video codecs,
- G.711, G.722, G.728, G.729, and G.723 audio codecs,
- T.120 series,
- T.38 real-time G3FE and T.37 store and forward fax.

3.4 ITU-T RECCOMENDATION T.37, STORE AND FORWARD FAX

ITU-T Recommendation T.37 [11] is a protocol designed to store and forward facsimile images for the Internet. It defines the chosen file format when storing a facsimile image on disk. Its key uses are:

- Used when trying to send an image to a facsimile device but the facsimile device is busy so it must be sent later.
- Used if a facsimile image must be sent to several recipients (batch running).

T.37 uses the TIFF (tagged image file format) image format to store data on disk. TIFF is a public file format made by Aldus Corporation. T.37 references in particular a document from IETF (Internet Engineering Task Force) called RFC 2301 File Format for Internet Fax [19].

The T.37 file format complies with the IETF image format RFC 2301 profile S. RFC 2301 references no other documents, but the full TIFF file format information is located in the document TIFF Revision 6.0 from Aldus Corporation. ITU-T Study Group 8 (a division from ITU-T that handles facsimile related recommendations) has not come further than explaining TIFF class F, whereas the newest revision from IETF have included the TIFF specification commonly known as TIFF-FX.

TIFF-FX formally defines minimal, extended, and lossless JBIG profiles (profiles S, F, J) for black-and-white fax, and base JPEG, lossless JBIG and mixed raster content profiles (profiles C, L, M) for color and grayscale fax. These profiles correspond to the content of the applicable ITU-T Recommendations. Files formatted according to this specification use the image/tiff MIME content type. Apart from referencing the IETF document, T.37 shows approximately how the TIFF class F file headers should look. TIFF has an ideal framework for FOIP and therefore it has been chosen by ITU-T and IETF because it adds functionality to both existing fax machines and future fax machines that will use colors and other compression algorithms than those existing today.

TIFF is such a vital image file format when it comes to the T.37, T.38, and other documents referencing FOIP , that Appendix C will further explain it.

3.5 ITU-T RECOMMENDATION T.38, REAL TIME G3FE

ITU-T Recommendation T.38 [12] is the most important ITU-T recommendation for interfacing G3FE equipment to the IP. The T.38 protocol defines the messages and data exchanged between facsimile gateways and/or internet aware facsimile (IAF) devices connected via an IP network. IAF devices are facsimile devices that have the ability to be connected directly to the IP network. Figure 12 shows how this can be done. ITU-T Recommendation T.38 has also become the chosen fax protocol for real time FOIP for the H.323 standard. Figure 12 shows an IP network that has two gateways connected. The IP gateway uses software and hardware to be able to communicate with fax and telephone equipment. Both of the gateways contain the T.38 protocol.

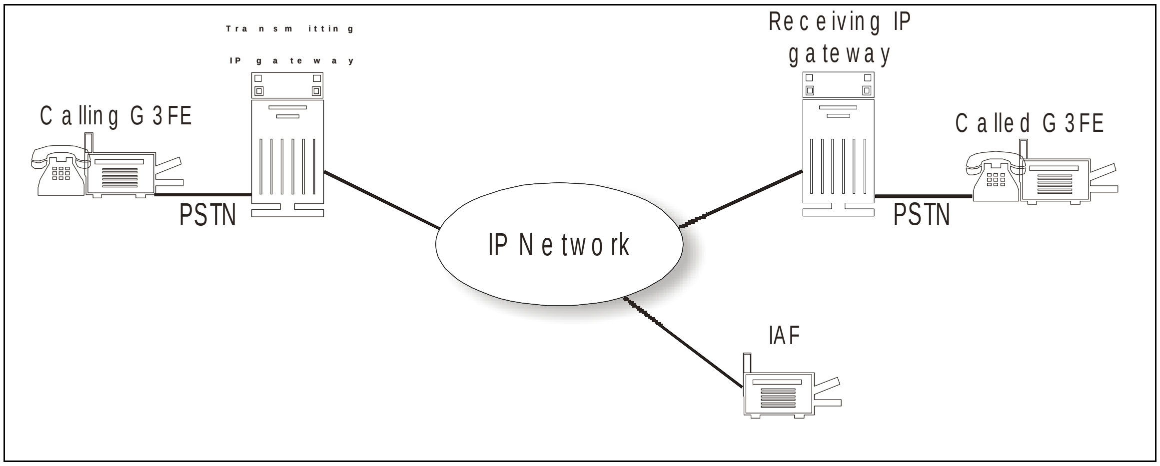

Figure 12 Model for T.38, G3FE transmission over IP networks

Figure 12 shows a calling G3FE machine on the left and a called G3FE machine on the right. The calling fax machine is the originator of a facsimile transmission, while the called fax machine is receiving the facsimile. The originator transmits a facsimile by typing in the phone number of the other fax machine, just the same way as one would on the normal PSTN. The IP gateway receives the request from the originating messenger. This message contains the fax number to the called fax machine. The gateway has a table that converts the phone number into an IP address. The message is then sent over the IP to a receiving gateway, which detects the IP packet that should be sent to its fax machine. It converts the IP packet to a format that the G3FE machine understands and sends it. The called fax machine detects this and sends some information back to its gateway. The called gateway then sends that information back to the originating gateway. The calling gateway understands the information and thus converts it to a format that the calling fax device understands. This information exchange continues until the whole fax message is sent and then the fax machines hang up the line.

Chapter 1 dealt with how two G3FE devices communicate with each other over the PSTN. The protocols inside the fax machine consist mostly of the T.4 image protocol, the T.30 state machine and the different V.XX modulation schemes. The gateways in the IP network case must act as they are fax machines. The G3FE devices only understand the T.30 state machine and T.4 related data. This means that the gateway must have the exact same protocols as the fax machine that it is connected to, but it must also contain a part to be able to communicate this data over the IP network. The T.38 specifies two ways of doing this, TCP or UDP. T.38 specifies a special kind of layer such that the T.38 messages exchanged for TCP and UDP look identical. This chapter only explains TCP. However, only small changes need to be made when using UDP.

Figure 13 shows the IFP/TCP packet structure that have been chosen for T.38. The IFP (internet facsimile protocol) packet form is specially built for facsimile devices. Figure 13 shows that the IFP packets are wrapped inside a TCP header. These are then wrapped inside an IP header. Error checking is built into the TCP protocol.

The IPF protocol conforms to the HDLC frames format used by the T.30 protocol (Appendix A). The IPF protocol contains 2 types of elements, TYPE and DATA. The

TYPE describes the type of message, while the DATA depends on the TYPE. Table 3 show the two fields that the TYPE can consist of. Tables of the different DATA entries have not been included, since they would be beyond the scope of this thesis.

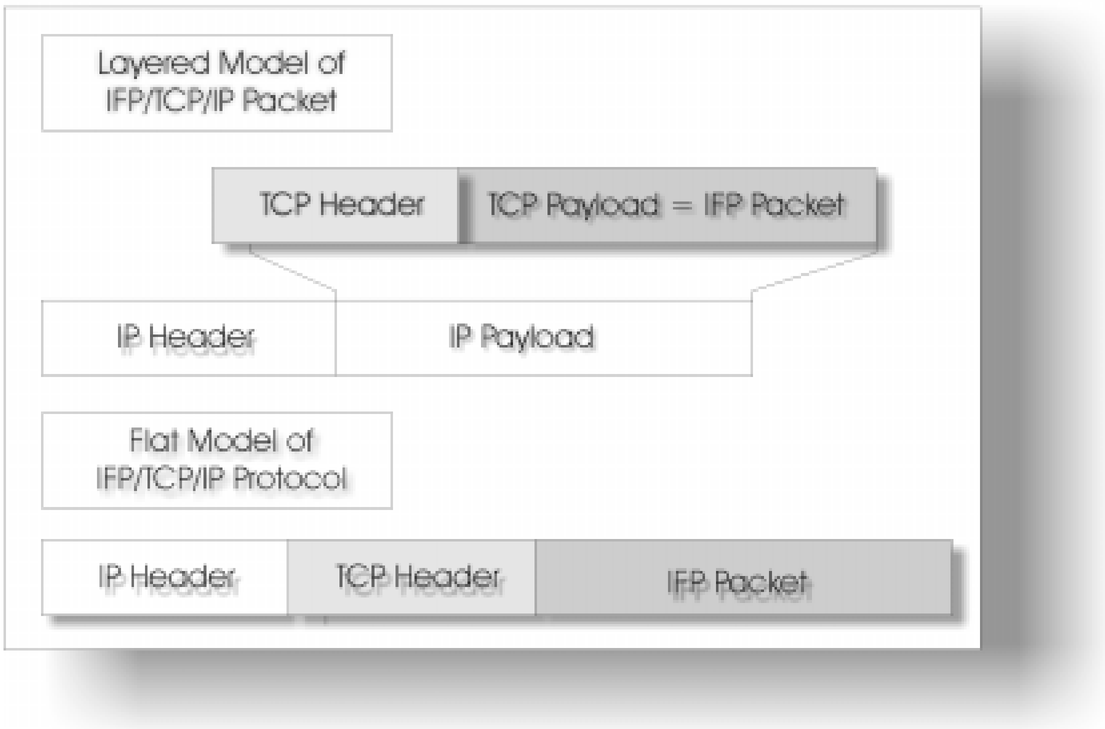

Figure 13 High-level IFP/TCP packet structure (T.38 recommendation)

Type	**Description**
T30_INDICATOR	Carries indication about the presence of a facsimile signal (CED/CNG), preamble flags or modulation indications.
T30_DATA	T.30 HDLC Control and Phase C data (e.g T.4 or T.6 image segments)

Table 3 The IFP packet TYPE field

Figure 14 and Figure 15 shows the IFP packets sent between two G3FE facsimile devices over an IP network. The sending G3FE is the fax machine that initiates the call, while the receiving G3FE is the machine that is being called. The emitting gateway is the computer/workstation with the T.38 protocol connected to the calling fax machine, while the receiving gateway is connected to the receiving G3FE device.

When a user dials a number on the sending fax machine (this is done typically by DTMF tones, see glossary). The sending fax machine then emits the normal CNG tone to identify itself as a fax machine. The gateway that it is connected to recognizes that a fax machine wants to initiate a session and it also knows the receiver because of the DTMF tones. It then searches its tables, and finds the IP address to the receiving IP gateway. Figure 14 shows that the emitting gateway creates an IPF packet with a TCP/IP header wrapped around it. Table 3 shows that the IPF TYPE field used for a CNG should be a T30_INDICATOR. Figure 14, shows that the emitting gateway creates a “T30 IND:CNG” packet and sends it off to the receiving gateway. The receiving gateway understands that it must create an actual CNG tone and send that to its fax machine. The receiving fax machine responds by sending a CED tone back to its gateway, which in turn creates a “T30 IND:CED” packet and sends it back to the emitting gateway. This process continues until the whole facsimile message has been sent. Figure 14 and Figure 15 contain the whole G3FE T.38 communication process. Every T.30 message has been mapped into a corresponding T.38 IFP message, so a G3FE device will not know that it is not communicating directly with another G3FE device. The communication process between an gateway connected to a G3FE device and an IAF machine happens the exact same way except that the gateway on the IAF is located inside the IAF machine.

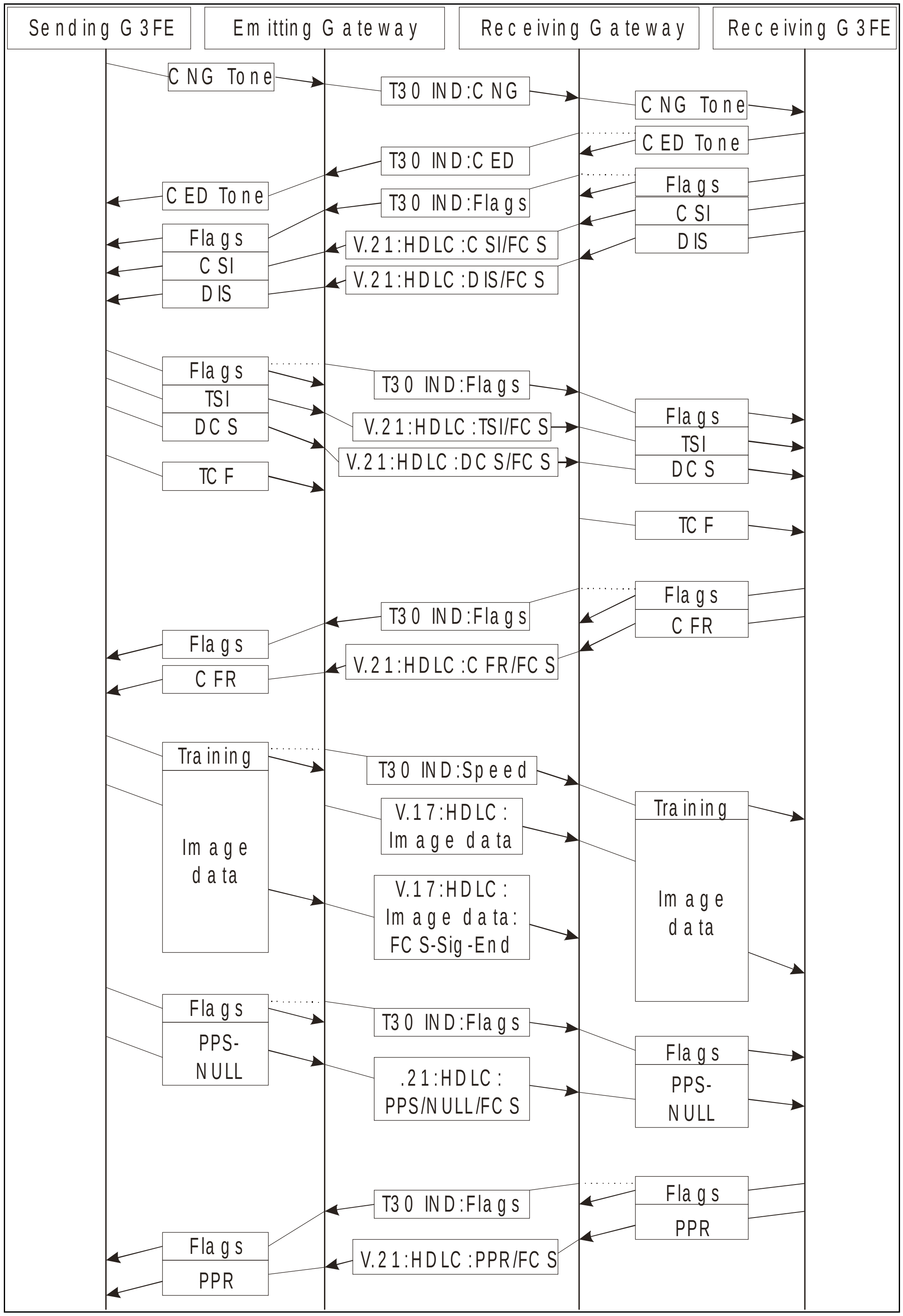

Figure 14 G3FE devices communicating over IP network using T.38, part 1

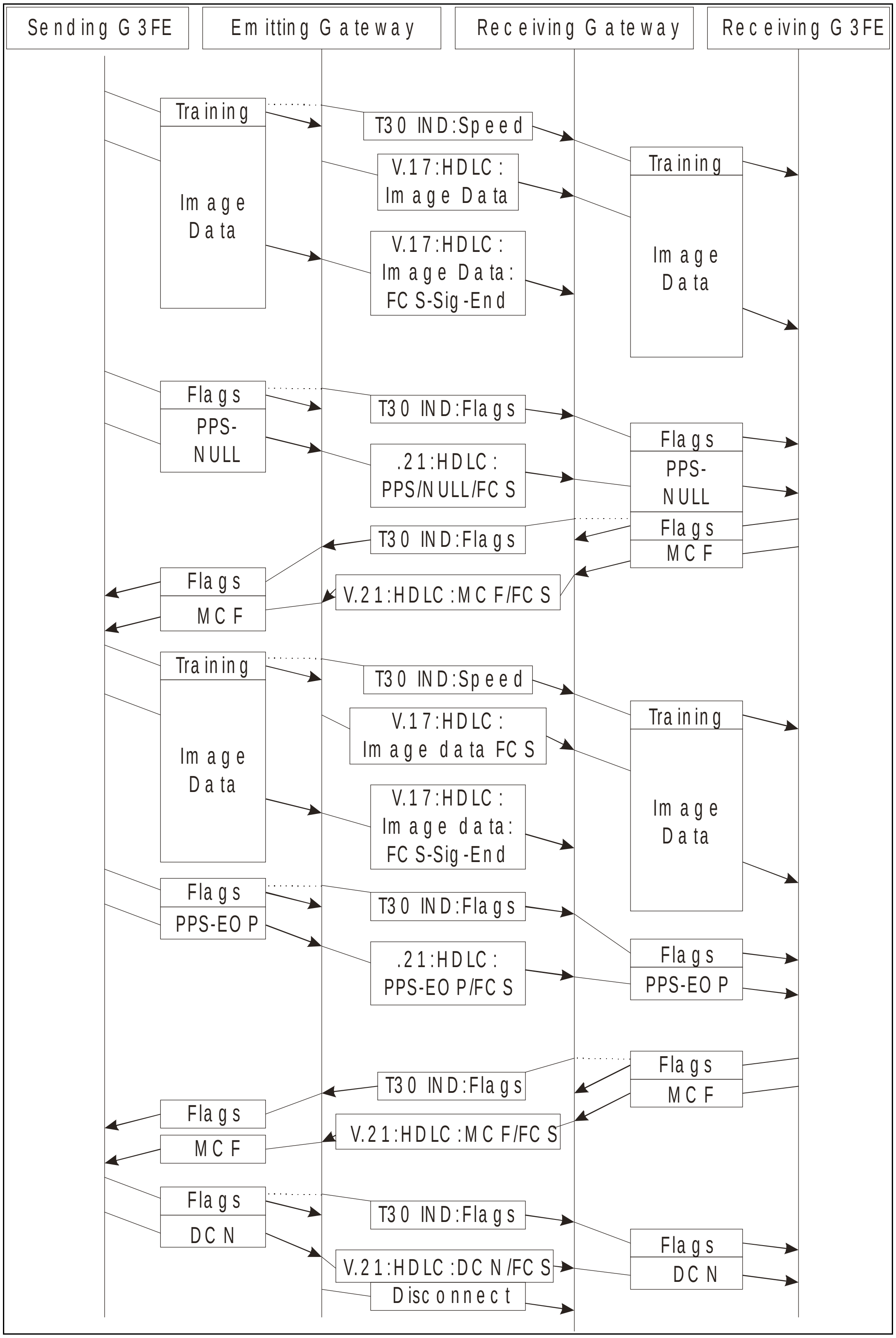

Figure 15 G3FE devices communicating over IP network using T.38, part 2

3.6 ITU-T RECOMMENDATION T.42, BINARY TRANSFER PROTOCOL

T.42 is used for transferring several kinds of data binary. The types of binary files that can be sent with the T.42 protocol are governed by recommendation T.30. T.42 was designed as an extension of G3FE fax, since it would be more versatile and support any kind of data. The T.4 protocol supports only MH, MR and MMR with specific page-widths. T.42 remedies this and can be used for sending for instance JPEG coded images or color images. The equipment on the receiver side must, however, be able to decode and identify the content of the data packets.

CONCLUSION

This thesis has briefly explained how Group 3 facsimile devices, designed for the public switched telephone network, communicate with each other, and the CCITT/ITU-T protocols that are involved to make them work. It has explored the modulation schemes, the compression algorithms and the fax state machine. It has used and explained where the protocols apply. It has further explored the most important ITU-T and IETF standards used for connecting the same fax devices to the internet protocol via IP Gateway cards. The standards related to fax over IP are in continuous change and there are sections of the standards that are yet to be released and are still in the development phases from ITU-T and IETF. This thesis has explored the most important sections of the CCITT/ITU-T recommendations regarding fax that have been released, giving basic insight in the world of fax.

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12. ITU-T Recommendation T.38 (1998), *Procedures for real-time Group 3 facsimile communication over IP networks.*
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17. ITU-T Recommendation V.8 (1998), *Procedure for starting sessions of data transmission over the public switched telephone network.*

18. ITU-T Recommendation V.34 (1998), *A modem operating at data signalling rates of up to 33 600 bit/s for use on the general switched telephone network and on leased point-to-point 2-wire telephone-type circuits.*

IETF:

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APPENDIX A: T.4 IN MORE DEPTH

STATISTICS OF A COMMON FACSIMILE DOCUMENT

So far, a normal facsimile document contains only 2 colors, black and white. Since these colors normally occupy large areas of a fax image (Figure 16), it would be inefficient to describe the image bit by bit (1 bit per pixel is all that is needed to describe black and white).

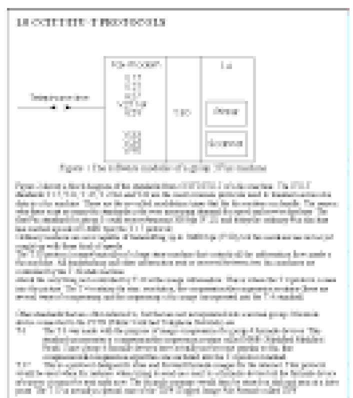


Figure 16 A typical facsimile document

Figure 16 shows a typical fax image that contains more white pixels than black pixels. The black areas consist mainly of text. From a coding perspective it is beneficial to describe the image by a run-length scheme. Run-length schemes are basically encoding algorithms that convert frequently occurring data strings with shorter individual codes. One method of encoding these run-lengths is by means of Huffman codes. The coding scheme must make sure that the conversion uses as few bits as possible. An interesting discovery made here is that there will be many fewer large area run-lengths than short area run-lengths. Therefore the conversion must contain fewer bits for short run-lengths. Statistics of fax images shows that Huffman codes yields the optimal run-length bitconversions. T.4 uses several forms of Huffman based encoding called:

- Modified Huffman encoding (MH or 1-D coding),
- Modified Read encoding (MR or 2-D coding),
- Modified Modified Read encoding (MMR or extended 2-D coding, formerly the T.6 protocols).

The T.4 protocol has also recently become more advanced by referencing JPEG (JBIC) compression and several other forms of TIFF (Tagged Image File Formats).

MODIFIED HUFFMAN CODING

MH coding consists basically of five tables that describe different run-lengths or the conversion between specifying a bit for each pixel to a bit pattern that describes the pixels as a run-length instead. These specific and individual MH codes can then be used for both coding and decoding the different run-lengths of a facsimile image.

The rules for the conversion are as follows:

- 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. There is a total of 1728 picture elements (pixels) which represent one horizontal scan line of 215 mm length (American sized letter 8½ inches wide).
- In order to ensure that the receiver maintains color 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 or white run lengths, up to a maximum length of one scan line (1728 picture elements or pels), are defined by the code words in Table 4, Table 5 and Table 6. The code words are of two types: terminating code words and make-up code words. Either one terminating code word or one make-up code word followed by a terminating code word represents each run length.
- Run lengths in the range of 0 to 63 pels are encoded with their appropriate terminating code word. Note that there is a different list of code words for black and white run lengths.
- Run lengths in the range of 64 to 1728 pels are encoded first by a 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) marker:

  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. The bit pattern of the EOL code is described in Table 4 and Table 5

Table 4, Table 5, and Table 6 describe the different make-up and terminating run-lengths that a MH decoded image uses. These tables can be converted to binary trees, so that from a coding perspective one does not need to check every run-length with every code. This is further explored later in this chapter.

White run length	Code word	Black run length	Code word
0	00110101	0	0000110111
1	000111	1	010
2	0111	2	11
3	1000	3	10
4	1011	4	011
5	1100	5	0011
6	1110	6	0010
7	1111	7	00011
8	10011	8	000101
9	10100	9	000100
10	00111	10	0000100
11	01000	11	0000101
12	001000	12	0000111
13	000011	13	00000100
14	110100	14	00000111
15	110101	15	000011000
16	101010	16	0000010111
17	101011	17	0000011000
18	0100111	18	0000001000
19	0001100	19	00001100111
20	0001000	20	00001101000
21	0010111	21	00001101100
22	0000011	22	00000110111
23	0000100	23	00000101000
24	0101000	24	00000010111
25	0101011	25	00000011000
26	0010011	26	000011001010
27	0100100	27	000011001011
28	0011000	28	000011001100
29	00000010	29	000011001101
30	00000011	30	000001101000
31	00011010	31	000001101001
32	00011011	32	000001101010
33	00010010	33	000001101011
34	00010011	34	000011010010
35	00010100	35	000011010011
36	00010101	36	000011010100
37	00010110	37	000011010101
38	00010111	38	000011010110
39	00101000	39	000011010111
40	00101001	40	000001101100
41	00101010	41	000001101101
42	00101011	42	000011011010
43	00101100	43	000011011011
44	00101101	44	000001010100
45	00000100	45	000001010101
46	00000101	46	000001010110
47	00001010	47	000001010111
48	00001011	48	000001100100
49	01010010	49	000001100101
50	01010011	50	000001010010
51	01010100	51	000001010011
52	01010101	52	000000100100
53	00100100	53	000000110111
54	00100101	54	000000111000
55	01011000	55	000000100111
56	01011001	56	000000101000
57	01011010	57	000001011000
58	01011011	58	000001011001
59	01001010	59	000000101011
60	01001011	60	000000101100
61	00110010	61	000001011010
62	00110011	62	000001100110
63	00110100	63	000001100111

Table 4 Black and white terminating codes

White run length	Code word	Black run length	Code word
64	11011	64	0000001111
128	10010	128	000011001000
192	010111	192	000011001001
256	0110111	256	000001011011
320	00110110	320	000000110011
384	00110111	384	000000110100
448	01100100	448	000000110101
512	01100101	512	0000001101100
576	01101000	576	0000001101101
640	01100111	640	0000001001010
704	011001100	704	0000001001011
768	011001101	768	0000001001100
832	011010010	832	0000001001101
896	011010011	896	0000001110010
960	011010100	960	0000001110011
1024	011010101	1024	0000001110100
1088	011010110	1088	0000001110101
1152	011010111	1152	0000001110110
1216	011011000	1216	0000001110111
1280	011011001	1280	0000001010010
1344	011011010	1344	0000001010011
1408	011011011	1408	0000001010100
1472	010011000	1472	0000001010101
1536	010011001	1536	0000001011010
1600	010011010	1600	0000001011011
1664	011000	1664	0000001100100
1728	010011011	1728	0000001100101
EOL	000000000001	EOL	000000000001

Table 5 Make-up codes 64-1728 bits

Run length (black and white)	Make-up codes
1792	00000001000
1856	00000001100
1920	00000001101
1984	000000010010
2048	000000010011
2112	000000010100
2176	000000010101
2240	000000010110
2304	000000010111
2368	000000011100
2432	000000011101
2496	000000011110
2560	000000011111

Table 6 Make-up codes 1792-2560 bits

MODIFIED HUFFMAN FROM A PROGRAMMING PERSPECTIVE

The make-up codes and the terminating codes from the MH tables can be represented in several ways. The most efficient way of coding these trees is to create statically allocated binary trees of the codes and use the codes as a look up table (LUT). Figure 17 to Figure 21 show the trees consisting of the make-up and terminating codes for the white run-lenghts. The level tells how many bits the code-word in the tree consists of so far. A negative number tells that a code-word has been found. Positive entries point to another index in the table. If a '0' is read from the 1-D coded image, then it will go down the left branch of the tree. If a '1' is read then it will continue down the right side. C++ code for the white tree follows Figure 21. One can follow both the entries in the binary tree and the binary array to see where the code ends. Figure 23 to Figure 26 shows the binary tree representing the black code-words. The C++ code representing the black tree is located after the figures.

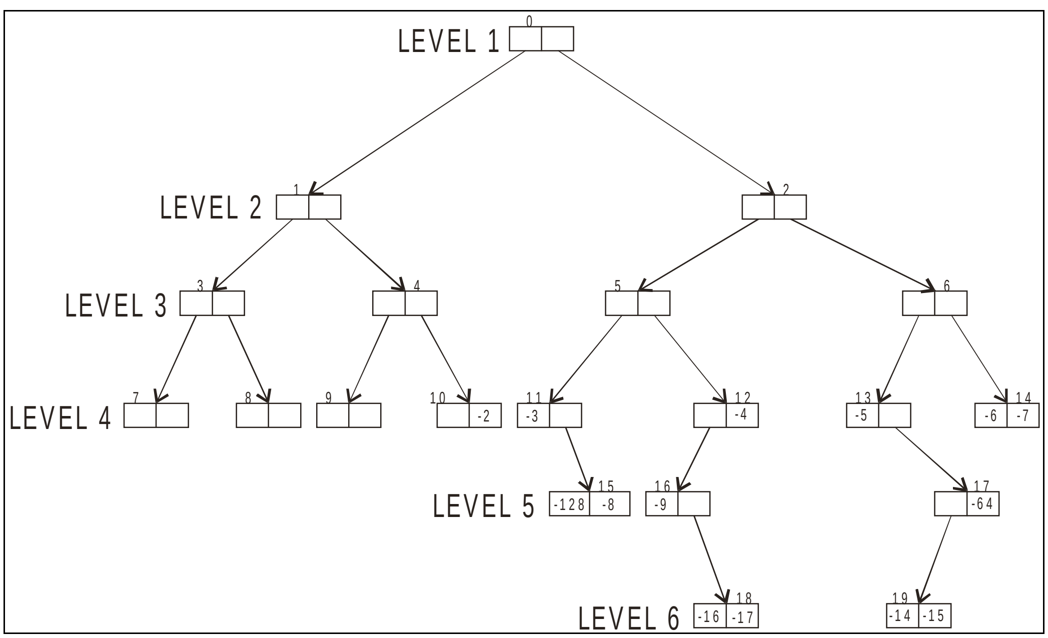


Figure 17 Modified Huffman white code-words represented as a binary tree. Part 1

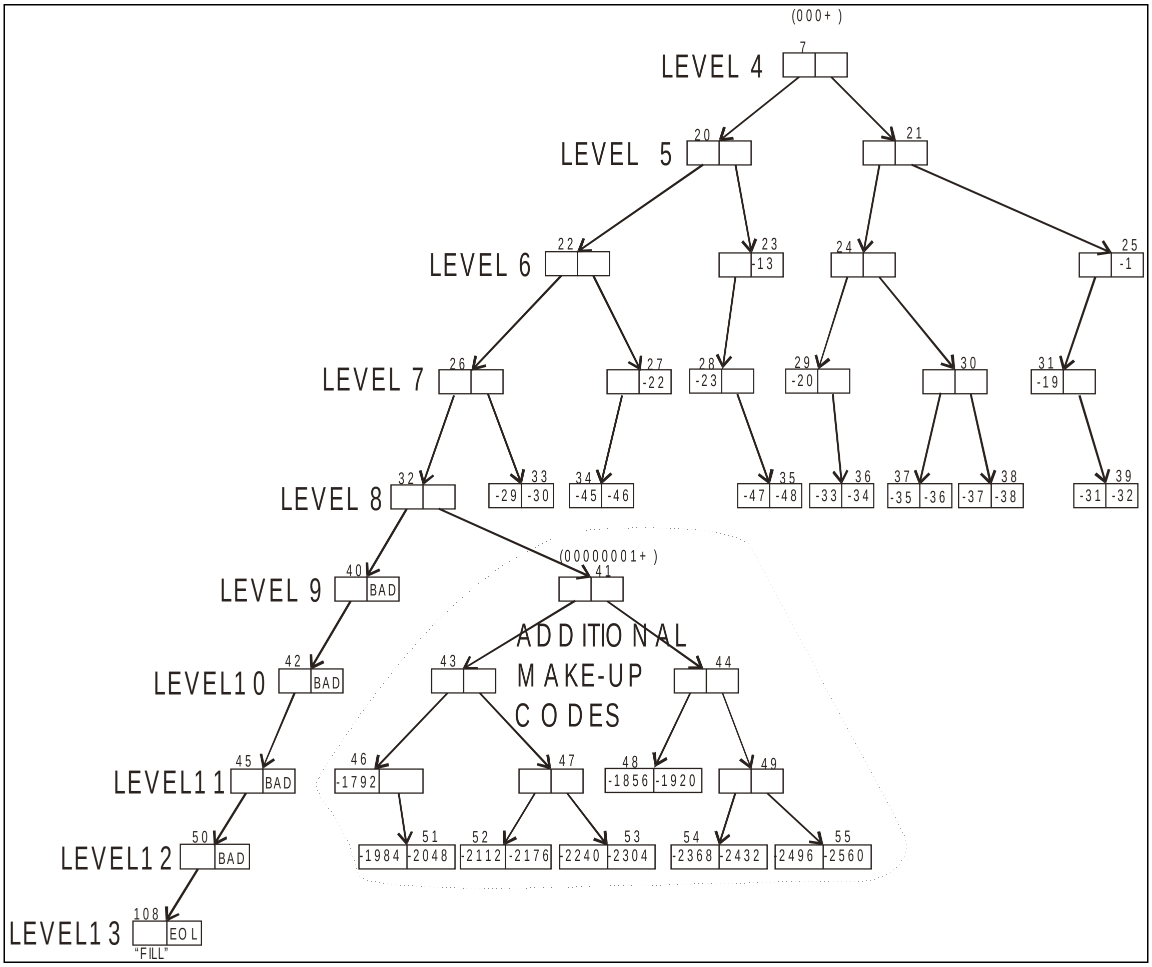


Figure 18 Modified Huffman white code-words represented as a binary tree. Part 2

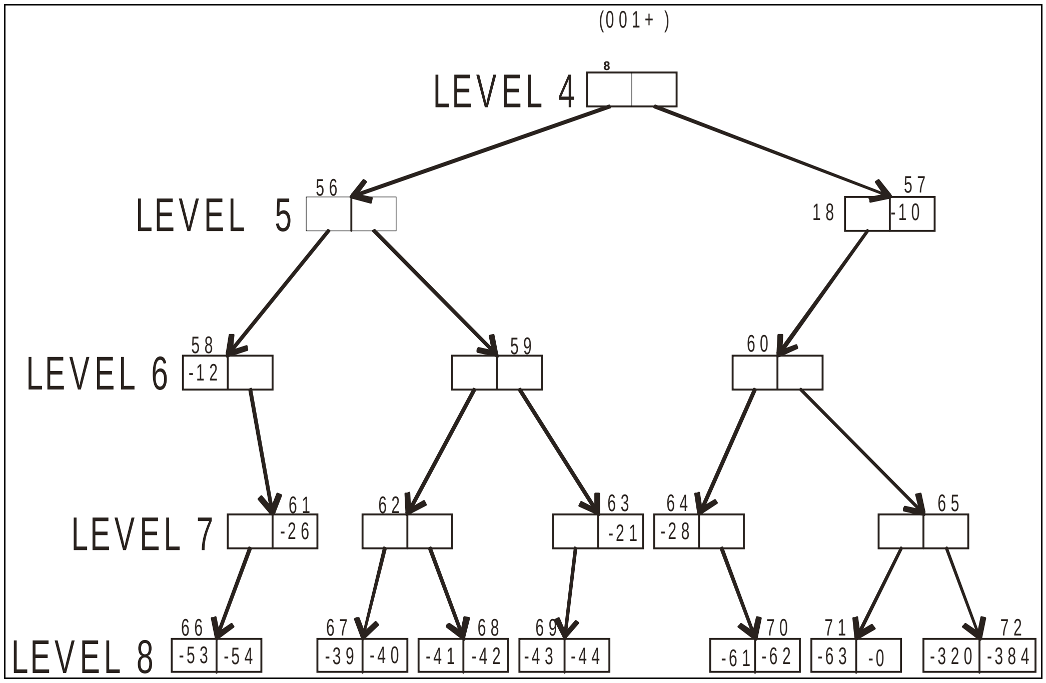


Figure 19 Modified Huffman white code-words represented as a binary tree. Part 3

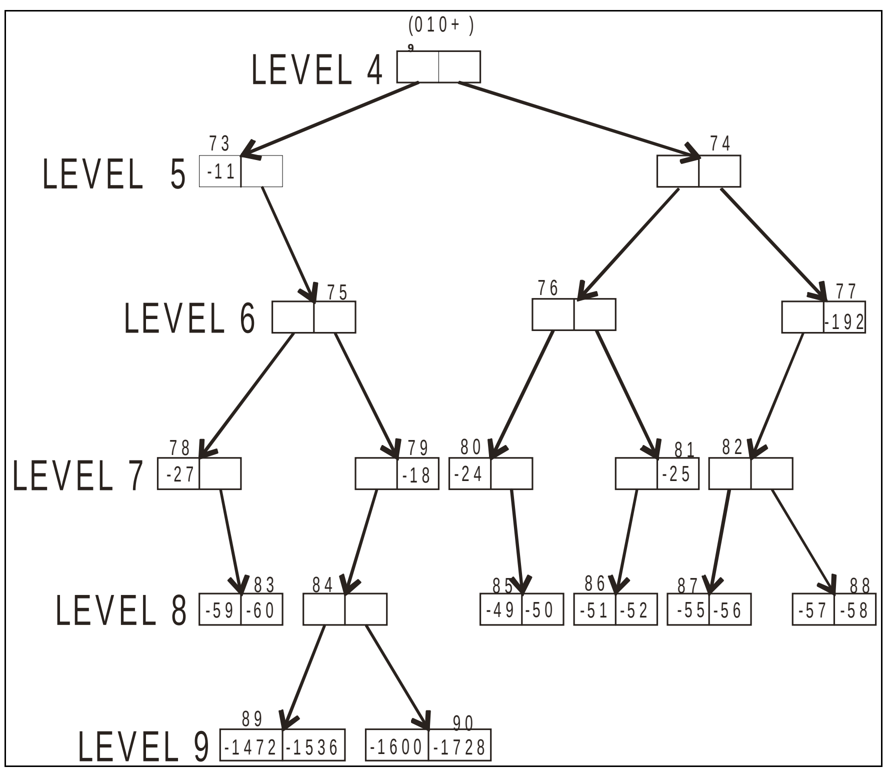


Figure 20 Modified Huffman white code-words represented as a binary tree. Part 4

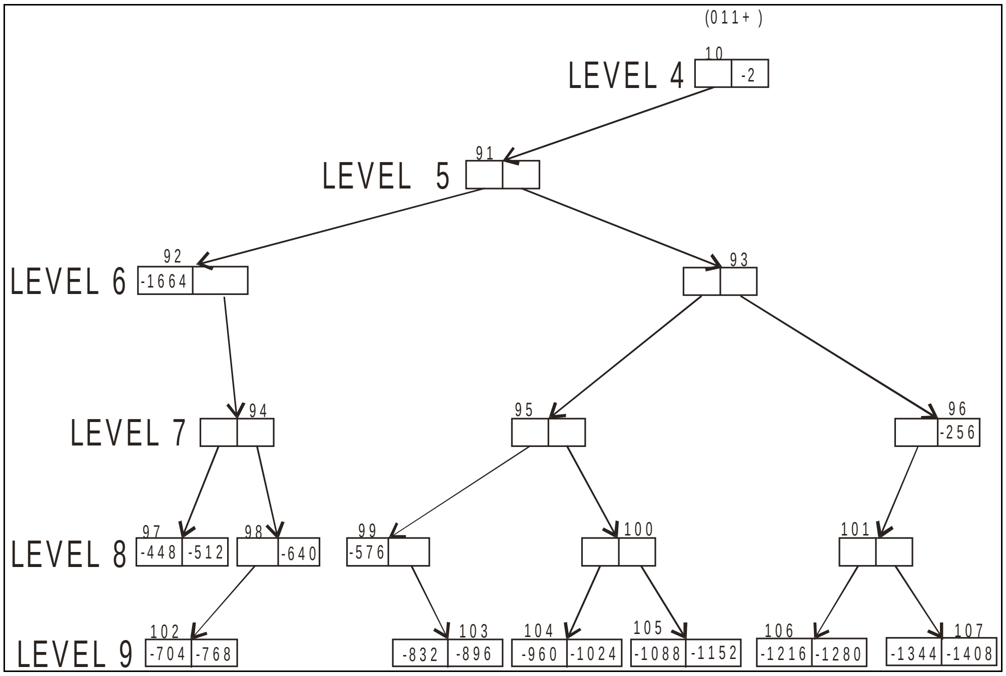


Figure 21 Modified Huffman white code-words represented as a binary tree. Part 5

Code for the Modified Huffman white code-words represented as a static binary tree.

```
#include <stdafx.h>

#define EOL 32767
#define BAD -32768


struct tRunLengthArray
{
   short int LeftValue;
   short int RightValue;
   short int RunLength;
};

const tRunLengthArray WhiteRunArray[] =
{
{    1,     2,  1}, // Pos 0
   {    3,     4,  2}, // Pos 1
   {    5,     6,  2}, // Pos 2
   {    7,     8,  3}, // Pos 3
   {    9,    10,  3}, // Pos 4
   {   11,    12,  3}, // Pos 5
   {   13,    14,  3}, // Pos 6
   {   20,    21,  4}, // Pos 7
   {   56,    57,  4}, // Pos 8
   {   73,    74,  4}, // Pos 9
   {   91,    -2,  4}, // Pos 10                  2="0111"
   {   -3,    15,  4}, // Pos 11   3="1000"
   {   16,    -4,  4}, // Pos 12                  4="1011"
   {   -5,    17,  4}, // Pos 13   5="1100"
   {   -6,    -7,  4}, // Pos 14   6="1110", 7="1111"
   { -128,    -8,  5}, // Pos 15   128="10010", 8="10011"
   {   -9,    18,  5}, // Pos 16   9="10100"
   {   19,   -64,  5}, // Pos 17                  64="11011"
   {  -16,   -17,  6}, // Pos 18   16="101010", 17="101011"
   {  -14,   -15,  6}, // Pos 19   14="110100", 15="110101"
   {   22,    23,  5}, // Pos 20
   {   24,    25,  5}, // Pos 21
   {   26,    27,  6}, // Pos 22
   {   28,   -13,  6}, // Pos 23                  13="000011"
   {   29,    30,  6}, // Pos 24
   {   31,    -1,  6}, // Pos 25                  1="000111"
   {   32,    33,  7}, // Pos 26
   {   34,   -22,  7}, // Pos 27                  22="0000011"
   {  -23,    35,  7}, // Pos 28   23="0000100"
   {  -20,    36,  7}, // Pos 29   20="0001000"
   {   37,    38,  7}, // Pos 30
   {  -19,    39,  7}, // Pos 31   19="0001100"
   {   40,    41,  8}, // Pos 32
   {  -29,   -30,  8}, // Pos 33   29="00000010", 30="00000011"
   {  -45,   -46,  8}, // Pos 34   45="00000100", 46="00000101"
   {  -47,   -48,  8}, // Pos 35   47="00001010", 48="00001011"
   {  -33,   -34,  8}, // Pos 36   33="00010010", 34="00010011"
   {  -35,   -36,  8}, // Pos 37   35="00010100", 36="00010101"
   {  -37,   -38,  8}, // Pos 38   37="00010110", 38="00010111"
   {  -31,   -32,  8}, // Pos 39   31="00011010", 32="00011011"
   {   42,   BAD,  9}, // Pos 40
   {   43,    44,  9}, // Pos 41
   {   45,   BAD, 10}, // Pos 42
   {   46,    47, 10}, // Pos 43
   {   48,    49, 10}, // Pos 44
   {   50,   BAD, 11}, // Pos 45
   {-1792,    51, 11}, // Pos 46   1792="00000001000"
   {   52,    53, 11}, // Pos 47
   {-1856, -1920, 11}, // Pos 48   1856="00000001100", 1920="00000001101"
   {   54,    55, 11}, // Pos 49
   {  108,   BAD, 12}, // Pos 50
   {-1984, -2048, 12}, // Pos 51   1984="000000010010", 2048="000000010011"
```

```
  {-2112, -2176, 12}, // Pos 52   2112="000000010100", 2176="000000010101"
  {-2240, -2304, 12}, // Pos 53   2240="000000010110", 2304="000000010111"
  {-2368, -2432, 12}, // Pos 54   2368="000000011100", 2432="000000011101"
  {-2496, -2560, 12}, // Pos 55   2496="000000011110", 2560="000000011111"
  {   58,    59,  5}, // Pos 56
  {   60,   -10,  5}, // Pos 57                  10="00111"
  {  -12,    61,  6}, // Pos 58   12="001000"
  {   62,    63,  6}, // Pos 59
  {   64,    65,  6}, // Pos 60
  {   66,   -26,  7}, // Pos 61                  26="0010011"
  {   67,    68,  7}, // Pos 62
  {   69,   -21,  7}, // Pos 63                  21="0010111"
  {  -28,    70,  7}, // Pos 64   28="0011000"
  {   71,    72,  7}, // Pos 65
  {  -53,   -54,  8}, // Pos 66   53="00100100", 54="00100101"
  {  -39,   -40,  8}, // Pos 67   39="00101000", 40="00101001"
  {  -41,   -42,  8}, // Pos 68   41="00101010", 42="00101011"
  {  -43,   -44,  8}, // Pos 69   43="00101100", 44="00101101"
  {  -61,   -62,  8}, // Pos 70   61="00110010", 62="00110011"
  {  -63,     0,  8}, // Pos 71   63="00110100"
  { -320,  -384,  8}, // Pos 72   320="00110110",384="00110111"
  {  -11,    75,  5}, // Pos 73   11="01000"
  {   76,    77,  5}, // Pos 74
  {   78,    79,  6}, // Pos 75
  {   80,    81,  6}, // Pos 76
  {   82,  -192,  6}, // Pos 77                  192="010111"
  {  -27,    83,  7}, // Pos 78   27="0100100"
  {   84,   -18,  7}, // Pos 79                  18="0100111"
  {  -24,    85,  7}, // Pos 80   24="0101000"
  {   86,   -25,  7}, // Pos 81                  25="0101011"
  {   87,    88,  7}, // Pos 82
  {  -59,   -60,  8}, // Pos 83   59="01001010", 60="01001011"
  {   89,    90,  8}, // Pos 84
  {  -49,   -50,  8}, // Pos 85   49="01010010", 50="01010011"
  {  -51,   -52,  8}, // Pos 86   51="01010100", 52="01010101"
  {  -55,   -56,  8}, // Pos 87   55="01011000", 56="01011001"
  {  -57,   -58,  8}, // Pos 88   57="01011010", 58="01011011"
  {-1472, -1536,  9}, // Pos 89   1472="010011000", 1536="010011001"
  {-1600, -1728,  9}, // Pos 90   1600="010011010", 1728="010011011"
  {   92,    93,  5}, // Pos 91
  {-1664,    94,  6}, // Pos 92   1664="011000"
  {   95,    96,  6}, // Pos 93
  {   97,    98,  7}, // Pos 94
  {   99,   100,  7}, // Pos 95
  {  101,  -256,  7}, // Pos 96                  256="0110111"
  { -448,  -512,  8}, // Pos 97   448="01100100", 512="01100101"
  {  102,  -640,  8}, // Pos 98                  640="01100111"
  { -576,   103,  8}, // Pos 99   576="01101000"
  {  104,   105,  8}, // Pos 100
  {  106,   107,  8}, // Pos 101
  { -704,  -768,  9}, // Pos 102  704="011001100", 768="011001101"
  { -832,  -896,  9}, // Pos 103  832="011010010", 896="011010011"
  { -960, -1024,  9}, // Pos 104  960="011010100", 1024="011010101"
  {-1088, -1152,  9}, // Pos 105  1088="011010110", 1152="011010111"
  {-1216, -1280,  9}, // Pos 106  1216="011011000", 1280="011011001"
  {-1344, -1408,  9}, // Pos 107  1344", "011011010", 1408", "011011011"
  {  108,   EOL, 13}  // Pos 108                 EOL="000000000001"
};
```

Figure 22 The binary-tree array for Modified Huffman white run lengths

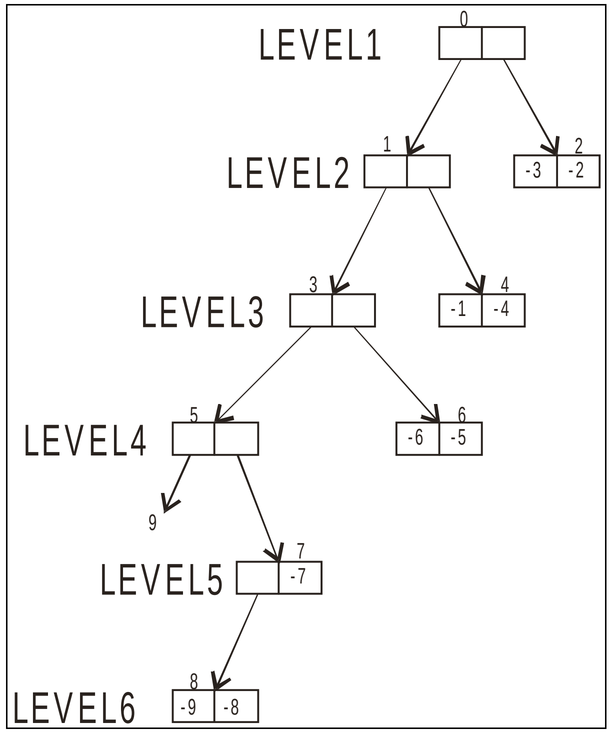


Figure 23 Modified Huffman black code-words represented as a binary tree. Part 1

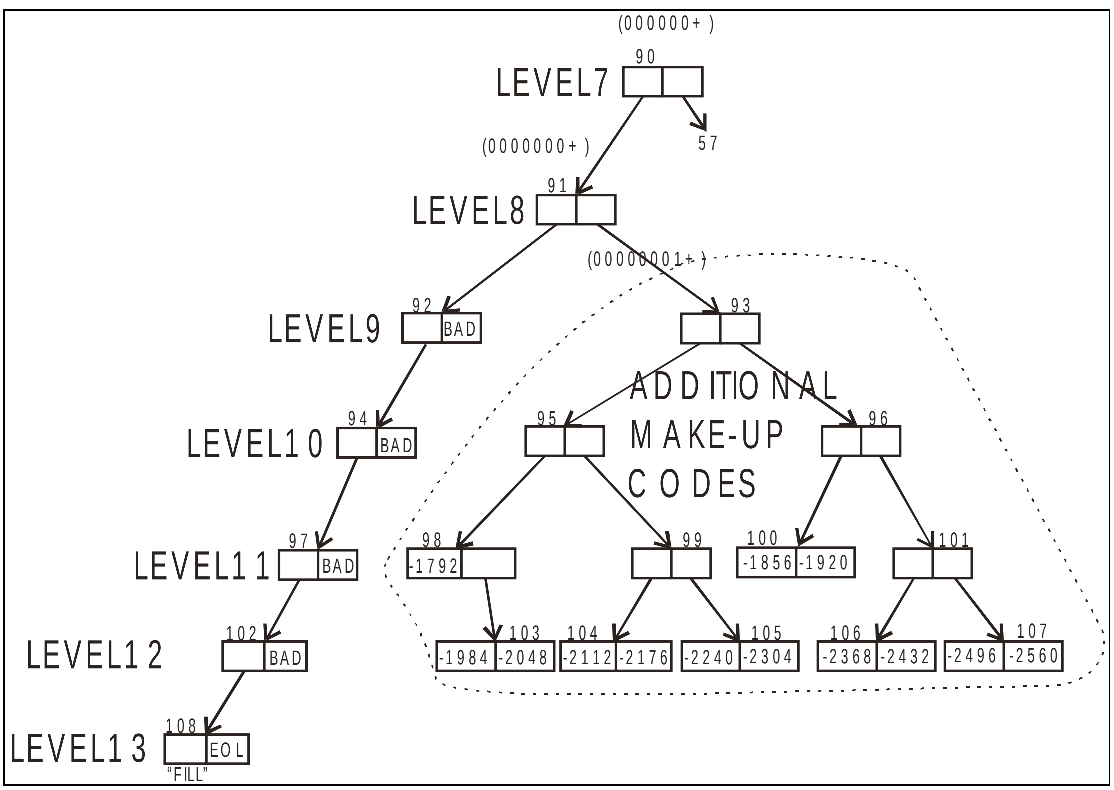


Figure 24 Modified Huffman black code-words represented as a binary tree. Part 2

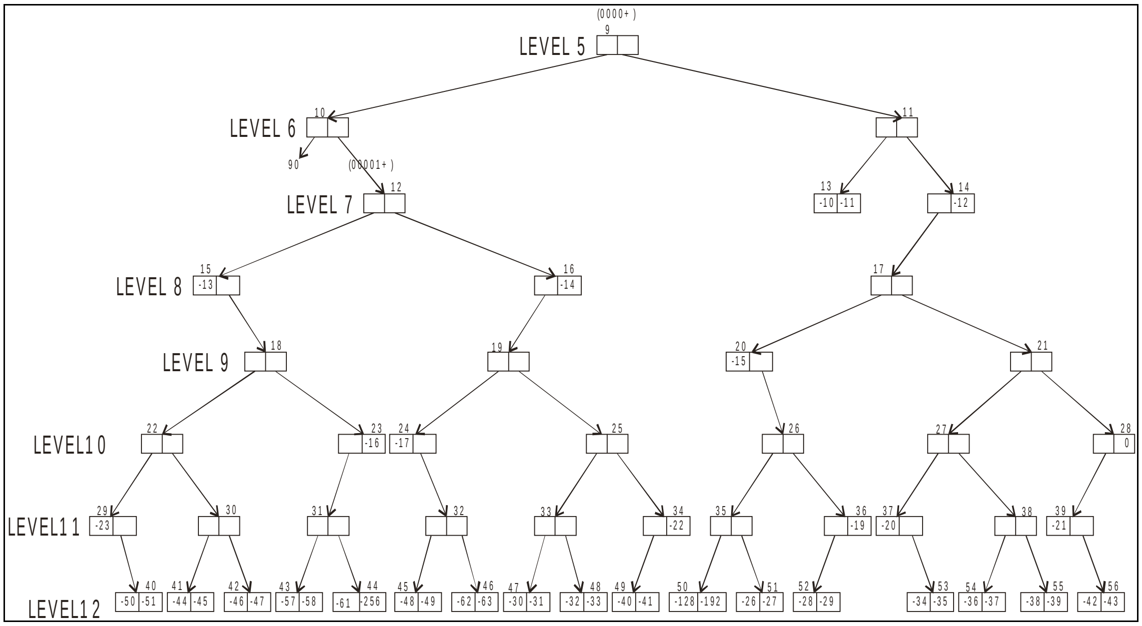


Figure 25 Modified Huffman black code-words represented as a binary tree. Part 3

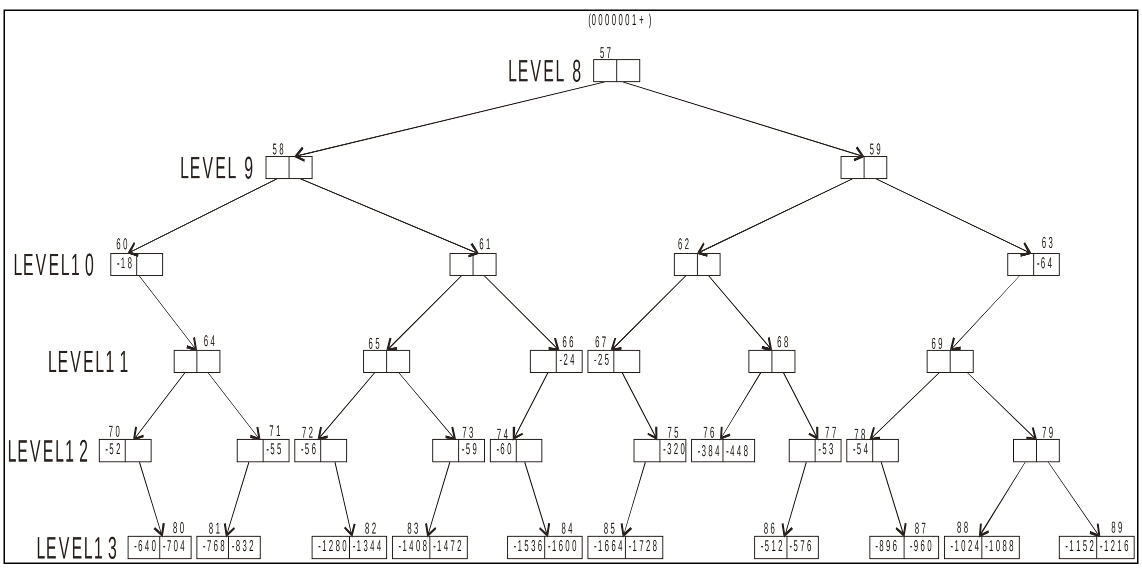


Figure 26 Modified Huffmas black code-words represented as a binary tree. Part 4

Code for the Modified Huffman black code-words represented as a static binary tree.

```
#include <stdafx.h>

#define EOL 32767
#define BAD -32768


struct tRunLengthArray
{
    short int LeftValue;
    short int RightValue;
    short int RunLength;
};

const tRunLengthArray BlackRunArray[] =
{
{    1,      2,  1}, // Pos 0
    {    3,      4,  2}, // Pos 1
    {   -3,     -2,  2}, // Pos 2    3="10", 2="11"
    {    5,      6,  3}, // Pos 3
    {   -1,     -4,  3}, // Pos 4    1="010", 4="011"
    {    9,      7,  4}, // Pos 5
    {   -6,     -5,  4}, // Pos 6    6="0010", 5="0011"
    {    8,     -7,  5}, // Pos 7                              7="00011"
    {   -9,     -8,  6}, // Pos 8    9="000100", 8="000101"
    {   10,     11,  5}, // Pos 9
    {   90,     12,  6}, // Pos 10
    {   13,     14,  6}, // Pos 11
    {   15,     16,  7}, // Pos 12
    {  -10,    -11,  7}, // Pos 13   10="0000100", 11="0000101"
    {   17,    -12,  7}, // Pos 14                             12="0000111"
    {  -13,     18,  8}, // Pos 15   13="00000100"
    {   19,    -14,  8}, // Pos 16                             14="00000111"
    {   20,     21,  8}, // Pos 17
    {   22,     23,  9}, // Pos 18
    {   24,     25,  9}, // Pos 19
    {  -15,     26,  9}, // Pos 20   15="000011000"
    {   27,     28,  9}, // Pos 21
    {   29,     30, 10}, // Pos 22
    {   31,    -16, 10}, // Pos 23                             16="0000010111"
    {  -17,     32, 10}, // Pos 24   17="0000011000"
    {   33,     34, 10}, // Pos 25
    {   35,     36, 10}, // Pos 26
    {   37,     38, 10}, // Pos 27
    {   39,      0, 10}, // Pos 28
    {  -23,     40, 11}, // Pos 29   23="00000101000"
    {   41,     42, 11}, // Pos 30
    {   43,     44, 11}, // Pos 31
    {   45,     46, 11}, // Pos 32
    {   47,     48, 11}, // Pos 33
    {   49,    -22, 11}, // Pos 34                             22="00000110111"
    {   50,     51, 11}, // Pos 35
    {   52,    -19, 11}, // Pos 36                             19="00001100111"
    {  -20,     53, 11}, // Pos 37   20="00001101000"
    {   54,     55, 11}, // Pos 38
    {  -21,     56, 11}, // Pos 39   21="00001101100"
    {  -50,    -51, 12}, // Pos 40   50="000001010010",        51="000001010011"
    {  -44,    -45, 12}, // Pos 41   44="000001010100",        45="000001010101"
    {  -46,    -47, 12}, // Pos 42   46="000001010110",        47="000001010111"
    {  -57,    -58, 12}, // Pos 43   57="000001011000",        58="000001011001"
    {  -61,   -256, 12}, // Pos 44   61="000001011010",        256="000001011011"
    {  -48,    -49, 12}, // Pos 45   48="000001100100",        49="000001100101"
    {  -62,    -63, 12}, // Pos 46   62="000001100110",        63="000001100111"
    {  -30,    -31, 12}, // Pos 47   30="000001101000",        31="000001101001"
    {  -32,    -33, 12}, // Pos 48   32="000001101010",        33="000001101011"
    {  -40,    -41, 12}, // Pos 49   40="000001101100",        41="000001101101"
    { -128,   -192, 12}, // Pos 50   128="000011001000",       192="000011001001"
    {  -26,    -27, 12}, // Pos 51   26="000011001010",        27="000011001011"
    {  -28,    -29, 12}, // Pos 52   28="000011001100",        29="000011001101"
    {  -34,    -35, 12}, // Pos 53   34="000011010010",        35="000011010011"
    {  -36,    -37, 12}, // Pos 54   36="000011010100",        37="000011010101"
    {  -38,    -39, 12}, // Pos 55   38="000011010110",        39="000011010111"
    {  -42,    -43, 12}, // Pos 56   42="000011011010",        43="000011011011"
    {   58,     59,  8}, // Pos 57
```

```
    {   60,    61,  9}, // Pos 58
    {   62,    63,  9}, // Pos 59
    {  -18,    64, 10}, // Pos 60   18="0000001000"
    {   65,    66, 10}, // Pos 61
    {   67,    68, 10}, // Pos 62
    {   69,   -64, 10}, // Pos 63                             64="0000001111"
    {   70,    71, 11}, // Pos 64
    {   72,    73, 11}, // Pos 65
    {   74,   -24, 11}, // Pos 66                             24="00000010111"
    {  -25,    75, 11}, // Pos 67   25="00000011000"
    {   76,    77, 11}, // Pos 68
    {   78,    79, 11}, // Pos 69
    {  -52,    80, 12}, // Pos 70   52="000000100100"
    {   81,   -55, 12}, // Pos 71                             55="000000100111"
    {  -56,    82, 12}, // Pos 72   56="000000101000"
    {   83,   -59, 12}, // Pos 73                             59="000000101011"
    {  -60,    84, 12}, // Pos 74   60="000000101100"
    {   85,  -320, 12}, // Pos 75                             320="000000110011"
    { -384,  -448, 12}, // Pos 76   384="000000110100",      448="000000110101"
    {   86,   -53, 12}, // Pos 77                             53="000000110111"
    {  -54,    87, 12}, // Pos 78   54="000000111000"
    {   88,    89, 12}, // Pos 79
    { -640,  -704, 13}, // Pos 80   640="0000001001010",     704="0000001001011"
    { -768,  -832, 13}, // Pos 81   768="0000001001100",     832="0000001001101"
    {-1280, -1344, 13}, // Pos 82   1280="0000001010010",    1344="0000001010011"
    {-1408, -1472, 13}, // Pos 83   1408="0000001010100",    1472="0000001010101"
    {-1536, -1600, 13}, // Pos 84   1536="0000001011010",    1600="0000001011011"
    {-1664, -1728, 13}, // Pos 85   1664="0000001100100",    1728="0000001100101"
    { -512,  -576, 13}, // Pos 86   512="0000001101100",     576="0000001101101"
    { -896,  -960, 13}, // Pos 87   896="0000001110010",     960="0000001110011"
    {-1024, -1088, 13}, // Pos 88   1024="0000001110100",    1088="0000001110101"
    {-1152, -1216, 13}, // Pos 89   1152="0000001110110",    1216="0000001110111"
    {   91,    57,  7}, // Pos 90
    {   92,    93,  8}, // Pos 91
    {   94,   BAD,  9}, // Pos 92
    {   95,    96,  9}, // Pos 93
    {   97,   BAD, 10}, // Pos 94
    {   98,    99, 10}, // Pos 95
    {  100,   101, 10}, // Pos 96
    {  102,   BAD, 11}, // Pos 97
    {-1792,   103, 11}, // Pos 98   1792="00000001000"
    {  104,   105, 11}, // Pos 99
    {-1856, -1920, 11}, // Pos 100  1856="00000001100",      1920="00000001101"
    {  106,   107, 11}, // Pos 101
    {  108,   BAD, 12}, // Pos 102
    {-1984, -2048, 12}, // Pos 103  1984="000000010010",     2048="000000010011"
    {-2112, -2176, 12}, // Pos 104  2112="000000010100",     2176="000000010101"
    {-2240, -2304, 12}, // Pos 105  2240="000000010110",     2304="000000010111"
    {-2368, -2432, 12}, // Pos 106  2368="000000011100",     2432="000000011101"
    {-2496, -2560, 12}, // Pos 107  2496="000000011110",     2560="000000011111"
    {  108,   EOL, 13}  // Pos 108                            EOL="000000000001"
};
```

Figure 27 The binary-tree array for Modified Huffman black run lengths

APPENDIX B: T.30 IN MORE DEPTH

ITU Recommendation T.30 shows how two G3FE devices can transmit and receive data and information to each other. T.30 complements the T.4 Recommendation by telling how data should be sent, while the T.4 contain the image formatting. T.30 contain a large state machine that contains all information two fax machines needs to be able to communicate with each other, like supported modulation speeds, standard facilities and other optional non-standard facilities. The T.30 is, in a way, the supervisor in a facsimile device that governs all actions from the initial call is made until the call end. T.30 tell when and which action that should be taken at each and every point in a fax conversation.

T.30 have been updated several times because of added features, such as grayscale and even facsimile images, support for Recommendation V.34 and Recommendation V.8 and others. The newest and most advanced T.30 state machine will be examined further later in this appendix. To be able to understand how the T.30 communicate, its necessary to understand the communication protocol the T.30 uses. This protocol is called HDLC (high-level data link control). The HDLC protocol will be examined next.

HDLC

HDLC frames are used for all binary coded facsimile control procedures. The basic HDLC structure consists of a number of frames of indeterminable length, each of which is subdivided into a number of fields. The HDLC structure provides frame labeling, error checking and confirmation of correctly received information. Figure 28 shows how the HDLC field is divided into sub-parts. The preamble precedes all binary coded signaling when the line have done a turnaround. The preamble is always sent, because of synchronization and conditioning of echo suppressors. This allows the binary coded information to pass unimpaired. The non-standard facilities frame, tells about special features that the fax machine has incorporated. The called subscriber identification frame tells the phone number of the fax machine. The digital identification frame is what is regarded as a HDLC frame in the T.30 protocol.

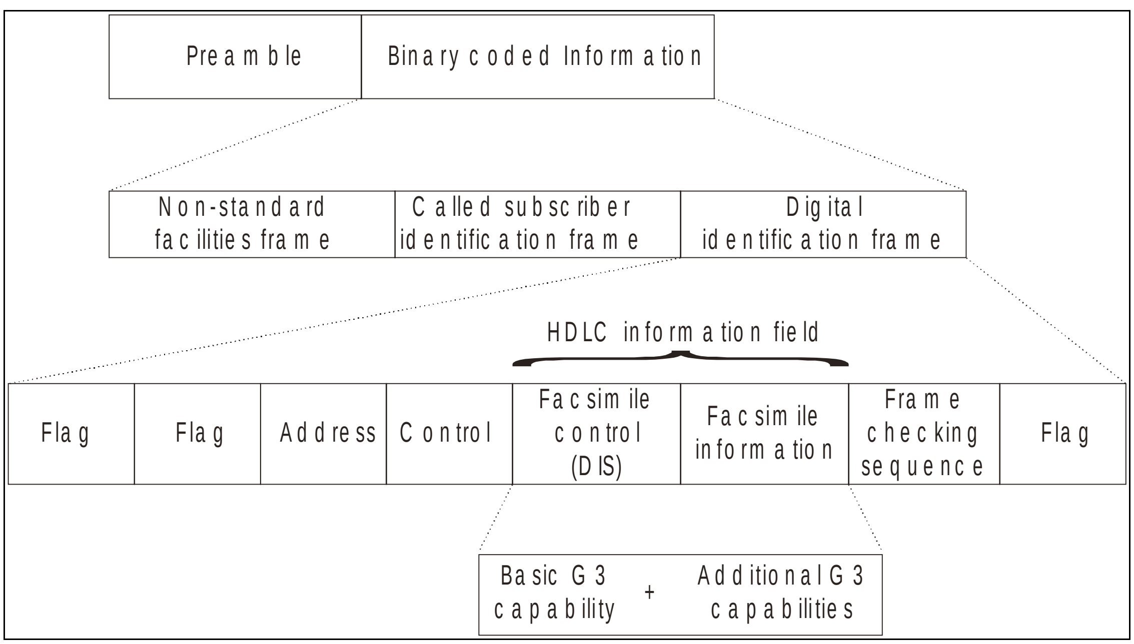


Figure 28 The structure of a HDLC field

The following fields are standard for a T.30 HDLC frame:

- **Flag:** This eight-bit HDLC flag sequence is used to denote the beginning and end of the frame. For the facsimile procedure, the flag sequence is used to establish bit and frame synchronization. The trailing flag of one frame may be the leading flag of the following frame. Continued transmission of the flag sequence may be used to signal to the distant terminal that the terminal remains on line but is not presently prepared to proceed with the facsimile procedure.

  Format: 0111 1110
- **Address field:** The eight bit HDLC address field is intended to provide special identification of the specific terminal. In the case of transmission on the PSTN, this field can only have one specific format (ISDN would have another format).

  Format: 1111 1111
- **Control field:** The eight bit HDLC control field provides the recipient of what sort of frame is being sent, whether it is to be followed by more frames, and whether a reply is expected. All fax frames are what is called unnumbered frames, so the control field always has a special format, where only bit 5 changes depending on the circumstance.

  Format: 1100 X000

  X = 0 for polling, which means that the sender expects the receiver to send a reply

  X = 1 means that a final frame has been sent and the sender does not expect a reply.

  This in essence means that all intermediate frames have 1100 0000, while the last frame has a format of 1100 1000.

- **Facsimile Information field (FIF) and Facsimile Control Field (FCF):** The HDLC information field is divided into two different parts when sending fax frames. These are the FIF and the FCF frames. FIF is of variable length and contains specific information for the control and message interchange between two facsimile terminals. The facsimile control field is defined to be the first 8 or 16 bits of the HDLC information field. An FCF of 16 bits should be applied only for the optional T.4 error correction mode (special topic that will not be examined in this thesis). This field contains the complete information regarding the type of information being exchanged and the position in the overall sequence. An FCF can for instance contain a code for DIS (answering capabilities), or NSS (non-standard facilities) or a MPS (end of the page in a multi document fax transmission), and a lot more.
- **Frame Checking Sequence (FCS):** The FCS frame consists of a standard CRC-16 checker. It consist of 16-bit with modulo 2, 1's complement of:

  1) Remainder of $x^k (x^{15} + x^{14} + x^{13} + \ldots + x^2 + x + 1)$ divided (modulo 2) by the generator polynomial $x^{16}+ x^{12} + x^5 + 1$, where k is the number of bits in the frame existing between, but not including, the final bit of the opening flag and the first bit of the FCS, excluding bits inserted for transparency; and
  2) the remainder after multiplication by x^{16} and then division (modulo 2) by the generator polynomial $x^{16} + x^{12} + x^5 + 1$, of the content of the frame, existing between, but not including, the final bit of the opening flag and the first bit of the FCS, excluding bits inserted for transparency.

  As a typical implementation, at the transmitter, the initial remainder of the division is preset to all 1s. Then division modifies it by the generator polynomial (as described above) on the address, control and information fields; the 1's complement of the resulting remainder is transmitted as the 16-bit FCS sequence.

At the receiver, the initial remainder is preset to all 1s and the serial incoming protected bits and the FCS when divided by the generator polynomial will result in a remainder of 0001110100001111 (x^{15} through x^{0}, respectively) in the absence of transmission errors. The FCS shall be transmitted to the line commencing with the coefficient of the highest term.

Figure 29 shows a summary of a typical HDLC frame for a G3FE connected to the PSTN network. The FCF format tell that this particular Fax HDLC frame is a DCS message. DCS is the answering capabilities after the originating caller has sent its capabilities in the shape of a DIS frame (part of the capabilities exchange procedures).

Flag	Flag	Address	Control	FCF	HDLC Info	FCS (CRC-16)	Flag
01111110	01111110	11111111	11001000	11000001	0000 0000 0111 0000 1011 1101	0001000001001011	01111110

Figure 29 Summary of the HDLC frame structure for T.30

T.30 STATE MACHINE

The most prominent feature of the T.30 is the state machine. When two fax machines communicate, the T.30 state machines will at all times keep track of the state of its fax machine. If an event occurs, then they will leave the current state and move on to another depending on what occurred. There are basically 5 phases that a fax machine must complete in order to transmit/receive a facsimile image. Figure 30 show the time sequence of these phases.

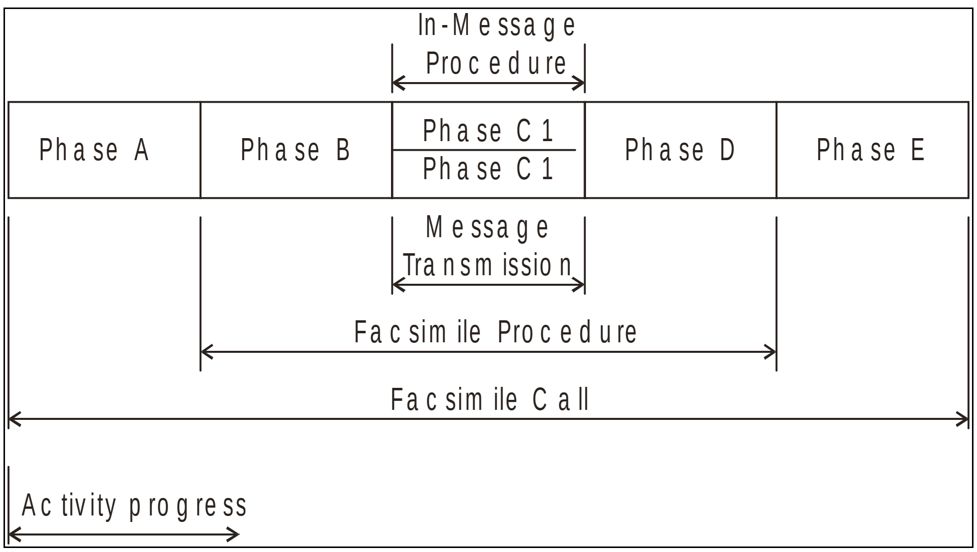


Figure 30 Time sequence of a facsimile call

The phases A through E will be covered next in some detail.

PHASE A: CALL ESTABLISHMENT

The call establishment connects two fax machines and makes sure that they both are responding as a G3FE device. The call establishment incorporates two signals called CNG and CED. T.30 state that a fax machine can be operated manually or have automatic operation. Table 7 shows the different operations that can occur:

Method No.	Description of operating method	Direction of facsimile transmission	Overall designation
1	*Manual* operation at calling terminal and	Calling terminal *transmits to* called terminal	1-T
	Manual operation at called terminal	Calling terminal *receives from* called terminal	1-R
2	*Manual* operation at calling terminal and	Calling terminal *transmits to* called terminal	2-T
	Automatic operation at called terminal	Calling terminal *receives from* called terminal	2-R
3	*Automatic* operation at calling terminal and	Calling terminal *transmits to* called terminal	3-T
	Manual operation at called terminal	Calling terminal *receives from* called terminal	3-R
4	*Automatic* operation at calling terminal and	Calling terminal *transmits to* called terminal	4-T
	Automatic operation at called terminal	Calling terminal *receives from* called terminal	4-R
4 *bis*	*Automatic* operation using the procedures defined in Recommendation V.8 at calling terminal and	Calling terminal *transmits to* called terminal using the procedures defined in Recommendation V.8	4-T
	Automatic operation using the procedures defined in Recommendation V.8 at called terminal	Calling terminal *receives from* called terminal using the procedures defined in Recommendation V.8	4-R

Table 7 The T.30 operation modes

The reason for all the operation methods is that the first version of the T.30 recommendation is quite old, and that it has been modified and enhanced a lot of times. The manually operated fax machines are hopefully obsolete these days, so the state machines for these systems are not that important anymore. The only important state machines are methods 4 and 4*bis*, but all modes should be supported for full compliance with the T.30 standard. The 4*bis*, incorporates V.8, which is a rather new standard. This incorporates new and upcoming features that are not necessary for the traditional fax machine today. However, virtually all fax machines manufactured the last year incorporate V.8 and V.34. Figure 31 and Figure 32 shows the how Phase B method 4 and method 4*bis* work (from Table 7). V.34 and V.8 is out of the scope of this thesis, so Figure 32 is shown for illustrative purposes only.

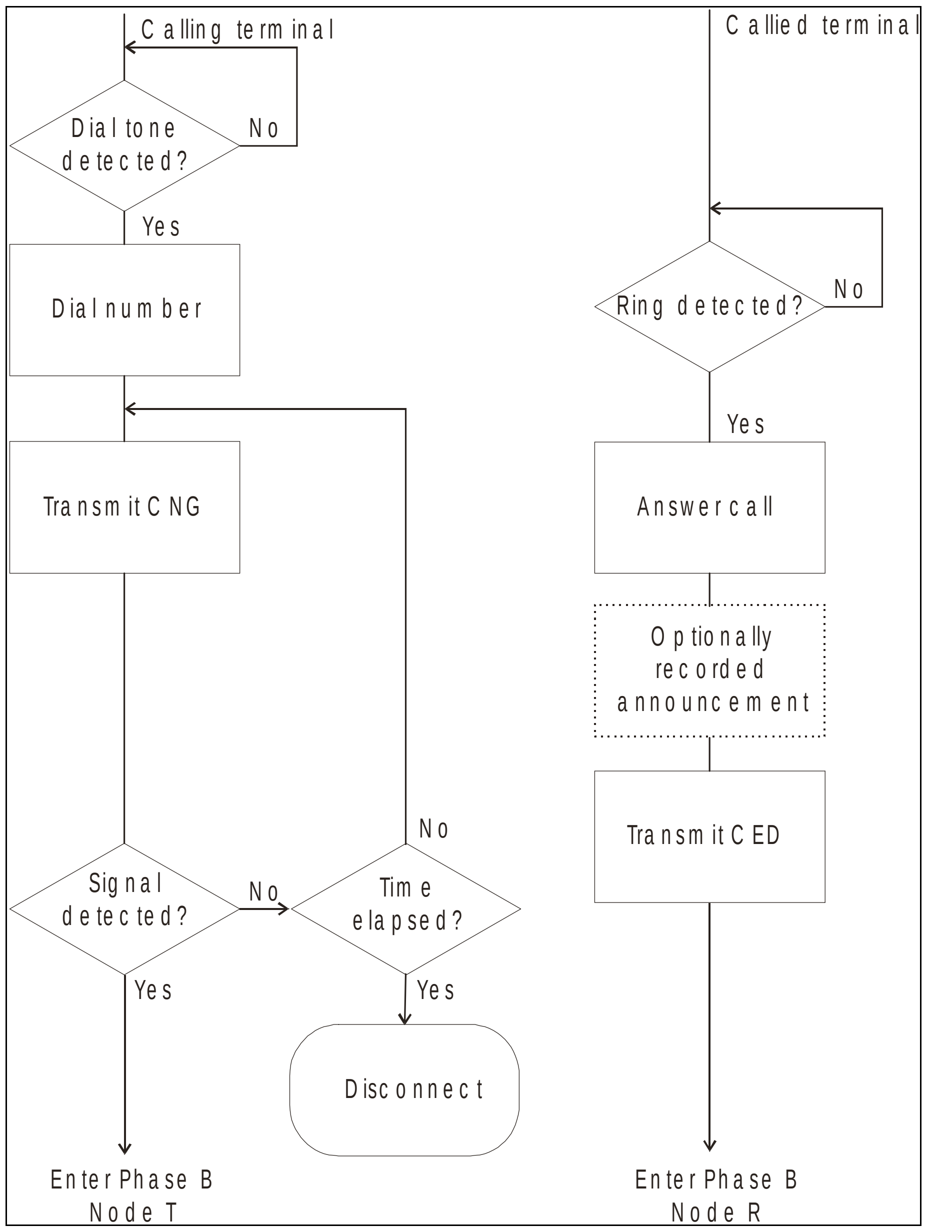


Figure 31 Call establishment, operating method 4

The calling structure for calling method 4 (Figure 31) is as follows:

- The calling fax machine (the originator of a call) checks for a busy signal on the line while a user can enter a fax number. When the line is available, it transmits the phone number, using DTMF (Dual-Tone Multi-Frequency) tones (DTMF is the same tones that can be heard when calling somebody over a normal phone). As soon as the number has been dialled, it sends a tone with frequency of 1100Hz for ½ second, then silence for 3s. This is then repeated. This tone sequence is called a CNG signal. This signal is used for identifying itself as a facsimile device. The called fax machine (the facsimile device that receives a call) listens to the line, and detects somebody trying to ring to it. The calling fax machine will then answer the call (just like a person would take the phone) and detects the CNG tone. The called fax machine can then either transmit an optional announcement and then a signal with 2100Hz for 3.3±0.7s or send the tone directly. The 2100Hz-tone sequence is called CED and is the normal response if the recipient is a fax machine. After the fax machine has sent the CED, it also sends a HDLC frame called the initial identification. If the originating fax machine detect the CED signal and the initial identification frame, before its timing circuits tell it to disconnect. Then the Fax machines enter Phase B (pre-message procedure).

- The initial identification is the first frame that is actually part of a fax negotiation. The frame contains both fax capability and identification. This frame should arguably be part of Phase B, but is actually part of Phase A. While it is the caller that initiates a session, it is the called fax machine who sends these first frames. Up to three frames are sent as part of the initial identification by the answering station in phase A:

1. Digital Identification Signal (DIS): This is the only compulsory frame, which gives the caller details of what capabilities of the called facsimile device has. The DIS is always the last of the frames sent in an identification sequence so the control field in this HDLC frame *must have* the format 11001000. The FCF for this frame has the format 00000001. The different bits that the DIS can consist of are located in Table 8. Bits 1-24 are the only compulsory frames that must be sent, since the higher numbered bits have been added with each new amendment of the T.30 protocol.
2. Called Subscriber Identification (CSI): The optional CSI frame usually precedes The DIS. The CSI frame's FCF has the format 00000010. The CSI frame conveys the identity of a fax machine by sending its telephone number as 20 ASCII characters in the facsimile information field (FIF).
3. Non-Standard Facilities (NSF): The optional NSF frame also precedes the DIS frame. The NSF's FCF frame has the format 00000100. This frame tells about additional capabilities that the fax machine has. It might concern security matters, image resolutions, higher speeds or something else. This frame allows manufacturers of facsimile machines to develop faster and better fax solutions, and thus allow competition in the market. Telecommunication advances so rapidly, that ITU-T made sure that the T.30 was flexible enough to support company specific enhancement by the use of the NSF frame.

When the DIS frame has been sent from the called G3FE device, it will wait for a command from the calling fax machine. If it does not receive a command within 3 seconds, it starts all over by sending a new CED, preamble, and a DIS frame. Once it get a command from the calling fax machine, Phase B starts.

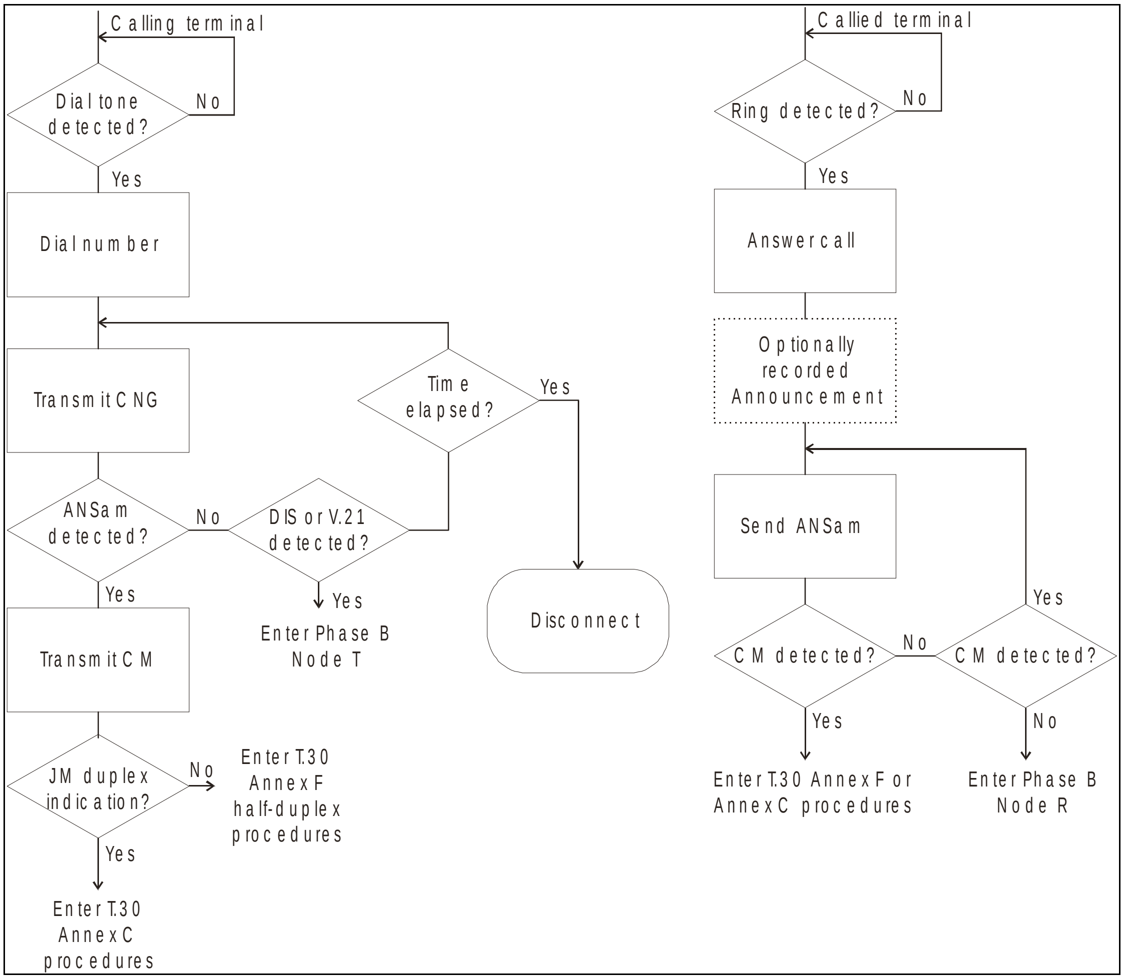


Figure 32 Call establishment, operating method 4 bis *a*

PHASE B:PRE-MESSAGE PROCEDURE.

This is the pre-message procedure, where the answering machine identifies itself, and describes its capabilities in a burst of digital information packed in frames conforming to the HDLC (High-level Data Link Control) standard. The frames the called fax machine sends as its initial identification sequence are the first of these, and the originating station can respond in a number of different ways. The most common reply to an identification sequence is for the originator to send a *command to receive.* By issuing this, a station claims the role of transmitter and the consequent right to control the rest of the session. The possibility of polling means the command to receive is not issued uniquely by a caller in response to an initial identification sequence. A called facsimile device in response to a poll command could equally issue it. The command to receive, can contain three types of frames:

- Digital command signal (DCS): The DCS frame corresponds to the DIS frame sent as *part* of the initial identification and is the only compulsory frame. The difference between a DIS frame and a DCS frame is that the DIS frame only conveys all the standard capabilities of a station, while the DCS is a frame that tells exactly which features the fax machines will use. This means that the selection of which of the available options is to be used has to be left to the transmitter. For example, the DIS frame might indicate that a station has the capability of receiving at any fax speed from 2400bps to 14400bps, but the decision as to which of those speeds will be used is taken by the transmitter and sent in the DCS frame.
- Transmitting subscriber identification frame (TSI): The DCS is usually preceded by the optional TSI. The format of the facsimile information field of the TSI is the same as that of the CSI frame, consisting of a 20 character ASCII coded telephone number.
- Non-standard facilities setup frame (NSS): The DCS can also be preceded by the optional TSI. The NSS is basically a response frame to a NSF frame. It tells about additional facilities of this fax machine. The NSS frame should therefore only be

generated if the called fax machine sent a NSF frame.

The details of the FIF bit-field for the DIS and DCS frames in the newest T.30 amendment are all listed in Table 8. The original T.30 only consisted of 24 bits, so they are the only ones that a facsimile device really must support. The extensions came as follows:

- 1988 fax extension, bits 25-40.
- 1993 fax extension, bits 41-50
- Data file extensions, bits 51-58
- Text transmission extensions, bits 59-64
- Open document/ISDN extensions, bits 65-72
- 1996 JPEG extensions, bits 73-80
- 1997 encryption extensions, bits 80-91
- Colors and rasterization extensions, bits 92-98
- 1998 binary file transfer extensions, bits 99-100

Most of the entries in Table 8 are self-explanatory and explaining all entries is out of the scope of this thesis. ITU-T Recommendation T.30 covers these in detail, however a few things are worth mentioned. Reserved fields should be set to 0. The extend fields (entry 24, 32, 40, 48 and so on) tell if there are more octets in the DIS/DTC/DCS table. Some fax machines incorporate all 23 octets (104 entries), while others might only support the features in the first 5 octets. Some of the fields involves other ITU-T recommendations, like entry 53 means that the facsimile device support BFT (Binary File Transfer) which invokes the T.42 protocol or entry 68 that invokes JPEG coding and some of its properties defined in T.81.

Bit No.	**DIS/DTC**	**DCS**
1	Reserved	Reserved
2	Reserved	Reserved
3	Reserved	Reserved
4	Reserved	Reserved
5	Reserved	Reserved
6	V.8 capabilities	Invalid
7	"0" = 256 octets preferred "1" = 64 octets preferred	Invalid
8	Reserved	Reserved
9	Ready to transmit a facsimile document (polling)	Set to "0"
10	Receiver fax operation	Receiver fax operation
11, 12, 13, 14	Data signalling rate	Data signalling rate
0, 0, 0, 0	V.27 *ter* fall-back mode	2400 bit/s, V.27 *ter*
0, 1, 0, 0	V.27 *ter*	4800 bit/s, V.27 *ter*
1, 0, 0, 0	V.29	9600 bit/s, V.29
1, 1, 0, 0	V.27 *ter* and V.29	7200 bit/s, V.29
0, 0, 1, 0	Not used	Invalid
0, 1, 1, 0	Reserved	Invalid
1, 0, 1, 0	Not used	Reserved
1, 1, 1, 0	Invalid	Reserved
0, 0, 0, 1	Not used	14 400 bit/s, V.17
0, 1, 0, 1	Reserved	12 000 bit/s, V.17
1, 0, 0, 1	Not used	9600 bit/s, V.17
1, 1, 0, 1	V.27 *ter*, V.29, and V.17	7200 bit/s, V.17
0, 0, 1, 1	Not used	Reserved
0, 1, 1, 1	Reserved	Reserved
1, 0, 1, 1	Not used	Reserved
1, 1, 1, 1	Reserved	Reserved
15	R8 $\times$ 7.7 lines/mm and/or 200 $\times$ 200 pels/25.4 mm	R8 $\times$ 7.7 lines/mm or 200 $\times$ 200 pels/25.4 mm
16	Two dimensional coding capability	Two dimensional coding
17, 18	Recording width capabilities	Recording width
(0,0)	Scan line length 215 mm ± 1%	Scan line length 215 mm ± 1%
(0,1)	Scan line length 215 mm ± 1% and scan line length 255 mm ± 1% and scan line length 303 mm ± 1%	Scan line length 303 mm ± 1%
(1,0)	Scan line length 215 mm ± 1% and scan line length 255 mm ± 1%	Scan line length 255 mm ± 1%
(1,1)	Invalid	Invalid
19, 20	Recording length capability	Recording length
(0,0)	A4 (297 mm)	A4 (297 mm)
(0,1)	Unlimited	Unlimited
(1,0)	A4 (297 mm) and B4 (364 mm)	B4 (364 mm)
(1,1)	Invalid	Invalid
21, 22, 23	Minimum scan line time capability at the receiver	Minimum scan line time
(0,0,0)	20 ms at 3.85 l/mm: $T_{7.7} = T_{3.85}$	20 ms
(0,0,1)	40 ms at 3.85 l/mm: $T_{7.7} = T_{3.85}$	40 ms
(0,1,0)	10 ms at 3.85 l/mm: $T_{7.7} = T_{3.85}$	10 ms
(1,0,0)	5 ms at 3.85 l/mm: $T_{7.7} = T_{3.85}$	5 ms
(0,1,1)	10 ms at 3.85 l/mm: $T_{7.7} = 1/2\ T_{3.85}$	
(1,1,0)	20 ms at 3.85 l/mm: $T_{7.7} = 1/2\ T_{3.85}$	
(1,0,1)	40 ms at 3.85 l/mm: $T_{7.7} = 1/2\ T_{3.85}$	
(1,1,1)	0 ms at 3.85 l/mm: $T_{7.7} = T_{3.85}$	0 ms

Bit No.	**DIS/DTC**	**DCS**
24	Extend field	Extend field
25	Reserved	Reserved
26	Uncompressed mode	Uncompressed mode
27	Error correction mode	Error correction mode
28	Set to "0"	Frame size 0 = 256 octets Frame size 1 = 64 octets
29	Reserved	Reserved
30	Reserved	Reserved
31	T.6 coding capability	T.6 coding enabled
32	Extend field	Extend field
33	Field not valid capability	Field not valid capability
34	Multiple selective polling	Set to "0"
35	Polled SubAddress	Set to "0"
36	T.43 coding	T.43 coding
37	Plane interleave	Plane interleave
38	Reserved	Reserved
39	Reserved	Reserved
40	Extend field	Extend field
41	R8 $\times$ 15.4 lines/mm	R8 $\times$ 15.4 lines/mm
42	300 $\times$ 300 pels/25.4 mm	300 $\times$ 300 pels/25.4 mm
43	R16 $\times$ 15.4 lines/mm and/or 400 $\times$ 400 pels/25.4 mm	R16 $\times$ 15.4 lines/mm and/or 400 $\times$ 400 pels/25.4 mm
44	Inch based resolution preferred	Resolution type selection "0": metric based resolution "1": inch based resolution
45	Metric based resolution preferred	Don’t care
46	Minimum scan line time capability for higher resolutions "0": $T_{15.4} = T_{7.7}$ "1": $T_{15.4} = 1/2\ T_{7.7}$	Don’t care
47	Selective polling	Set to "0"
48	Extend field	Extend field
49	Subaddressing capability	Subaddressing transmission
50	Password	Sender Identification transmission
51	Ready to transmit a data file (polling)	Set to "0"
52	Reserved	Reserved
53	Binary File Transfer (BFT)	Binary File Transfer (BFT)
54	Document Transfer Mode (DTM)	Document Transfer Mode (DTM)
55	Electronic Data Interchange (EDI)	Electronic Data Interchange (EDI)
56	Extend field	Extend field
57	Basic Transfer Mode (BTM)	Basic Transfer Mode (BTM)
58	Reserved	Reserved
59	Ready to transmit a character or mixed mode document (polling)	Set to "0"
60	Character mode	Character mode
61	Reserved	Reserved
62	Mixed mode (Annex D/T.4)	Mixed mode (Annex D/T.4)
63	Reserved	Reserved
64	Extend field	Extend field
65	Processable mode 26 (T.505)	Processable mode 26 (T.505)
66	Digital network capability	Digital network capability
67 (0) (1)	Duplex and half duplex capabilities Half duplex operation only Duplex and half duplex operation	Duplex and half duplex capabilities Half duplex operation only Duplex operation
68	JPEG coding	JPEG coding
69	Full colour mode	Full colour mode
70	Set to "0"	Preferred Huffman tables
71	12 bits/pel component	12 bits/pel component
72	Extend field	Extend field
73	No subsampling (1:1:1)	No subsampling (1:1:1)
74	Custom illuminant	Custom illuminant

Bit No.	**DIS/DTC**	**DCS**
75	Custom gamut range	Custom gamut range
76	North American Letter (215.9 × 279.4 mm) capability	North American Letter (215.9 × 279.4 mm)
77	North American Legal (215.9 × 355.6 mm) capability	North American Legal (215.9 × 355.6 mm)
78	Single-progression sequential coding (T.85) basic capability	Single-progression sequential coding (T.85) basic
79	Single-progression sequential coding (T.85) optional L0 capability	Single-progression sequential coding (T.85) optional L0
80	Extend field	Extend field
81	HKM key management capability	HKM key management selected
82	RSA key management capability	RSA key management selected
83	Override mode capability	Override mode selected
84	HFX40 cipher capability	HFX40 cipher selected
85	Alternative cipher number 2 capability	Alternative cipher number 2 selected
86	Alternative cipher number 3 capability	Alternative cipher number 3 selected
87	HFX40-I hashing capability	HFX40-I hashing selected
88	Extend field	Extend field
89	Alternative hashing system number 2 capability	Alternative hashing system number 2 selected
90	Alternative hashing system number 3 capability	Alternative hashing system number 3 selected
91	Reserved for future security features	Reserved for future security features
92	T.44 (Mixed Raster Content) mode	T.44 (Mixed Raster Content) mode
93	T.44 (Mixed Raster Content) mode	T.44 (Mixed Raster Content) mode
94	T.44 (Mixed Raster Content) mode	T.44 (Mixed Raster Content) mode
95	Page length maximum strip size for T.44 (Mixed Raster Content)	Page length maximum strip size for T.44 (Mixed Raster Content)
96	Extend field	Extend field
97	Color/gray-scale 300 × 300 or 400 × 400 pels/25.4 mm resolution	Color/gray-scale 300 × 300 or 400 × 400 pels/25.4 mm resolution
98	R4 × 3.85 lines/mm and/or 100 × 100 pels/25.4 mm for color/gray-scale	R4 × 3.85 lines/mm and/or 100 × 100 pels/25.4 mm for color/gray-scale
99	Simple Phase C BFT Negotiations capability	Simple Phase C BFT Negotiations capability
100	Reserved for Extended BFT Negotiations capability	Set to “0”
101	Reserved	Reserved
102	Reserved	Reserved
103	Reserved	Reserved
104	Extend field	Extend field

Table 8 The Facsimile Identification Field (FIF) bits for DIS/DTC and DCS frames

If the capability exchange worked as expected without errors, the calling fax machine will send a frame called TCF (Training Check Frame). The TCF is not a real HDLC frame. It only consists of a series of 0’s sent for 1.35-1.65 seconds. The receiver analyzes the received data and figures if it is good or not. If it is good, then it sends a CRF (confirmation to receive frame) and wait for the fax image. If the data is no good, then it sends a FTT (failure to train) frame instead. This means that the negotiation of capabilities will commence again and new parameters for the fax transfer will be used. Normally the re-negotiation consists of lowering the modulation speeds, or the modulation protocol. The two fax machines will continue negotiating until a CFR frame is being sent. This concludes phase B

PHASE C: MESSAGE TRANSMISSION

This is the fax transmission portion of the operation. The transmission speeds and other capabilities have been determined, so the transmitting fax machine should wait approximately 75 ms until stating sending the fax page. The rules for sending the fax images are governed by the T.4 protocol. When the receiver detects RTC (return to control), which is 6 consecutive EOL codes, then phase C is over and the receiver and transmitter return to the low-speed modulation scheme.

PHASE D: POST-MESSAGE PROCEDURE

This phase begins once a page has been transmitted. Both the sender and receiver revert to using HDLC packets as during phase B. The transmitter can now send one out of three post-message commands:

- End of message (EOM): This message instructs the receiver that the page has been transmitted and that it wants to start all over in phase B. There might be several reasons why the transmitter want to do this. It can for instance be that the next page should be sent with another resolution, or that the page width of the next paper is different.
- Multi page signal (MPS): This message tell that the former page transmitted is only one out of several, so the fax machine want to go back to phase C and transmit a

new page using the exact same negotiation parameters as before.

- End of procedure (EOP): The transmitter have no more pages or information to be transmitted, so it wants to disconnect.

PHASE E: CALL RELEASE

The call release portion. The side that transmitted last sends a DCN frame and hangs up without awaiting a response.

This concludes the summary of ITU-T Recommendation T.30. Further information on T.30 can be obtained from ITU-T [2].

APPENDIX C: TIFF (TAGGED IMAGE FILE FORMAT)

BACKGROUND

TIFF is a image file format developed by Aldus Corporation. TIFF is a tag-based file format for storing and interchanging raster images. The first TIFF standard was published in the fall of 1986. It did not have a revision number, but would be called Revision 3.0, according to Aldus since they have released two major draft releases before Revision 3.0. Revision 4.0 was released in April 1987 with mostly minor enhancements. Revision 5.0 was released in October 1988 and added support for palette color images and LZW compression. TIFF Revision 6.0 was finalized and released June 3, 1992 and is the newest TIFF Revision. TIFF has been chosen as the standard to use for facsimile applications. TIFF is the only file format that incorporates the existing T.4 and T.6
compression algorithms and that it will also support future expansions.

TIFF has the following properties that make it an ideal candidate for facsimile images:

- Supports multiple pages and resolutions.
- Incorporates the MH, MR, and MMR coding algorithms.
- Includes support for JPEG compression algorithms.
- Supports palettes, true color images and other up-coming standards for facsimile images.
- Can be expanded indefinitely with new tags and new coding algorithms and options.
- Contains tags with image information, like copyright, author, page name, page numbers and others.

BASIC TIFF FILE FORMAT

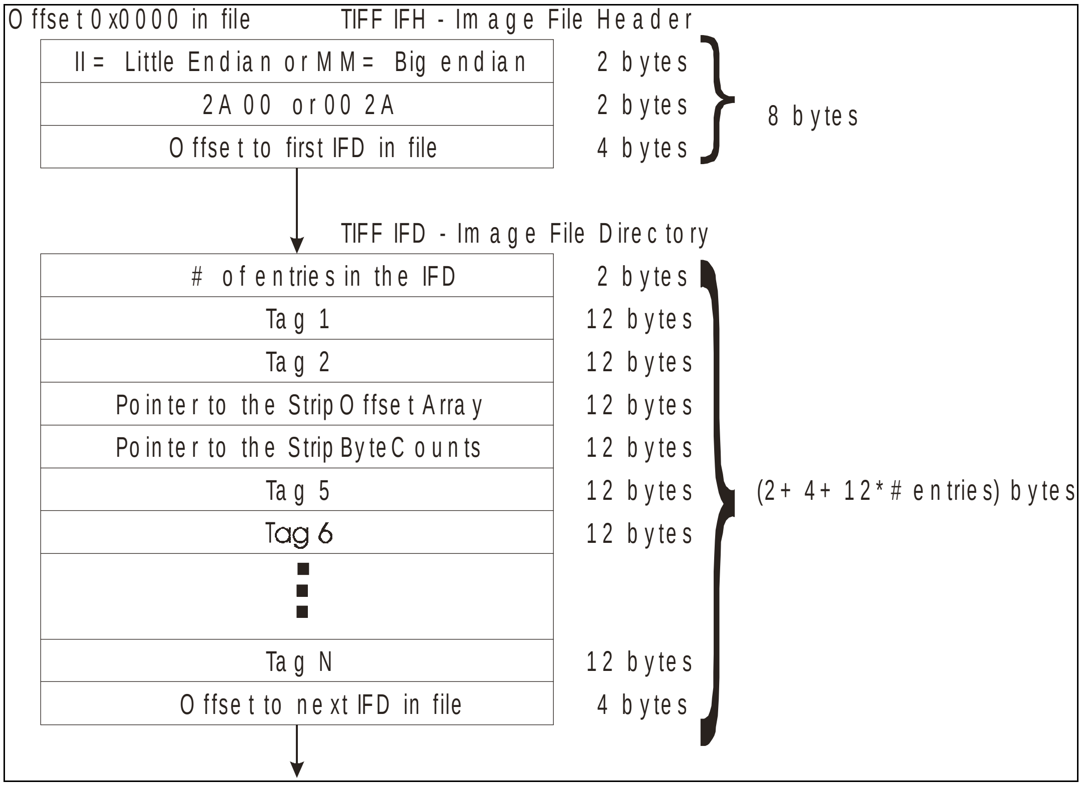


Figure 33 Basic TIFF file structure

Figure 33 shows how a TIFF image file is structured. A TIFF file always starts with an 8-byte header called the image file header (IFH). The first two bytes contain either the ASCII letters ‘II’(hex value 0x4949) telling that the file uses Intel little endian byte order or ‘MM’ (hex value 0x4D4D) which means that the file uses Motorola big endian byte ordering. This information together with the next two bytes (which are 0x002a or 0x2a00), identify the file as a TIFF file that follows revision 6.0. The last four bytes contain the offset to the first image file directory (IFD) in the TIFF file.

An IFD contains all the information necessary to determine the features, compression and other information of the TIFF image that belongs to that IFD. A TIFF file can contain many IFDs and each of the IFDs are individual image descriptors. This means that a TIFF file can contain several images that use different compression algorithms and different dimensions and other information. At the end of an IFD, there are four bytes that contain the offset to the next IFD. If the four bytes equals zero, then there are no more IFDs in the TIFF file. The first two bytes of an IFD contain information about how many Tags there are in this particular IFD. A normal number of Tags is about 11.

Figure 34 shows how a tag-field is structured. The first entry (two bytes) can be a number between 0 and 65535. This information identifies the tag number (Table 9 shows all the tags specified in TIFF Revision 6.0). The next entry specifies the type of data in the tag. The data can for instance be a byte, word, double-word, float or even a rational number with a denominator and a numerator (Table 10 shows all data types supported in TIFF Rev. 6.0). The third entry contains 4 bytes and it identifies the number of data-types belonging to the tag. The last entry in the tag-field is the offset. The offset can either be an offset to another place in the TIFF-file (if number exceeds four bytes) or it can be an actual value (meaning that the value is located over less than four bytes).

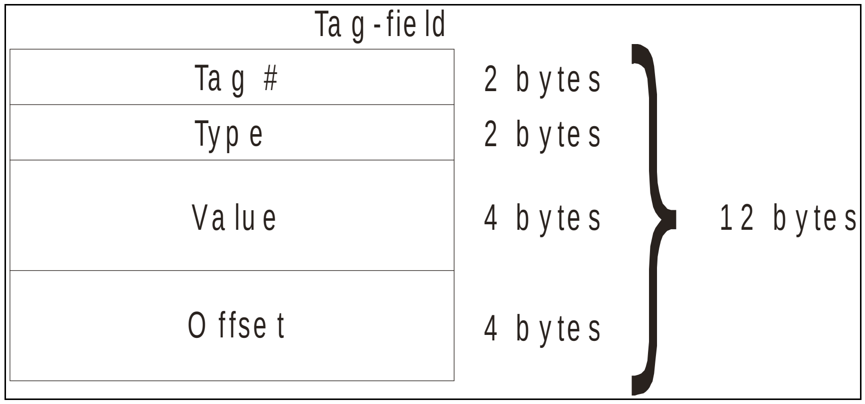


Figure 34 The structure of a TIFF tag-field

TIFF revision 6.0 contain 74 official tags, where some are required in all TIFF IFDs, some are required only in special cases, and some are not required for any IFDs and can therefore be used at ones own leisure. Table 9 shows the tags that are specified in the TIFF Revision 6.0 document from Aldus. A TIFF image will only contain a small subset of these. Some of the tags are more important than others, e.g. the Compression, ImageLength, and ImageWidth are more important for a TIFF reader than for instance the Software or Artist tags. Since this chapter deals with TIFF class F, then the required tags for this class will be examined further in Table 9 and Table 10.

TagName	Tag #	Hex	Type	Number of values
NewSubfileType	254	FE	LONG	1
SubfileType	255	FF	SHORT	1
ImageWidth	256	100	SHORT or LONG	1
ImageLength	257	101	SHORT or LONG	1
BitsPerSample	258	102	SHORT	SamplesPerPixel
Compression	259	103	SHORT	1
Uncompressed	1			
CCITT 1D	2			
Group 3 Fax	3			
Group 4 Fax	4			
LZW	5			
JPEG	6			
PackBits	32773			
PhotometricInterpretation	262	106	SHORT	1
WhiteIsZero	0			
BlackIsZero	1			
RGB	2			
RGB Palette	3			
Transparency mask	4			
CMYK	5			
YcbCr	6			
CIELab	8			
Threshholding	263	107	SHORT	1
CellWidth	264	108	SHORT	1
CellLength	265	109	SHORT	1
FillOrder	266	10A	SHORT	1
DocumentName	269	10D	ASCII	
ImageDescription	270	10E	ASCII	
Make	271	10F	ASCII	
Model	272	110	ASCII	
StripOffsets	273	111	SHORT or LONG	StripsPerImage
Orientation	274	112	SHORT	1
SamplesPerPixel	277	115	SHORT	1
RowsPerStrip	278	116	SHORT or LONG	1
StripByteCounts	279	117	SHORT or LONG	StripsPerImage
MinSampleValue	280	118	SHORT	SamplesPerPixel
MaxSampleValue	281	119	SHORT	SamplesPerPixel
XResolution	282	11A	RATIONAL	1
YResolution	283	11B	RATIONAL	1
PlanarConfiguration	284	11C	SHORT	1
PageName	285	11D	ASCII	
XPosition	286	11E	RATIONAL	
YPosition	287	11F	RATIONAL	
FreeOffsets	288	120	LONG	
FreeByteCounts	289	121	LONG	
GrayResponseUnit	290	122	SHORT	1
GrayResponseCurve	291	123	SHORT	2**BitsPerSample
T4Options	292	124	LONG	1
T6Options	293	125	LONG	1
ResolutionUnit	296	128	SHORT	1
PageNumber	297	129	SHORT	2
TransferFunction	301	12D	SHORT	(1 or SamplesPerPixel)* 2** BitsPerSample
Software	305	131	ASCII	
DateTime	306	132	ASCII	20
Artist	315	13B	ASCII	
HostComputer	316	13C	ASCII	
Predictor	317	13D	SHORT	1
WhitePoint	318	13E	RATIONAL	2
PrimaryChromaticities	319	13F	RATIONAL	6
ColorMap	320	140	SHORT	3 * (2**BitsPerSample)

TagName	Tag #	Hex	Type	Number of values
HalftoneHints	321	141	SHORT	2
TileWidth	322	142	SHORT or LONG	1
TileLength	323	143	SHORT or LONG	1
TileOffsets	324	144	LONG	TilesPerImage
TileByteCounts	325	145	SHORT or LONG	TilesPerImage
InkSet	332	14C	SHORT	1
InkNames	333	14D	ASCII	total number of characters in all ink name strings, including zeros
NumberOfInks	334	14E	SHORT	1
DotRange	336	150	Any	2, or 2*
TargetPrinter	337	151	ASCII	Any
ExtraSamples	338	152	BYTE	number of extra components per pixel
SampleFormat	339	153	SHORT	SamplesPerPixel
SminSampleValue	340	154	Any	SamplesPerPixel
SmaxSampleValue	341	155	Any	SamplesPerPixel
TransferRange	342	156	SHORT	6
JPEGProc	512	200	SHORT	1
JPEGInterchangeFormat	513	201	LONG	1
JPEGInterchangeFormatLength	514	202	LONG	1
JPEGRestartInterval	515	203	SHORT	1
JPEGLosslessPredictors	517	205	SHORT	SamplesPerPixel
JPEGPointTransforms	518	206	SHORT	SamplesPerPixel
JPEGQTables	519	207	LONG	SamplesPerPixel
JPEGDCTables	520	208	LONG	SamplesPerPixel
JPEGACTables	521	209	LONG	SamplesPerPixel
YCbCrCoefficients	529	211	RATIONAL	3
YCbCrSubSampling	530	212	SHORT	2
YCbCrPositioning	531	213	SHORT	1
ReferenceBlackWhite	532	214	LONG	2*SamplesPerPixel
Copyright	33432	8298	ASCII	Any

Table 9 Tag fields for TIFF Revision 6.0

Type	Value	Size of the type
BYTE	1	8-bit unsigned integer
ASCII	2	8-bit byte that contains a 7-bit ASCII code
SHORT	3	16-bit (2-byte) unsigned integer.
LONG	4	32-bit (4-byte) unsigned integer.
RATIONAL	5	Two LONG's: the first represents the numerator of a fraction; the second, the denominator
SBYTE	6	An 8-bit signed (two's complement) integer
UNDEFINED	7	An 8-bit byte that may contain anything, depending on the definition of the field.
SSHORT	8	A 16-bit (2-byte) signed (twos-complement) integer.
SLONG	9	A 32-bit (4-byte) signed (twos-complement) integer.
SRATIONAL	10	Two SLONG's: the first represents the numerator of a fraction; the second, the denominator.
FLOAT	11	Single precision (4-byte) IEEE format.
DOUBLE	12	Double precision (8-byte) IEEE format.

Table 10 The different TIFF data types

Table 11 contains some examples of real-life TIFF tags. The first tag in the table is identified as the image width tag since the tag value is 256. This is an example of a required tag in any TIFF IFD. The next two bytes contain the number four which means that the offset contain an unsigned 32-bit number. Entry number three in the table has a tag value of 306 which identifies this tag as the DateTime tag. This is an example of an optional tag, which one does not need for decoding and encoding the image. The type field in the DataTime tag is two, which identifies that the data in this tag is 8-bit bytes that contains a 7-bit ASCII code. The value-entry states that there are 20 occurrences of the ASCII code. Since the offset only contain four bytes, there is no room to put the 20 ASCII characters in the offset-entry. In this case the offset contain an offset to another place in the TIFF file that contain the information. The ImageWidth tag in the table has a value of 1. This in combination with the data being 32-bit, means that the total number of bytes is four. This is less than or equal to the four bytes the offset tag can contain and therefore the offset tag contains the real number. The image in the example has therefore a height of 1078 and a width of 1728.

TagName	**Tag value**	**Tag value (hex)**	**Type**	**Value**	**Offset**
ImageWidth	256	0x0100	(4)LONG	1	1728
ImageLength	257	0x0101	(4)LONG	1	1078
DateTime	306	0x0132	(2)ASCII	20	320

Table 11 Examples of TIFF tags

The TIFF IFD in Figure 33 shows two tags that are especially important when it comes to reading or writing a TIFF image. These are the StripOffset and StripByteCount tags. One of the important features of a TIFF image is that it can be divided into several strips and thus each strip can be placed anywhere in the TIFF file. Figure 35 shows how an image can be divided into several parts that are located in different places of a file. A StripOffset tells where in the file that the particular strip is found.

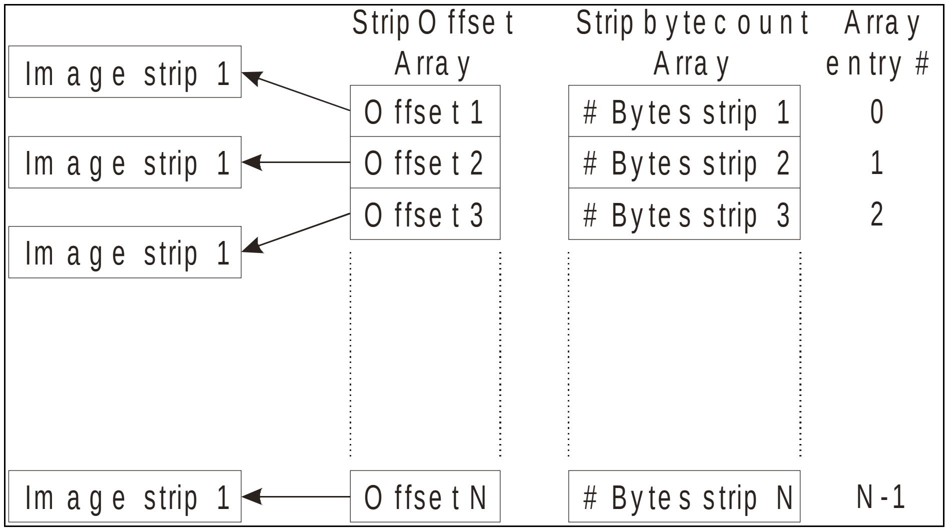


Figure 35 The structure of the Stripbytecount and the StipOffset tags

Table 11 shows what the tags for the StripOffsets and StripByteCounts tags can look like. Since the Type tags are longs (4-bytes) and the Value tags equal to 29, then the total bytes adds up to 116 bytes for each. The image is composed of 29 image strips so there should be 29 entries in a StripOffsets array and 29 entries in the StripByteCounts array. The StripOffsets say where to find each strip, while the StripByteCounts contains an array of how many bytes each strip takes in the file.

TagName	**Tag value**	**Tag value (hex)**	**Type**	**Value**	**Offset**
StripOffsets	273	0x0111	(4)LONG	29	280
StripByteCounts	279	0x0117	(4)LONG	29	396

Table 12 Example of StripOffset and StripByteCount tags

This concludes the general TIFF information. It is time for some more specific information regarding TIFF bi-level images and TIFF class F images.

TIFF BI-LEVEL IMAGES

TIFF class F is a subset of images in TIFF revision 6.0 called bi-level images. Bi-level images contain only two colors. These colors are normally black and white. The required tags for bi-level images are located in Table 13. The tags in Table 13 are further explained in Table 14.

TagName	Tag #	Hex	Type	Number of values
ImageWidth	256	100	SHORT or LONG	1
ImageLength	257	101	SHORT or LONG	1
Compression	259	103	SHORT	1
PhotometricInterpretation	262	106	SHORT	1
StripOffsets	273	111	SHORT or LONG	StripsPerImage
RowsPerStrip	278	116	SHORT or LONG	1
StripByteCounts	279	117	SHORT or LONG	StripsPerImage
Xresolution	282	11A	RATIONAL	1
YResolution	283	11B	RATIONAL	1

Table 13 Required TIFF tag fields for bi-level images

ImageWidth	The number of columns in the image, i.e., the number of pixels per scanline.	
ImageLength	The number of rows (sometimes described as *scanlines)* in the image	
Compression	Values: 1 = No compression. 2 = CCITT Group 3 1-D MH. 3 = Group 3 Fax 4 = Group 4 Fax 5 = LZW 6 = JPEG 32773 = PackBits.	The Compression tag identify the compression algorithm that has been used on the image For pure bi-level images the value must be either 1, 2 or 32773. For TIFF class F, the value must be 3 or 4.
PhotometricInterpretation	Values: 0 = WhiteIsZero. 1 = BlackIsZero. 2 = RGB 3 = RGB Palette 4 = Transparency mask 5 = CMYK 6 = YcbCr 8 = CIELab	Identifies how the color information is stored on the image data. For bi-level data, PhotometricInterpretation must be 0 or 1.
StripOffsets	For each strip, the byte offset of that strip.	
RowsPerStrip	The number of rows in each strip (except possibly the last strip.) For example, if ImageLength is 24, and RowsPerStrip is 10, then there are 3 strips, with 10 rows in the first strip, 10 rows in the second strip, and 4 rows in the third strip. (The data in the last strip is not padded with 6 extra rows of dummy data.)	
StripByteCounts	For each strip, the number of bytes in that strip *after any compression.*	
Xresolution	The number of pixels per ResolutionUnit in the ImageWidth (typically, horizontal - see Orientation) direction.	
Yresolution	The number of pixels per ResolutionUnit in the ImageLength (typically, vertical) direction	
ResolutionUnit	Values: 1= No absolute unit. 2= Inch. 3= Centimeter.	The ResolutionUnit combined with Imagewidth, ImageLength, XResolution and YResolution give away the physical dimensions of an image

Table 14 Explanation of required tags for bi-level TIFF images

All tags required for bi-level images are also required for TIFF class F. TIFF class F adds some required tags however, and some of the bi-level tags have some special meaning when it comes to TIFF class F.

TIFF CLASS F IMAGES

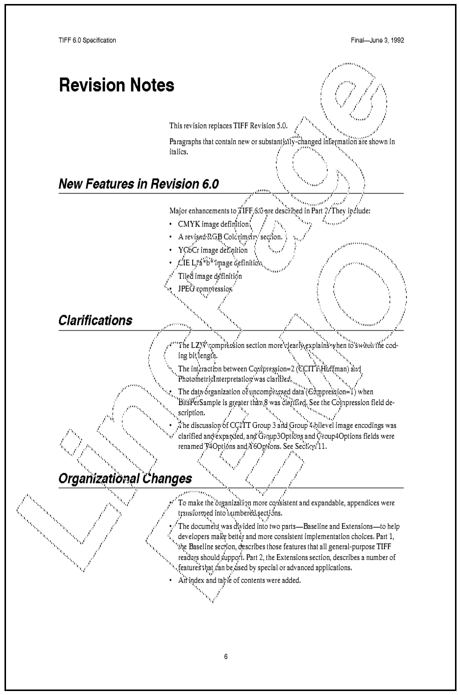
TIFF class F images are an extension to the TIFF bi-level images. TIFF revisions lower than 6.0 classified the different TIFF subsets as classes. This disappeared with revision 6.0, so TIFF Revision 6.0 only refers to TIFF class F, or TIFF profile F as stated in IETF RFC 2301. In the IETF RFC 2301 standard, bi-level TIFF is classified as TIFF profile S or TIFF class S. Also, the earlier TIFF class F included support for A5 and A6 paper-widths. In the new Profile F, these paper-sizes are considered obsolete, so TIFF Profile F readers and writers do not need to support them anymore. Table 15 shows the required tags and values for the newest TIFF profile F standard.

NewSubfileType	Must be 2. Tells that this is a single page of a multipage image. All class F images must have a value of 2 even though they only contain 1 image.
ImageWidth	Must be a number that correspond to standard fax-sheets. Valid values are: 1728, 2592 and 3456 (corresponds to North American Letter, Legal and ISO A4 paper) 2048, 3072 and 4096 corresponding to ISO B4 paper size. 2432, 3648 and 4864 corresponding to ISO A3 paper size
ImageLength	The number of rows (sometimes described as *scanlines)* in the image
BitsPerSample	Default =1. May be omitted if data is binary only.
Compression	Valid values are: 3 – Group 3 Fax. Means that the T4Options tag must also exist. 4 - Group 4 Fax. Means that the T6Options tag must also exist. This corresponds to MH, MR and MMR decoding.
PhotometricInterpretation	Valid values are: 0 – WhiteIsZero. White pixels are described by pixel values of 0. 1 – BlackIsZero. Black pixels are described by pixel values of 0
FillOrder	Tells about the logical order of bits within a byte. Valid values are: 1 – The first bit of an image is stored in the Most Significant Bit (MSB) of the first byte. 2 – The first bit of an image is stored in the Least Significant Bit (LSB) of the first byte.
StripOffsets	For each strip, the byte offset of that strip.
SamplesPerPixel	Valid only for 1. Tells that image is monochrome. Field may be omitted since default is 1.
RowsPerStrip	The number of rows in each strip (except possibly the last strip.) For example, if ImageLength is 24, and RowsPerStrip is 10, then there are 3 strips, with 10 rows in the first strip, 10 rows in the second strip, and 4 rows in the third strip. (The data in the last strip is not padded with 6 extra rows of dummy data.)
StripByteCounts	For each strip, the number of bytes in that strip *after any compression.*
Xresolution	The number of pixels per ResolutionUnit in the ImageWidth. Valid values for Fax depends on if the ResolutionUnit tag specify Inch based or cm: Inches: 100, 200, 204, 300, 400 and 408 (pixels/inch). cm: 80 and 160 pixels/cm. This corresponds to 204 and 408 pixels/inch
Yresolution	The number of pixels per ResolutionUnit in the ImageHeight. Valid values for Fax depends on if the ResolutionUnit tag specify Inch based or cm: Inches: 98, 100, 196, 200, 300, 391 and 400 (pixels/inch). cm: 38.5, 77 and 154 pixels/cm. This corresponds to 98, 196 and 391 pixels/inch
T4Options	Is required if the compression tag is 3. Valid values are: 0x00 –Compression is 1D MH coding. EOL is not byte aligned. 0x01 – Compression is 2D MR coding. EOL is not byte aligned. 0x04 – Compression is 1D MH coding. EOL is byte aligned 0x05– Compression is 2D MR coding. EOL is byte aligned.
T6Options	Is required if the compression tag is 4. Valid values are: 0x00 – Compression is 2D MMR coding. Uncompressed data is not allowed.
ResolutionUnit	Valid values are: 2 - Inch. 3 – Centimeter.
PageNumber	2 bytes of offset tell the current pagenumber while the other two bytes tell total # of pages.

Table 15 Required tag fields for TIFF class F images

EXAMPLE OF A TIFF CLASS F FAX IMAGE

Figure 36 shows the TIFF image that was being used as an example. This particular image almost conforms to TIFF Class F. TIFF class F is the most common standard of facsimile that exists today and probably will be for some years to come.



TIFF 6.0 Specification — Final—June 3, 1992

Revision Notes

This revision replaces TIFF Revision 5.0.

Paragraphs that contain new or substantially-changed information are shown in italics.

New Features in Revision 6.0

Major enhancements to TIFF 6.0 are described in Part 2. They include:

- CMYK image definition
- A revised RGB Colorimetry section.
- YCbCr image definition
- CIE L*a*b* image definition
- Tiled image definition
- JPEG compression

Clarifications

- The LZW compression section more clearly explains when to switch the coding bit length.
- The interaction between Compression=2 (CCITT Huffman) and PhotometricInterpretation was clarified.
- The data organization of uncompressed data (Compression=1) when BitsPerSample is greater than 8 was clarified. See the Compression field description.
- The discussion of CCITT Group 3 and Group 4 bilevel image encodings was clarified and expanded, and Group3Options and Group4Options fields were renamed T4Options and T6Options. See Section 11.

Organizational Changes

- To make the organization more consistent and expandable, appendices were transformed into numbered sections.
- The document was divided into two parts—Baseline and Extensions—to help developers make better and more consistent implementation choices. Part 1, the Baseline section, describes those features that all general-purpose TIFF readers should support. Part 2, the Extensions section, describes a number of features that can be used by special or advanced applications.
- An index and table of contents were added.

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Figure 36 TIFF image with CCITT 1D MH compression

Figure 37 shows a file dump of the tags of the image in Figure 36. One can see that this particular image has all the required tags for it to be a valid TIFF class F image. The compression type is 3, and hence the tag T4Options exist. The XResolution tag consists of a numerator and a denominator. These are respectively 20400 and 100. This means that the horizontal resolution is 20400/100 = 204 pixels/inch. The vertical resolution is 9800/100 = 98 dpi. This information tells that this the paper size corresponds to legal or

A4 legal. T4Options identify the compression as CCITT 1D Modified Huffman coding where fill bits have been added. See Appendix T.4 for an explanation of how that coding works.

```
TIFF FILE INFORMATION:
        ======================

Inputfile: p036il1j.tif
Output Info filename: p036il1j.txt
II:  Intel's little endian
Offset to IFD: 10
                        THE TAGS IN THE FILE
                        ====================
  TagName:                  Tag#: Type:     Value: Offset: Extra info:
  ========                 =====  =====     ====== ======= ===========
NewSubfileType              254  (4)LONG       1       2   Single page of Multi page
ImageWidth                  256  (4)LONG       1    1728   Width: 1728
ImageLength                 257  (4)LONG       1    1078   Height: 1078
BitsPerSample               258  (3)SHORT      1       1   1
Compression                 259  (3)SHORT      1       3   CCITT Group 3 Fax
PhotometricInterpretation   262  (3)SHORT      1       0   WhiteIsZero
FillOrder                   266  (3)SHORT      1       1   Low Pixel stored-high bits of
                                                           byte
StripOffsets                273  (4)LONG       1     340   Offsets: 0x154
SamplesPerPixel             277  (3)SHORT      1       1   SPP: 1
RowsPerStrip                278  (4)LONG       1    1078   RowsPerStrip: 1078
StripByteCounts             279  (4)LONG       1   26563   ByteCounts: 26563
XResolution                 282  (5)RATIONAL   1     256   Resolutions: Den:20400,
                                                           Num:100
YResolution                 283  (5)RATIONAL   1     264   Resolutions: Den:9800,
Num:100
XPosition                   286  (5)RATIONAL   1     272
YPosition                   287  (5)RATIONAL   1     280
T4Options                   292  (4)LONG       1       4   CCITT-1D, With fill bits
ResolutionUnit              296  (3)SHORT      1       2   Inch
PageNumber                  297  (3)SHORT      2   65541   Page #5 of 1 pages.
Software                    305  (2)ASCII     32     288   EP/FaxAPI 4.16.7, Lincoln &
                                                           Co.
DateTime                    306  (2)ASCII     20     320   2000:03:06 18:45:27

Offset to next IFD: 0
```

Figure 37 Example of the TIFF tags in a 1D MH coded image

This concludes the section of the TIFF file format and how it relates to G3FE compatible codec algorithms.

GLOSSARY

BAUD

The number of changes in signal state per second in a signal sent by a modem. A baud may contain several bits. Some times baud is confused with the bps (bits per second) transmitted on the channel. The baud rate is always equal or less than the bits per second transmitted.

BFT

Binary File Transfer

CCITT

Comiteé Consulttatif International de Télégrafique et Téléphonique.

See ITU-T

DPSK

Differential Phase-Shift Keying. A modulation scheme used for transmitting data involving only phase shifting.

FACSIMILE GROUP 3

A digital fax standard that allows high-speed, reliable transmission over voice grade phone lines. All modern fax devices use Group 3, which is based on ITU-T Recommendation T.4. (which accounts for more than 90% of all fax machines today)

FALLBACK

Most of the modulation schemes (the V.xx ITU-T Recommendations) have so called fallback rates. When a modulation scheme fails to transfer at its highest bits per second rate then it will reduce the bits per second it transmits. For instance V.17 can transfer 14400 bps, but if this fails then it can also fall back to rates of 12000 bps, 9600 bps or 7200 bps.

FSK

Frequency Shift Keying. A modulation scheme used for transmitting data involving only different frequencies.

G3F

See FACSIMILE GROUP 3

HUFFMAN CODING

In fax machines, Huffman encoding is a lossless (no loss of image information) compression algorithm, which replaces a runlength of pixels into a small bitstream.

IETF

Internet Engineering Task Force. A standardization institution working in the same field as ITU-T.

ITU-T

International Telecommunication Union. Formerly known as Comiteé Consulttatif

International de Télégrafique et Téléphonique (CCITT) before 1993. The leading standardization agency for different telecommunication standards and recommendations. Almost all new telecommunication products have incorporated the ITU-T recommendations.

JPEG

Joint Photographic Experts Group. JPEG is a standardized image compression mechanism. JPEG is designed for compressing either full-color or gray-scale images of natural, real-world scenes. It works well on photographs, naturalistic artwork, and similar material; not so well on lettering, simple cartoons, or line drawings. JPEG handles only still images, but there is a related standard called MPEG for motion pictures.

MODIFIED HUFFMAN (MH)

MH is the most common facsimile group3 image encoding scheme. It uses two look up tables called a make-up codes and terminating codes to replace a string of one color into a shorter bitstream.

MODIFIED READ (MR)

Relative element address differentiation code. MR is a 2-dimensional compression technique for fax-machines that handles the data compression of the vertical line and that concentrates on space between the lines and within given characters.

MODIFIED MODIFIED READ (MMR)

A two-dimensional coding scheme originally intended for Group 4 Facsimile devices, but is now incorporated and used in Group 3 Fax machines.

T.4

ITU-T Recommendation for group 3 devices, providing definitions of various v-series protocols and signals used during group 3 operations including: all supported resolutions, one dimensional encoding (Modified Huffman encoding or MH), two dimensional coding (Modified Read (MR) and Modified Modified Read (MMR)), and optional error control and error-limiting modes.

T.30

ITU-T Recommendation for transmission of facsimile documents in the general switched telephone network (or PSTN). T.30 consists basically of a huge state machine that controls which signals are to be transmitted (handshaking). T.30 describes the overall procedure for establishing and managing communication between two fax devices. It covers five phases of operation: call setup, pre-message procedure (selecting the communication mode), message transmission (including both phasing and synchronization), post-message procedure (EOM and confirmation), and call release.

T.42

ITU-T Recommendation for continuous tone color representation method for facsimile. This is basically the same as the TIFF CIELAB standard.

TCM

Trellis Coded Modulation. This is a special and more advanced version of the Quadrature Amplitude Modulation technique where an extra bit is transmitted with the purpose of error checking and correction.

TIFF

Tagged Image File Format. An image standard developed by Adobe. TIFF class F is the only file format that has the T.4 compression/decompression Huffman encoding standards incorporated. It is therefore the image format chosen to store facsimile images on disk.

V.8

This recommendation defines signals to be exchanged between DCEs over the PSTN when a session of data transmission needs to be established, but before signals are exchanged which are specific to a particular modem recommendation. It provides means to automatically determine the best available operational mode between two DCEs connected via the PSTN. It provides a timely indication to circuit multiplication equipment on the v-series modulation to be employed in a new session of data transmission. It also provides a means to enable a PSTN call to be passed on automatically to an appropriate DCE, and provides signals for interacting with PSTN echo-control equipment. This revised recommendation defines additional call function types, defines procedures for the exchange of non-standard facilities information, and adds support for V.90 modulation modes.

V.17

ITU-T Recommendation for simplex modulation technique used in extended group 3 facsimile applications only. Provides up to 14400bps and has fallback rates of 12000bps, 9600bps and 7200bps. The modulation scheme used is TCM.

V.21

ITU-T Recommendation for 300bps duplex modems used on the public switched telephone network (PSTN). V.21 modulation is used in a half-duplex mode for Group 3 fax negotiation and control procedures. The modulation scheme it uses is FSK.

V.27ter

ITU-T Recommendation for 2400/4800bps duplex modems used on the public switched telephone network. This modulation scheme uses half-duplex only and the modulation scheme used is DPSK.

V.29

ITU-T's Recommendation for 9600 bps modems that are used on point-to-point leased circuits. It also incorporates a fallback rate of 7200 bps. The modulation scheme used is QAM.

V.34

A modem operating at data signaling rates of up to 33 600 bit/s for use on the general switched telephone network and on leased point-to-point 2-wire telephone-type circuits. The modulation scheme used is QAM.

QAM

Quadrature Amplitude Modulation. A modulation scheme used for transmitting data involving both phase shifting and amplitude shifting.

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