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Digital Communication Performance Parameters for Proposed Federal Standard 1033

VOLUME II : APPLICATION EXAMPLES

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DIGITAL COMMUNICATION PERFORMANCE PARAMETERS FOR PROPOSED FEDERAL STANDARD 1033

VOLUME II: APPLICATION EXAMPLES

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This volume presents three examples of the use of proposed Federal Standard 1033, "Digital Communication Performance Parameters," in specifying end-to-end telecommunication system performance. The examples illustrate, for the particular configurations assumed, the processes of defining user/system boundaries and interaction sequences; identifying communication functions and their associated outcomes; and calculating performance parameter values.

Key words: Data communications; federal standard; performance parameters; information transfer transaction; access; user information transfer; disengagement; circuit switching; message switching

1. INTRODUCTION

1.1. Purpose and Scope

The purpose of this volume is to illustrate use of the performance parameters defined in proposed Federal Standard 1033, "Digital Communication Performance Parameters," in specifying end-to-end performance of representative telecommunication services. Three example services are described: (1) a non-switched private line, teletypewriter-to-teletypewriter communication service connecting only two operators; (2) a circuit-switched teletypewriter-to-teletypewriter service connecting selected pairs of operators through the public switched network; and (3) a message-switched teletypewriter-to-teletypewriter service providing communication between pairs of operators through an automated store-and-forward switching center. Each example application consists of four parts:

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1. Specification of equipment configuration and operating protocol.
2. Definition of a representative transaction profile.
3. Identification of reference events, which define the start and end of the primary communication functions and signify changes in "responsibility" for their completion.
4. Calculation of performance parameter values based on assumed performance outcomes.

The sole purpose of specifying particular communication components and services in the application examples is to make the examples more concrete. Such specification in no way implies an endorsement of those products or services by the National Telecommunications and Information Administration, or any branch of the U.S. Government. Performance parameter values are calculated, based on assumed transaction profiles and performance outcomes, for the purpose of illustrating the calculation process. Although published performance data are used where available in specifying the assumed performance outcomes, it is not suggested that the parameter values calculated in the examples can be used to characterize the performance of actual offered services.

1.2. Report Organization

Volume I of this two-volume report provides a detailed description of the technical considerations which influenced development of the proposed Federal Standard; and defines the selected parameters in logical and mathematical terms. This volume (Volume II) is organized into five sections. The remainder of this section presents certain interface and protocol information which is common to all three selected examples; and provides a brief overview of key results presented in the subsequent sections. Sections 2, 3, and 4 each describe one of the three selected examples. Section 5 summarizes and compares the calculated parameter values for all three examples and presents overall conclusions. Concise definitions of relevant USASCII communication control characters and RS-232-C interchange circuits are given in appendices A and B, respectively.

1.3. Common Interface and Protocol Features

The following interface and protocol features are common to all three of the selected examples:

1. The functional interface between "the user" and "the telecommunication system" corresponds to the physical interface between a Model 37 (M37) teletypewriter station and the human terminal operator or unattended non-magnetic medium (punched paper tape) on its drop side.
2. "User information" includes the graphic subset of the USASCII code (ANSI, 1967) plus the following format control characters: space (SP); line feed (LF); horizontal tabulation (HT); vertical tabulation (VT); form feed (FF); carriage return (CR); and null (NUL)[1].
3. USASCII "overhead information" characters employed include data link escape (DLE), end of transmission (EOT), device controls 1 and 3 (DC1 and DC3), and enquiry (ENQ); plus any control characters generated and utilized within the system, e.g., acknowledge (ACK), negative acknowledgement (NAK), and synchronous/idle (SYN). All USASCII characters not specified above are assumed unused. All USASCII characters are transmitted in a 10-bit sequence comprising a start bit, 7 ASCII information bits, a parity bit, and a stop bit. Various changes in the states of the M37 control switches and indicators (e.g., ORIG button, data lamp) also represent overhead information transfers; these are identified in each specific example.
4. Except as noted, data communication protocols follow the conventions established in ANSI X3.28 (ANSI, 1971).

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[1]Two minor variations in the third example are explained in Section 4.2.

5. Interface communications between data terminal equipment (DTE) and data circuit-terminating equipment (DCE) follow RS-232-C (EIA, 1969). Events occurring at these interfaces are identified for completeness in the second and third examples, although they are system-internal from the end user point of view.

Specific user/system interface events are identified in each example. In the first example, the user message is input on-line at the source TTY keyboard; in the second and third examples, the user message is input from a source paper tape prepared off-line. The user message is output at the destination terminal printer in each case.

The nonprinting format control characters listed in (2) above are regarded as user information on the following basis: (1) they do not affect the system state, i.e., all system components are transparent to them; and (2) they do produce an observable output at the destination which uniquely represents information input by the source. A delivered user message would look noticeably different if all spaces or line feeds input by the source were omitted.

1.4. Overview of Results

Table 1.1 is a compilation of estimated performance parameter values for the three selected examples. It is emphasized that these values characterize the examples, under stated assumptions, and are not intended to be used in characterizing or comparing actual offered services. The example services are vastly different in performance, by design; and they would be appropriately used in meeting correspondingly different end-to-end service requirements.

With the exception of the error probabilities and transfer rates, the bit-oriented and block-oriented user information transfer parameter values within each individual example are the same. This is true because the bits within each user information block (character) cross the user/system interface

Table 1.1. Compilation of Parameter Values

PERFORMANCE PARAMETER	NONSWITCHED PRIVATE LINE Example	CIRCUIT-SWITCHED EXAMPLE	MESSAGE-SWITCHED EXAMPLE
Access Time	5.2 Seconds	37.5 Seconds	15.4 Minutes
Incorrect Access Probability	0	1.1×10^{-4}	0
Access Denial Probability	1.7×10^{-3}	1.1×10^{-2}	6.8×10^{-4}
Block Transfer Time	68 milliseconds	68 milliseconds	16.2 minutes
Bit Transfer Time	68 milliseconds	68 milliseconds	16.2 minutes
Block Error Probability	1.5×10^{-4}	1.5×10^{-4}	2.5×10^{-4}
Bit Error Probability	$1.5x10^{-5} \leq P(bl_e) \leq 1.5x10^{-4}$	$1.5x10^{-5} \leq P(bl_e) \leq 1.5x10^{-4}$	$2.5x10^{-5} \leq P(bl_e) 2.5x10^{-4}$
Block Misdelivery Probability	0	1.1×10^{-4}	6×10^{-7}
Bit Misdelivery Probability	0	1.1×10^{-4}	6×10^{-7}
Block Loss Probability	4.7×10^{-5}	6.8×10^{-4}	1.7×10^{-3}
Bit Loss Probability	4.7×10^{-5}	6.8×10^{-4}	1.7×10^{-3}
Extra Block Probability	0	0	7×10^{-7}
Extra Bit Probability	0	0	7×10^{-7}
Block Transfer Rate	5 blocks/second	14.6 blocks/second	36.2 blocks/minute
Bit Transfer Rate	35 bits/second	102.4 bits/second	4.2 bits/second
Block Rate Efficiency	23 percent	68 percent	2.8 percent
Bit Rate Efficiency	25 percent	68 percent	2.8 percent
Disengagement Time	0.5 seconds	2.25 seconds	1.5 seconds
Disengagement Denial Probability	4×10^{-4}	5.7×10^{-5}	1.1×10^{-4}
Outage Probability	8×10^{-4}	1.4×10^{-3}	3×10^{-3}
Service Time Between Outages	43 UIT hours	8.2 UIT hours	93 UIT hours
Outage Duration	1 hour	38 minutes	42 minutes
User Access Time Fraction	0.19	0.4	0
User Block Transfer Time Fraction	0	0	0
User Message Transfer Time Fraction	0.67	0.02	0
User Disengagement Time Fraction	0.8	0	0

in parallel; and each block represents a fixed number of bits. The bit- and block-oriented parameter values will differ wherever these special conditions are not met. (Note that the term "block" is used here as defined in proposed Federal Standard 1033, rather than as defined in ANSI X3.28.)

A summary and comparison of the estimated parameter values for each example is presented in Section 5. In summarizing these results, two general observations are made:

1. In each of the three example services described it was possible, with reasonable effort, to develop representative values for all 26 specified performance parameters. More precise estimates of parameter values, and additional performance information such as parameter distributions, could be developed with additional analysis or measurement effort.
2. With a single exception (User Block Transfer Time Fraction), none of the specified parameters had a value of zero in all three examples. The latter parameter will have a nonzero value in various other types of services, as noted in Section 5.

These observations provide general support for the conclusion that the specified parameters are in fact consistent with the four "desired parameter attributes" listed in Section 1.1 of Volume I: user orientation, universal applicability, simplicity, and completeness. It is anticipated that additional application examples will be developed to illustrate use of the proposed standard parameters in characterizing computer-to-computer and teleprocessing services.

2. NONSWITCHED PRIVATE LINE EXAMPLE

2.1. Equipment Configuration

The example presented in this section is a nonswitched private line, teletypewriter-to-teletypewriter communication service which interconnects two operators. Figure 2.1 is a block diagram of the assumed equipment configuration. Two primary communication interfaces are identified: the user/system functional interface, between the operator and the data terminal; and the information transfer channel interface, between the data terminal and data set. The latter interface is internal to the system from the end user (operator) point of view.

2.2. Procedure Flowcharts and Transaction Profile

ANSI X3.28 operating procedure flowcharts for the nonswitched private line example are presented in Figures 2.2 and 2.3, for master and slave stations, respectively. These flowcharts are adapted from Bell System Pub. 41713 and identify the ASCII control characters that may be exchanged between the user (operator) and half-system (terminal) entities during an information transfer transaction.

Before message transmission can begin, the two teletypewriter terminals must be started and placed in appropriate master (transmit) and slave (receive) states. An operator wishing to transmit a message starts his local terminal, by switch action; starts the distant terminal, by sending the communication control character ENQ; and then bids for master status by sending a second ENQ character. A terminal which has not transmitted ENQ, but which has received ENQ, first inhibits the sending of ENQ so that its station may not bid for master status. If the nonoriginating terminal is ready to receive, it assumes slave status and sends the communication control character ACK as an affirmative reply. The bidding (or originating) terminal then assumes master status, and user information transfer proceeds. If the nonoriginating terminal is not ready to receive, it sends the

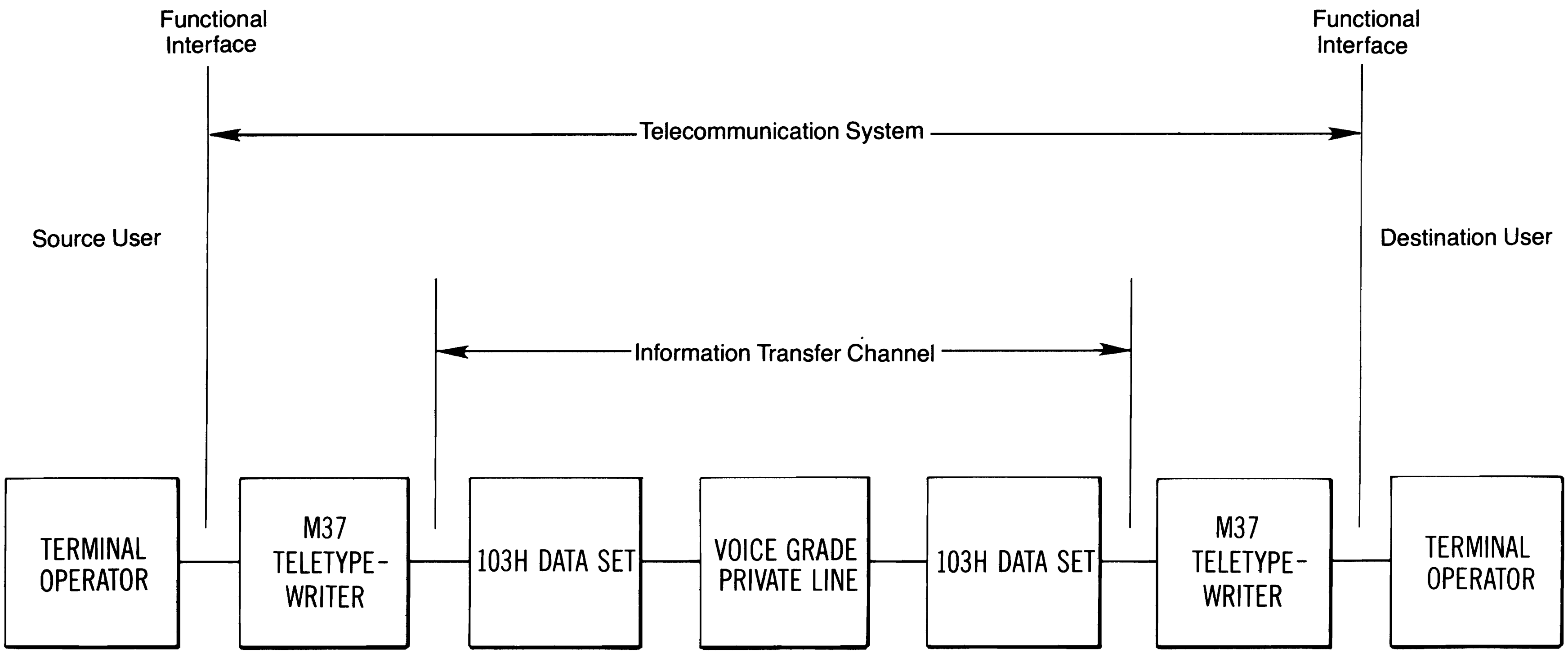


Figure 2.1. Equipment configuration for the nonswitched private line example.

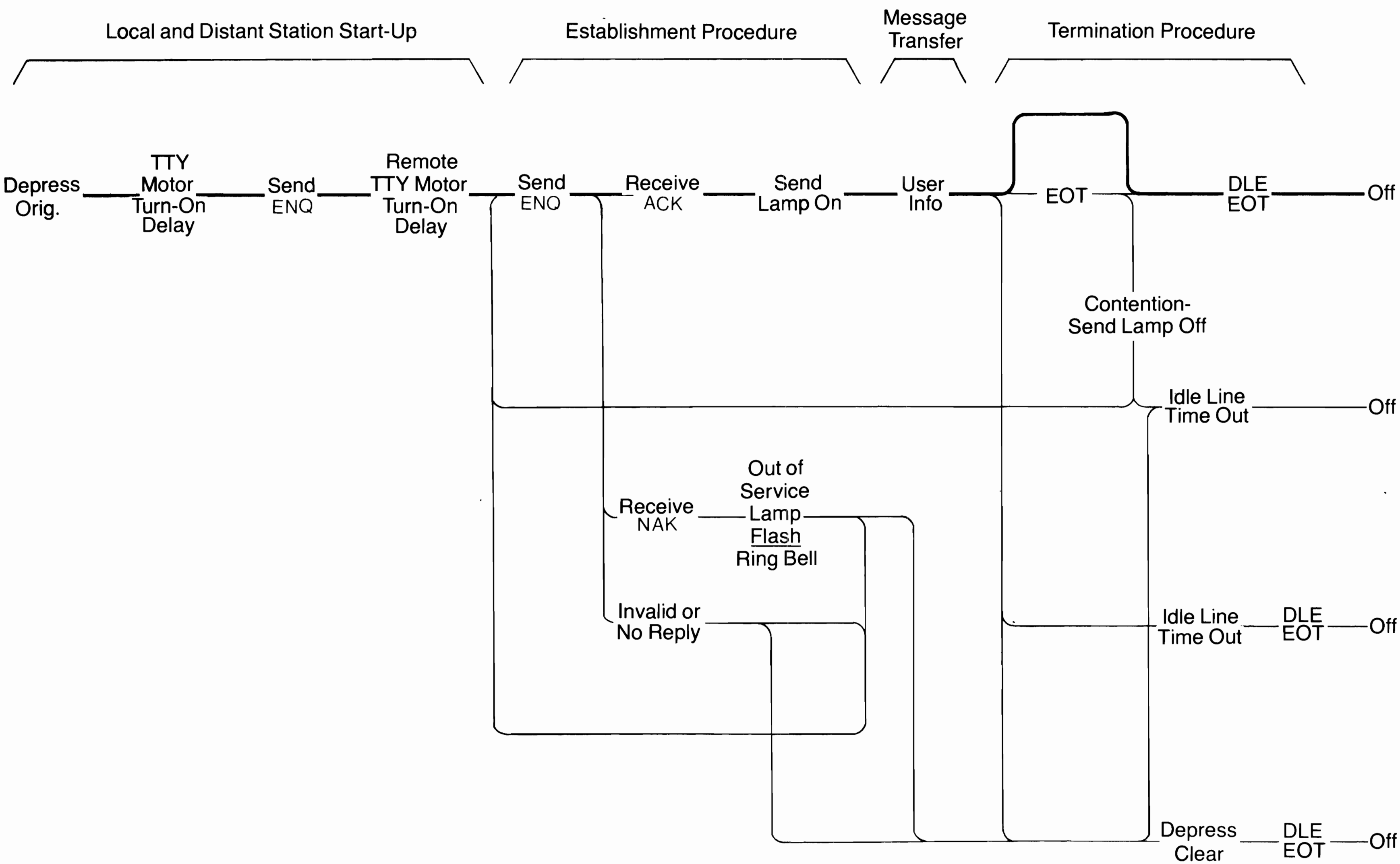
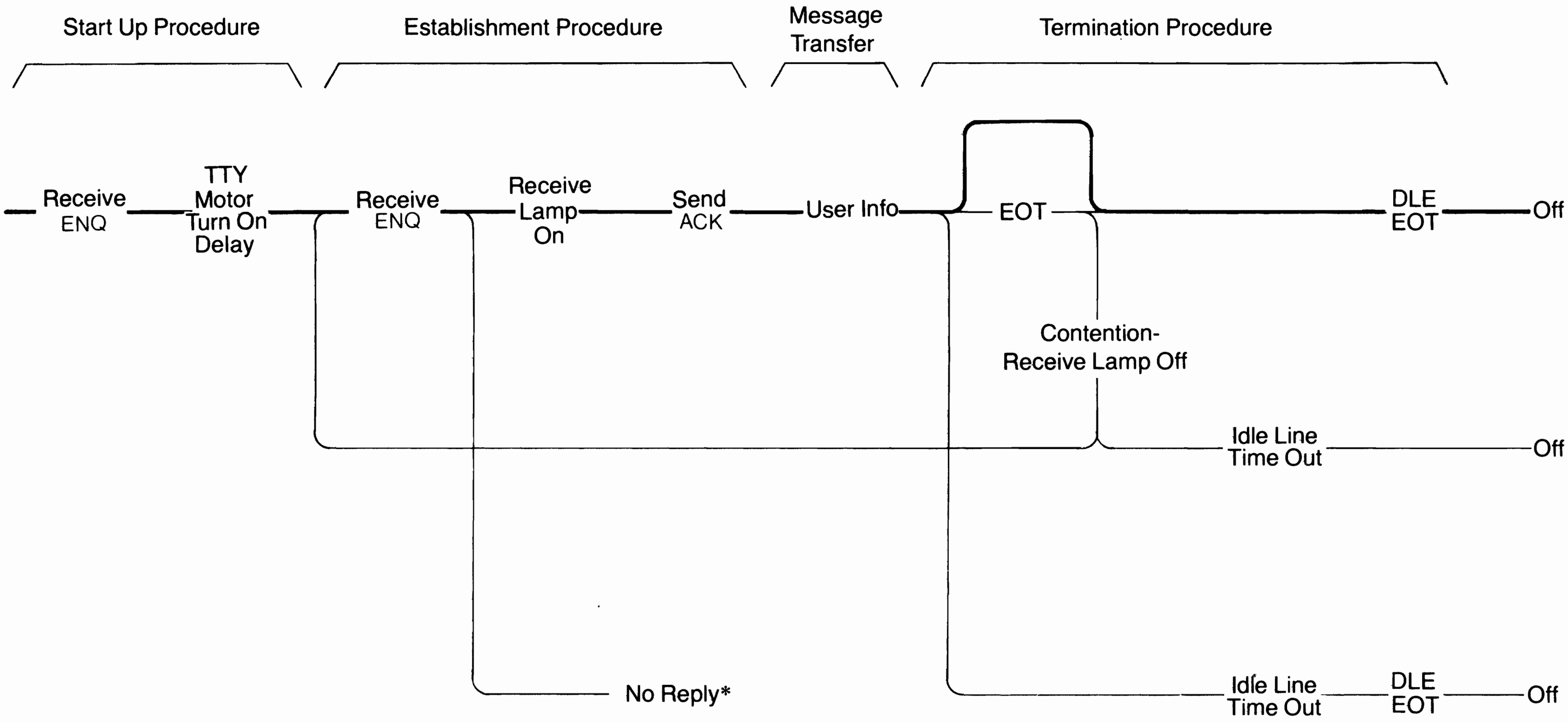


Figure 2.2. ANSI X3.28 operating procedure flowchart for example 1 (master status).



*Receiving Terminal Out of Service, in Local or in Paper Alarm Condition.

Figure 2.3. ANSI X3.28 operating procedure flowchart for example 1 (slave status).

control character NAK. The originating operator may then reinitiate a bid for master status or may exit to a recovery position. When the master status operator has typed all user information he wishes to transfer, he may either send EOT, to give the slave station an opportunity to assume master (transmit) status; or send DLE EOT, to terminate the transaction and turn off the two teletypewriter motors.

A transaction profile for the nonswitched private line example is presented in Figure 2.4. The profile is developed from Bell System Technical Reference Pub. 41713 (AT&T, 1971b) and its references. A single pass through the top line of the procedure flowcharts of Figures 2.2 and 2.3, and a unidirectional flow of user information from the originating to the nonoriginating user, is assumed. The user information message is assumed to begin with a 2-word, 12-character heading consisting of an alphanumeric date-time group; no address or routing information is required since the service is nonswitched. The balance of the user information transferred during the transaction consists of text characters selected from the USASCII "user information" subset defined in paragraph 1.3.1. An average text length of 100 words and a typing speed of 50 words per minute is assumed. It is assumed that start of heading, start of text, and end of text are indicated by asterisks (*).

2.3. Reference Events

The following paragraphs describe the sequence of user/system interface events during the nonswitched private-line transaction, and identify the specific reference events which delimit the start and end of each of the five primary communication functions.

ACCESS FUNCTION (a) [2]

The purpose of the access function is to place a source (master) user in a position to begin transferring user information

[2] Symbols and notation are explained in Section 3.4.2 of Volume I.

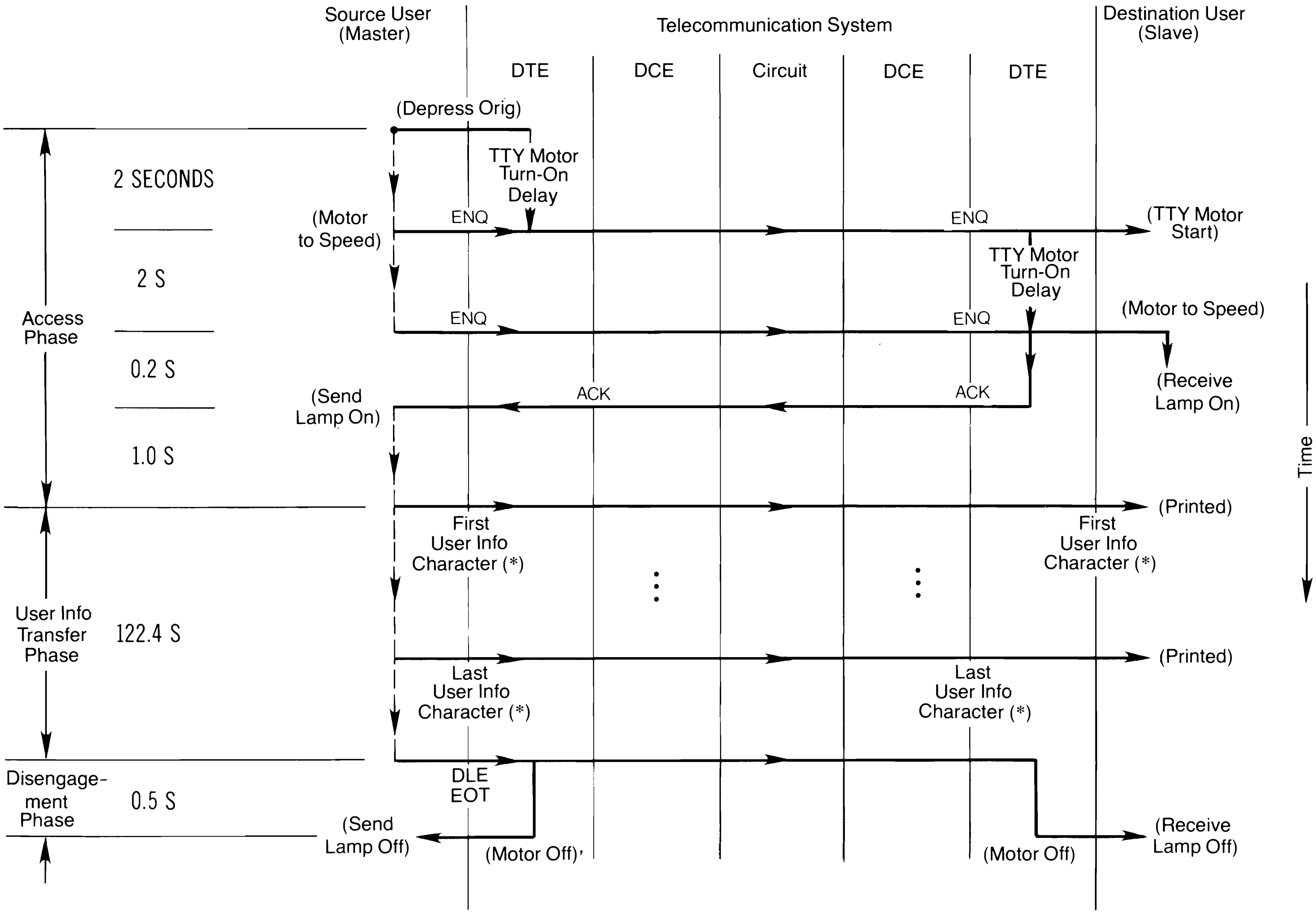


Figure 2.4. Transaction profile for the nonswitched private line example.

characters. The sequence of interface events during the access phase is as follows:

1. The operator of the station desiring master status activates a control switch (ORIG) to start the teletypewriter motor at the local station. This action represents the reference event start of access (a).
2. An elapsed time interval of 2 seconds is required to allow the teletypewriter motor to attain operating speed.
3. The operator of the station desiring master status depresses the ASCII control character ENQ and this action transmits a wake-up signal over the private line to start the teletypewriter motor at the distant terminal.
4. The remote station receives ENQ and its teletypewriter motor is turned on. A time interval of 2 seconds is required to allow the teletypewriter motor to attain operating speed.
5. The operator of the originating station makes a bid for master status by transmitting a second ENQ.
6. The nonoriginating terminal receives the transmitted ENQ. The terminal assumes slave status; illuminates the receive condition lamp; and responds with the control character ACK.
7. The terminal bidding for master status acquires that status upon receipt of the ACK character, and its send condition lamp illuminates.
8. The operator of the master status teletypewriter types the first user information character (*). This action represents the reference event end of access (a*).

USER INFORMATION TRANSFER FUNCTIONS (b1, b2, and b3)

During the user information transfer phase, the master station operator types the message and heading text and the slave teletypewriter prints the corresponding received characters. Note that the heading and delimiters are considered user information here, since they do not affect the communication system state. Reference events for the three UIT functions are defined as follows:

1. Start of bit (and block) transfer events (b1, b2) occur each time the master operator types a user information character. Each character is regarded as a block, containing seven user information bits; and each typing action thus initiates seven bit transfer functions and one block transfer function.
2. End of bit (and block) transfer events (b1*, b2*) occur each time the slave terminal prints a user information character. Again, one block transfer function and seven bit transfer functions are ended by each character printing.
3. For simplicity, the message transfer function is defined to comprise 4284 bits; i.e., the number of user information bits transferred during a single (average) information transfer transaction. The event start of message transfer (b3) thus occurs on typing of the first user information character of each information transfer transaction; and the event end of message transfer (b3*) occurs on printing of the last user information character of each transaction[3].

DISENGAGEMENT FUNCTIONS (d)

The disengagement functions nullify the master/slave relationship established during an information transfer transaction, and turn off the teletypewriter motors. Two distinct disengagement functions are considered during each transaction, one associated with each user interface. The sequence of disengagement events is as follows:

1. The master operator types the control characters DLE-EOT. These characters are interpreted as a disengagement request signal by the M37 teletypewriters; and typing of the DLE character thus represents the

[3] In practice, a somewhat longer message might be required to attain more confidence in the measured parameter values.

reference event start of disengagement (d) for both user interfaces.

2. About 500 milliseconds after start of typing of the DLE-EOT character sequence at the master terminal, this terminal detects the shutdown request and responds by turning off the send lamp and teletypewriter motor. This event represents the end of the disengagement function (d*) at the master terminal. The same event occurs approximately one millisecond later at the slave terminal.

RESPONSIBILITY TRANSFER EVENTS

The timing of the nonswitched private line example transaction is such that there are no periods of "split" responsibility; either the master station operator or the system is always responsible for producing the "next" interface event in the transaction sequence. Referring to Figure 2.4, during the access phase:

1. The system is responsible between ORIG and ACK (assuming the ENQ's are sent at 2-second intervals); and
2. The user is responsible between ACK and first block transfer (*).

The periods between ORIG and the first ENQ, and between the first and second ENQ's, are attributable to the system since the originating operator is precluded from typing characters during the 2-second warm-up period. Any delay beyond 2 seconds would be attributable to the user. Expiration of the 2-second warm-up period is an example of a "referred event" of the type described in Section 2.5 of Volume I.

During the UIT phase, responsibility alternates between the system and the master operator. The first 67 milliseconds (ms) after typing of each user information character are attributable to the system, since the M37 terminal has a maximum character input rate of 15 characters per second. All time between expiration of the 67 millisecond delay (another "referred event") and initiation of the next user information character is attributable to the master operator. The average duration of user responsibility between characters is 133 milliseconds, since a 5 characters-per-second user typing rate is assumed.

During the disengagement phase, the user typing time for DLE-EOT (assumed to be 200 ms in excess of the minimum typing time) is attributable to the user; and the remaining time is attributable to the system.

2.4. Parameter Values

Probable performance parameter values for the nonswitched private line example are derived on the basis of the procedure flowcharts of Figures 2.2 and 2.3; the transaction profile of Figure 2.4; and the following assumptions.

1. Information from Table 2.1, which is reproduced from the Bell System Telecommunications Network Connection Survey, 1969-70 (AT&T, 1971a) is used in estimating bit and block (character) error and loss probabilities[4].
2. Path length is taken to be 20 miles and the telephone line wiring and loading is considered to result in a propagation velocity of 20,400 miles per second.
3. An average of 48 independent and separate messages are assumed to be transmitted each day by the source terminal operator. As described above, each message consists of a heading (date-time group) equivalent to 2 words; and a message text with an average of 100 words. Messages are transmitted "on-line" by the source operator at an average typing rate of 50 words per minute (5 characters per second).

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[4] Strictly speaking, these statistics are applicable only to switched data communications. The reported Character Error Rate is used directly in estimating private line Block Error Probability, since the data indicate this statistic was not dominated by a few bad calls. The observed Lost Character Rate is reduced by a factor of 14.5 to 1 (to 4.7×10^{-5}) in estimating private line Block Loss Probability, to eliminate the effect of the eight worst calls observed in the survey.

Table 2.1. Total Survey Character Error and Lost Character Statistics (AT&T, 1971a)

	All Calls	Mileage Band		
		Short	Medium	Long
Calls	534	171	186	177
Characters Transmitted	21.31×10^6	7.00×10^6	7.48×10^6	6.83×10^6
Character Errors	3,110	751	1,053	1,306
Lost Characters	14,511	9,581	1,476	3,454
Character Error Rate	1.46×10^{-4}	1.07×10^{-4}	1.42×10^{-4}	1.90×10^{-4}
Lost Character Rate	6.81×10^{-4}	13.7×10^{-4}	1.98×10^{-4}	5.03×10^{-4}

4. Two types of phenomena are assumed to affect the availability of the nonswitched private line service: total failures in essential transmission equipment (e.g., power supply failures, broken wires); and degraded performance (e.g., adverse weather conditions impairing microwave transmission). Total failures are assumed to occur at an average rate of twice per year and are assumed to last an average of four hours. These failures are assumed to be uncorrelated with service usage. If they begin during a period of usage, they will result in an observed outage; if they begin during a period of non-usage, they will result in a series of access denials. It is assumed that the operator retries unsuccessful access attempts three times initially, and once each half hour thereafter, producing a total of 10 access denials during a 4-hour outage. Degraded performance events are assumed to cause below-threshold values for one or more supported primary parameters (outages) in the case of one message per month.

5. Loss or incorrect transmission of either the DLE or EOT control character will result in a disengagement failure at the nonoriginating user; the probability of this event is derived from the data presented in Table 2.1, under the assumption of independent errors.

PRIMARY PARAMETER VALUES, NONSWITCHED PRIVATE LINE EXAMPLE

(1) Access Time $W(a_s) = 5.2$ seconds
See Figure 2.4.

(2) Incorrect Access Probability $P(a_m) = 0$
Example used is for a nonswitched private line service.

(3) Access Denial Probability $P(a_\ell) = 1.7\times10^{-3}$

$$30\ \frac{\text{denials}}{\text{year}}/17520\ \frac{\text{messages}}{\text{year}} = 1.7\times10^{-3}$$

Total failures produce 20 denials per year (10 during each of two 4-hour outages, as noted in (4) above). Combined character error <u>or</u> loss probability is about 2×10^{-4}, $(1.5\times10^{-4}+4.7\times10^{-5})$. Three characters must be successfully transferred to achieve successful access.

$$6\times10^{-4}\ \frac{\text{denials}}{\text{message}} \times (17520-20)\frac{\text{messages}}{\text{year}} = \text{10 denials per year due to character loss or error.}$$

(4a) Block Transfer Time $W(b2_s) = 68$ milliseconds
Signal Element (Baud) Time:
6.67 milliseconds/bit × 10 bits/character
= 66.7 milliseconds.

Propagation Time: $\frac{1}{20{,}400}\ \frac{\text{seconds}}{\text{mile}}\times 20 \text{ miles} = 9.8\times10^{-4}$ seconds.

(4b) Bit Transfer Time $W(b1_s) = 68$ milliseconds
See 4a.

(5a) Block Error Probability $P(b2_e) = 1.5\times10^{-4}$
See Table 2.1.

(5b) Bit Error Probability: $1.5\times10^{-5} \le P(b1_e) \le 1.5\times10^{-4}$
Error in a single bit or all bits produces a single character error. See Table 2.1.

(6a) Block Misdelivery Probability $P(b2_m) = 0$
Example used is for a nonswitched private line service.

(6b) Bit Misdelivery Probability $P(b1_m) = 0$

See 6a.

(7a) Block Loss Probability $P(b2_\ell) = 4.7\times10^{-5}$

See assumption 1, Section 2.4, and associated footnote 4.

(7b) Bit Loss Probability $P(b1_\ell) = 4.7\times10^{-5}$

See assumptions. Loss of a block loses all bits in the block.

(8a) Extra Block Probability $P(b2_x) = 0$

Transmit protocol has no retransmission or buffering.

(8b) Extra Bit Probability $P(b1_x) = 0$

See 8a.

(9a) Block Transfer Rate $R(b2_s) \cong 5$ blocks/second

$$\frac{612(1-(0.5+1.5)10^{-4})\frac{\text{good blocks}}{\text{message}}}{122.4\ \frac{\text{UIT seconds}}{\text{message}}} = 4.999\ \frac{\text{good blocks}}{\text{second}}.$$

(9b) Bit Transfer Rate $R(b1_s) \cong 35$ bits/second

7 user bits/block × 4.999 good blocks/second

= 34.99 bits/second.

(10a) Block Rate Efficiency $Q(b2_s) = 23$ percent

$$5\ \frac{\text{blocks}}{\text{second}} \times 7\ \frac{\text{bits(user)}}{\text{block}} / 150\ \frac{\text{bits}}{\text{second}} = 0.233.$$

(10b) Bit Rate Efficiency $Q(b1_s) = 23$ percent

$$35\ \frac{\text{bits}}{\text{second}} / 150\ \frac{\text{bits}}{\text{second}} = 0.233.$$

(11) Disengagement Time = 0.5 seconds

See Figure 2.4. Master and slave disengagement functions are assumed concurrent.

(12) Disengagement Denial Probability $P(d_\ell) = 4\times10^{-4}$

$2(2\times10^{-4}) = 4\times10^{-4}$

Loss or error in either DLE or EOT will cause denial. Combined character error or loss probability is 2×10^{-4}; see (3) above.

SECONDARY PARAMETER VALUES, NONSWITCHED PRIVATE LINE

(1) Outage Probability $P(b3_z) = 8\times10^{-4}$

$$14 \text{ outages/year} \div 17520 \frac{\text{messages}}{\text{year}} = 8 \times 0^{-4}$$

Two total failures plus twelve degraded performance periods per year (one per month).

(2) Service Time Between Outages $W(y^*)$ = 43 UIT hours

$$596 \frac{\text{UIT hours}}{\text{year}} \div 14 \frac{\text{outages}}{\text{year}} = 42.6 \frac{\text{UIT hours}}{\text{outage}} .$$

(3) Outage Duration $W(z^*)$ = 1 hour

$$\frac{(12 \text{ outages})(1/2 \text{ hour}) + (2 \text{ outages})(4 \text{ hours})}{14 \text{ outages}} = 1 \text{ hour.}$$

Resulting availability value would be 0.98.

ANCILLARY PARAMETER VALUES, NONSWITCHED PRIVATE LINE

(1) User Access Time Fraction:

$p(a) = 0.19$

Access Time $W(a_s)$ = 5.2 seconds

Operator responsibility $W_u(a_s)$ = 1.0 seconds

Split responsibility $W_r(a_s)$ = 0 seconds

$$p(a) = \frac{W_u(a_s) + 0.5\ W_v(a_s)}{W(a_s)} = \frac{1+0.5(0)}{5.2} = 0.19.$$

(2) User Block Transfer Time Fraction:

$p(b2) = 0$

Block Transfer Time $W(b2_s)$ = 68 milliseconds

Operator responsibility $W_u b2_s)$ = 0.0 milliseconds

Split responsibility $W_v(b2_s)$ = 0.0 milliseconds.

(3) User Message Transfer Time Fraction:

$p(b3) = 0.67$

Message Transfer Time $W(b3_y)$ = 122.4 seconds

Operator responsibility $W_u(b3_y)$:

0.133 s/character × 612 characters = 81.6 seconds

Split responsibility $W_v(b3_y)$ = 0.0 seconds

User is typing at one-third the maximum input rate.

(4) User Disengagement Time Fraction:

$p(d) = 0.8$

Disengagement Time $W(d_s)$ = 0.5 seconds

Operator responsibility $W_u(d_s)$ = 0.4 seconds

Split responsibility $W_v d_s)$ = 0.0 seconds.

3. CIRCUIT-SWITCHED EXAMPLE

3.1. Equipment Configuration

The example presented in this section is a circuit-switched teletypewriter-to-teletypewriter service connecting selected pairs of users through the public switched network. A typical circuit-switching arrangement is shown in Figure 3.1, which is an example of a basic single-stage relay matrix. To expand the capability of the system, several matrices are typically interconnected into a grid network, forming more than one switching stage. The end-to-end equipment configuration for the circuit-switched example is identical to the one shown in Figure 2.1, except that the public switched network replaces the private line block. A block diagram of the M37 teletypewriter is shown in Figure 3.2, which also identifies the relevant interchange circuit connections. This diagram is adapted from Teletype (1969).

3.2. Procedure Flowchart and Transaction Profile

An ANSI X.28 master station operating procedure flowchart for the circuit-switched example is presented in Figure 3.3. The procedure is similar to that specified for the private-line example, except for addition of the physical connection and disconnection activities. These activities establish and terminate a conventional circuit-switched telephone connection between the master and slave terminal operators.

A transaction profile for the circuit-switched example is presented in Figure 3.4. The profile is developed from information in Bell System Technical References (AT&T, 1968a; AT&T, 1968b); and represents a single pass through the top line of the procedure flowchart of Figure 3.3, exiting via the "depress clear" route. The example assumes that the user information message to be transferred is prepared off line in paper tape form; and that the completed message tape is mounted in the M37 paper tape reader at the master station prior to the start of the transaction. This enables message transfer at the full M37 operating speed of 150 words per minute. The same message format

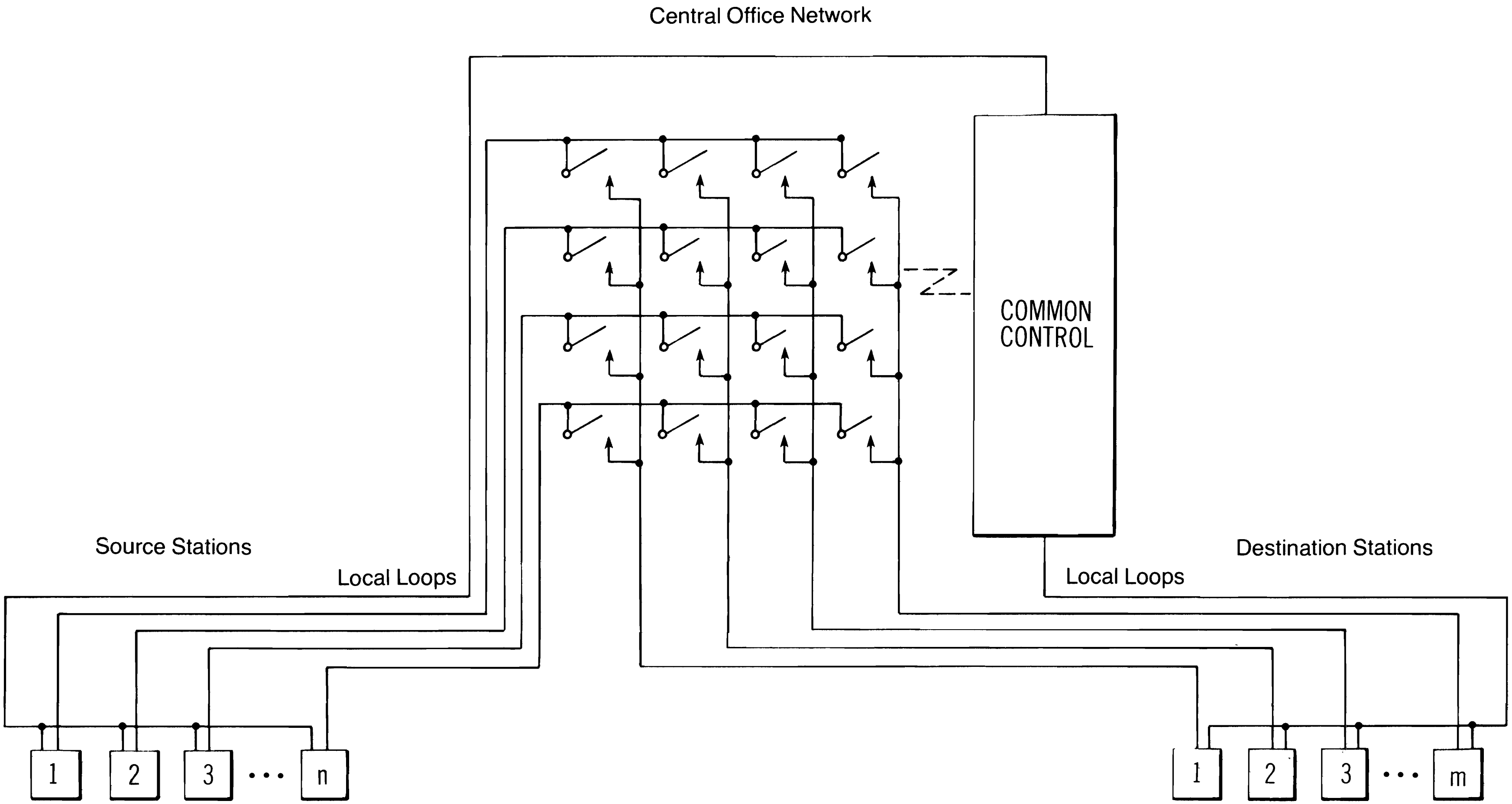

Figure 3.1. Circuit switching overview.

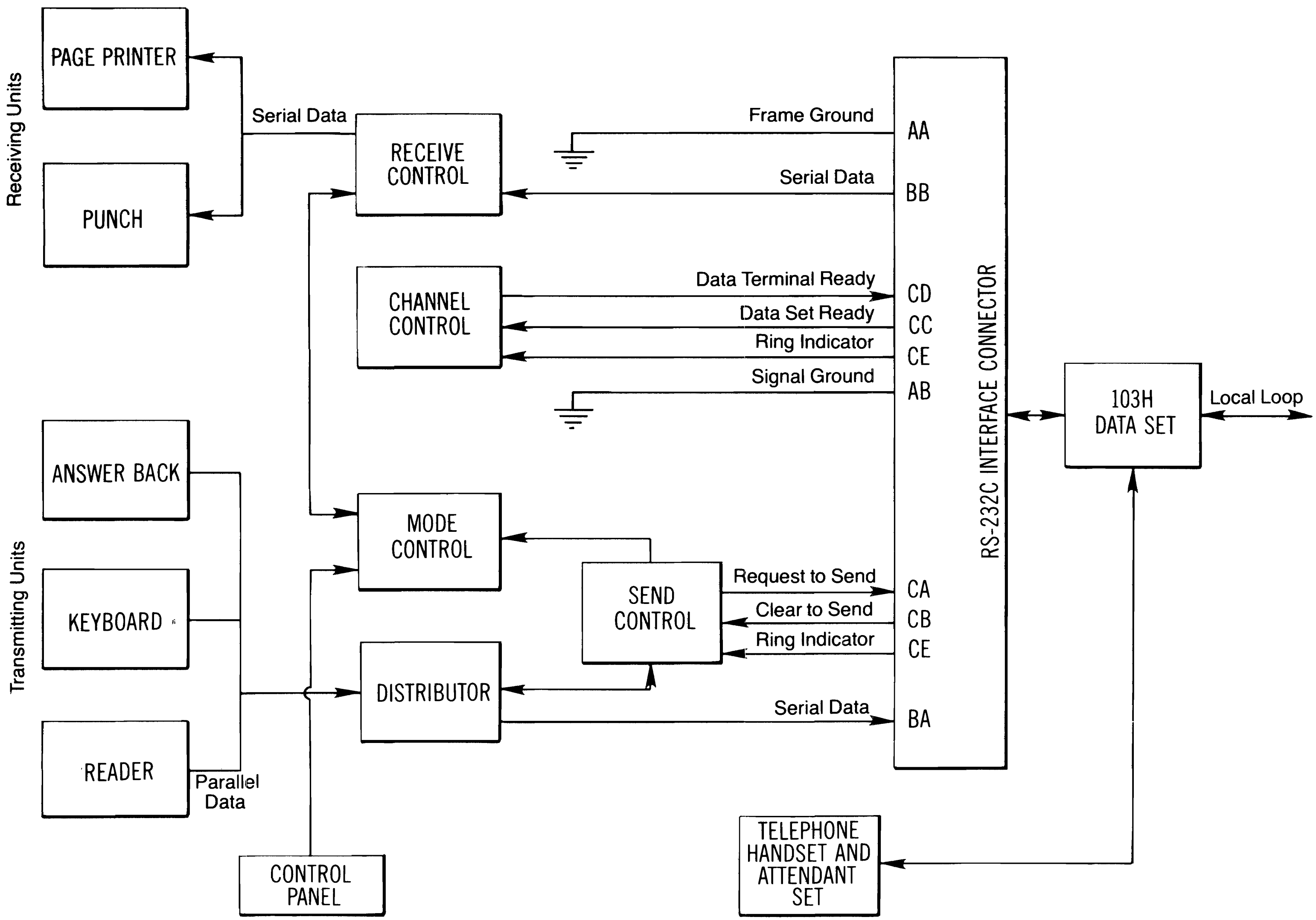

Figure 3.2. Block diagram of M37 teletypewriter (on-line) operation.

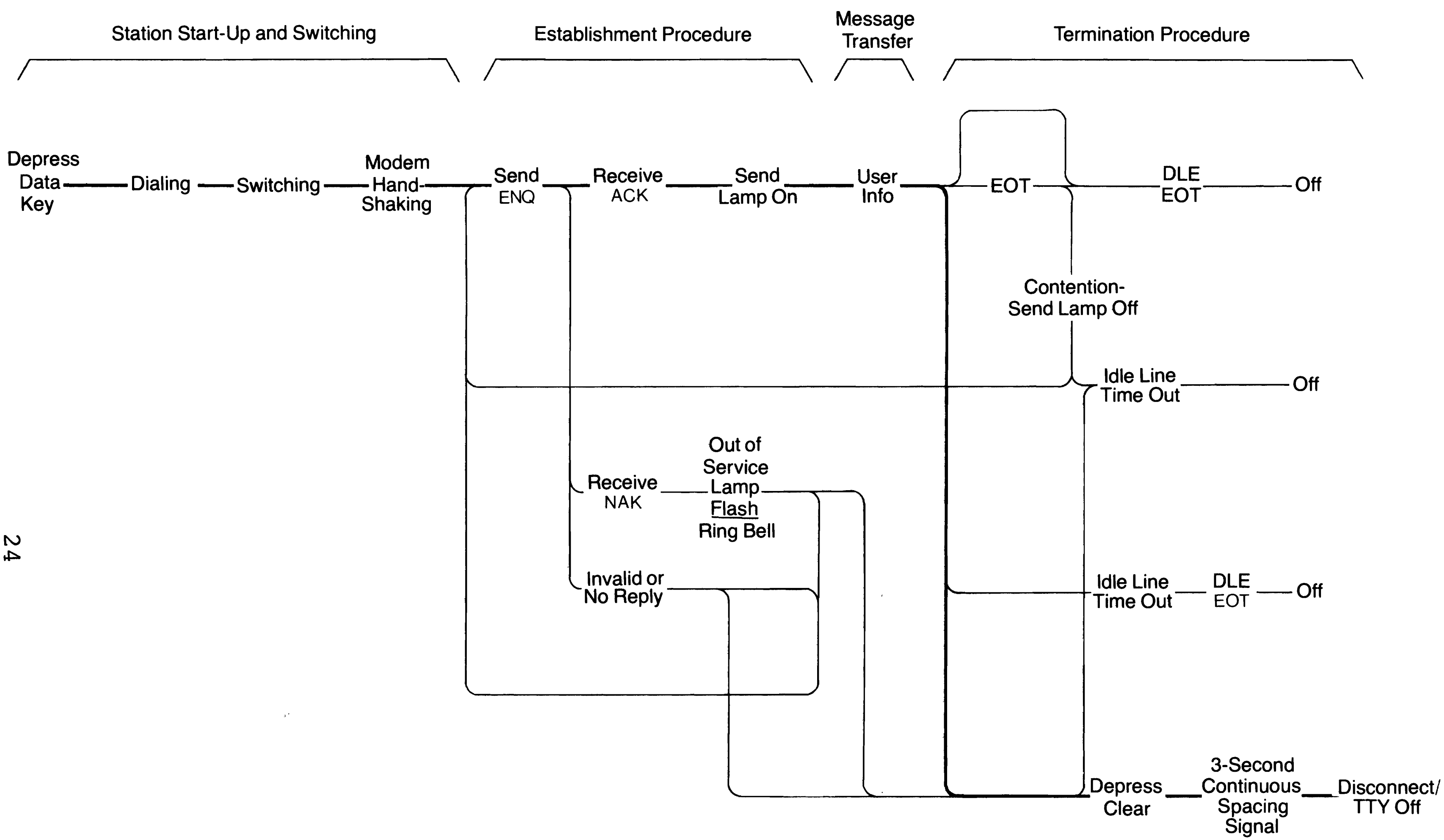

Figure 3.3. ANSI X3.28 operating procedure for example 2 (master status).

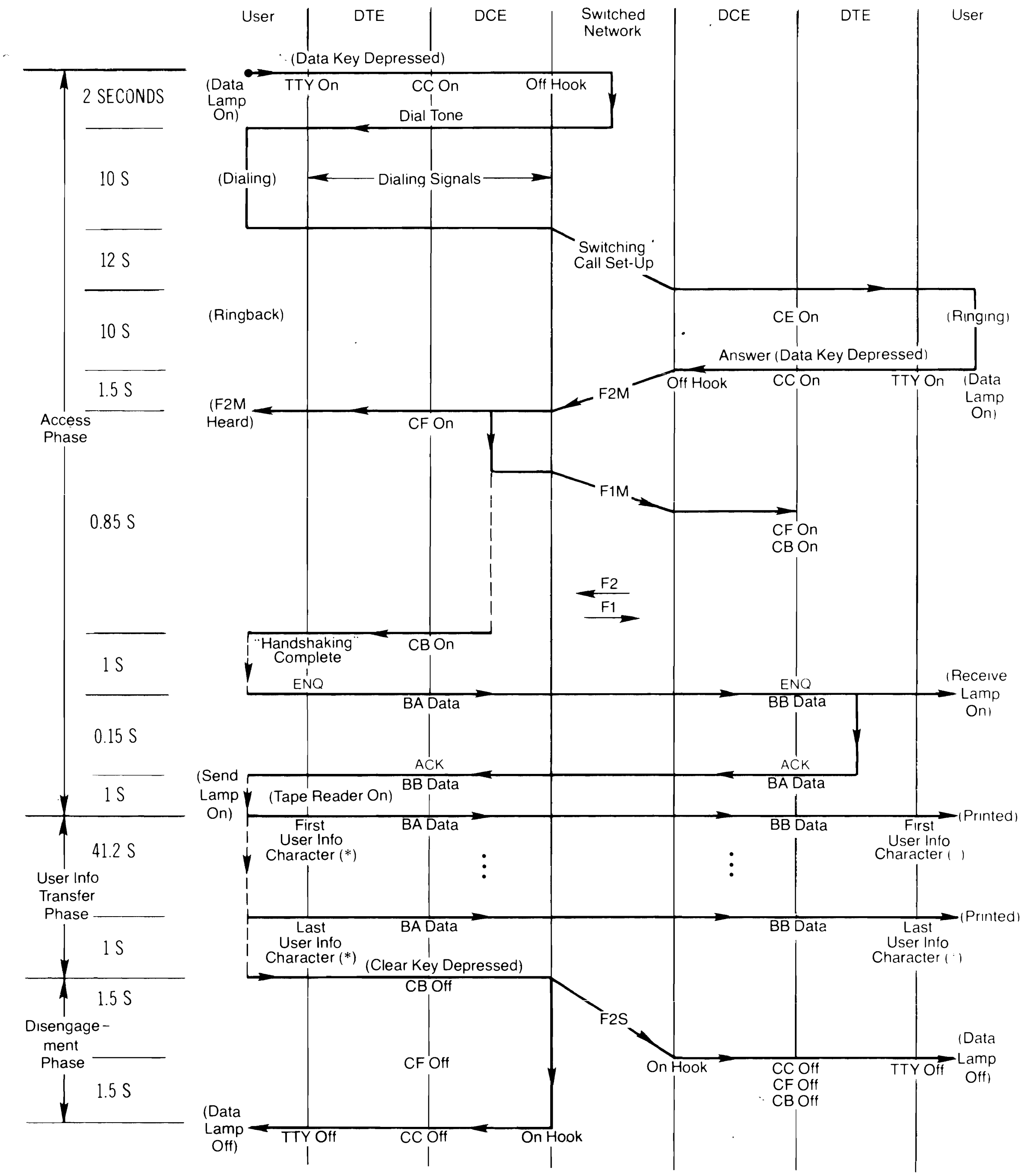

Figure 3.4. Transaction profile for the circuit-switched example.

and length used in the private line example are assumed, except that the heading is defined to include a one-word originator ID in addition to the date-time group. The call is assumed to be answered manually (in data mode) by an operator at the receiving terminal. For completeness, events at both the user/DTE and DTE/DCE interfaces are indicated; but the latter events are still viewed as system-internal.

In order to estimate total access time, it is necessary to make some assumptions about the duration of the physical dialing process. The dial speed of a typical rotary dial is 10 pulses per second. Total dialing time for a 7-digit telephone number is estimated at 10 seconds: 4 seconds operator time (for positioning the dialed digits) and 6 seconds system time (for dial rotation back to stop). Total switching time is estimated at 12 seconds, and answering time is estimated at 10 seconds.

3.3. Reference Events

The following paragraphs describe the sequence of user/system interface events during the circuit-switched transaction; and identify the specific reference events which delimit the start and end of each of the five primary communication functions.

1. The originating operator initiates the call by depressing the M37 data key (with the handset on-hook). The calling DCE goes off-hook, and turns on interchange circuit CC (Data Set Ready); and the teletypewriter motor starts. Depression of the data key corresponds to the reference event start of access (a).
2. The local central office extends a dial tone signal to the calling terminal. The signal is transmitted to the calling operator via loudspeaker.
3. The normal rotary dialing process takes place.
4. The network establishes a circuit switched connection to the called station and initiates ringing (CE on). A ringback signal is heard at the calling station.
5. The called terminal operator answers the call by depressing the M37 data key. The called DCE goes

off-hook, and turns on interchange circuit CC (Data Set Ready); and the teletypewriter motor starts.

6. The called DCE transmits an F2M (mark) line signal to the calling station. The signal is heard by the calling operator; and the calling DCE turns interchange circuit CF (Received Line Signal Detector) on.
7. The calling DCE responds with an F1M line signal. This signal causes the called DCE to turn on interchange circuits CF (Received Line Signal Detector), and CB (Clear to Send).
8. After a timed delay period, interchange circuit CB (Clear to Send) is turned on by the calling data set. Modem "handshaking" is now complete; and the two M37 terminals are in a position to communicate directly.
9. The calling operator bids for master status by sending the ASCII control character ENQ.
10. The called terminal receives the transmitted ENQ. The terminal assumes slave status; illuminates the receive condition lamp; and responds with the control character ACK.
11. Receipt of the ACK character causes the tape reader at the calling terminal to turn on; and the first user information character (*) is read and transmitted. This event represents the end of access (a*).

USER INFORMATION TRANSFER FUNCTIONS (b1, b2, and b3)

During the user information transfer phase the master (originating) terminal automatically reads the paper tape containing the user information message; and the slave terminal prints the corresponding received message. Reference events for the UIT functions are the same as those defined for the private-line example, except that the starting events occur on reading of user information characters by the paper tape reader, rather than on typing of characters at the keyboard.

DISENGAGEMENT FUNCTIONS (d)

The disengagement functions nullify the master/slave relationship established during an information transfer transaction; turn off the teletypewriter motors; and disconnect the circuit-switched connection between the communicating stations. Both stations are returned to the idle state to await subsequent transactions. The sequence of disengagement events is as follows:

1. The calling operator initiates disconnection by depressing the M37 clear key. This action represents the reference event start of disengagement (d) for both user interfaces.
2. The originating data set turns interchange circuit CB (Clear to Send) off; and transmits a 3-second continuous-spacing (F2S) signal to the called data set.
3. The called data set detects the continuous-spacing signal and disconnects (goes on-hook) after a nominal 1.5-second delay. The called DCE turns off interchange circuits CC (Data Set Ready), CF (Received Line Signal Detector) and CB (Clear to Send). The called DCE data lamp goes out. This event corresponds to the reference event end of disengagement for the called station. The called DCE's on-hook action also causes interchange circuit CF (Received Line Signal Detector) to go off at the calling station.
4. After transmitting the continuous-spacing signal for three seconds, the calling data set goes on-hook; and turns interchange circuit CC (Data Set Ready), and the data lamp, off. This event corresponds to the reference event end of disengagement for the calling station.

RESPONSIBILITY TRANSFER EVENTS

The timing of the circuit-switched teletypewriter-to-teletypewriter transaction is such that there are no periods of "split" responsibility; either a user or system entity is always responsible for advancing the overall transaction to successful completion. Referring to Figure 3.4, during the access phase:

1. The system is responsible between depression of the data key and dial tone;

2. Responsibility alternates between the system and the originating operator during the dialing period, with the user responsible (on the average) 40% of the time;
3. The system is responsible between end of dialing and start of ringing;
4. The nonoriginating user is responsible between start of ringing and answer;
5. The system is responsible between answer and completion of modem "handshaking;"
6. The originating user is responsible between completion of "handshaking" and typing of the ENQ character; and
7. The system is responsible between typing of ENQ and the end of the phase.

During the UIT phase, the system has responsibility until the last user information character is read (and printed); and the originating user has responsibility from that point until the end of the phase (when the clear key is depressed). The system has responsibility for both disengagement functions throughout the disengagement phase.

3.4. Parameter Values

Probable performance parameter values for the circuit-switched example are derived on the basis of the procedure flow-chart of Figure 3.3; the transaction profile of Figure 3.4; and the following assumptions.

1. Assumptions 1 through 4 of Section 2.4 apply, except that in defining availability (assumption 4), "total failure" events are assumed to occur once rather than twice per year; and "degraded performance" events are assumed to affect two messages (rather than one message) per month.
2. Messages are prepared "off-line" on separate teletypewriter equipment by the terminal operator; and are transmitted, using the paper tape reader, at a rate of 150 words per minute.

3. It is assumed that two complete message transmissions per year are misdelivered (to other compatible terminals in a subnetwork within the public-switched network) as a result of system switching errors.

4. It is assumed that 1 out of 100 calls will be blocked within the switching network, resulting in Access Denial. This corresponds to a Grade of Service of 1%.

5. Loss or error in the continuous-spacing (disconnect) signal can cause Disengagement Failure at the non-originating user. This event is assumed to occur once per year.

PRIMARY PARAMETER VALUES, CIRCUIT-SWITCHED EXAMPLE

(1) Access Time $W(a_s)$ = 37.5 seconds
See Figure 3.4. Includes the time required during physical connection (including dialing, set-up, and ringing); during modem handshaking; and during terminal handshaking.

(2) Incorrect Access Probability $P(a_m) = 1.1 \times 10^{-4}$

$$2\ \frac{\text{messages}}{\text{year}} / 17520\ \frac{\text{messages}}{\text{year}} = 1.14 \times 10^{-4}$$

Incorrect access is a result of a system switching error which connects the originating terminal to an unintended (but compatible) terminal in the subnetwork.

(3) Access Denial Probability $P(a_\ell) = 1.1 \times 10^{-2}$

$$185\ \frac{\text{denials}}{\text{year}} \div 17520\ \frac{\text{messages}}{\text{year}} = 1.06 \times 10^{-2}$$

One total failure produces 10 denials per year; (note 4, Section 2.4); 1% grade of service produces 175 denials per year.

(4a) Block Transfer Time $W(b2_s)$ = 68 milliseconds
Signal Element (Baud) Time:
6.67 milliseconds/bit × 10 bits/character
= 66.7 milliseconds.

Propagation Time: $\frac{1}{20{,}400}\ \frac{\text{seconds}}{\text{mile}} \times 20$ miles
$= 9.8 \times 10^{-4}$ seconds.

(4b) Bit Transfer Time $W(bl_s)$ = 68 milliseconds

See 4a.

(5a) Block Error Probability $P(b2_e) = 1.5\times10^{-4}$

See Table 2.1.

(5b) Bit Error Probability $P(bl_e) = 1.5\times10^{-5} \le P(bl_e) \le 1.5\times10^{-4}$.

Error in a single bit or all bits produces a single character error. See Table 2.1.

(6a) Block Misdelivery Probability $P(b2_m) = 1.1\times10^{-4}$

$$2\ \frac{\text{messages}}{\text{year}} / 17520\ \frac{\text{messages}}{\text{year}} = 1.14\times10^{-4}.$$

(6b) Bit Misdelivery Probability $P(bl_m) = 1.1\times10^{-4}$

Same as Block Misdelivery Probability.

(7a) Block Loss Probability $P(b2_\ell) = 6.8\times10^{-4}$

See Table 2.1.

(7b) Bit Loss Probability $P(bl_\ell) = 6.8\times10^{-4}$

See Table 2.1.

(8a) Extra Block Probability = 0

Transmit protocol has no retransmission or buffering.

(8b) Extra Bit Probability = 0

See 8a.

(9a) Block Transfer Rate $R(b2_s)$ = 14.6 blocks/second

$$\frac{618(1-(6.8+1.5)10^{-4})\ \frac{\text{good blocks}}{\text{message}}}{42.2\ \frac{\text{UIT seconds}}{\text{message}}} = 14.63\ \frac{\text{good blocks}}{\text{message}}\ .$$

User clear response adds 1 second to UIT time.

(9b) Bit Transfer Rate $R(bl_s)$ = 102.4 bits per second

7 user bits/block × 14.63 good blocks/second = 102.41 bits/second.

(10a) Block Rate Efficiency $Q(b2_s)$ = 68 percent

$$14.63\ \frac{\text{blocks}}{\text{second}} \times 7\ \frac{\text{bits (user)}}{\text{block}} / 150\ \frac{\text{bits}}{\text{second}} = 0.683.$$

(10b) Bit Rate Efficiency $Q(bl_s)$ = 68 percent

$$102.41\ \frac{\text{bits}}{\text{second}} / 150\ \frac{\text{bits}}{\text{second}} = 0.683.$$

(11) Disengagement Time = 2.25 seconds

See Figure 3.4. Originating user disengagement time (3 s.) and nonoriginating user disengagement time (1.5 s.) are averaged in determining the Disengagement Time value.

(12) Disengagement Denial Probability $P(d_\ell) = 5.75\times10^{-5}$

1 failure/year ÷ 17520 messages/year = 5.7×10^{-5}

SECONDARY PARAMETER VALUES, CIRCUIT-SWITCHED EXAMPLE

(1) Outage Probability $P(b3_z) = 1.4\times10^{-3}$

25 outages/year ÷ 17520 messages/year = 1.43×10^{-3}.

(2) Service Time Between Outages $W(y^*)$ = 8.2 UIT

$$205\ \frac{\text{UIT hours}}{\text{year}} \div 25\ \frac{\text{outages}}{\text{year}} = 8.2\ \frac{\text{UIT hours}}{\text{outage}}\ .$$

(3) Outage Duration $W(z^*)$ = 38 minutes

$$\frac{(24\ \text{outages})(1/2\ \text{hour})+(1\ \text{outage})(4\ \text{hours})}{25\ \text{outages}}$$

$$= 8.2\ \frac{\text{UIT hours}}{\text{outage}}\ .$$

Note that blocking does not influence the secondary parameter values.

ANCILLARY PARAMETER VALUES, CIRCUIT-SWITCHED EXAMPLE

(1) User Access Time Fraction:

$p(a) = 0.4$

Access time $W(a_s)$ = 37.5 seconds

Operator responsibility $W_u(a_s)$ = 15 seconds

Split responsibility $W_v(a_s)$ = 0 seconds

$$p(a) = \frac{W_u(a_s)+W_v(a_s)}{W(a_s)} = \frac{15+0.5(0)}{37.5} = 0.4.$$

(2) User Block Transfer Time Fraction:

$p(b2) = 0$

Block Transfer Time $W(b2_s)$ = 68 milliseconds

Operator responsibility $W_u(b2_s)$ = 0 seconds

Split responsibility $W_v(b2_s)$ = 0 seconds.

(3) User Message Transfer Time Fraction:

$p(b3) = .0237$

Message Transfer Time $W(b3_y)$ = 42.2 seconds
Operator responsibility $W_u(b3_y)$ = 1 second
Split responsibility $W_v(b3_y)$ = 0 seconds.

(4) User Disengagement Time Fraction:
$p(d) = 0$
Disengagement Time $W(d_s)$ = 2.25 seconds
Operator responsibility $W_u(d_s)$ = 0 seconds
Split responsibility $W_v(d_s)$ = 0 seconds.

4. MESSAGE SWITCHED EXAMPLE

4.1. Equipment Configuration

The example presented in this section is a message-switched teletypewriter-to-teletypewriter service providing communication between pairs of users through an automated store-and-forward switching center. The switching center is assumed to be implemented in a general-purpose digital computer supported by appropriate local peripherals. The center is connected with remote (user) M37 teletypewriters via conventional Data-Phone® service supported by auto-dial and auto-answer equipment (Fig. 4.1). The switching center automatically calls each remote user terminal in sequence; reads any previously prepared messages awaiting transfer to other users, and stores these messages for later delivery; and delivers any previously stored messages addressed to the called user. Each end-to-end message-switched transaction thus consists of two circuit-switched sub-transactions, separated by a period of message storage in the switch: one transaction between the source terminal and the switch, and one transaction between the switch and the destination terminal. This method of end-to-end communication is similar to that illustrated by the message telegram example in Section 2.5 of Volume I. Store-and-forward switching centers of this type are commercially available; e.g., see Teleswitcher Corporation (1974).

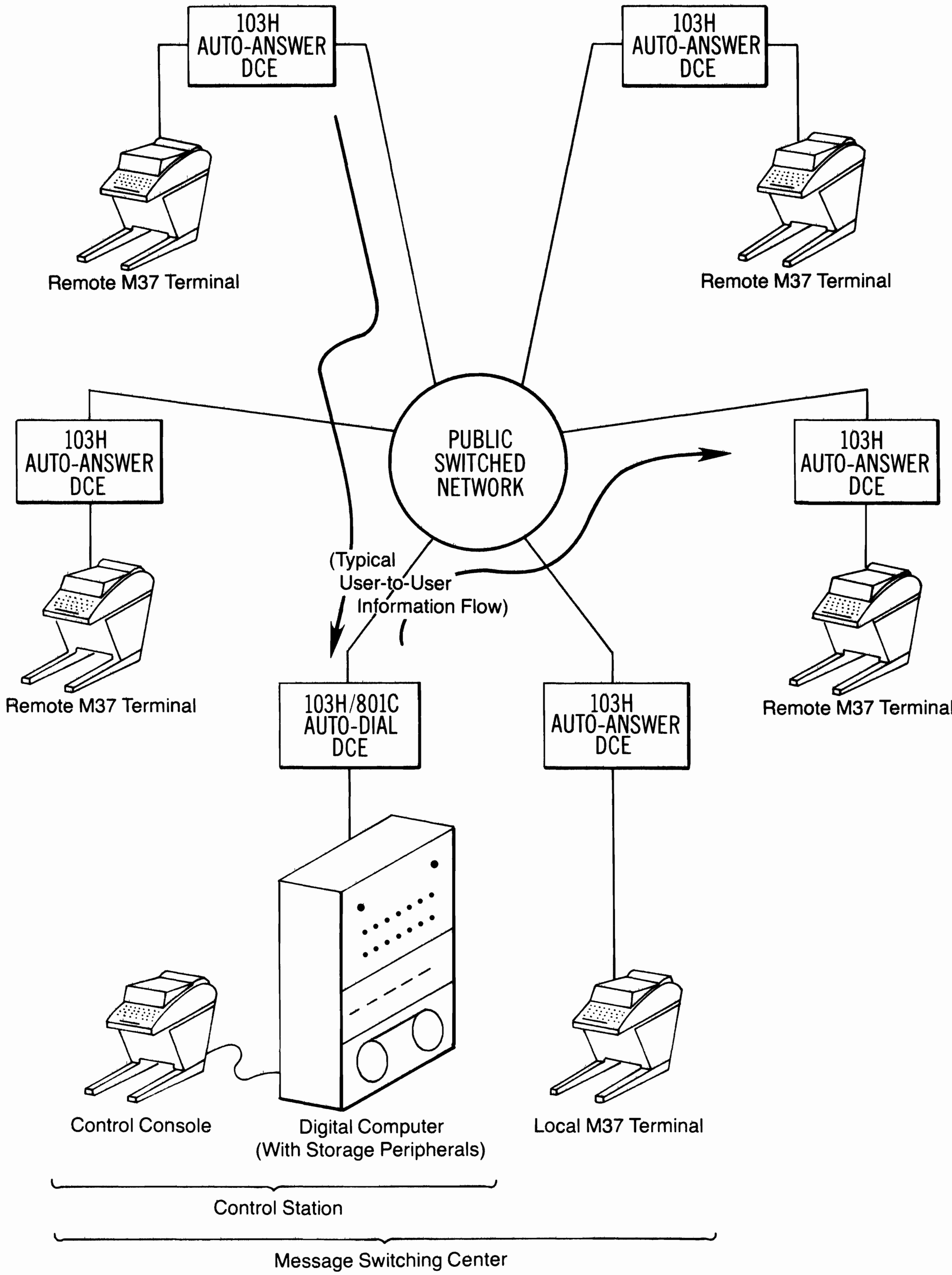

Figure 4.1. Message-switched communication system.

4.2. Procedure Flowchart and Transacton Profile

The operating procedures for each circuit-switched sub-transaction can be represented by the flowchart illustrated in Figure 3.3. In each sub-transaction, the switch initially assumes master status and confirms correct connection by eliciting and checking the user terminal answerback (a sequence of 20 preset characters ending with ACK). The switch then relinquishes master status to receive any waiting messages; and reassumes master status to deliver any outgoing messages and terminate the call. If an incorrect answerback is received, the switch will disconnect the call and will attempt to redial the proper terminal. If repeated redialing still results in unsuccessful connection, the switch will bypass that terminal in the polling sequence; if a message is being held for that terminal, it will be retained or alternately routed to another previously selected terminal for delivery.

A transaction profile for the message-switched example is presented in Figure 4.2. The profile is developed from the same sources listed (for the circuit switched transaction) in Section 3.2. Various general information from Teleswitcher Corporation (1974) and other message-switching literature is also used. The example follows the progress of a single message through a complete end-to-end message-switched transaction, from activation of the source terminal through completion of printing at the destination. The example assumes that the message is prepared off-line in paper tape form; and that the completed message tape is mounted in the M37 paper tape reader prior to the start of the transaction. This enables message transfer at 150 wpm during the UIT phases of both sub-transactions. The same message format and length used in the circuit-switched example are used, with the following exceptions:

1. A one-word destination ID is added to the heading field. This ID enables the switch to route the message to the intended destination. It is viewed as overhead rather than user information (based on the criteria defined in

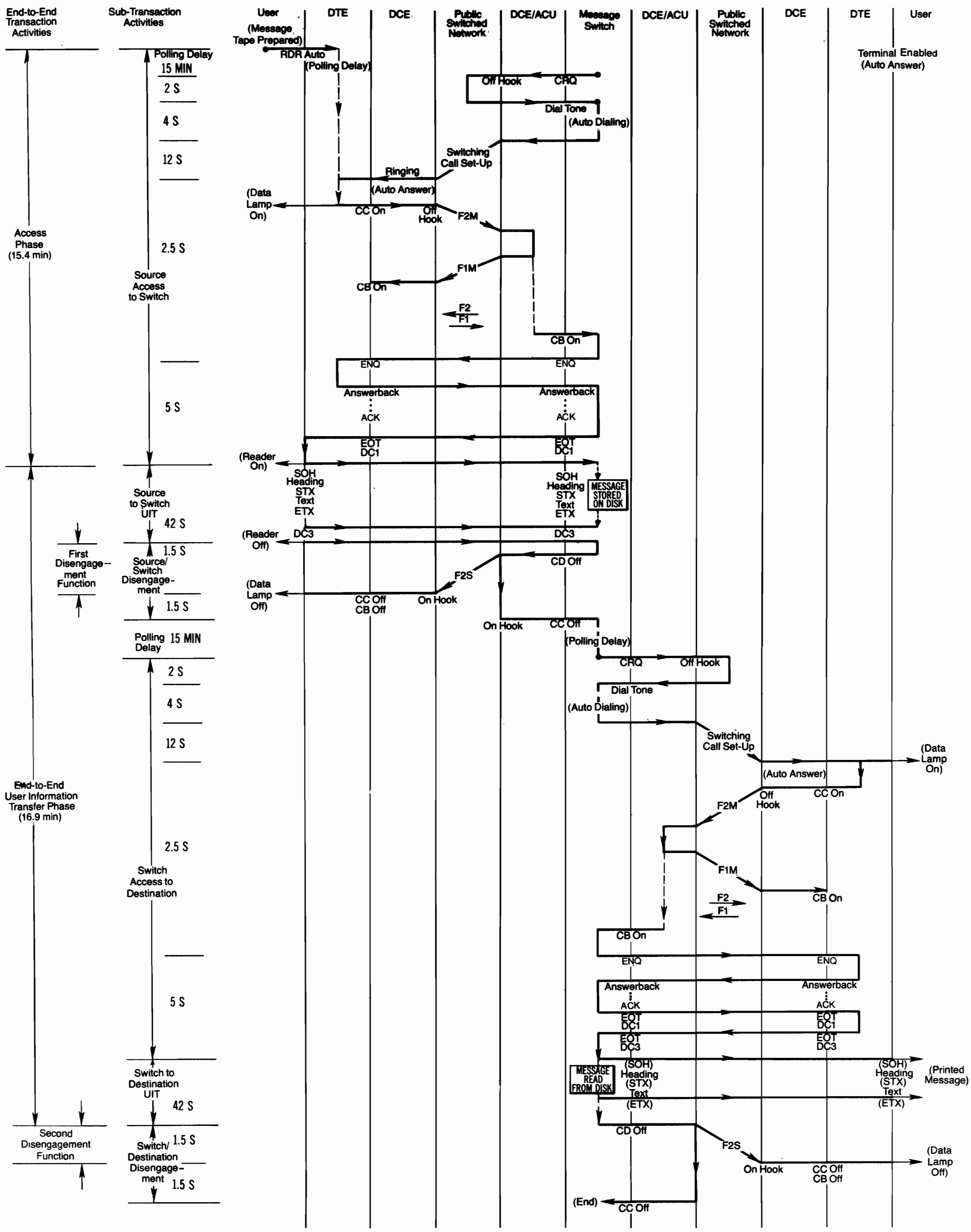

Figure 4.2. Transaction profile for the message-switched example.

Section 2.3 of Volume I), and is not printed at the destination terminal.

2. The heading delimiter characters (*) are replaced with their ANSI X3.4 control equivalents: i.e., start of heading (SOH), start of text (STX), and end of text (ETX). These nonprinting characters are assumed to affect the format of the printed message in a defined way, and are thus regarded as user information[5].

Both sub-transactions (calls) are initiated and terminated by the switching center; and in fact, the only user participation in the entire transaction is the initiating event (activation of the paper tape reader at the source terminal). It is assumed that the switch initiates a call to each user terminal in the sub-network at 30-minute intervals; the average delay between user activation of the tape reader and the start of the next call is thus 15 minutes. The remote M37 data terminals are assumed to be arranged to provide a 20-character automatic answerback sequence ending with ACK, in response to ENQ. Message input to the switch is assumed to preceed message output to the user terminal if both directions of transfer are required during an individual sub-transaction. For simplicity, it is assumed that only one message is transferred between the participating users during the example transaction. It is assumed that the destination user notifies the switch when he has no user information to transfer by leaving an "EOT tape" in the paper tape reader.

4.3. Reference Events

The following paragraphs describe the sequence of user/system interface events during the message-switched transaction; and identify the specific reference events which delimit the start and end of each of the five primary communication functions.

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[5]As an example, the control character ETX might cause the switching center to generate, and transmit to the destination terminal, a specified number of line feeds followed by a carriage return.

For completeness, reference events are defined for each of three separate transactions:

Source-to-Switch Sub-Transaction

Switch-to-Destination Sub-Transaction

End-to-End Transaction.

Only the latter events would actually be required in specifying end-to-end performance, since the switch (like the telegraph operator in the message telegram example) is internal to the system from the end user point of view.

4.3.1. Source-to-Switch Sub-Transaction

ACCESS PHASE, SOURCE TO SWITCH

The sequence of interface events during the access phase of the source-to-switch sub-transaction is as follows:

1. The operator at the source terminal station places a message (previously prepared in paper tape form) on the paper tape reader of the teletypewriter, and sets the reader auto switch on to enable automatic message transmission. This action represents the reference event start of access for the source-to-switch sub-transaction.
2. After a polling delay averaging 15 minutes, the computer at the message switching center initiates a circuit-switched call to the source terminal by activating the Call Request (CRQ) signal to the 801C automatic calling unit.
3. Automatic dialing, answering, modem handshaking, and answerback take place in the conventional manner, ending with the switch having master status.
4. The switch relinquishes master status and turns on the paper tape reader at the source terminal by sending the control sequence EOT DC1.
5. The source terminal reads and transmits the first user information character (SOH). This event represents the reference event end of access for the source-to-switch sub-transaction.

USER INFORMATION TRANSFER PHASE, SOURCE TO SWITCH

During the source-to-switch user information transfer phase the source terminal reads and transmits the paper tape message; and the message is received and stored at the switching center. Reference events for the three UIT functions within the source-to-switch sub-transaction are the same as those defined for the private-line example, except that the starting events occur on reading of user information characters by the paper tape reader; and the ending events occur on storage of user information characters on disk at the switching center. The source-to-switch UIT phase ends upon reading of a DC3 character by the source terminal. This character would be punched on the source tape by the operator during off-line message preparation.

DISENGAGEMENT PHASE, SOURCE TO SWITCH

Source-to-switch disengagement terminates the circuit-switched connection between the message switching center and the source terminal, and turns the source paper tape reader off. The sequence of disengagement events is as follows:

1. The source terminal reads the DC3 character from the source paper tape. This character notifies the switch that the source has nothing further to transmit; and turns off the source paper tape reader. Reading of the DC3 character represents the start of source-to-switch disengagement.
2. The switch responds to the DC3 signal by turning off interchange circuit CD (Data Terminal Ready). This event causes source-to-switch disengagement via a 3-second continuous spacing signal, in the same manner described in Section 3.3.

4.3.2. Switch-to-Destination Transaction

ACCESS PHASE, SWITCH TO DESTINATION

Completion of storage of the source message at the switch is presumed to result in queueing of a transmit request (specifying the intended destination) within the computer's message output software. This action programs the switch to output the message during its next call to the destination terminal (assumed to occur during the normal polling sequence, after a delay averaging 15 minutes). The sequence of interface events during the "access phase" of the switch-to-destination sub-transaction is as follows:

1. Queueing of the transmit request represents the reference event start of access for the switch-to-destination sub-transaction.
2. After a polling delay averaging 15 minutes, the computer at the message switching center initiates a circuit-switched call to the destination terminal, in the same manner as described above.
3. Automatic dialing, answer, modem handshaking, and answerback take place in the conventional manner, ending with the switch having master status.
4. The switch determines that the destination terminal has no message ready for output via an exchange of EOT signals.
5. The switch reads a record containing the first user information character from disk storage, and begins message transmission. Reading of the first user information character from storage represents the reference event end of access for the switch-to-destination sub-transaction.

USER INFORMATION TRANSFER PHASE, SWITCH TO DESTINATION

During the switch-to-destination user information transfer phase, the switch reads and transmits the source message characters, and the destination terminal prints the corresponding received characters. Reference events for the UIT functions are the same as those defined above, except that the starting events occur on reading of user information characters from disk storage; and the ending events occur on printing of user information characters at the destination. The switch-to-destination UIT phase ends on initiation of circuit disengagement by the message switching computer, as described below.

DISENGAGEMENT PHASE, SWITCH TO DESTINATION

Switch-to-destination disengagement terminates the circuit-switched connection between the message switching center and the destination terminal. The sequence of disengagement events is as follows:

1. The switching computer initiates disengagement by turning off interchange circuit CD (Data Terminal Ready). This event represents the start of switch-to-destination disengagement.
2. Switch-to-destination disengagement is then effected via a 3-second continuous spacing signal, in the same manner described in Section 3.3.

<u>4.3.3. End-to-End Transaction</u>

To facilitate understanding of reference events for the end-to-end (source-to-destination) message-switched transaction, essential elements of the access and disengagement definitions are repeated below:

Access: relates only to the source-to-switch portion of the end-to-end message-switched transaction.

Disengagement: is a general function referring to disconnection and clearing at either user interface. Source user disengagement and destination user disengagement are thus regarded as separate "trials" of a general disengagement function; and each complete end-to-end transaction will include two disengagement trials.

A more complete presentation of these definitions is provided in Section 3.2 of Volume I.

ACCESS FUNCTION (a)

- The access function starts when the source terminal operator turns on the M37 reader auto switch (with the completed message tape mounted in the tape reader). A system with zero access time would begin reading the message immediately after this action.

- The access function ends when the source terminal reads the first user information character off the source tape.

USER INFORMATION TRANSFER FUNCTIONS (b1, b2, and b3)

- Each function starts with reading of a specified user information character (off the source tape) by the source terminal.
- Each function ends with printing of a specified received character by the destination terminal.

The block and message information units are specified in the same way as in Section 2.3.

DISENGAGEMENT FUNCTIONS (d)

Two disengagement functions take place during the end-to-end transaction: source user disengagement and destination user disengagement.

- The start (d) of the source user disengagement function occurs when the source termination reads the DC3 control character.
- The end (d*) of the source user disengagement function occurs when circuit CC (and the data lamp) go off at the source terminal. At this point, the source user and terminal are free to participate in subsequent transactions[6].
- The start (d) of the destination user disengagement function occurs when the destination user receives the last character of the programmed ETX sequence (Sec. 4.2).
- The end (d*) of the destination user disengagement function occurs when circuit CC (and the data lamp) go off at the destination terminal.

---

[6]As an example, the station might provide circuit-switched access to a population of users within a different subnetwork, as described in Section 3.

RESPONSIBILITY TRANSFER EVENTS

The system has unilateral responsibility throughout the assumed end-to-end transaction; hence there are no responsibility transfer events.

4.4. Parameter Values

Probable performance parameter values for the message-switched example are derived on the basis of the transaction profile of Figure 4.3; and the following assumptions.

1. Assumptions 1 through 4 of Section 2.4 apply, except that in defining availability (assumption 4), "total failure" events are assumed to occur once per year, and degraded performance events are assumed to affect two messages per month, on each user-switch circuit.
2. Messages are prepared "off-line" on separate teletypewriter equipment by the source terminal operator; and are transmitted over both circuit-switched connections at 150 wpm.
3. The switch polls each user terminal every half hour, in a continuous round-robin cycle, independent of the destinations of locally stored messages.
4. A 1% Grade of Service is assumed for each circuit-switched sub-transaction. The message switch will attempt to redial blocked calls three times, and will then skip the subject terminal in the polling sequence, resulting in an Access Denial. The probability of three successive blocked calls is assumed to be 10^{-4} for each circuit-switched sub-transaction.
5. Incorrect connection (connection of the message switch to an unintended, but compatible terminal) is assumed to have the same probability of occurrence specified for Incorrect Access in Section 3; i.e., 1.1×10^{-4}. Checking of the user terminal answerback sequence will reduce the sub-transaction Incorrect Access Probabilities by at least a factor of 10^{-6}, to essentially negligible proportions. Detected incorrect answer-

backs will result in automatic redialing by the message switching center, contributing (negligibly) to Access Denial Probability.

6. Loss or error in the continuous spacing disconnect signal can cause Disengagement Failure at either user terminal. This event is assumed to occur once per year at each terminal.
7. It is assumed that the message switch will discard one received source message a month as a result of detection of "substantial" (i.e., multiple) character errors or losses. In all such cases, the switch will notify the source user of the message non-delivery via a control printout. This feature provides a rudimentary form of retransmission error control.
8. In addition to outages in the circuit-switched network, outages may occur (independently) at the switching center. Power failure is assumed to be the dominant cause of switching center outages. Such outages are assumed to have the same frequency and average duration as circuit outages, i.e., one 4-hour outage per year. The switch will assume that any message being transmitted at the time of onset of a power outage is lost, and will retransmit the message in its entirety. This feature will result in duplicate delivery of a message fragment averaging half a message (300 characters) in length about every 3.6 years.
9. Misdelivery will occur (in the end-to-end transaction) whenever an undetected source-to-switch line error changes a message destination address to the valid address of another user in the subnetwork. The undetected address error rate is assumed to be 10^{-6}; and the probability of an address word error producing an assigned but unintended address is assumed to be 10^{-3}.

Values are developed independently for each of the three communication transactions defined in Section 4.3. Parameter values for the source-to-switch and switch-to-destination sub-transactions are presented in Table 4.1. These values are based on the same calculations used in the circuit-switched example, with the following exceptions:

1. Access Times include the assumed 15 minute average polling delay in each case.
2. Source-to-switch block and bit loss probabilities are increased from the "raw channel" values by the assumption that the switch discards messages received with "substantial" detected errors. The source-to-switch block and bit error probabilities are correspondingly reduced.
3. Extra bits and blocks occur as a result of switch outage during switch-to-destination transmission, as described above.
4. Ancillary parameter values are not calculated for the sub-transactions. Values for these parameters could be determined, by defining an "intermediate user" (of the public switched network) within the switch; but these values would not be useful in characterizing the end-to-end transaction since the switch is not a user from the end-to-end viewpoint.
5. Source messages discarded by the switch as a result of "substantial" errors or losses are counted as outages in characterizing the source-to-switch service.

PRIMARY PARAMETER VALUES, END-TO-END MESSAGE-SWITCHED EXAMPLE

(1) Access Time $W(a_s)$ = 15.4 minutes

See Figure 4.3. The access function relates only to the source-to-switch portion of the end-to-end message-switched transaction. A 15-minute average polling delay is included.

(2) Incorrect Access Probability $P(a_m)$ = 0

Incorrect access cannot occur in message-switched systems since user information transfer begins before the intended destination user is contacted.

Table 4.1. Sub-Transaction Performance Parameter Values

Parameter	Source-to-Switch Sub-Transaction	Switch-to-Destination Sub-Transaction
Access Time	15.4 minutes	15.4 minutes
Incorrect Access Probability	0	0
Access Denial Probability	6.7×10^{-4}	6.7×10^{-4}
Block Transfer Time	68 milliseconds	68 milliseconds
Bit Transfer Time	68 milliseconds	68 milliseconds
Block Error Probability	10^{-4}	1.5×10^{-4}
Bit Error Probability	$10^{-5} \leq P(bl_e) \leq 10^{-4}$	$1.5 \times 10^{-5} \leq P(bl_e) \leq 1.5 \times 10^{-4}$
Block Misdelivery Probability	0	0
Bit Misdelivery Probability	0	0
Block Loss Probability	10^{-3}	6.8×10^{-4}
Bit Loss Probability	10^{-3}	6.8×10^{-4}
Extra Block Probability	0	7.7×10^{-6}
Extra Bit Probability	0	7.7×10^{-6}
Block Transfer Rate	14.8 blocks/ second	14.8 blocks/second
Bit Transfer Rate	104 bits/second	104 bits/second
Block Rate Efficiency	69%	69%
Bit Rate Efficiency	69%	69%
Disengagement Time	2.25 seconds	2.25 seconds
Disengagement Denial Probability	5.7×10^{-5}	5.7×10^{-5}
Outage Probability	1.4×10^{-3}	1.4×10^{-3}
Service Time Between Outages	8.2 UIT hours	8.2 UIT hours
Outage Duration	38 minutes	38 minutes

Note: See text for assumptions and explanation.

(3) Access Denial Probability $P(a_\ell)=6.8\times10^{-4}$

$$12\ \frac{\text{denials}}{\text{year}} \div 17520\ \frac{\text{messages}}{\text{year}} = 6.8\times10^{-4}$$

One total failure produces 10 denials per year (see note 4, Section 2.4); 10^{-4} 3-call blocking probability produces about 2 denials per year.

(4a) Block Transfer Time $W(b2_s)$ = 16.2 minutes

See Figure 4.2. Includes all time between start of source-to-switch UIT and start of switch-to-destination UIT.

(4b) Bit Transfer Time $W(b1_s)$ = 16.2 minutes

See 4a.

(5a) Block Error Probability $P(b2_e) = 2.5\times10^{-4}$

See Table 4.1. Errors in the source-to-switch link are reduced (by a factor of 30%) by the switch's error detection feature.

(5b) Bit Error Probability: $2.5\times10^{-5} \le P(b1_e) \le 2.5\times10^{-4}$

Error in a single bit or all bits produces a single character error.

(6a) Block Misdelivery Probability $P(b2_m) = 6\times10^{-7}$

$$10^{-6}\ \frac{\text{undetected address errors}}{\text{message}} \times 10^{-3}\ \frac{\text{valid addresses}}{\text{error}}$$

$$\times\ 600\ \frac{\text{misdelivered blocks}}{\text{valid address}} = 6\times10^{-7}.$$

(6b) Bit Misdelivery Probability $P(b1_m) = 6\times10^{-7}$

See 6a. Both numerator and denominator are multiplied by 7 in the bit misdelivery case.

(7a) Block Loss Probability $P(b2_\ell) = 1.7\times10^{-3}$

See Table 4.1. The separate loss probabilities for each sub-transaction are added to produce the end-to-end loss probability.

(7b) Bit Loss Probability $P(b1_\ell) = 1.7\times10^{-3}$

See 7a.

(8a) Added Block Probability $P(b2_x) = 7\times10^{-7}$

$$2.3\times10^{-2}\ \frac{\text{switch outages (during transmission to given destination)}}{\text{year}} \times 300\ \frac{\text{extra blocks}}{\text{outage}}$$

$$= 7\ \frac{\text{extra blocks}}{\text{year}}$$

One switch outage is assumed per year; probability that the switch is transmitting to a given destination at outage onset is 84 seconds/hr transmission time ÷3600 seconds/hr total time=2.3%.

$7\ \frac{\text{extra blocks}}{\text{year}} \div 1\times10^{7}$ blocks/year $= 7\times10^{-7}$.

(8b) Added Bit Probability $P(b1_x) = 7\times10^{-7}$

See 8a.

(9a) Bit Transfer Rate $R(b2_s) = 36.2$ blocks/minute

$$\frac{618(1-10^{-3})\ \frac{\text{good blocks}}{\text{message}}}{16.9\ \text{UIT minutes/message}} = 36.2\ \text{blocks/minute}$$

15 minutes (average) message storage is counted as UIT time.

(9b) Bit Transfer Rate $R(b1_s) = 4.2$ bits/second

7 bits (information)/block × 0.6 blocks/second
= 4.2 bits/second.

(10a) Block Rate Efficiency $Q(b2_s) = 2.8$ percent

$$0.6\ \frac{\text{blocks}}{\text{second}} \times 7\ \frac{\text{bits (user)}}{\text{block}} / 150\ \frac{\text{bits}}{\text{second}} = 0.028.$$

(10b) Bit Rate Efficiency $Q(b1_s) = 2.8$ percent

$$4.2\ \frac{\text{bits}}{\text{second}} / 150\ \frac{\text{bits}}{\text{second}} = 0.028.$$

(11) Disengagement Time $W(d_s) = 1.5$ seconds

See Figure 4.3. Both user terminals are cleared 1.5 seconds after request issuance.

(12) Disengagement Denial Probability $= 1.1\times10^{-4}$

$$1\ \text{failure/terminal year} \times 2\ \text{terminals} \div 17520\ \frac{\text{messages}}{\text{year}} = 1.14\times10^{-4}.$$

SECONDARY PARAMETER VALUES, END-TO-END MESSAGE SWITCHED EXAMPLE

(1) Outage Probability = $P(b3_z) = 3\times10^{-3}$

51 outages/year ÷ 17520 messages/year = 2.9×10^{-3}.

(2) Service Time Between Outages W(y*) = 96 hours

$$4.9\times10^{3}\ \frac{\text{UIT hours}}{\text{year}} \div 51\ \frac{\text{outages}}{\text{year}} = 96\ \frac{\text{UIT hours}}{\text{outage}}\ .$$

(3) Outage Duration W(z*) = 42 minutes

$$\frac{(48\text{ outages})(1/2\text{ hour})+(3\text{ outages})(4\text{ hours})}{51\text{ outages}} = 0.7\text{ hours.}$$

1 outage/month/link×2 links×12 months/year=48 outages/year.

ANCILLARY PARAMETER VALUES, END-TO-END MESSAGE-SWITCHED EXAMPLE

All user performance time fractions are zero since the system has unilateral responsibility throughout the end-to-end transaction.

5. SUMMARY AND CONCLUSIONS

This volume has illustrated application of the performance parameters specified in proposed Federal Standard 1033 to the characterization of three example telecommunication services. The selected examples are similar in having a common data terminal (the M37 teletypewriter) as the user interface point; but differ widely in system transmission and switching facilities and user/system interaction sequences.

Table 5.1 is a compilation of performance parameter values for the three selected examples. It is emphasized that these values characterized the examples, under the stated assumptions, and are not intended to be used in characterizing or comparing actual offered services. The example services are vastly different in performance, by design; and they would be appropriately used in meeting correspondingly different end-to-end service requirements. A brief summary and comparison of the estimated parameter values for each example follows.

Access Time varies widely between the three examples, as would be expected from their differing approaches to the funda-

Table 5.1. Compilation of Parameter Values

PERFORMANCE PARAMETER	NONSWITCHED PRIVATE LINE Example	CIRCUIT-SWITCHED EXAMPLE	MESSAGE-SWITCHED EXAMPLE
Access Time	5.2 Seconds	37.5 Seconds	15.4 Minutes
Incorrect Access Probability	0	1.1×10^{-4}	0
Access Denial Probability	1.7×10^{-3}	1.1×10^{-2}	6.8×10^{-4}
Block Transfer Time	68 milliseconds	68 milliseconds	16.2 minutes
Bit Transfer Time	68 milliseconds	68 milliseconds	16.2 minutes
Block Error Probability	1.5×10^{-4}	1.5×10^{-4}	2.5×10^{-4}
Bit Error Probability	$1.5\text{x}10^{-5} \leq P(bl_e) \leq 1.5\text{x}10^{-4}$	$1.5\text{x}10^{-5} \leq P(bl_e) \leq 1.5\text{x}10^{-4}$	$2.5\text{x}10^{-5} \leq P(bl_e) 2.5\text{x}10^{-4}$
Block Misdelivery Probability	0	1.1×10^{-4}	6×10^{-7}
Bit Misdelivery Probability	0	1.1×10^{-4}	6×10^{-7}
Block Loss Probability	4.7×10^{-5}	6.8×10^{-4}	1.7×10^{-3}
Bit Loss Probability	4.7×10^{-5}	6.8×10^{-4}	1.7×10^{-3}
Extra Block Probability	0	0	7×10^{-7}
Extra Bit Probability	0	0	7×10^{-7}
Block Transfer Rate	5 blocks/second	14.6 blocks/second	36.2 blocks/minute
Bit Transfer Rate	35 bits/second	102.4 bits/second	4.2 bits/second
Block Rate Efficiency	23 percent	68 percent	2.8 percent
Bit Rate Efficiency	25 percent	68 percent	2.8 percent
Disengagement Time	0.5 seconds	2.25 seconds	1.5 seconds
Disengagement Denial Probability	4×10^{-4}	5.7×10^{-5}	1.1×10^{-4}
Outage Probability	8×10^{-4}	1.4×10^{-3}	3×10^{-3}
Service Time Between Outages	43 UIT hours	8.2 UIT hours	93 UIT hours
Outage Duration	1 hour	38 minutes	42 minutes
User Access Time Fraction	0.19	0.4	0
User Block Transfer Time Fraction	0	0	0
User Message Transfer Time Fraction	0.67	0.02	0
User Disengagement Time Fraction	0.8	0	0

mental issue of resource sharing. Access Time is shortest in the nonswitched example, where no resource sharing is attempted; is intermediate in the circuit-switched example, where an end-to-end information path is established between user terminals on request, for each individual transaction; and is longest in the message-switched example, where user access opportunities are afforded at relatively infrequent intervals, independent of user demand.

Incorrect Access Probability is nonzero only in the circuit-switched case. There is no switching in the private line case; and in the message-switched case, the first system contact with the destination user takes place after the end of access.

Access Denial Probability values also vary as a function of the "priority" given individual users by the resource sharing approach. Access Denial Probability is highest in the circuit-switched case, as a result of the assumed 1% Grade of Service; is intermediate in the nonswitched case, which is nonblocking but relatively vulnerable to errors in the Access Request characters; and is lowest in the message-switched case, which provides access via circuit switching but allows automatic redialing to reduce call blocking probability.

With the exception of the error probabilities and transfer rates, the bit-oriented and block-oriented UIT parameter values within each individual example are the same. This is true because the bits within each user information block (character) cross the user/system interface in parallel; and each block contains (represents) a fixed number of bits. In this special case, separate values for the corresponding bit- and block-oriented UIT parameters are not really required; but they will be required in general, since the bits within a block may cross the user/system interface serially and may vary in number.

Block (and Bit) Transfer Times are extremely low (and essentially identical) in the nonswitched and circuit-switched examples, reflecting the fact that each service provides an essentially real-time information path between users. The corresponding times are substantially longer in the message-switched case as a result of the relatively long polling delay assumed. While the message-switched Block Transfer Time does seem excessive in comparison with the values for the other examples, it is substantially shorter than that provided by many alternative message transfer services (e.g., U.S. mail); and a 16-minute delay can be quite acceptable in the type of non-real time applications to which message switching has traditionally been applied. This delay could of course be shortened substantially by a traffic-sensitive polling algorithm, at some cost in circuit and switch utilization.

Block (and Bit) Error Probabilities are estimated to be essentially the same in each case, since none of the example systems has any significant error control capability. Error probabilities are estimated to be slightly higher in the message-switched case, since this service requires transmission of each message character over two (tandem) links. Delivered error probabilities are improved slightly in the latter case by the switch's provision for discarding source messages received with substantial detected errors; but this provision increases the loss (nondelivery) probabilities correspondingly. It would be advantageous to distinguish nondelivery with notification from loss in describing the performance of systems with this feature.

Block (and Bit) Misdelivery Probabilities are nonzero in both the circuit-switched and message-switched services. In each case, the estimated values are highly dependent on two factors: the probability of address errors, and the probability of connection (or delivery) to an unintended but compatible terminal, given an address error. Misdelivery is assumed to be more likely in the circuit-switched case, since the public switched network has relatively little provision for detecting signalling errors.

Block (and Bit) Loss Probabilities are lowest in the non-switched case, as a result of the less variable transmission quality of private line services; are intermediate in the circuit-switched case; and are highest in the message switched case, for two reasons:

1. The switch intentionally discards messages with substantial detected errors, and the blocks in such messages are counted as lost;
2. Each block must traverse two tandem links in transit between end users.

Extra Block (and Bit) Probability is estimated to be non-zero only in the message-switched case, since neither of the other services has provision for "remembering" previously transferred blocks. In principle, bit errors in the Disengagement Request characters (DLE EOT and the continuous spacing signal) can result in printing of extra characters in the nonswitched and circuit-switched services; we disregard this possibility here since these characters are most likely to be transformed into other (nonprinting) control characters. The message-switching service will deliver a substantial message fragment containing many Extra Blocks to the destination user whenever switch operation is interrupted by a power outage, since the switch retransmits such interrupted messages in their entirety.

Block (and Bit) Transfer Rates and Rate Efficiencies differ widely between the three examples as a result of the same design differences discussed above in connection with Access Time and Block Transfer Time. The differences between the nonswitched and circuit-switched values are primarily a result of differences in user input delay, as can be demonstrated by comparing the corresponding user-independent values (see Sec. 5.3 of Volume I). The message-switched rate and rate efficiency values are low as a result of (1) storage in the switch, and (2) the absence of "pipelining" in traditional message-switched systems (Kleinrock, 1976).

Disengagement Time values are essentially similar in the three examples, and are relatively insignificant under the assumed loading conditions. Disengagement Time values become more significant as service utilization increases, since disengagement delays postpone subsequent access whenever the queue of user messages awaiting transmission is not empty.

Disengagement Denial Probability estimates reflect differences in the disengagement procedures employed in each example service. Disengagement Denial is least likely in the circuit-switched case, since the 3-second continuous spacing signal represents a highly redundant (and hence reliable) disconnect signal. Disengagement Denial is roughly twice as likely in the message-switched case, since there are two possibilities for transmission errors in the continuous spacing signal - one associated with each user terminal. The nonswitched service is most vulnerable to disengagement failure, since the Disengagement Request is transmitted via a single (DLE-EOT) character pair: all the "eggs" are in one "basket."

Outage Probability estimates are affected by the assumption that two distinct phenomena, "total" failures and degraded performance, can produce observed outages. Outage Probability is lowest in the nonswitched case, where performance is assumed to be least variable; is intermediate in the circuit-switched case, where more frequent instances of degraded performance are assumed; and is highest in the message-switched case, for two reasons:

1. The tandem link effect described previously;
2. The fact that the switch itself can fail.

Service Time Between Outage estimates are sensitive to two factors: the number of assumed outages per measurement period; and the UIT time required to obtain a given "increment" of service (e.g., complete message transfer) from each example system. Service Time Between Outages is lowest in the circuit-switched case, since the number of assumed outages is relatively high and the UIT time required to transfer a message is low. Service Time Between Outages is intermediate in the nonswitched case, where the number of "degraded performance" outages is lower and the UIT time per message longer; and is highest in the message switched case, which has a much longer UIT time per unit of service than either of the other examples as a result of storage time in the switch. In effect, the message storage time adds to the end-to-end UIT time without providing any UIT service (or risking any outages); and this time "inflates" the W(y*) parameter value. This points up a fundamental difference between Service Time Between Outages and Outage Probability: the former expresses the frequency of outages in units of time, irrespective of service (UIT) rate; whereas the latter expresses the frequency of outages in units of service provided (messages transferred), irrespective of time. Separate W(y*) values can only be directly compared between services having the same UIT rate; whereas Outage Probability values can be directly compared irrespective of service rate.

Outage Duration estimates are determined simply by the mix of short and long outages assumed. Outage Duration is lowest in the circuit-switched example, which has the highest proportion of short (degraded performance) to long (total failure) outages; is intermediate in the message-switched example; and is highest in the nonswitched example, which has the lowest proportion of short to long outages. This relationship is consistent with intuitive expectation, since switched services will (in general) transfer information over a different physical path on each transaction, thus producing more variable performance.

User Performance Time Fraction values reflect differences in the user component of primary function performance time between the example services. User Access Time Fraction is zero in the message-switched case, since this is a polling application in which the system has unilateral access responsibility. User Access Time Fraction is relatively low in the nonswitched case, where the only user delay is his response to the "clear to send" indication; and is highest in the circuit-switched case, reflecting the users' dialing and answer responsibilities. User Block Transfer Time Fraction is zero in all three examples, since the system has unilateral responsibility for block transfer in each case; but this parameter will have a nonzero value in any service where the user takes an active role during the block transfer performance period[7]. User Message Transfer Time Fraction is zero in the message-switched example, again reflecting the system's unilateral responsibility; is low in the circuit-switched example, where the only user responsibility during the UIT phase is to terminate the phase after the last message character has been read; and is highest in the nonswitched case, where the source user's input (typing) rate reduces the UIT rate by about a factor of 3. User Disengagement Time Fraction is nonzero only in the nonswitched case, where a small amount of excess DLE EOT typing time is technically attributable to the source user. There is no instance of "split" responsibility in the examples chosen, but this situation can occur in more sophisticated services, as was described in Section 5.2 of Volume I.

In surveying the results summarized in Table 4.1, two general observations can be made:

1. In each of the three example services described it was possible, with reasonable effort, to develop representative values for all 26 specified performance parameters. More precise estimates of parameter values, and additional performance information such as parameter distributions, could be developed with additional analysis (or measurement) effort.
2. With a single exception (User Block Transfer Time Fraction), none of the specified parameters had a value of zero in all three examples. The latter parameter will have a nonzero value in various other types of services, as was noted above.

These observations provide general support for the conclusion that the specified parameters are in fact consistent with

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[7] "Mailbox" services provide one example of this situation: a destination user must place a call to a remote message storage facility (within the system) to "read his mail" from other (source) users. One well-known computer network which provides this service to subscribers is the ARPA network.

the four "desired parameter attributes" listed in Section 1.1 of Volume I.

It is anticipated that additional application examples will be developed to illustrate use of the proposed standard parameters in characterizing computer-to-computer and teleprocessing services[8]. Several of the specified parameters have already been measured on the ARPA network (Payne, 1978); and measurement plans for the remaining parameters are under development.

[8]One such example (communication between remote "user processes" on the ARPA network) is outlined in Appendix B of the published draft standard (National Communications System, 1977).

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APPENDIX A. USASCII COMMUNICATION CONTROL CHARACTERS

ENQ Enquiry - A communication control character used in data communication systems as a request for a response from a remote station.

ACK Acknowledgment - A communication control character transmitted by a receiver as an affirmative response to a sender.

NAK Negative Acknowledgment - A communication control character transmitted by a receiver as a negative response to the sender.

SOH Start of Heading - A communication control character used at the beginning of a sequence of characters which constitute a machine-sensible address or routing information. Such a sequence is referred to as the heading.

STX Start of Text - A communication control character which precedes a sequence of characters that is to be treated as an entity and entirely transmitted through to the ultimate destination. Such a sequence is referred to as text.

ETX End of Text - A communication control character used to terminate a sequence of characters started with STX and transmitted as an entity.

EOT End of Transmission - A communication control character used to indicate the conclusion of a transmission, which may have contained one or more texts and associated headings.

DLE Used as a prefix to additional USASCII characters to form a sequence representing a communication control function not directly represented by a single control character.

NOTE

For a more complete description of USASCII control character functions, refer to ANSI (1967).

APPENDIX B. RS-232 INTERCHANGE CIRCUITS

Interface between Data Terminal Equipment and Data Communication Equipment employing Serial Binary Data Interchange.

CIRCUIT AA - Protective Ground

Ground conductor that is electrically bonded to the machine or equipment frame.

CIRCUIT AB - Signal Ground or Common Return

Establishes common ground reference potential for all interchange circuits except circuit AA (protective ground).

CIRCUIT BA - Transmitted Data

Generated by the Data Terminal Equipment and transferred to the local transmitting signal converter for transmission to remote data terminal equipment.

CIRCUIT BB - Received Data

Generated by the receiving signal converter in response to data signals received from remote data terminal equipment via the remote transmitting signal converter.

CIRCUIT CA - Request to Send

Conditions the local data communication equipment for data transmission.

CIRCUIT CB - Clear to Send

Data set is ready to transmit data.

CIRCUIT CC - Data Set Ready

Indicates the status of the local data set.

CIRCUIT CD - Data Terminal Ready

Used to control switching of the data communication equipment to the communication channel.

CIRCUIT CE - Ring Indicator

Ringing signal being received.

CIRCUIT CF - Received Line Signal Detector

Suitability criteria being met.

NOTE

For a more complete description of RS-232-C interchange circuits, refer to EIA (1969).