IBM Synchronous Data Link Control (SDLC)

In this report:

Note: The subject of this report is a mature standard. No significant developments are anticipated, but Datapro will provide a new report when the topic warrants it.

Datapro Summary

IBM introduced Synchronous Data Link Control (SDLC) to permit the exchange of information among the components of a data processing system. SDLC is a bit-oriented protocol for the data link control of a communications channel. Channel configurations are either multipoint or point-to-point and may be either switched or nonswitched. Transmission may be full or half duplex. SDLC provides error detection and recovery procedures for those errors introduced by the communications channel. It permits multiframe transmission before an acknowledgment is required. Since its introduction in 1973, SDLC has become the primary data link control procedure offered by IBM for wide area networks. It is used for operations within the IBM Systems Network Architecture (SNA) and is gradually replacing a less efficient transmission procedure, IBM Binary Synchronous Communications (BSC).

SDLC provides a uniform technique for managing a single communications line. In a multiple-line environment where, for example, several communications lines are connected to a remote concentrator and several regional concentrators feed a central host, overall control of the communications environment requires a higher level of control. Network control is implemented in the software of the concentrators, host computer front ends, and the host computer itself. SDLC can be used on each communications link independently (i.e., between each terminal and its concentrator and between each concentrator and the host).

Configurations

Using SDLC, a number of data link configurations are possible. As with most protocols, stations can be configured as either point-to-point or multipoint. SDLC allows for five basic configuration variations: half-duplex, point-to-point, nonswitched; full-duplex, point-to-point, nonswitched; half-duplex, multipoint, nonswitched; full-duplex, multipoint, nonswitched; and half-duplex, point-to-point, switched. Station variations are also possible. For example, the primary station may operate in full-duplex mode while the other stations on the multipoint link operate in half-duplex mode.

SDLC is also capable of loop operation, or "hub polling." In this arrangement, the primary station (loop controller) sends command frames to any or all stations on the loop. The secondary stations decode the address field and either accept the frame or pass the frame down the loop. A loop configuration essentially uses a simplex (one-way) line with the originating and ending points terminated at the primary station. Timing is the same as for half-duplex operation without the need for turnarounds. While it is practical for connecting devices close together, the use of the loop configuration for widely separated geographical points incurs substantial line costs. IBM uses a loop configuration for its banking and retail terminal systems to connect multiple stations at the same location.

Stations

A station is the device located at one end of a communications link. Only one station on an SDLC line is a **primary station**; all other stations on that line are **secondary stations**. The primary station initiates all transmissions from secondary stations by inviting or commanding responses from the addressed secondary stations. The primary station can also initiate one-way or interspersed communications between itself and a secondary station. In normal practice, the primary station deals with one secondary station at a time.

The same station can function as either a primary or secondary station in certain situations. For example, a remote processor may function as a primary station when communicating with the terminals and as a secondary station when communicating with the host processor. Procedures exist for requesting that a station return to its primary or secondary status. This capability is normally used for switched network (dial-up) arrangements, but it could be used, with appropriate station programming, to allow alterations in the primary/secondary status of stations connected to a line.

Modes of Operation

An SDLC link can be in one of three **transmission states**: Transient, Idle, and Active. The *Transient State* occurs when a station is preparing to transmit; it follows the poll (secondary station) and precedes the actual transmission of control information or data. Normally, this is the period between the station signaling the modem with Request-to-Send (RTS) and the modem responding with Clear-to-Send (CTS).

During the *Idle State*, there is no transmission of control information or data; it is identified by a succession of 15 or more consecutive binary 1s. In the *Active State*, control information or data is being transferred.

The primary station is in a permanent command mode. Secondary stations can be in one of three **active modes**, established by the primary station:

- *Normal Response Mode (NRM):* Responds to poll.
- *Normal Disconnect Mode (NDM):* Responds to polls with a request to be put on-line or to be initialized; it ignores other commands. A secondary station that receives and accepts a DISC (Disconnect) command assumes NDM. It also assumes NDM when power is turned on; when the station is enabled for data link operation, following a transient disabling condition such as a power failure; or when a switched connection is made.
- *Initialization Mode:* Procedures are specified by system components.

If the secondary station is disabled and does not respond to a poll or responds with bits that do not result in frames, a **time-out** procedure is initiated by the primary station to determine the response condition. After a given number of retries, as determined by the procedures for the primary station (typically internal programming), recovery action can be taken. SDLC includes a provision for a transmitting station, either primary or secondary, to abort specific transmission. Recovery is the responsibility of the primary station. A further discussion of the time-out procedure appears later in this report.

Frame Structure

A specific frame layout is used for all transmissions. As illustrated in Figure 2, the transmission frame consists of FLAG-ADDRESS-CONTROL-INFORMATION-FRAME CHECK SEQUENCE-FLAG. Each field contains either eight bits or a multiple of eight bits. Only the Information field is of variable length. The frame format enables a receiving station to determine the beginning and ending of a transmission, the station address, what actions should be taken, specific information for the receiving station, and whether the frame was received without error. Zero insertion prevents unwanted flags from occurring in any of the other fields; it permits completely transparent data transfer.

The **Flag** field, both beginning and ending, is binary 01111110 (Hex 7E). The Idle state of the communications link is all 1s; the presence of a 0 causes the examination of the following bits to see if it matches the Flag pattern. If so, interpretation of the frame begins.

The **Address** field always contains the identity of the secondary station that is communicating with the primary station. In a poll, the Address field identifies the station being polled. In a response, it identifies the transmitting secondary station. For certain applications, it is common to have special addresses that direct frames to certain stations or to all stations on the link. In such cases, a secondary station may have three address types:

- A *station address*, its own individual address;
- A *group address*, common to several stations; or
- A *broadcast address*, acceptable to all stations on the link.

The **Control** field identifies the function of the frame. This field can be in one of three formats: the unnumbered format, the supervisory format, or the information transfer format. These formats are discussed in detail under the heading Control Procedures.

The optional **Information** field contains control information or data. The interpretation of the Control field determines whether an Information field is present. The Information field may be expanded to accommodate as much information as necessary, as long as it is expanded in eight-bit increments. Both numbered and unnumbered Information fields are possible.

The **Frame Check Sequence** field is used to check the received frame for errors introduced by the channel. It contains the *Cyclic Redundancy Check (CRC)* constant. CRC is computed using the Address, Control, and Information (if present) fields as a continuous bit string. The basic computation is division by the polynomial $x^{16} + x^{12} + x^5 + 1$. The inverted 16-bit remainder is the Frame Check Sequence field. The result of the computation at the receiving end is the constant if there have been no errors in transmission. The computation method also permits detection of missing or added 0 bits at the high-order ends of the bit string.

Control Procedures

The Control (C) field defines one of three frame formats:

- Information Transfer Format—The vehicle used for information or data transfer.
- Supervisory Format—Used in conjunction with Information Transfer Format to convey ready or busy status and to request retransmission when an error is detected, or when frames are received out of sequence.
- Unnumbered Format—Command format for data link management.

The general layout of the Control field formats is shown in Figure 3. Codes are conventionally written by IBM with the low-order bit on the left reading to the right; IBM transmits the high-order bit first. Conversely, ANSI ADCCP transmits the least significant bit of the control field first. SDLC is a bit-oriented procedure; bit transmission order is vital to the understanding of the protocol. The frame is shown with the leading edge of transmission to the left, while individual fields are shown with the leading edge of transmission to the right. Thus, the Control field is the third field transmitted (following the Flag and Address fields), and the rightmost bit in Figure 3 is the first bit of the Control field transmitted. In the Control field, the first two bits transmitted identify the format as either Information, Supervisory, or Unnumbered.

All three Control field formats contain a poll/final (P/F) bit. A secondary station receives the P (poll) bit from the primary station. The P bit requires the secondary station to initiate transmission. The F (final) bit is transmitted by the secondary station to the primary station; it is inserted into the last frame to indicate the end of a transmission.

The bit patterns of the commands and responses are summarized in Table 1.

Table 1. Summary of Command and Response Control Fields

Field Format	Sent Last➡	Binary Configuration	Sent First➡	Acronym	Command	Response	Defining Characteristics
Unnumbered	000	P/F	0011	UI	X	X	Unnumbered command or response that carries information
	000	F	0111	RIM		X	Request initialization mode; initialization needed; expect SIM
	000	P	0111	SIM	X		Set initialization mode; the using system prescribes the procedure
	100	P	0011	SNRM	X		Set normal response mode; transmit on command only
	000	F	1111	DM		X	This station is in disconnect mode
	010	P	0011	DISC	X		Do not transmit or receive information (disconnected)
	011	F	0011	UA		X	Acknowledgment for unnumbered commands (SNRM, DISC, SIM)
	100	F	0111	FRMR		X	Frame reject; invalid frame received; must receive SNRM, DISC, or SIM

In the **Information Transfer Format**, the Control Field contains information that tracks the number and sequence of frames sent and received. A station transmitting numbered information frames counts each frame and sends the count with the frame. This count is a sequence number known as **Ns.** This sequence number is checked at the receiving end for missing or duplicated frames.

A station receiving numbered information frames accepts each numbered information frame that it receives; checks that it is error free and in sequence; and, if so, advances its receive count for each such frame. The receiver count is called **Nr.** If the received frame is error free, a receiving station's Nr count is the same as the Ns count that it will receive in the next frame; that is, a count of one greater than the Ns count of the last frame received. The receiver confirms accepted numbered information frames by returning its Nr count to the transmitting station.

The Nr count at the receiving station advances when a frame is checked and found to be error free and in sequence; Nr then becomes the count of the "next-expected" frame and should agree with the next incoming Ns count. If the incoming Ns does not agree with Nr, the frame is out of sequence and Nr does not advance. Out-of-sequence frames are not accepted. The receiver does, however, accept the incoming Nr count (for confirmation purposes) if the out-of-sequence frame is otherwise error free.

The counting capacity for Nr and Ns is 128. Up to 127 unconfirmed, numbered information frames may be outstanding (transmitted but not confirmed) at the transmitter. All unconfirmed frames are retained by the transmitter in case it is necessary to retransmit some or all of them if transmission errors or buffering constraints occur. The reported Nr count is the number of the next frame that the receiver expects to receive.

The Nr and Ns counts of both stations are initialized—set to 0—by the primary station. The counts advance as numbered frames are sent and received.

In the **Supervisory Format**, a code identifies three supervisory commands/responses: RR, RNR, and REJ. These commands and responses are interspersed with Information frames to supplement traffic control.

Table 1. Summary of Command and Response Control Fields (Continued)

Field Format	Sent Last➡	Binary Configuration	Sent First➡	Acronym	Command	Response	Defining Characteristics
	111	F	1111	BCN		X	Beacon; signals loss of input
	110	P/F	0111	CFGR	X	X	Configure; contains function descriptor in information field
	010	F	0011	RD		X	Request disconnect; this station wants to disconnect
	101	P/F	1111	XID	X	X	Exchange station identification; identification in information field
	001	P	0011	UP	X		Unnumbered poll; response optional if P bit not on
	111	P/F	0011	TEST	X	X	Test pattern in information field
Supervisory	Nr	P/F	0001	RR	X	X	Ready to receive
	Nr	P/F	0101	RNR	X	X	Not ready to receive
	Nr	P/F	1001	REJ	X	X	Reject; transmit or retransmit, starting with frame Nr
Information	Nr	P/F	Ns 0	I	X	X	Sequenced I-frame

Receive Ready (RR) is sent by either the primary or a secondary station. It acknowledges numbered frames through Nr–1 and indicates that the station sending RR is ready to receive.

Receive Not Ready (RNR) is sent by either the primary or a secondary station and indicates a temporary busy condition due to buffering or other internal constraints. To indicate the clearing of an RNR condition, a primary station transmits an I frame with the P bit on, or an RR or REJ frame with the P bit on or off. A secondary station indicates that an RNR condition has been cleared by transmitting an I frame with the F bit on, or an RR or REJ frame with the F bit on or off.

The *Reject (REJ)* command or response is sent by either the primary or a secondary station to request transmission or retransmission of numbered frames. REJ acknowledges that frames through Nr–1 were received without error and requests retransmission of numbered information frames starting at the Nr contained in the REJ frame. The REJ command or response may be interspersed in the sequence of transmitted frames. The REJ condition is cleared by the receipt of the requested frame or when a mode setting command has been correctly received.

The **Unnumbered Format** provides the commands and responses for the basic control of information exchanges. There are a total of 14 Unnumbered Information (UI) commands and responses. One command and response pair (Set Initialization Mode and Request for Initialization) uses the same code, but is assigned different names. The interpretation is established according to which station sent the frame (primary or secondary).

The three commands most often used by a primary station are the mode setting commands: SNRM, DISC, and SIM.

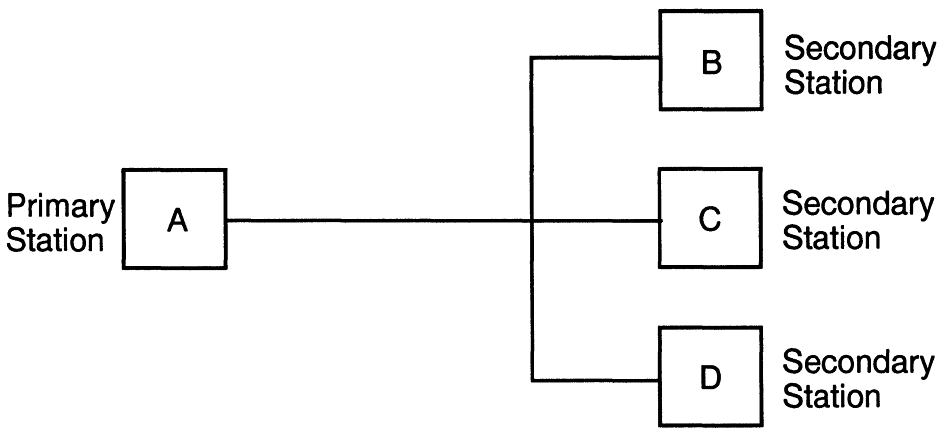
The *Set Normal Response Mode (SNRM)* command is used typically in line start-up procedures, when a secondary station has been previously disconnected, either through a UI command or a transient terminal condition, and to recover from a garbled command to which the secondary station has given a Frame Reject (FRMR) response.

The *Disconnect (DISC)* command terminates other modes while placing the receiving station in disconnected mode.

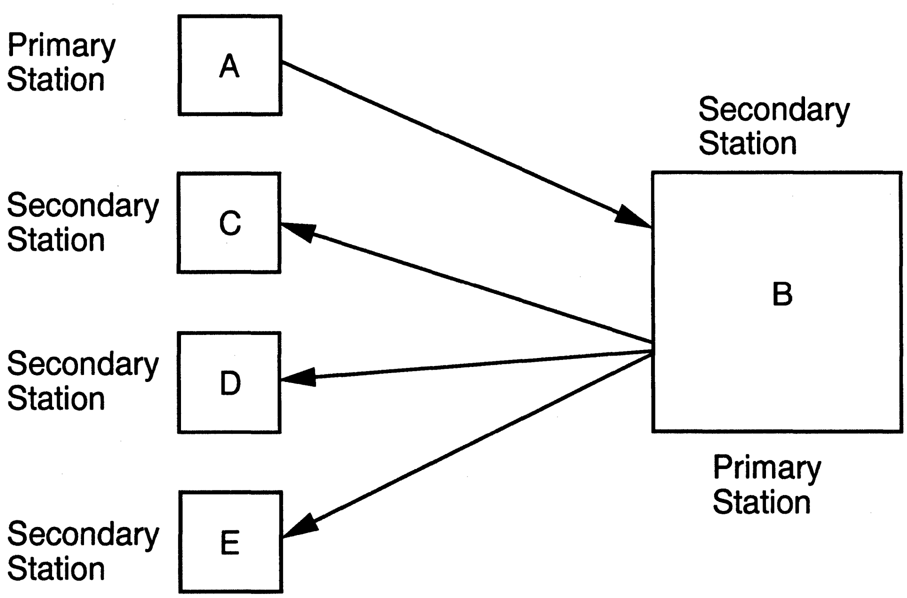
The *Set Initialization Mode (SIM)* command initiates system procedures to initialize link-level functions. SIM resets the primary and secondary station Nr and Ns counts to zero.

Figure 1.
Station Configurations

A. Point-to-Point Station Configuration



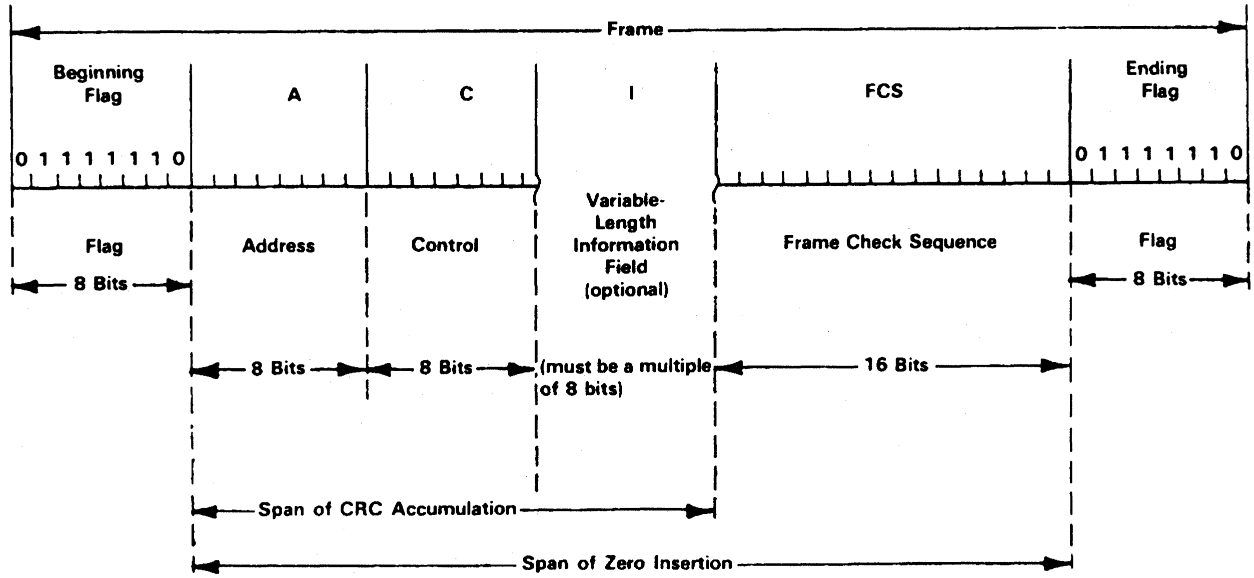
B. Multipoint Station Configuration



C. Dual Role of a Station in a Complex System

Besides the basic point-to-point or multipoint configurations, SDLC allows for configuration variations including half- or full-duplex and switched or nonswitched configurations.

Figure 2.
SDLC Frame Format



The transmission frame consists of Flag-Address-control-information-Frame Check Sequence-Flag. Each field has either eight bits or a multiple of eight bits.

The four most common unnumbered responses from a secondary station are UA, RIM, DM, and FRMR.

Unnumbered Acknowledgment (UA) is the affirmative response to a DISC, SIM, or SNRM command.

Request Initialization Mode (RIM) is sent by the secondary station to notify the primary station that a SIM command is needed. Following a RIM response, a secondary station will only recognize a SIM command.

Disconnect Mode (DM) is the response of a disconnected secondary station to indicate its status.

Frame Reject (FRMR) is the response of a secondary station when it receives an invalid frame. A frame may be invalid if the I field is longer than the receiving station's buffers, if the C field is not implemented by the receiving station, if the C field prohibits a received I field within a frame, or if a sequence error is discovered that cannot be resolved by retransmission. The receiving station responds with FRMR until it receives an acceptable mode setting command: SNRM, DISC, or SIM.

The remaining seven commands/responses, outlined below, are used for special purposes.

Unnumbered Information (UI) is used to transfer commands or responses that use the I field for supplemental information. This frame is not acknowledged and is not counted in sequence checking procedures. Successful transfer can only be checked by subsequent actions or UI transfers.

Exchange Station Identification (XID), whether as a command or response, solicits or returns the identification of the receiving station. A system-defined I field can be included. The principal use of this command is to establish station identities when completing a switched network connection, although it is not restricted to this use.

Unnumbered Poll (UP) permits an uninvited poll with no response required or a command poll with response required. The use of the P bit determines which is intended. (It is a command when the P bit is on and an invitation when the P bit is off.) This command is convenient for loop operations, although it is not restricted to this use.

Test (TEST) as a command requests a response from a secondary station. The response is a TEST frame with the received information field, if any, repeated. If the secondary station has insufficient buffering for the information field, a TEST response with no information field is returned.

Beacon (BCN) is a response that a secondary station in a loop transmits when it detects the loss of communication at its input. This permits the primary station in the loop to locate the problem and to take appropriate action. As soon as the input resumes normal status (the problem is corrected), the secondary stops transmitting the Beacon response.

Configure (CFGR) is a response that a secondary station in a loop transmits in response to a configure command. The structure of the response is identical to that of the command. If the low-order bit in the information field is 1, it indicates that the configure function has been sent. If it is 0, it indicates that the configure function has been cleared.

Request Disconnect (RD) is transmitted by a secondary station desiring to be disconnected by the DISC command.

Time-Outs

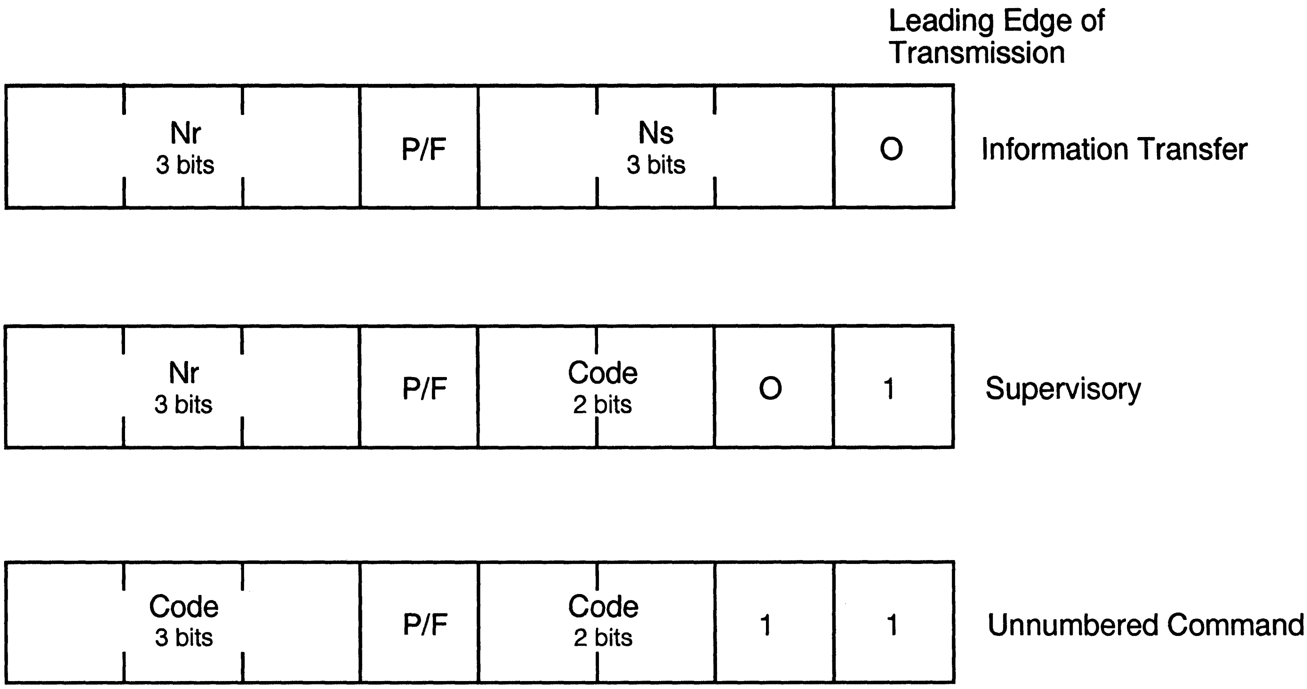
The primary station operates time-outs for the purpose of maintaining orderly, continuous operation of a data link and for checking for responses to its commands. The time-outs operated for these purposes are idle detect and nonproductive receive.

Idle detect occurs when the primary station transmits a frame with the P bit on in the C field; a response is expected within a specific period of time. In two-way alternate operation, the data link is usually in the idle state when no transmission is taking place. If the idle state continues beyond the time when a response should have been initiated (for example, when the secondary station does not respond to a frame), the primary station detects the idle condition and initiates recovery action.

The interval allowed before recovery action is initiated should include the following:

- propagation time to the secondary station
- clear-to-send time at the secondary station DCE

Figure 3.
Control Field Formats



Nr—Number of correct frames received since last acknowledgement, 7 maximum.

Ns—Number of frames sent since last acknowledgement, 7 maximum.

P—Poll bit, sent by primary station.

F—Final frame, sent by secondary station.

Code—Supervisory and Nonsequenced Command control codes.

The Control field format is the third field transmitted.

- appropriate time for secondary station processing
- propagation time from the secondary station

With either switched or nonswitched configuration, the minimum time-out includes the processing time at the secondary station. The sum of the other variables may be as great as 850 to 900 milliseconds (for a satellite data link). The time-out is reset when a response is received or being received before the time-out expires.

When bits that do not result in frames are being received, a **nonproductive receive** condition exists. This condition could be caused by a secondary station malfunction that causes continuous transmission. The primary station provides a time-out when nonproductive receive occurs. The usual time period ranges from 3 to 30 seconds. If the nonproductive receive condition continues after the time-out, the problem normally is not recoverable at the data link level and must be handled by a method above the data link level.

Abort Conditions

An abort is the termination of the transmission of a frame.

The abort pattern, a minimum of seven consecutive binary 1s with no zero insertion, terminates the frame without an FCS field or an ending flag. An abort is sent by the transmitting station. Zero insertion prevents an unintentional abort.

Following the abort, the link may go to the idle state (15 or more contiguous 1s) or may remain in the active state.

Either a primary or secondary station may send an abort. An abort pattern of seven 1s may be followed by a minimum of eight additional 1s (a total of at least 15 contiguous 1s), or it may be followed by a frame. Seven to fourteen 1s constitute an abort; fifteen or more 1s constitute an idle that continues until a binary zero is detected.

Error Recovery

The methods used to recover from an error condition or data link impasse are Link-Level Recovery and Higher Level Recovery.

Link-Level Recovery occurs at the data link level. SDLC procedures detect errors that may be recovered by retry or by retransmission. For example:

- A busy station that is temporarily incapable of continuing to receive, reports its condition to the transmitting station.
- Retransmission is initiated when a received Nr count does not confirm the previously transmitted numbered information frames.
- A receiving station rejects a frame when there is a CRC error, a numbered frame is out of numerical order, an information frame is unaccepted because of a busy condition, the ending

Table 2. SDLC—BSC Comparison

Capability	SDLC	BSC
Acknowledgment to text	May be combined with data	Separate sequence
Addressing	In every frame	Separate sequence
Block checking	In every frame	Text/header sequences only
Capable of handling long propagation delays	Yes	No
Character-code sensitive	No	Yes
Half or full duplex	Both	Half duplex
Line/mode dependent	No	Yes
Modulo (message) count	128	2
Polling	In every frame	Separate sequence
Susceptible to missed or duplicated blocks	No	Yes
Transparent text	Inherent	Special feature
Topology dependent	No	Yes
Variable-length text	Yes	Yes

flag is not separated from the beginning flag by a multiple of 8 bits, or a frame is less than 32 bits long.

- A poll is usually repeated if a response is not received.
- When an attempt to bring a secondary station on-line fails, the command is repeated.

SDLC does not specify procedures for counting retry or retransmission attempts. Retries and retransmissions may be counted by a system that detects whether the situation is link-level recoverable. Usually, they are counted within the DTE and, at a prespecified number, n, the situation is reported as unrecoverable at the data link level. Actions that should be retried are attempts to:

- Obtain acknowledgment of a command.
- Resume communication with a busy station.
- Achieve initial, on-line status at a secondary station.
- Initiate active communication at a secondary station.

Higher-Level Recovery detects errors at the link level. It applies to the address, control, information, and frame check sequence fields of a frame. Errors that cannot be recovered from at the link level include the following:

- If a secondary station rejects a command with which it is incompatible, only an acceptable alternative command can relieve its error condition. Higher-level intervention is required to analyze and act on the status report in the secondary station response.
- If the transmitting station has aborted transmission because of an internal malfunction or an expended retry count, higher-level intervention is required to analyze and act on the situation.
- If a secondary station response to the exchange of station identification contains the wrong identification, intervention from a higher level is required to analyze and act on the situation.

The station's decision-making power at a level higher than the data link level determines the type of intervention required. At a terminal, for example, operator intervention may be needed.

Zero Insertion

Two basic characteristics of SDLC require the use of a zero insertion technique:

1. The opening and closing Flag field must be unique to properly define the transmission frame, and
2. The protocol must be transparent to the data bit patterns.

Zero insertion prevents the occurrence of more than five consecutive binary 1s in the Address, Control, Information, and Frame Check Sequence fields. The transmitting station automatically inserts a binary 0 following five binary 1s in every field except a Flag field or when transmitting an abort. The code patterns of the Flag and abort are easily distinguishable. The receiving station automatically discards any 0 following five consecutive 1s. If a 0 does not follow the five 1s, the receiving station checks for a Flag or an abort condition.

Signaling Modes

When using modems that do not provide timing, the station (DTE or terminal) must provide its own. IBM uses the Non-Return-to-Zero-Inverted (NRZI) encoding technique to facilitate this. This invert-on-zero transmission coding method provides a signal change any time a binary 0 is received. Strings of 0s provide transitions that can be detected to maintain synchronization with the received data. Strings of 1s cause zero insertion, which again provides transitions for maintaining synchronization. With modems that provide timing signals, NRZI may or may not be used or required. If NRZI is used, however, it must be used by all DCEs on the data link.

SDLC Versus BSC

Binary Synchronous Communications was developed in the mid-1960s, and was well suited for the major applications of that time: simple remote job entry and batch transmission. As networking applications and data communications facilities became more sophisticated, however, more powerful SDLC methods gained popularity.

BSC, a simpler protocol than SDLC, is byte oriented, operates in half duplex only, and requires that each block of data be acknowledged by the receiving station before any further blocks are transmitted. BSC uses the EBCDIC, ASCII, or Six-Bit Transcode and is device dependent, meaning that incompatibilities in the implementation of the protocol may exist between different types of BSC devices.

SDLC is a bit-oriented protocol, permits both half- and full-duplex operation, and can operate with any code. Its frame sequence numbering scheme allows multiple frames (SDLC message units) to be sent before requiring an acknowledgment (buffer storage must be set aside to store the unacknowledged frames). The protocol uses a Module 8 scheme that permits up to 7 frames to be sent before requiring an acknowledgment and an optional Module 128 scheme that allows up to 127 frames to be outstanding.

One problem associated with BSC is that of propagation delay. BSC's requirement that every block of data be acknowledged is not propagation delay tolerable. SDLC handles this problem. The fact that the Module 8 (optionally Module 128) allows one acknowledgment frame to confirm up to 7 (127 in some implementations) data frames, coupled with full-duplex capability, permits better performance at higher propagation delays and link speeds. ■

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Synopsis

Editor's Note
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Report Highlights
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Analysis

Configurations

Using SDLC, a number of data link configurations are possible. As with most protocols, stations can be configured as either point-to-point or multipoint. SDLC allows for five basic configuration variations: half-duplex, point-to-point, nonswitched; full-duplex, point-to-point, nonswitched; half-duplex, multipoint, nonswitched; full-duplex, multipoint, nonswitched; and half-duplex, point-to-point, switched. Station variations are also possible. For example, the primary station may operate in full-duplex mode while the other stations on the multipoint link operate in half-duplex mode.

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Modes of Operation

An SDLC link can be in one of three **transmission states**: transient, idle, and active. The *Transient State* occurs when a station is preparing to transmit; it follows the poll (secondary station) and precedes the actual transmission of control information or data. Normally, this is the period between the station signaling the modem with Request-to-Send (RTS) and the modem responding with Clear-to-Send (CTS).

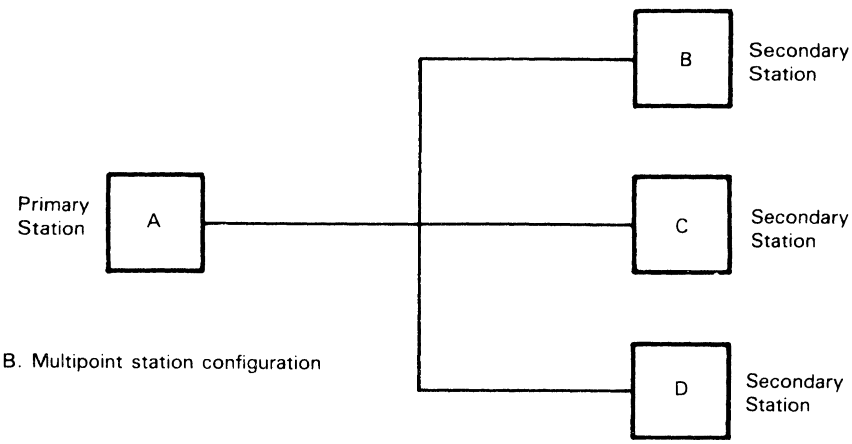
During the *Idle State*, there is no transmission of control information or data; it is identified by a succession of 15 or more consecutive binary 1s. In the *Active State*, control information or data is being transferred.

The primary station is in a permanent command mode. Secondary stations can be in one of three **active modes**, established by the primary station:

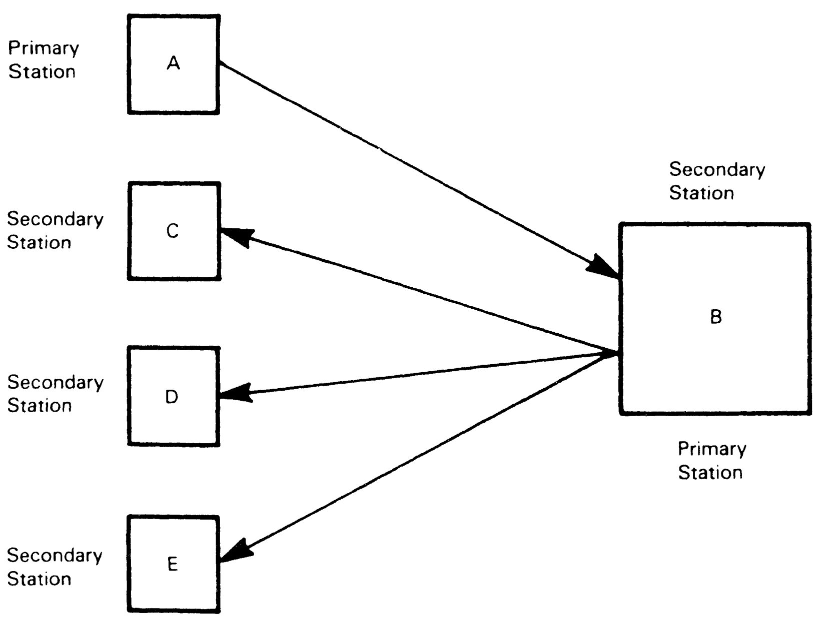
- *Normal Response Mode (NRM):* Responds to poll.
- *Normal Disconnect Mode (NDM):* Responds to polls with a request to be put on-line or to be initialized; it ignores other commands. A secondary station that receives and accepts a DISC (Disconnect) command assumes NDM. It also assumes NDM when power is turned on, when the station is enabled for data link operation, following a transient disabling condition such as a power failure, or when a switched connection is made.

Figure 1.
Station Configurations

A. Point-to-point station configuration



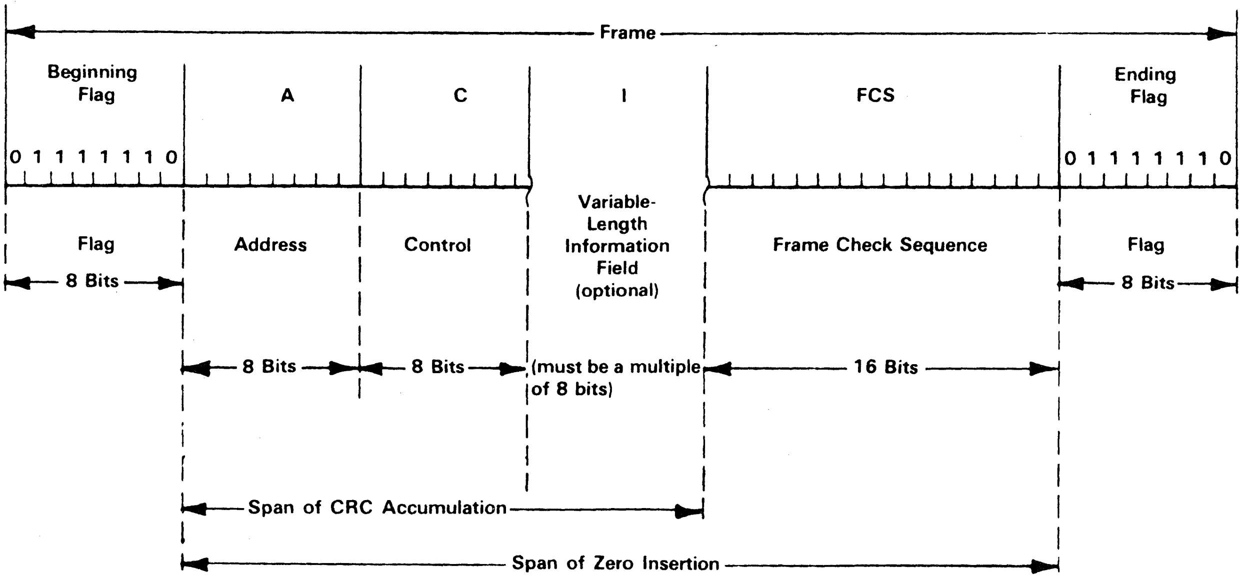
B. Multipoint station configuration



C. Dual role of a station in a complex system

Besides the basic point-to-point or multipoint configurations, SDLC allows for configuration variations including half or full duplex and switched or nonswitched configurations.

Figure 2.
SDLC Frame Format



The transmission frame consists of Flag-Address-control-information-Frame Check Sequence-Flag. Each field has either eight bits or a multiple of eight bits.

- *Initialization Mode:* Procedures are specified by system components.

If the secondary station is disabled and does not respond to a poll or responds with bits that do not result in frames, a **time-out** procedure is initiated by the primary station to determine the response condition. After a given number of retries, as determined by the procedures for the primary station (typically internal programming), recovery action can be taken. SDLC includes a provision for a transmitting station, either primary or secondary, to abort specific transmission. Recovery is the responsibility of the primary station. A further discussion of the time-out procedure appears later in this report.

Frame Structure

A specific frame layout is used for all transmissions. As illustrated in Figure 2, the transmission frame consists of FLAG-ADDRESS-CONTROL-INFORMATION-FRAME CHECK SEQUENCE-FLAG. Each field contains either eight bits or a multiple of eight bits. Only the Information field is of variable length. The frame format enables a receiving station to determine the beginning and ending of a transmission, the station address, what actions should be taken, specific information for the receiving station, and whether the frame was received without error. Zero insertion prevents unwanted flags from occurring in any of the other fields; it permits completely transparent data transfer.

The **Flag** field, both beginning and ending, is binary 01111110 (Hex 7E). The Idle state of the communications link is all 1s; the presence of a 0 causes the examination of the following bits to see if it matches the Flag pattern. If so, interpretation of the frame begins.

The **Address** field always contains the identity of the secondary station that is communicating with the primary station. In a poll, the Address field identifies the station being polled. In a response, it identifies the transmitting secondary station. For certain applications, it is common to have special addresses that direct frames to certain stations or to all stations on the link. In such cases, a secondary station may have three address types:

- A *station address*, its own individual address;

Figure 3.
Control Field Formats

Leading Edge of Transmission

Nr 3 bits	P/F	Ns 3 bits		0	Information Transfer
Nr 3 bits	P/F	Code 2 bits	0	1	Supervisory
Code 3 bits	P/F	Code 2 bits	1	1	**Unnumbered Command**

Nr Number of correct frames received since last acknowledgement; 7 maximum

Ns Number of frames sent since last acknowledgement, 7 maximum

P Poll bit, sent by primary station

F Final frame, sent by secondary station

Code Supervisory and Nonsequenced Command control codes

The Control field format is the third field transmitted.

- A *group address*, common to several stations; or
- A *broadcast address*, acceptable to all stations on the link.

The **Control** field identifies the function of the frame. This field can be in one of three formats: the unnumbered format, the supervisory format, or the information transfer format. These formats are discussed in detail under the heading Control Procedures.

The optional **Information** field contains control information or data. The interpretation of the Control field determines whether an Information field is present. The Information field may be expanded to accommodate as much information as necessary, as long as it is expanded in eight-bit increments. Both numbered and unnumbered Information fields are possible.

The **Frame Check Sequence** field is used to check the received frame for errors introduced by the channel. It contains the *Cyclic Redundancy Check (CRC)* constant. CRC is computed using the Address, Control, and Information (if present) fields as a continuous bit string. The basic computation is division by the polynomial $x^{16} + x^{12} + x^5 + 1$. The inverted 16-bit remainder is the Frame Check Sequence field. The result of the computation at the receiving end is the constant if there have been no errors in transmission. The computation method also permits detection of missing or added 0 bits at the high-order ends of the bit string.

Control Procedures

The Control (C) field defines one of three frame formats:

Table 1. Summary of Command and Response Control Fields

Field Format	Sent Last▼	Binary Configuration	Sent First▼	Acronym	Command	Response	Defining Characteristics
Unnumbered	000	P/F	0011	UI	X	X	Unnumbered command or response that carries information
	000	F	0111	RIM		X	Request initialization mode; initialization needed; expect SIM
	000	P	0111	SIM	X		Set initialization mode; the using system prescribes the procedure
	100	P	0011	SNRM	X		Set normal response mode; transmit on command only
	000	F	1111	DM		X	This station is in disconnect mode
	010	P	0011	DISC	X		Do not transmit or receive information (disconnected)
	011	F	0011	UA		X	Acknowledgement for unnumbered commands (SNRM, DISC, SIM)
	100	F	0111	FRMR		X	Frame reject; invalid frame received; must receive SNRM, DISC, or SIM

- Information Transfer Format—The vehicle used for information or data transfer.
- Supervisory Format—Used in conjunction with Information Transfer Format to convey ready or busy status and to request retransmission when an error is detected, or when frames are received out of sequence.
- Unnumbered Format—Command format for data link management.

The general layout of the Control field formats is shown in Figure 3. Codes are conventionally written by IBM with the low order bit on the left reading to the right; IBM transmits the high-order bit first. Conversely, ANSI ADCCP transmits the least significant bit of the control field first. SDLC is a bit-oriented procedure; bit transmission order is vital to the understanding of the protocol. The frame is shown with the leading edge of transmission to the left, while individual fields are shown with the leading edge of transmission to the right. Thus, the Control field is the third field transmitted (following the Flag and Address fields), and the rightmost bit in Figure 3 is the first bit of the Control field transmitted. In the Control field, the first two bits transmitted identify the format as either Information, Supervisory, or Unnumbered.

All three Control field formats contain a poll/final (P/F) bit. A secondary station receives the P

Table 1. Summary of Command and Response Control Fields (Continued)

Field Format	Sent Last▼	Binary Configuration	Sent First▼	Acronym	Command	Response	Defining Characteristics
	111	F	1111	BCN		X	Beacon; signals loss of input
	110	P/F	0111	CFGR	X	X	Configure; contains function descriptor in information field
	010	F	0011	RD		X	Request disconnect; this station wants to disconnect
	101	P/F	1111	XID	X	X	Exchange station identification; identification in information field
	001	P	0011	UP	X		Unnumbered poll; response optional if P bit not on
	111	P/F	0011	TEST	X	X	Test pattern in information field
Supervisory	Nr	P/F	0001	RR	X	X	Ready to receive
	Nr	P/F	0101	RNR	X	X	Not ready to receive
	Nr	P/F	1001	REJ	X	X	Reject; transmit or retransmit, starting with frame Nr
Information	Nr	P/F	Ns 0	I	X	X	Sequenced I-frame

(poll) bit from the primary station. The P bit requires the secondary station to initiate transmission. The F (final) bit is transmitted by the secondary station to the primary station; it is inserted into the last frame to indicate the end of a transmission.

The bit patterns of the commands and responses are summarized in Table 1.

In the **Information Transfer Format**, the Control Field contains information that tracks the number and sequence of frames sent and received. A station transmitting numbered information frames counts each frame and sends the count with the frame. This count is a sequence number known as **Ns**. This sequence number is checked at the receiving end for missing or duplicated frames.

A station receiving numbered information frames accepts each numbered information frame that it receives, checks that it is error free and in sequence and, if so, advances its receive count for each such frame. The receiver count is called **Nr**. If the received frame is error free, a receiving station's Nr count is the same as the Ns count that it will receive in the next frame; that is, a count of one greater than the Ns count of the last frame received. The receiver confirms accepted numbered information frames by returning its Nr count to the transmitting station.

The Nr count at the receiving station advances when a frame is checked and found to be error free and in sequence; Nr then becomes the count of the "next-expected" frame and should

Table 2. SDLC — BSC Comparison

Capability	SDLC	BSC
Acknowledgement to text	May be combined with data	Separate sequence
Addressing	In every frame	Separate sequence
Block checking	In every frame	Text/header sequences only
Capable of handling long propagation delays	Yes	No
Character-code sensitive	No	Yes
Half or full duplex	Both	half duplex
Line/mode dependent	No	Yes
Modulo (message) count	128	2
Polling	In every frame	Separate sequence
Susceptible to missed or duplicated blocks	No	Yes
Transparent text	Inherent	Special feature
Topology dependent	No	Yes
Variable-length text	Yes	Yes

agree with the next incoming Ns count. If the incoming Ns does not agree with Nr, the frame is out of sequence and Nr does not advance. Out-of-sequence frames are not accepted. The receiver does, however, accept the incoming Nr count (for confirmation purposes) if the out-of-sequence frame is otherwise error free.

The counting capacity for Nr and Ns is 128. Up to 127 unconfirmed, numbered information frames may be outstanding (transmitted but not confirmed) at the transmitter. All unconfirmed frames are retained by the transmitter in case it is necessary to retransmit some or all of them if transmission errors or buffering constraints occur. The reported Nr count is the number of the next frame that the receiver expects to receive.

The Nr and Ns counts of both stations are initialized—set to 0—by the primary station. The counts advance as numbered frames are sent and received.

In the **Supervisory Format**, a code identifies three supervisory commands/responses: RR, RNR, and REJ. These commands and responses are interspersed with Information frames to supplement traffic control.

Receive Ready (RR) is sent by either the primary or a secondary station. It acknowledges numbered frames through Nr-1 and indicates that the station sending RR is ready to receive.

Receive Not Ready (RNR) is sent by either the primary or a secondary station and indicates a temporary busy condition due to buffering or other internal constraints. To indicate the clearing of an RNR condition, a primary station transmits an I frame with the P bit on, or an RR or REJ frame with the P bit on or off. A secondary station indicates that an RNR condition has been cleared by transmitting an I frame with the F bit on, or an RR or REJ frame with the F bit on or off.

The *Reject (REJ)* command or response is sent by either the primary or a secondary station to request transmission or retransmission of numbered frames. REJ acknowledges that frames through Nr-1 were received without error and requests retransmission of numbered information frames starting at the Nr contained in the REJ frame. The REJ command or response may be interspersed in the sequence of transmitted frames. The REJ condition is cleared by the receipt of the requested frame or when a mode setting command has been correctly received.

The **Unnumbered Format** provides the commands and responses for the basic control of information exchanges. There are a total of 14 Unnumbered Information (UI) commands and responses. One command and response pair (Set Initialization Mode and Request for Initialization) uses the same code, but is assigned different names. The interpretation is established according to which station sent the frame (primary or secondary).

The three commands most often used by a primary station are the mode setting commands: SNRM, DISC, and SIM.

The *Set Normal Response Mode (SNRM)* command is used typically in line start-up procedures, when a secondary station has been previously disconnected, either through a UI command or a transient terminal condition, and to recover from a garbled command to which the secondary station has given a Frame Reject (FRMR) response.

The *Disconnect (DISC)* command terminates other modes while placing the receiving station in disconnected mode.

The *Set Initialization Mode (SIM)* command initiates system procedures to initialize link-level functions. SIM resets the primary and secondary station Nr and Ns counts to zero.

The four most common unnumbered responses from a secondary station are UA, RIM, DM, and FRMR.

Unnumbered Acknowledgment (UA) is the affirmative response to a DISC, SIM, or SNRM command.

Request Initialization Mode (RIM) is sent by the secondary station to notify the primary station that a SIM command is needed. Following a RIM response, a secondary station will only recognize a SIM command.

Disconnect Mode (DM) is the response of a disconnected secondary station to indicate its status.

Frame Reject (FRMR) is the response of a secondary station when it receives an invalid frame. A frame may be invalid if the I field is longer than the receiving station's buffers, if the C field is not implemented by the receiving station, if the C field prohibits a received I field within a frame, or if a sequence error is discovered that cannot be resolved by retransmission. The receiving station responds with FRMR until it receives an acceptable mode setting command: SNRM, DISC, or SIM.

The remaining seven commands/responses, outlined below, are used for special purposes.

Unnumbered Information (UI) is used to transfer commands or responses that use the I field for supplemental information. This frame is not acknowledged and is not counted in sequence checking procedures. Successful transfer can only be checked by subsequent actions or UI transfers.

Exchange Station Identification (XID), whether as a command or response, solicits or returns the identification of the receiving station. A system-defined I field can be included. The principal use of this command is to establish station identities when completing a switched network connection, although it is not restricted to this use.

Unnumbered Poll (UP) permits an uninvited poll with no response required or a command poll with response required. The use of the P bit determines which is intended. (It is a command when the P bit is on and an invitation when the P bit is off.) This command is convenient for loop operations, although it is not restricted to this use.

Test (TEST) as a command requests a response from a secondary station. The response is a TEST frame with the received information field, if any, repeated. If the secondary station has insufficient buffering for the information field, a TEST response with no information field is returned.

Beacon (BCN) is a response that a secondary station in a loop transmits when it detects the loss of communication at its input. This permits the primary station in the loop to locate the problem and to take appropriate action. As soon as the input resumes normal status (the problem is corrected), the secondary stops transmitting the Beacon response.

Configure (CFGR) is a response that a secondary station in a loop transmits in response to a configure command. The structure of the response is identical to that of the command. If the low-order bit in the information field is 1, it indicates that the configure function has been sent. If it is 0, it indicates that the configure function has been cleared.

Request Disconnect (RD) is transmitted by a secondary station desiring to be disconnected by the DISC command.

Time-Outs

The primary station operates time-outs for the purpose of maintaining orderly, continuous operation of a data link and for checking for responses to its commands. The time-outs operated for these purposes are idle detect and nonproductive receive.

Idle detect occurs when the primary station transmits a frame with the P bit on in the C field; a response is expected within a specific period of time. In two-way alternate operation, the data link is usually in the idle state when no transmission is taking place. If the idle state continues beyond the time when a response should have been initiated (for example, when the secondary station does not respond to a frame), the primary station detects the idle condition and initiates recovery action.

The interval allowed before recovery action is initiated should include:

- propagation time to the secondary station
- clear-to-send time at the secondary station DCE
- appropriate time for secondary station processing
- propagation time from the secondary station

With either switched or nonswitched configuration, the minimum time-out includes the processing time at the secondary station. The sum of the other variables may be as great as 850 to 900 milliseconds (for a satellite data link). The time-out is reset when a response is received or being received before the time-out expires.

When bits that do not result in frames are being received, a **nonproductive receive** condition exists. This condition could be caused by a secondary station malfunction that causes continuous transmission. The primary station provides a time-out when nonproductive receive occurs. The usual time period ranges from 3 to 30 seconds. If the nonproductive receive condition continues after the time-out, the problem normally is not recoverable at the data link level and must be handled by a method above the data link level.

Abort Conditions

An abort is the termination of the transmission of a frame.

The abort pattern, a minimum of seven consecutive binary 1s with no zero insertion, terminates the frame without an FCS field or an ending flag. An abort is sent by the transmitting station. Zero insertion prevents an unintentional abort.

Following the abort, the link may go to the idle state (15 or more contiguous 1s) or may remain in the active state.

Either a primary or secondary station may send an abort. An abort pattern of seven 1s may be followed by a minimum of eight additional 1s (a total of at least 15 contiguous 1s), or it may be followed by a frame. Seven to fourteen 1s constitute an abort; fifteen or more 1s constitute an idle that continues until a binary zero is detected.

Error Recovery

The methods used to recover from an error condition or data link impasse are Link-Level Recovery and Higher Level Recovery.

Link-Level Recovery occurs at the data link level. SDLC procedures detect errors that may be recovered by retry or by retransmission. For example:

- A busy station that is temporarily unable to continue to receive, reports its condition to the transmitting station.
- Retransmission is initiated when a received Nr count does not confirm the previously transmitted numbered information frames.
- A receiving station rejects a frame when there is a CRC error, a numbered frame is out of numerical order, an information frame is unaccepted because of a busy condition, the ending flag is not separated from the beginning flag by a multiple of 8 bits, or a frame is less than 32 bits long.
- A poll is usually repeated if a response is not received.
- When an attempt to bring a secondary station on-line fails, the command is repeated.

SDLC does not specify procedures for counting retry or retransmission attempts. Retries and retransmissions may be counted by a system that detects whether the situation is link-level recoverable. Usually, they are counted within the DTE and, at a prespecified number, n, the situation is reported as unrecoverable at the data link level. Actions that should be retried are attempts to:

- Obtain acknowledgment of a command.
- Resume communication with a busy station.
- Achieve initial, online status at a secondary station.
- Initiate active communication at a secondary station.

Higher Level Recovery detects errors at the link level. It applies to the address, control, information, and frame check sequence fields of a frame. Errors that cannot be recovered from at the link level include:

- If a secondary station rejects a command with which it is incompatible, only an acceptable alternative command can relieve its error condition. Higher level intervention is required to analyze and act on the status report in the secondary station response.
- If the transmitting station has aborted transmission because of an internal malfunction or an expended retry count, higher level intervention is required to analyze and act on the situation.
- If a secondary station response to the exchange of station identification contains the wrong identification, intervention from a higher level is required to analyze and act on the situation.

The station's decision-making power at a level higher than the data link level determines the type of intervention required. At a terminal, for example, operator intervention may be needed.

Zero Insertion

Two basic characteristics of SDLC require the use of a zero insertion technique:

1. The opening and closing Flag field must be unique to properly define the transmission frame, and
2. The protocol must be transparent to the data bit patterns.

Zero insertion prevents the occurrence of more than five consecutive binary 1s in the Address, Control, Information, and Frame Check Sequence fields. The transmitting station automatically inserts a binary 0 following five binary 1s in every field except a Flag field or when transmitting an abort. The code patterns of the Flag and abort are easily distinguishable. The receiving station automatically discards any 0 following five consecutive 1s. If a 0 does not follow the five 1s, the receiving station checks for a Flag or an abort condition.

Signaling Modes

When using modems that do not provide timing, the station (DTE or terminal) must provide its own. IBM uses the NRZI (Non-Return-to-Zero-Inverted) encoding technique to facilitate this. This invert-on-zero transmission coding method provides a signal change any time a binary 0 is received. Strings of 0s provide transitions that can be detected to maintain synchronization with the received data. Strings of 1s cause zero insertion, which again provides transitions for maintaining synchronization. With modems that provide timing signals, NRZI may or may not be used or required. If NRZI is used, however, it must be used by all DCEs on the data link.

SDLC versus BSC

Binary Synchronous Communications (BSC) was developed in the mid-1960s, and was well suited for the major applications of that time: simple remote job entry and batch transmission. As networking applications and data communications facilities became more sophisticated, however, more powerful SDLC methods gained popularity.

BSC, a simpler protocol than SDLC, is byte oriented, operates in half-duplex only, and requires that each block of data be acknowledged by the receiving station before any further blocks are transmitted. BSC uses the EBCDIC, ASCII, or Six-Bit Transcode and is device dependent, meaning that incompatibilities in the implementation of the protocol may exist between different types of BSC devices.

SDLC is a bit-oriented protocol, permits both half- and full-duplex operation, and can operate with any code. Its frame sequence numbering scheme allows multiple frames (SDLC message units) to be sent before requiring an acknowledgment (buffer storage must be set aside to store the unacknowledged frames). The protocol uses a Module 8 scheme that permits up to seven frames to be sent before requiring an acknowledgment and an optional Module 128 scheme that allows up to 127 frames to be outstanding.

One problem associated with BSC is that of propagation delay. BSC's requirement that every block of data be acknowledged is not propagation delay tolerable. SDLC handles this problem. The fact that the Module 8 (optionally Module 128) allows one acknowledgment frame to confirm up to 7 (127 in some implementations) data frames, coupled with full duplex capability, permits better performance at higher propagation delays and link speeds. ■

IBM Synchronous Data Link Control (SDLC)

In this report:

Synopsis

Editor's Note
SDLC is a bit-oriented protocol for the data link control of a communications channel. Channel configurations are either multipoint or point-to-point, and may be either switched or nonswitched. Transmission may be full- or half-duplex. SDLC provides error detection and recovery procedures for those errors introduced by the communications channel. It permits multiframe transmission before an acknowledgment is required.

Report Highlights
IBM introduced Synchronous Data Link Control (SDLC) to permit the exchange of information among the components of a data processing system. Since its introduction in 1973, SDLC has become the primary data link control procedure offered by IBM. It is used for operations within the IBM Systems Network Architecture (SNA) and is gradually replacing a less efficient transmission procedure, IBM Binary Synchronous Communications (BSC). All of IBM's newer equipment is based on the SDLC protocol.

SDLC provides a uniform technique for managing a single communications line. In a multiple-line environment where, for example, several communications lines are connected to a remote concentrator and several regional concentrators feed a central host, overall control of the communications environment requires a higher level of control. Network control is implemented in the software of the concentrators, host computer front ends, and the host computer itself. SDLC can be used on each communications link independently (i.e., between each terminal and its concentrator and between each concentrator and the host).

Analysis

Configurations

Using SDLC, a number of data link configurations are possible. As with most protocols, stations can be configured as either point-to-point or multipoint. SDLC allows for five basic configuration variations: half-duplex, point-to-point, nonswitched; full-duplex, point-to-point, nonswitched; half-duplex, multipoint, nonswitched; full-duplex, multipoint, nonswitched; and, half-duplex, point-to-point, switched. Station variations are also possible. For example, the primary station may operate in full-duplex mode while the other stations on the multipoint link operate in half-duplex mode.

SDLC is also capable of loop operation, or "hub polling." In this arrangement, the primary station (loop controller) sends command frames to any or all stations on the loop. The secondary stations decode the address field and either accept the frame or pass the frame down the loop. A loop configuration essentially uses a simplex (one-way) line with the originating and ending points terminated at the primary station. Timing is the same as for half-duplex operation without the need for turnarounds. While it is practical for connecting devices close together, the use of the loop configuration for widely separated geographical points incurs substantial line costs. IBM uses a loop configuration for its banking and retail terminal systems to connect multiple stations at the same location.

Stations

A station is the device located at one end of a communications link. Only one station on an SDLC line is a **primary station**; all other stations on that line are **secondary stations**. The primary station initiates all transmissions from secondary stations by inviting or commanding responses from the addressed secondary stations. The primary station can also initiate one-way or interspersed communications between itself and a secondary station. In normal practice, the primary station deals with one secondary station at a time.

The same station can function as either a primary or secondary station in certain situations. For example, a remote processor may function as a primary station when communicating with the terminals and as a secondary station when communicating with the host processor. Procedures exist for requesting that a station return to its primary or secondary status. This capability is normally used for switched network (dial-up) arrangements, but it could be used, with appropriate station programming, to allow alterations in the primary/secondary status of stations connected to a line.

Modes of Operation

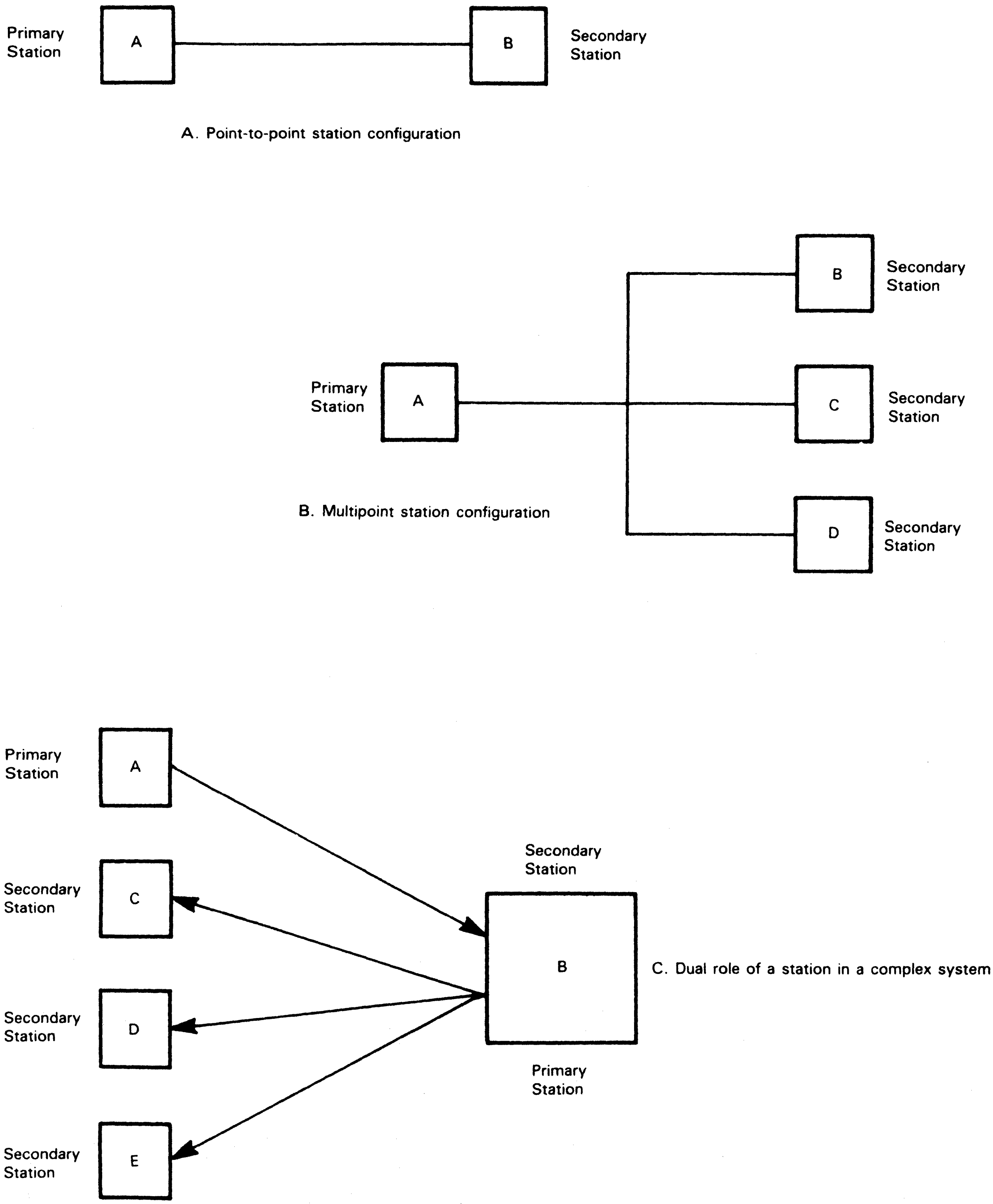
An SDLC link can be in one of three **transmission states**: transient, idle, and active. The *Transient* state occurs when a station is preparing to transmit; it follows the poll (secondary station) and precedes the actual transmission of control information or data. Normally, this is the period between the station signaling the modem with Request-to-Send (RTS) and the modem responding with Clear-to-Send (CTS).

During the *Idle State*, there is no transmission of control information or data; it is identified by a succession of 15 or more consecutive binary 1s. In the *Active State*, control information or data is being transferred.

The primary station is in a permanent command mode. Secondary stations can be in one of three **active modes**, established by the primary station:

- *Normal Response Mode (NRM):* Responds to poll.
- *Normal Disconnect Mode (NDM):* Responds to polls with a request to be put on-line or to be initialized; it ignores other commands. A secondary station that receives and accepts a DISC (Disconnect) command assumes NDM. It also assumes NDM when power is turned on, when the station is enabled for data link operation, following a transient disabling condition such as a power failure, or when a switched connection is made.

Figure 1.
Station Configurations



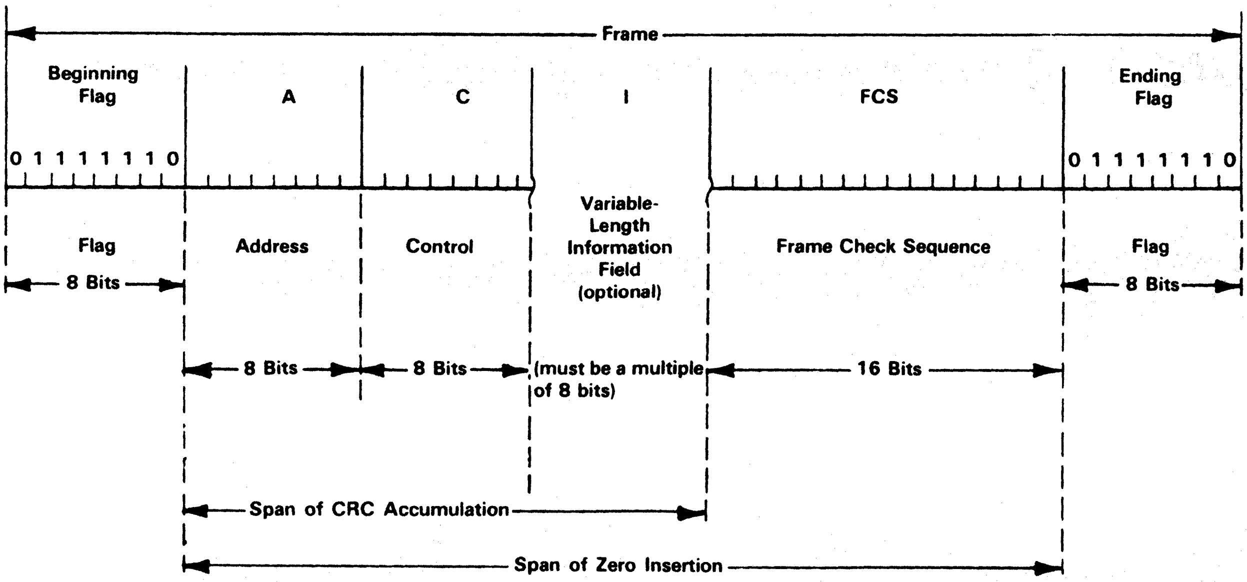
A. Point-to-point station configuration

B. Multipoint station configuration

C. Dual role of a station in a complex system

Besides the basic point-to-point or multipoint configurations, SDLC allows for configuration variations including half or full duplex and switched or nonswitched configurations.

Figure 2.
SDLC Frame Format



The transmission frame consists of Flag-Address-control-information-Frame Check Sequence-Flag. Each field has either eight bits or a multiple of eight bits.

- *Initialization Mode:* Procedures are specified by system components.

If the secondary station is disabled and does not respond to a poll or responds with bits that do not result in frames, a **time-out** procedure is initiated by the primary station to determine the response condition. After a given number of retries, as determined by the procedures for the primary station (typically internal programming), recovery action can be taken. SDLC includes a provision for a transmitting station, either primary or secondary, to abort specific transmission. Recovery is the responsibility of the primary station. A further discussion of the time-out procedure appears later in this report.

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A specific frame layout is used for all transmissions. As illustrated in Figure 2, the transmission frame consists of FLAG-ADDRESS-CONTROL-INFORMATION-FRAME CHECK SEQUENCE-FLAG. Each field contains either eight bits or a multiple of eight bits. Only the Information field is of variable length. The frame format enables a receiving station to determine the beginning and ending of a transmission, the station address, what actions should be taken, specific information for the receiving station, and whether the frame was received without error. Zero insertion prevents unwanted flags from occurring in any of the other fields; it permits completely transparent data transfer.

The **Flag** field, both beginning and ending, is binary 01111110 (Hex 7E). The Idle state of the communications link is all 1s; the presence of a 0 causes the examination of the following bits to see if it matches the Flag pattern. If so, interpretation of the frame begins.

The **Address** field always contains the identity of the secondary station that is communicating with the primary station. In a poll, the Address field identifies the station being polled. In a response, it identifies the transmitting secondary station. For certain applications, it is common to have special addresses that direct frames to certain stations or to all stations on the link. In such cases, a secondary station may have three address types:

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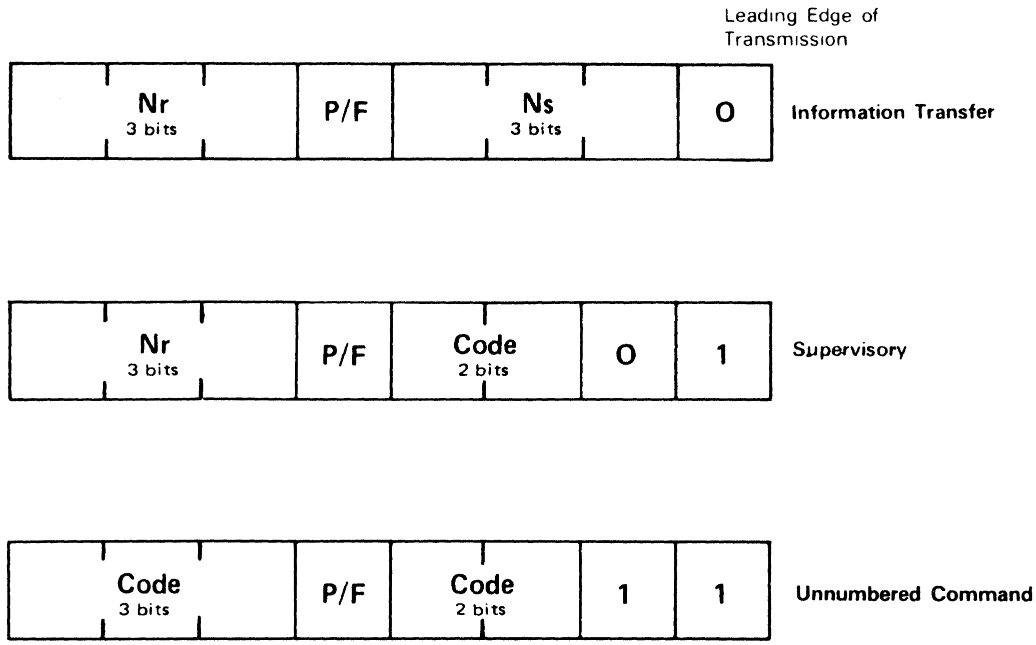

Nr Number of correct frames received since last acknowledgement; 7 maximum

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The Control (C) field defines one of three frame formats:

Table 1. Summary of Command and Response Control Fields

Field Format	Sent Last▼	Binary Configuration	Sent First▼	Acronym	Command	Response	Defining Characteristics
Unnumbered	000	P/F	0011	UI	X	X	Unnumbered command or response that carries information
	000	F	0111	RIM		X	Request initialization mode; initialization needed; expect SIM
	000	P	0111	SIM	X		Set initialization mode; the using system prescribes the procedure
	100	P	0011	SNRM	X		Set normal response mode; transmit on command only
	000	F	1111	DM		X	This station is in disconnect mode
	010	P	0011	DISC	X		Do not transmit or receive information (disconnected)
	011	F	0011	UA		X	Acknowledgement for unnumbered commands (SNRM, DISC, SIM)
	100	F	0111	FRMR		X	Frame reject; invalid frame received; must receive SNRM, DISC, or SIM

- Information Transfer Format—The vehicle used for information or data transfer.
- Supervisory Format—Used in conjunction with Information Transfer Format to convey ready or busy status and to request retransmission when an error is detected, or when frames are received out of sequence.
- Unnumbered Format—Command format for data link management.

The general layout of the Control field formats is shown in Figure 3. Codes are conventionally written by IBM with the low order bit on the left reading to the right; IBM transmits the high-order bit first. Conversely, ANSI ADCCP transmits the least significant bit of the control field first. SDLC is a bit-oriented procedure; bit transmission order is vital to the understanding of the protocol. The frame is shown with the leading edge of transmission to the left, while individual fields are shown with the leading edge of transmission to the right. Thus, the Control field is the third field transmitted (following the Flag and Address fields), and the rightmost bit in Figure 3 is the first bit of the Control field transmitted. In the Control field, the first two bits transmitted identify the format as either Information, Supervisory, or Unnumbered.

All three Control field formats contain a poll/final (P/F) bit. A secondary station receives the P

Table 1. Summary of Command and Response Control Fields (Continued)

Field Format	Sent Last♦	Binary Configuration	Sent First♦	Acronym	Command	Response	Defining Characteristics
	111	F	1111	BCN		X	Beacon; signals loss of input
	110	P/F	0111	CFGR	X	X	Configure; contains function descriptor in information field
	010	F	0011	RD		X	Request disconnect; this station wants to disconnect
	101	P/F	1111	XID	X	X	Exchange station identification; identification in information field
	001	P	0011	UP	X		Unnumbered poll; response optional if P bit not on
	111	P/F	0011	TEST	X	X	Test pattern in information field
Supervisory	Nr	P/F	0001	RR	X	X	Ready to receive
	Nr	P/F	0101	RNR	X	X	Not ready to receive
	Nr	P/F	1001	REJ	X	X	Reject; transmit or retransmit, starting with frame Nr
Information	Nr	P/F	Ns 0	I	X	X	Sequenced I-frame

(poll) bit from the primary station. The P bit requires the secondary station to initiate transmission. The F (final) bit is transmitted by the secondary station to the primary station; it is inserted into the last frame to indicate the end of a transmission.

The bit patterns of the commands and responses are summarized in Table 1.

In the **Information Transfer Format**, the Control Field contains information that tracks the number and sequence of frames sent and received. A station transmitting numbered information frames counts each frame and sends the count with the frame. This count is a sequence number known as **Ns**. This sequence number is checked at the receiving end for missing or duplicated frames.

A station receiving numbered information frames accepts each numbered information frame that it receives, checks that it is error free and in sequence and, if so, advances its receive count for each such frame. The receiver count is called **Nr**. If the received frame is error free, a receiving station's Nr count is the same as the Ns count that it will receive in the next frame; that is, a count of one greater than the Ns count of the last frame received. The receiver confirms accepted numbered information frames by returning its Nr count to the transmitting station.

The Nr count at the receiving station advances when a frame is checked and found to be error free and in sequence; Nr then becomes the count of the "next-expected" frame and should

Table 2. SDLC — BSC Comparison

Capability	SDLC	BSC
Acknowledgement to text	May be combined with data	Separate sequence
Addressing	In every frame	Separate sequence
Block checking	In every frame	Text/header sequences only
Capable of handling long propagation delays	Yes	No
Character-code sensitive	No	Yes
Half or full duplex	Both	half duplex
Line/mode dependent	No	Yes
Modulo (message) count	128	2
Polling	In every frame	Separate sequence
Susceptible to missed or duplicated blocks	No	Yes
Transparent text	Inherent	Special feature
Topology dependent	No	Yes
Variable-length text	Yes	Yes

agree with the next incoming Ns count. If the incoming Ns does not agree with Nr, the frame is out of sequence and Nr does not advance. Out-of-sequence frames are not accepted. The receiver does, however, accept the incoming Nr count (for confirmation purposes) if the out-of-sequence frame is otherwise error free.

The counting capacity for Nr and Ns is 128. Up to 127 unconfirmed, numbered information frames may be outstanding (transmitted but not confirmed) at the transmitter. All unconfirmed frames are retained by the transmitter in case it is necessary to retransmit some or all of them if transmission errors or buffering constraints occur. The reported Nr count is the number of the next frame that the receiver expects to receive.

The Nr and Ns counts of both stations are initialized—set to 0—by the primary station. The counts advance as numbered frames are sent and received.

In the **Supervisory Format**, a code identifies three supervisory commands/responses: RR, RNR, and REJ. These commands and responses are interspersed with Information frames to supplement traffic control.

Receive Ready (RR) is sent by either the primary or a secondary station. It acknowledges numbered frames through Nr-1 and indicates that the station sending RR is ready to receive.

Receive Not Ready (RNR) is sent by either the primary or a secondary station and indicates a temporary busy condition due to buffering or other internal constraints. To indicate the clearing of an RNR condition, a primary station transmits an I frame with the P bit on, or an RR or REJ frame with the P bit on or off. A secondary station indicates that an RNR condition has been cleared by transmitting an I frame with the F bit on, or an RR or REJ frame with the F bit on or off.

The *Reject (REJ)* command or response is sent by either the primary or a secondary station to request transmission or retransmission of numbered frames. REJ acknowledges that frames through Nr-1 were received without error and requests retransmission of numbered information frames starting at the Nr contained in the REJ frame. The REJ command or response may be interspersed in the sequence of transmitted frames. The REJ condition is cleared by the receipt of the requested frame or when a mode setting command has been correctly received.

The **Unnumbered Format** provides the commands and responses for the basic control of information exchanges. There are a total of 14 Unnumbered Information (UI) commands and responses. One command and response pair (Set Initialization Mode and Request for Initialization) uses the same code, but is assigned different names. The interpretation is established according to which station sent the frame (primary or secondary).

The three commands most often used by a primary station are the mode setting commands: SNRM, DISC, and SIM.

The *Set Normal Response Mode (SNRM)* command is used typically in line start-up procedures, when a secondary station has been previously disconnected, either through a UI command or a transient terminal condition, and to recover from a garbled command to which the secondary station has given a Frame Reject (FRMR) response.

The *Disconnect (DISC)* command terminates other modes while placing the receiving station in disconnected mode.

The *Set Initialization Mode (SIM)* command initiates system procedures to initialize link-level functions. SIM resets the primary and secondary station Nr and Ns counts to zero.

The four most common unnumbered responses from a secondary station are UA, RIM, DM, and FRMR.

Unnumbered Acknowledgment (UA) is the affirmative response to a DISC, SIM, or SNRM command.

Request Initialization Mode (RIM) is sent by the secondary station to notify the primary station that a SIM command is needed. Following a RIM response, a secondary station will only recognize a SIM command.

Disconnect Mode (DM) is the response of a disconnected secondary station to indicate its status.

Frame Reject (FRMR) is the response of a secondary station when it receives an invalid frame. A frame may be invalid if the I field is longer than the receiving station's buffers, if the C field is not implemented by the receiving station, if the C field prohibits a received I field within a frame, or if a sequence error is discovered that cannot be resolved by retransmission. The receiving station responds with FRMR until it receives an acceptable mode setting command: SNRM, DISC, or SIM.

The remaining seven commands/responses, outlined below, are used for special purposes.

Unnumbered Information (UI) is used to transfer commands or responses that use the I field for supplemental information. This frame is not acknowledged and is not counted in sequence checking procedures. Successful transfer can only be checked by subsequent actions or UI transfers.

Exchange Station Identification (XID), whether as a command or response, solicits or returns the identification of the receiving station. A system-defined I field can be included. The principal use of this command is to establish station identities when completing a switched network connection, although it is not restricted to this use.

Unnumbered Poll (UP) permits an uninvited poll with no response required or a command poll with response required. The use of the P bit determines which is intended. (It is a command when the P bit is on and an invitation when the P bit is off.) This command is convenient for loop operations, although it is not restricted to this use.

Test (TEST) as a command requests a response from a secondary station. The response is a TEST frame with the received information field, if any, repeated. If the secondary station has insufficient buffering for the information field, a TEST response with no information field is returned.

Beacon (BCN) is a response that a secondary station in a loop transmits when it detects the loss of communication at its input. This permits the primary station in the loop to locate the problem and to take appropriate action. As soon as the input resumes normal status (the problem is corrected), the secondary stops transmitting the Beacon response.

Configure (CFGR) is a response that a secondary station in a loop transmits in response to a configure command. The structure of the response is identical to that of the command. If the low-order bit in the information field is 1, it indicates that the configure function has been sent. If it is 0, it indicates that the configure function has been cleared.

Request Disconnect (RD) is transmitted by a secondary station desiring to be disconnected by the DISC command.

Time-Outs

The primary station operates time-outs for the purpose of maintaining orderly, continuous operation of a data link and for checking for responses to its commands. The time-outs operated for these purposes are idle detect and nonproductive receive.

Idle detect occurs when the primary station transmits a frame with the P bit on in the C field; a response is expected within a specific period of time. In two-way alternate operation, the data link is usually in the idle state when no transmission is taking place. If the idle state continues beyond the time when a response should have been initiated (for example, when the secondary station does not respond to a frame), the primary station detects the idle condition and initiates recovery action.

The interval allowed before recovery action is initiated should include:

- propagation time to the secondary station
- clear-to-send time at the secondary station DCE
- appropriate time for secondary station processing
- propagation time from the secondary station

With either switched or nonswitched configuration, the minimum time-out includes the processing time at the secondary station. The sum of the other variables may be as great as 850 to 900 milliseconds (for a satellite data link). The time-out is reset when a response is received or being received before the time-out expires.

When bits that do not result in frames are being received, a **nonproductive receive** condition exists. This condition could be caused by a secondary station malfunction that causes continuous transmission. The primary station provides a time-out when nonproductive receive occurs. The usual time period ranges from 3 to 30 seconds. If the nonproductive receive condition continues after the time-out, the problem normally is not recoverable at the data link level and must be handled by a method above the data link level.

Abort Conditions

An abort is the termination of the transmission of a frame.

The abort pattern, a minimum of seven consecutive binary 1s with no zero insertion, terminates the frame without an FCS field or an ending flag. An abort is sent by the transmitting station. Zero insertion prevents an unintentional abort.

Following the abort, the link may go to the idle state (15 or more contiguous 1s) or may remain in the active state.

Either a primary or secondary station may send an abort. An abort pattern of seven 1s may be followed by a minimum of eight additional 1s (a total of at least 15 contiguous 1s), or it may be followed by a frame. Seven to fourteen 1s constitute an abort; fifteen or more 1s constitute an idle that continues until a binary zero is detected.

Error Recovery

The methods used to recover from an error condition or data link impasse are Link-Level Recovery and Higher Level Recovery.

Link-Level Recovery occurs at the data link level. SDLC procedures detect errors that may be recovered by retry or by retransmission. For example:

- A busy station that is temporarily unable to continue to receive, reports its condition to the transmitting station.
- Retransmission is initiated when a received Nr count does not confirm the previously transmitted numbered information frames.
- A receiving station rejects a frame when there is a CRC error, a numbered frame is out of numerical order, an information frame is unaccepted because of a busy condition, the ending flag is not separated from the beginning flag by a multiple of 8 bits, or a frame is less than 32 bits long.
- A poll is usually repeated if a response is not received.
- When an attempt to bring a secondary station on-line fails, the command is repeated.

SDLC does not specify procedures for counting retry or retransmission attempts. Retries and retransmissions may be counted by a system that detects whether the situation is link-level recoverable. Usually, they are counted within the DTE and, at a prespecified number, n, the situation is reported as unrecoverable at the data link level. Actions that should be retried are attempts to:

- Obtain acknowledgment of a command.
- Resume communication with a busy station.
- Achieve initial, online status at a secondary station.
- Initiate active communication at a secondary station.

Higher-Level Recovery detects errors at the link level. It applies to the address, control, information, and frame check sequence fields of a frame. Errors that cannot be recovered from at the link level include:

- If a secondary station rejects a command with which it is incompatible, only an acceptable alternative command can relieve its error condition. Higher level intervention is required to analyze and act on the status report in the secondary station response.
- If the transmitting station has aborted transmission because of an internal malfunction or an expended retry count, higher level intervention is required to analyze and act on the situation.
- If a secondary station response to the exchange of station identification contains the wrong identification, intervention from a higher level is required to analyze and act on the situation.

The station's decision-making power at a level higher than the data link level determines the type of intervention required. At a terminal, for example, operator intervention may be needed.

Zero Insertion

Two basic characteristics of SDLC require the use of a zero insertion technique:

1. the opening and closing Flag field must be unique to properly define the transmission frame and,
2. the protocol must be transparent to the data bit patterns.

Zero insertion prevents the occurrence of more than five consecutive binary 1s in the Address, Control, Information, and Frame Check Sequence fields. The transmitting station automatically inserts a binary 0 following five binary 1s in every field except a Flag field or when transmitting an abort. The code patterns of the Flag and abort are easily distinguishable. The receiving station automatically discards any 0 following five consecutive 1s. If a 0 does not follow the five 1s, the receiving station checks for a Flag or an abort condition.

Signaling Modes

When using modems that do not provide timing, the station (DTE or terminal) must provide its own. IBM uses the NRZI (Non-Return-to-Zero-Inverted) encoding technique to facilitate this. This invert-on-zero transmission coding method provides a signal change any time a binary 0 is received. Strings of 0s provide transitions that can be detected to maintain synchronization with the received data. Strings of 1s cause zero insertion, which again provides transitions for maintaining synchronization. With modems that provide timing signals, NRZI may or may not be used or required. If NRZI is used, however, it must be used by all DCEs on the data link.

SDLC vs. BSC

Binary Synchronous Communications (BSC) was developed in the mid-1960s, and was well suited for the major applications of that time: simple remote job entry and batch transmission. As networking applications and data communications facilities became more sophisticated, however, more powerful SDLC methods gained popularity.

BSC, a simpler protocol than SDLC, is byte oriented, operates in half-duplex only, and requires that each block of data be acknowledged by the receiving station before any further blocks are transmitted. BSC uses the EBCDIC, ASCII, or Six-Bit Transcode and is device dependent, meaning that incompatibilities in the implementation of the protocol may exist between different types of BSC devices.

SDLC is a bit-oriented protocol, permits both half- and full-duplex operation, and can operate with any code. Its frame sequence numbering scheme allows multiple frames (SDLC message units) to be sent before requiring an acknowledgment (buffer storage must be set aside to store the unacknowledged frames). The protocol uses a Module 8 scheme that permits up to seven frames to be sent before requiring an acknowledgment and an optional Module 128 scheme that allows up to 127 frames to be outstanding.

One problem associated with BSC is that of propagation delay. BSC's requirement that every block of data be acknowledged is not propagation delay tolerable. SDLC handles this problem. The fact that the Module 8 (optionally Module 128) allows one acknowledgment frame to confirm up to 7 (127 in some implementations) data frames, coupled with full duplex capability, permits better performance at higher propagation delays and link speeds. ■