HDLC (High level Data Link Control)

Modem, EIA-232,
HDLC Framing and Procedures

Agenda

- **Line Management, Modems**
- **Introduction HDLC**
- **Station Types, Modes of Operation**
- **Frame Format, Frame Types**
- **Protocol Procedures**
- **HDLC Classes**

Line Protocol Basics

- **line protocol basics already explained**
  - serial transmission techniques
    - bit-synchronization
    - asynchronous/synchronous transmission, encoding
    - frame-synchronization, bitstuffing
    - frame protection, error detection
  - connectionless versus connected oriented service
  - error recovery based on ARQ
    - IdleRQ, Continuos RQ
    - error control strategies (e.g. GoBackN)
    - sequence numbers
    - windowing
  - flow control

Additional Issues

- **connection oriented service requires**
  - line management procedures in order to establish, to maintain and to clear a connection
- **in the early days of data communications**
  - analogous telephone network for data transport
    - Modem in order to transport digital data
  - line protocols must handle additional line management procedures
    - for support of half duplex physical lines
    - for support of multipoint lines
    - done with help of modem control functions
- **line protocol standards used today reflect this early days requirements**

Modem

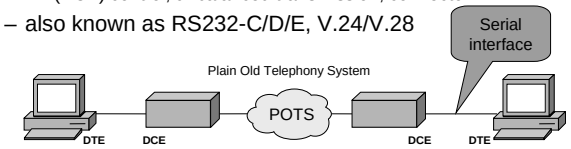
- **Modulator / Demodulator**
  - modem adapts digital (rectangle) signals in order to be transported over analogous telephone network
    - limited bandwidth (200 - 3500 Hz)
  - done by different modulation techniques
    - AM, FM, Phase-Modulation, QAM, Trellis-Code, etc.
  - 1st Wave
    - Frequency Division Protocols, all rates to 2400 bits/s
      - Modems: advanced analog filters
      - Telco: pass audio frequencies of 200 Hz to 2.4 KHz
  - 2nd Wave
    - 1st generation Echo Canceling Protocols, 9600 & 14400 bits/s
      - Modems: low cost DSPs
      - Telco: pass audio frequencies of 200 Hz to 2.4 KHz

Modem (cont.)

  - 3rd Wave
    - 2nd gen. Echo Canceling Protocols, rates to 28.8 Kbits/s
      - Modems: higher performing, low cost DSPs
      - Telco: pass audio frequencies of 200 Hz to 2.8 KHz
  - 4th Wave
    - extending Echo Canceling Protocols, rates to 33.6 Kbits/s
      - Modems: higher performing, low cost DSPs
      - Telco: pass audio frequencies of 200 Hz to 3.1 KH
  - 5th Wave
    - Digital stepping protocols, 34 Kbits/s to 56 Kbits/s
      - Modems: higher performing, low cost DSPs
      - Telco: pass audio frequencies of 200 Hz to 3.1 KHz, all digital path to subscriber line, 64K PCM digital to analog conversion, limited loop length, no line conditioners

Modem Control by EIA-232 / V.24

- **EIA-232 / V.24 standard**
  - serial interface definition between a DCE and DTE
    - DTE (Data Terminal Equipment e.g. end system)
    - DCE (Data Circuit Terminating Equipment e.g. modem)
  - for short distance and low speed connectivity
  - specifies a set of physical lines and necessary electrical / mechanical aspects
    - data signals for serial transmission, control signals for modem (DCE) control, unbalanced transmission, connector
  - also known as RS232-C/D/E, V.24/V.28



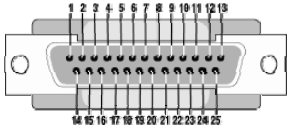
EIA-232 Data and Control Signals

  - data signals:
    - transport of serial data bitstream
    - TxD (Transmit Data) DTE -> DCD
    - RxD (Receive Data) DCE -> DTE
  - control signals:
    - control function between modem and end system
    - RTS (Request To Send) DTE -> DCE
      - DTE requests permission to send data to modem
    - CTS (Clear To Send) DCE-> DTE
      - DCE grants permission to send
    - DCD (Data Carrier Detect) DCE -> DTE
      - DCE indicates that it is receiving carrier from remote modem
    - DSR (Data Set Ready) DCE -> DTE
      - DCE indicates that it is operational (the modem is powered on)

EIA-232 Control Signals (cont.)

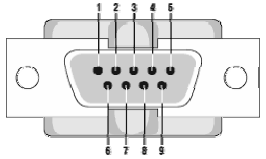
- control signals (cont.)
  - DTR (Data Terminal Ready) DTE -> DCE
    - DTE indicates that it is operational (the end system is powered on)
  - RI (Ring Indicator) DCE -> DTE
    - DCE indicates that the phone is ringing
  - Transmitter Signal Element Timing DCE -> DTE
    - used in synchronous mode to provide clock to the DTE for TxD
  - Receiver Signal Element Timing DCE -> DTE
    - used in synchronous mode to provide clock to the DTE for RxD
  - Transmitter Signal Element Timing Return DTE -> DCE
- EIA-232 specified limits:
  - Length: 15m, 30m
  - Speed: 20kbit/sec, 64kbit/sec / Practice: up to 200kbit/sec

EIA-232 Pinout DB-25



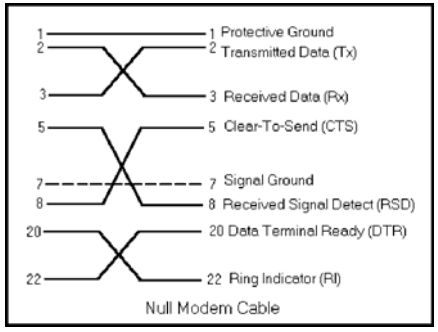
2 Transmit Data (TxD)
3 Receive Data (RxD)
4 Request to Send (RTS)
5 Clear to Send (CTS)
6 Dataset Ready (DSR)
7 Signal Ground
8 Data Carrier Detect (DCD)
15 Transmit Clock
17 Receive Clock
20 Data Terminal Ready (DTR)
24 Auxiliary Clock

EIA-232 Pinout DE-9



1 Data Carrier Detect (DCD)
2 Transmit Data (TxD)
3 Receive Data (RxD)
4 Data Terminal Ready (DTR)
5 Signal Ground
6 Dataset Ready (DSR)
7 Request to Send (RTS)
8 Clear to Send (CTS)
9 Ring Indicator (RI)

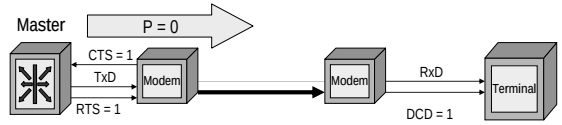
EIA-232 Null Modem Cable



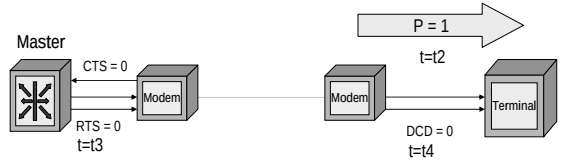
Half Duplex Support

- **half duplex line means**
  - only one side can use physical line for transmitting (operation mode of old modems)
- **control of half duplex line**
  - right to use the physical line (right to send a frame) is exchanged between partners
    - could be compared with Token rotation in Token ring LANs
  - only possessor of the Token is allowed to send frames
    - P/F functions as Token in HDLC procedures
  - possessor of first Token is determined through a fixed Master - Slave relationship

P/F Procedure on Half Duplex Line 1

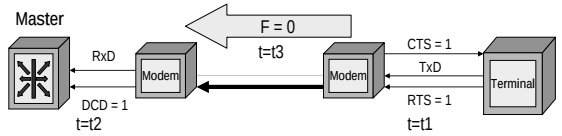


t=t1 master sends frame(s) to slave, modems allow physical transmission left-to-right

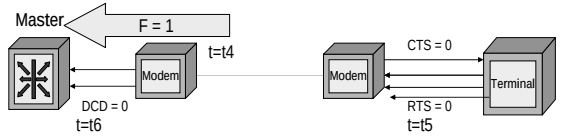


master send last frame to slave, modem left is deactivated for sending by removing of RTS signal, modem right stops receiving

P/F Procedure on Half Duplex Line 2



modem right is activated for sending by RTS signal, modem left starts receiving, slave sends frame(s) to master



slave send last frame to master, modem right is deactivated for sending by removing of RTS signal, modem left stops receiving

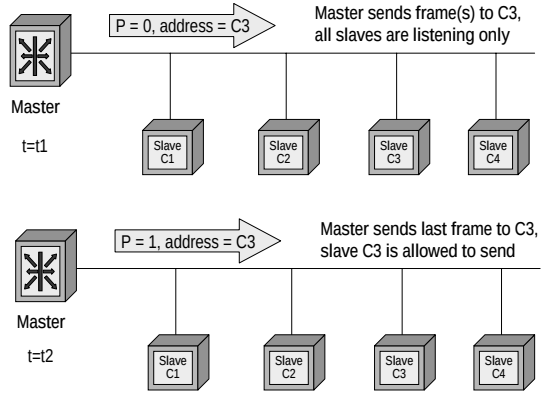
Multipoint Support

- **in order to save costs for transmission lines**
  - modem sharing devices were developed
  - many stations share one physical line
- **physical line can be used only by two stations at the same time**
  - in case of a full duplex physical line
- **in most cases**
  - star shaped point-to-point communication between one central station and many remote stations was needed
    - one central mainframe computer, many terminals
      - FEP (Front-End-Processor), CCs (Cluster Controllers)
    - note: roots of line protocols were terminal networks

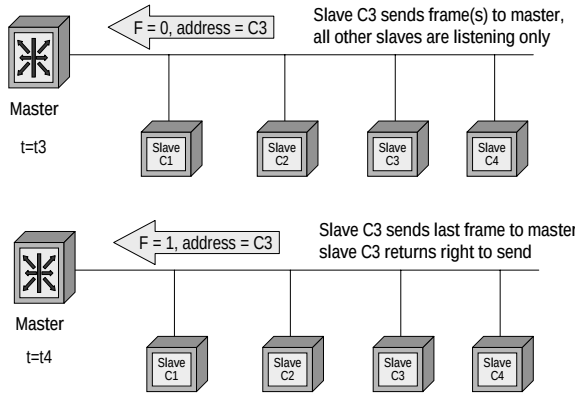
P/F Procedure

- **simple station hierarchy was sufficient for star shaped communication**
  - central station is master of multipoint line
  - remote stations are slaves of multipoint line
  - slaves can not communicate among each other
- **master of multipoint line**
  - is responsible for control of multipoint line
- **control is done by P(oll)/F(inal) procedure**
  - P invites a slave to transmit frame(s) to the master
  - F marks last frame sent by a slave
  - slave identification is done by an address

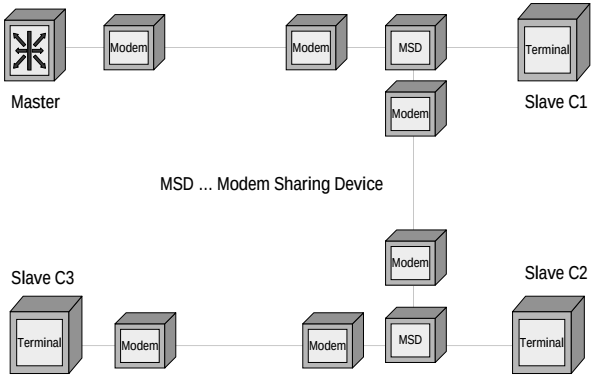
P/F Procedure on Multipoint Line 1



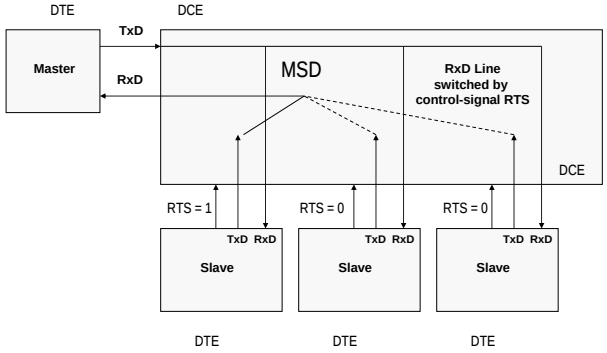
P/F Procedure on Multipoint Line 2



Multipoint Line in Reality



Modem Sharing Device



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- **Protocol Procedures**
- **HDLC Classes**

HDLC

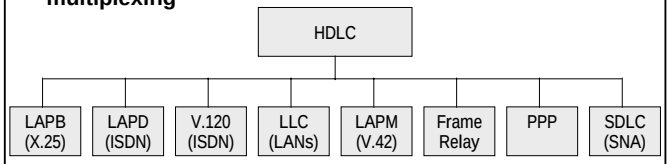
- **High-level Data Link Control**
- **most widely used data link control protocol based on building elements**
  - synchronous transmission
  - bit-oriented line protocol using bitstuffing
  - Continuos RQ with GoBackN, piggybacked ACK
  - P/F procedure
- **provides many options**
  - half-duplex and full-duplex transmission
  - point-to-point and multipoint configuration
  - switched or non-switched channels

HDLC

- **covers therefore a broad range of applications**
- **HDLC roots are**
  - terminal networks
- **because of the universal procedures**
  - successful also in computer networks
- **HDLC standardization was done by ISO**
- **has been used as a basis for a number of other data link layer protocols**

HDLC Family

- **LAPB - Link Access Procedure Balanced**
  - link layer protocol for X.25
- **LAPD - Link Access Procedure D-Channel**
  - ISDN
- **V.120 - used on ISDN terminal adapters for multiplexing**
- **LAPM - Link Access Procedure for Modems**
- **PPP - Point-to-Point Protocol**
  - encapsulates network PDUs and identifies protocol type
- **SDLC - Synchronous Data Link Control (IBM)**



Standards HDLC and Family

- **HDLC standards**
  - ISO 3309 HDLC frame structure
  - ISO 4335 HDLC elements of procedure
  - ISO 7478 HDLC multilink procedures (MLP)
  - ISO 7809 HDLC class of procedures
  - ISO 8885 HDLC exchange data link identification (XID)
- **Family**
  - ISO 7776 LAPB
  - ISO 8471 LAPB address information
  - ISO 8802/2 LLC
  - ITU-T I.441 LAPD

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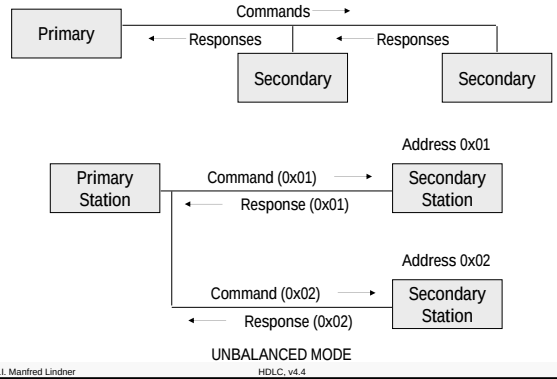
Primary / Secondary Station

- **primary station**
  - acts as a master
  - transmits command frames
  - receives response frames
  - maintains a separate session with each station on multipoint line
- **secondary station**
  - acts as a slave to the primary station
  - receive command frames
  - transmits response frames
  - secondary stations cannot communicate directly

Line Configuration Unbalanced Mode

- **unbalanced mode**
  - one primary and one or more secondary stations
  - primary is responsible for controlling each secondary
  - primary establishes and maintains the link and is responsible for triggering error recovery
  - can be used on point-to-point and multipoint lines
- **addressing**
  - secondary stations only have an address
  - command frames contain address of selected secondary station
  - response frames contain address of responding secondary station

Unbalanced Mode / HDLC Addressing



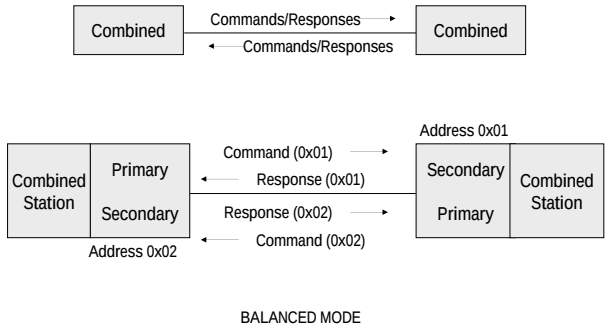
Line Configuration Balanced Mode

- **balanced mode**
  - can be used on point-to-point lines only
  - stations are peers on the link and share equal responsibility for error recovery and line management
  - combined station type is required
- **for peers with equal responsibility**
  - a new type of station was necessary
  - combined station

Combined Station

- **combined station**
  - contains protocol components of primary and secondary in one physical station
  - transmits both commands and responses
  - receives both commands and responses
  - uses line addresses to distinguish between command and response frames
    - frame received with own address -> command
    - frame received with partner address -> response
    - frame transmitted with own address -> response
    - frame transmitted with partner address -> command

Balanced Mode / HDLC Addressing



Modes of Operation

- **for unbalanced line configuration two operating modes are defined**
  - NRM Normal Response Mode
  - ARM Asynchronous Response Mode
- **for balanced line configuration one operating mode is defined**
  - ABM Asynchronous Balanced Mode

Modes of Operation

- **Normal Response Mode - NRM**
  - requires the secondary to receive explicit permission from the primary before transmitting
  - after permission, secondary initiates a response transmission that may contain data
  - the last response frame returns the permission for transmitting to the primary
  - after the last frame transmission, secondary must again wait for explicit permission
  - polling done by primary
  - mode best suited to half duplex physical lines and used frequently on multipoint lines

Modes of Operation

- **Asynchronous Response Mode - ARM**
  - allows a secondary to initiate transmission without explicit permission from the primary
  - a full duplex physical line is necessary
  - can reduce overhead because secondary does not need to wait for polling sequence
  - primary still responsible for line management and triggering of error recovery
  - on multipoint lines only one secondary can be in ARM mode
  - ARM is used very little today

Modes of Operation

- **Asynchronous Balanced Mode - ABM**
  - uses combined stations
  - station may initiate transmission without prior permission from the other station
  - both stations are equally responsible for error recovery and can establish and clear a connection
  - ABM is the best choice for point-to-point links

Non Operational Modes

- **Normal Disconnected Mode - NDM**
  - for unbalanced mode
  - secondary not ready to receive any I or S frame
- **Asynchronous Disconnected Mode - ADM**
  - for balanced mode
  - combined station not ready to receive any I or S frame
- **Initialization Mode - IM**
  - used for initialization of stations (download of software) or exchange of parameters between stations
    - e.g. SNA NCP download using U frames of type RIM or SIM

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Frame Format

- **an HDLC frame consists of**
  - flag fields (F) - 8 bit
  - address field (A) - 8 or 16 bit
    - in unbalanced mode, commands AND responses contain the address of the secondary station
    - in balanced mode, commands contain the receiver address and responses contain the sender address
  - control field (C) - 8 or 16 bit
    - contains frame type and corresponding protocol elements
  - information field (I) - variable, not used in some frames
    - contains the actual data
  - frame check sequence (FCS) - 16 or 32 bit
    - uses standard CRC-16, CRC-32

Frame Format

- **special sequences**
  - flag 01111110 (7E hex)
  - abort at least 7, but fewer than 15 Ones
  - idle 15 or more Ones
- **HDLC is code transparent**
  - uses bit stuffing (zero insertion) if flag sequence would appear within frame
- **control field**
  - three formats and hence three principle frame types
    - I (Information) format -> I - frame
    - S (Supervisory) format -> S - frame
    - U (Unnumbered) format -> U - frame

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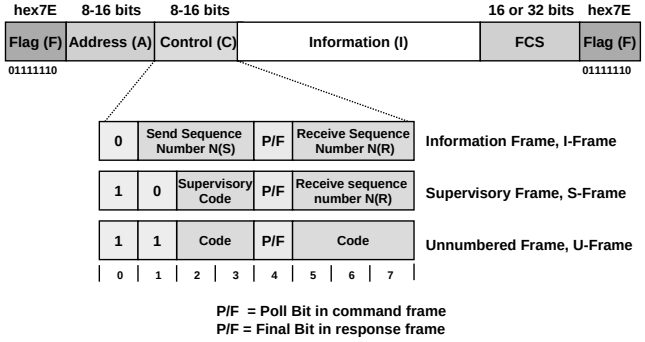
HDLC Frame Format



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Supervisory Frames

1	0	Supervisory Code	P/F	Receive Sequence Number N(R)

Supervisory Code	
0	0	RR (Receiver Ready)
0	1	REJ (Reject)
1	0	RNR (Receiver Not Ready)
1	1	SREJ (Selective Reject)

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Unnumbered Frames

1	1	Code	P/F	Code

Code		Code			Command	Response
0	0	0	0	0	UI	UI
0	0	0	0	1	SNRM	
0	0	0	1	0	DISC	RD
0	0	1	0	0	UP	
0	0	1	1	0		UA
0	1	0	0	0	NR0	NR0
0	1	0	0	1	NR1	NR1
0	1	0	1	0	NR2	NR2
0	1	0	1	1	NR3	NR3
1	0	0	0	0	SIM	RIM
1	0	0	0	1		FRMR
1	1	0	0	0	SARM	DM
1	1	0	0	1	RSET	
1	1	0	1	0	SARME	
1	1	0	1	1	SNRME	
1	1	1	0	0	SABM	
1	1	1	0	1	XID	XID
1	1	1	1	0	SABME	

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Frame-Types

Connection-Oriented

I	Information
RR	Receiver Ready
REJ	Reject
RNR	Receiver Not Ready
SREJ	Selective Reject
SNRM	Set Normal Response Mode
SABM	Set Async Balanced Mode
SARM	Set Async Response Mode
SNRME	Set NRM Extended Mode
SABME	Set ABM Extended Mode
SARME	Set ARM Extended Mode
DISC	Disconnect
UA	Unnumbered Acknowledge
RSET	Reset
FRMR	Frame Reject
RD	Request Disconnect
DM	Disconnect Mode

Connection-Less

UI	Unnumbered Information

Miscellaneous

XID	Exchange Identification
UP	Unnumbered Poll
SIM	Set Initialization Mode
RIM	Request Initialization Mode
NR0-3	Non-Reserved 0

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HDLC Data Link Services

- **HDLC can provide connection-oriented service**
  - setup of connection done by U-frames
    - SNRM, SARM, SABM, UA
  - I-frames and S-frame can be used only after connection setup
    - I, RR, RNR, REJ, SREJ
  - clearing of a connection done by U-frames
    - DISC, UA
- **HDLC can provide connectionless service**
  - only U-frames can be used
    - UI for data transport

I - Frames

- **are used to transmit user data between stations**
  - requires connection setup
  - Send Sequence Number N(S)
  - Receive Sequence Number N(R)
    - piggyback acknowledgement
  - range of sequence numbers (3 bit)
    - normal mode (SNRM, SARM, SABM)
    - 0 - 7
    - maximum send window = 7
  - range of sequence numbers (7 bit)
    - extended mode (SNRME, SARME, SABME)
    - 0 - 127
    - maximum send window = 127

S - Frames

- **perform control functions**
  - like acknowledgement, request for retransmission, flow control
  - usage depends on the operation mode / class of procedures
  - Receiver Ready (RR) is used as acknowledgement in case no I frame is waiting to transmit
  - additionally RR indicates that station can accept frames (flow control - GO)
  - Receiver Not Ready (RNR) indicates that a station is temporarily not ready to receive frames (flow control - STOP) but also used to acknowledge
  - RR and RNR can be used for keepalive, RR can be used for polling in case of NRM

Error Recovery with Checkpointing

- **request for retransmission**
  - is done with checkpointing
  - primary triggers with P = 1 exchange information of current/actual state of N(R) numbers
  - retransmission in case of missing acknowledgements
    - GoBackN with N = N(R)
  - delayed or triggered GoBackN
    - no explicit NACK frame used
    - RR or RNR contains corresponding N(R) number for GoBackN
- **checkpointing is**
  - basic error recovery method for all HDLC operational modes

Error Recovery with REJ / SREJ

- **optional methods for error recovery use reject (REJ) or selective reject (SREJ) frames**
- **REJ can be used to initiate retransmission as soon as error is recognized**
  - REJ is real NACK frame
  - it is not necessary to wait for triggering of checkpoint done by primary
  - GoBackN with N = N(R) of REJ frame
- **SREJ can be used to request selectively retransmission of a frame**
  - requests frame with number N(R)

The P/F-Bit

- **use of P/F-bit depends on mode of operation**
  - NRM, ARM, ABM
- **name of P/F-bit (P = poll, F= final)**
  - can be explained with its original usage in NRM mode on half duplex physical lines
- **general rule for all modes**
  - bit is a P bit in command frames (the address field contains the address of the receiving station)
  - bit is a F bit in response frames (the address field contains the address of the sending station)
  - only recognized when set to 1

The P/F-Bit

- **general rule for all modes (cont.)**
  - primary station uses the P bit to trigger a response from the secondary
  - secondary station uses the F bit to indicate the corresponding response
  - if primary station has sent a command with P = 1, the primary must wait until secondary has sent a response frame with F = 1, before a new command with P = 1 can be transmitted
  - this exchange of P and F marks a synchronization point for error recovery -> checkpointing

P/F-Bit in NRM Mode

- **used for exchange of transmission right (Token) between primary and secondary**
  - primary station gives Token to secondary station with a command frame and P = 1 (primary polls secondary)
  - after a command frame with P = 1 is received the secondary station can send a sequence of response frames to the primary with F = 0
  - the last response frame is marked with F = 1 and returns the Token back to the primary station
  - after a response frame with F = 1 is received the primary station can use the half duplex link again
- **used for checkpointing**
  - the adequate error recovery method for half duplex lines

P/F-Bit in ARM/ABM Mode

- **remember:**
  - in ARM or ABM mode secondary station (secondary component in case of combined station) can transmit without explicit permission by the primary
- **P/F - bit used to trigger error recovery only**
  - if primary station sends a command frame with P = 1 the secondary should send a response frame with F = 1 as soon as possible
  - checkpoint marking

Checkpointing in ARM/ABM mode

- **checkpointing method**
  - ARM: whenever a frame with P = 1 or F = 1 is received
    - stations perform a check which frames are not acknowledged so far using the N(R) field of these frames
    - if there are any unacknowledged frames retransmission is started with GoBackN method (N = value of received N(R)
  - in ABM mode this is done only if a frame with F = 1 is received
    - combined station contains primary and secondary component
- **checkpointing is of course the adequate error recovery method for NRM**
  - combined with Token exchange for half duplex control

U - Frames

- **are used for control purposes**
  - like link establishment
    - SNRM (set normal response mode), SARM, SABM
    - UA (unnumbered acknowledgement)
    - SNRME, SARME, SABME (E ... extended sequence numbers)
  - link disconnection
    - DISC, RD (request disconnect mode)
  - reset of connection
    - FRMR (frame reject), RSET (reset)
  - initialization, testing, exchange ID, signaling mode
    - RIM, SIM, TEST, XID, DM (disconnect mode),
  - connectionless information transfer
    - UI unnumbered information -> datagram service

Handling of U Frames

- **SNRM, SARM, SABM, SNRME, SARME, SABME**
  - sets secondary station in corresponding mode
  - expected answer: UA
- **DISC**
  - terminates actual mode, expected answer: UA
  - partner station -> NDM, ADM (disconnected mode)
- **DM**
  - response of secondary to every command frame except set mode frames while in disconnected mode
- **RD**
  - station wants that other station issues an DISC command

Handling of U Frames

- **FRMR**
  - response of secondary in case of protocol errors
    - invalid control field
    - invalid N(R)
    - information field too long or not expected in this frame
- **RSET**
  - command sent by primary on receipt of FRMR
  - resets N(R) = 0 in secondary, resets N(S) = 0 in primary
  - expected answer: UA
- **TEST**
  - basic link test
  - expected answer: UA

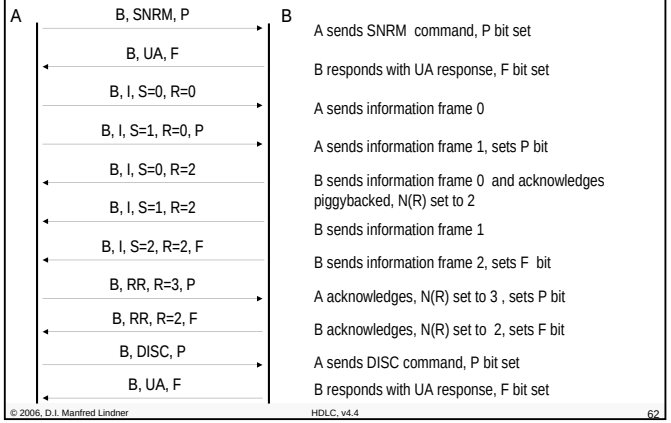
Handling of U Frames

- **SIM**
  - sets secondary in initialization mode
  - expected answer: UA
  - SW download from primary to secondary with UI frames
- **RIM**
  - sent by secondary as response to a mode setting command when secondary wants to be initialized first
- **XID**
  - requests identification from other station
  - expected answer: XID

XID Exchange

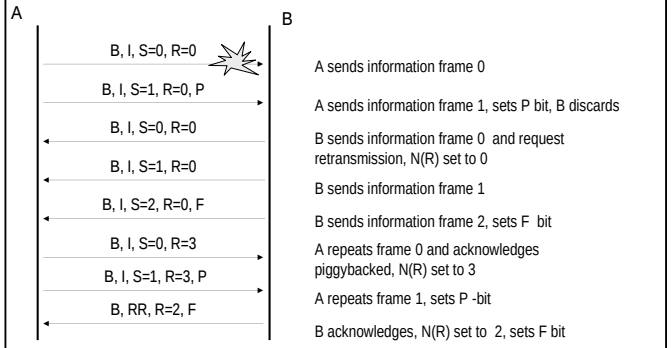
- **three XID types**
  - user data exchange
    - information for upper protocol layers before connection setup
  - address resolution
    - used on switched lines only
  - parameter negotiation
    - class of procedures
    - functional extensions
    - maximum transmit frame size
    - maximum receive frame size
    - send window
    - receive window

NRM Example (no errors)



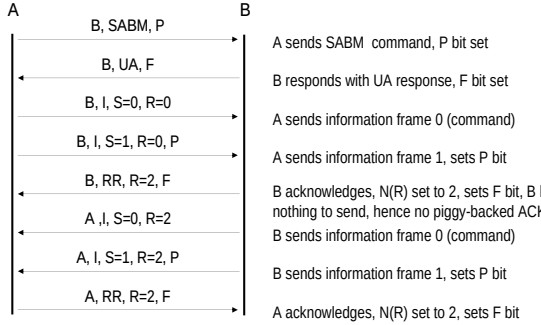
NRM Example (errors)

- **error recovery with checkpointing**



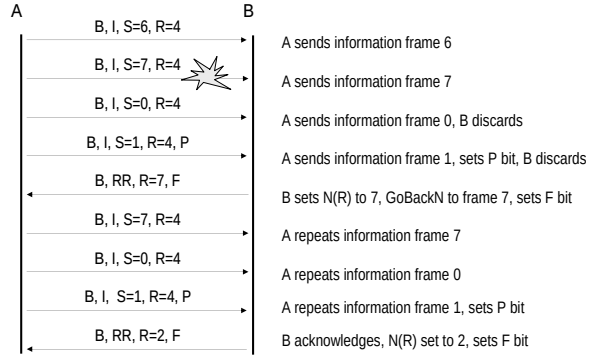
ABM Example (no errors)

- **ABM with data flow from A to B first, then B to A**



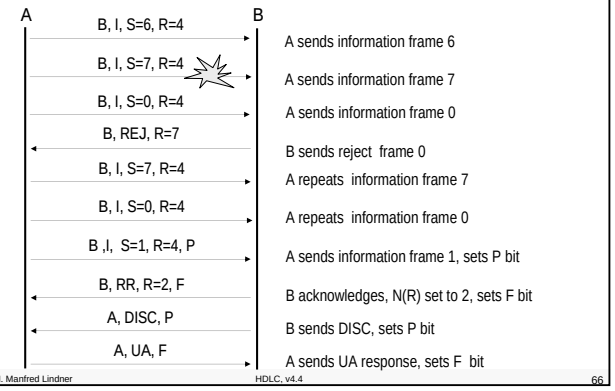
ABM Example (errors)

- **error recovery with checkpointing**



ABM Example (errors)

- **error recovery with REJ frame, disconnect by B**



Agenda

- **Line Management, Modems**
- **Introduction HDLC**
- **Station Types, Modes of Operation**
- **Frame Format, Frame Types**
- **Protocol Procedures**
- **HDLC Classes**

HDLC Classes of Procedures

- **used to classify HDLC implementations**
  - basic repertoire (standard modes of operation)
    - Class UN (NRM), Class UA (ARM), Class BA (ABM)
    - must be implemented for HDLC standard compliance
  - functional extensions (see next page)
    - may be implemented, matter of negotiations between implementers

Unbalanced Normal (UN)

Primary	Secondary
Command	Response
I RR RNR SNRM DISC	I RR RNR UA DM FRMR

Unbalanced Asynchronous (UA)

Primary	Secondary
Command	Response
I RR RNR SARM DISC	I RR RNR UA DM FRMR

Balanced Asynchronous (BA)

Primary	Secondary
Command	Response
I RR RNR SABM DISC	I RR RNR UA DM FRMR

HDLC Functional Extensions

1. for switched circuits XID << ADD >> XID RD	7. extended addressing	13. request disconnect ADD >> RD
2. for 2-way simultaneous REJ << ADD >> REJ	8. delete “Response” I frames	14. 32 bit FCS
3. for single frame retrans. SREJ << ADD >> SREJ	9. delete “Command” I frames	
4. for information UI << ADD >> UI	10. extended sequence numbering	
5. for initialization SIM << ADD >> RIM	11. for mode reset RESET << ADD	
6. for group polling UP << ADD	12. Data link test TEST << ADD >> TEST	

for example UN 3.7
–> unbalanced normal
–> mode and selective
–> reject and extended
–> address extensions

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