Protocol Principles

Layering, CL versus CO Service, ARQ Techniques, Sequence Numbers, Windowing, Flow Control

Agenda

- **Introduction**
  – 3 Layer Model and Service Types
- **ARQ Techniques**
  – Introduction
  – Idle RQ
  – Continuous RQ
    - Selective Acknowledgement
    - GoBackN
    - Positive Acknowledgement
  – Sequence Numbers and Windowing
  – Delay Bandwidth Product
  – Flow Control
  – HDLC Overview

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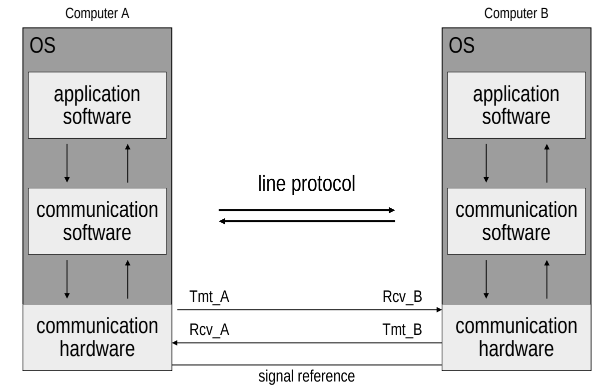
L02 - Protocol Principles

Line Protocols

- **line protocols regulate and control communication between two devices over point-to-point line**
- **basic elements**
  – frame synchronization
  – frame protection
  – error detection
  – usually implemented in hardware
- **optional elements**
  – connection and line management
  – error recovery
  – flow control
  – usually implemented in software

3 Layer Model



Software Aspects

- **application software uses**
  - the communication software (normally part of an operating system , OS) in order to exchange data
- **mailbox and queueing techniques**
  - allow cooperation of application and communication software within a computer system
- **the communication software**
  - uses a line protocol for peer to peer communication
    - virtual communication relationship on a given layer
  - hides the details of line protocols and other related tasks from the application software
- **procedural approach**

Cooperation of Software Layers

- **if information has to be transmitted from A to B**
  - the application SW of device A forwards some data blocks to the communication SW
  - the communication SW transmits the data using the communication hardware and the line protocol
  - the communication SW of device B receives the data and forwards it to the application SW
- **that means, the communication SW provides a service for the application SW**
  - this service can be

    <u>connection-less</u> or <u>connection-oriented</u>

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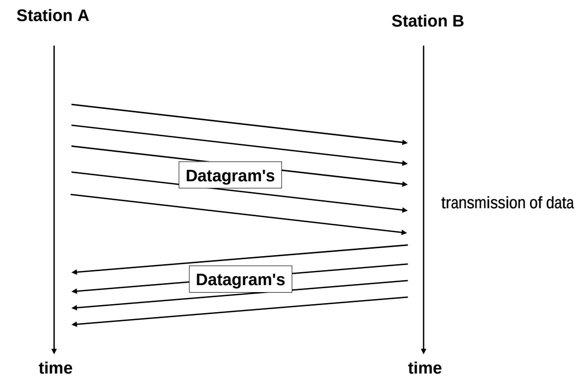
L02 - Protocol Principles

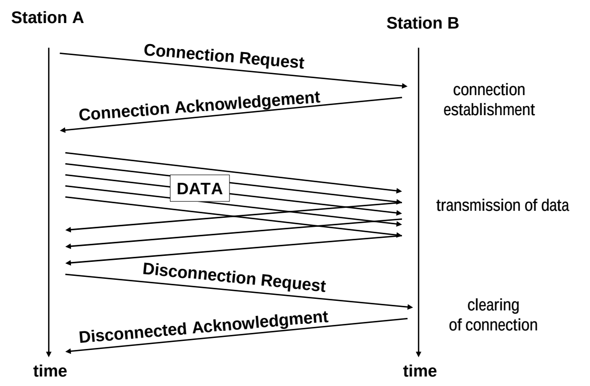
Connectionless Service



Line Protocol Services - CL

- **Connection-Less (CL) - type of service**
  - communication SW uses only basic elements (frame synchronization, frame protection, error detection) to transmit data blocks
  - transmission errors causes receiver to discard data blocks
  - <u>best effort service</u>
  - no special frame types are necessary to implement this protocol strategy
  - low implementation requirements for communication SW
  - but error recovery (correction of errors) must be done by application

Phases with Connection-Oriented Service



Line Protocol Services - CO

- **Connection-Oriented (CO) - type of service**
  - a communication channel must be established before data blocks can be transmitted
    - logical connection
  - transmission errors will be detected and corrected by the communication SW using feedback error control
    - retransmission of corrupted data blocks
    - **Automatic Repeat reQuest (ARQ) method**
  - reliable transmission service for application SW
    - error recovery done by communication SW
  - special frame types are necessary (connect, disconnect)
  - more sophisticated communication SW is necessary in order to implement ARQ strategy

Agenda

Automatic Repeat Request (ARQ)

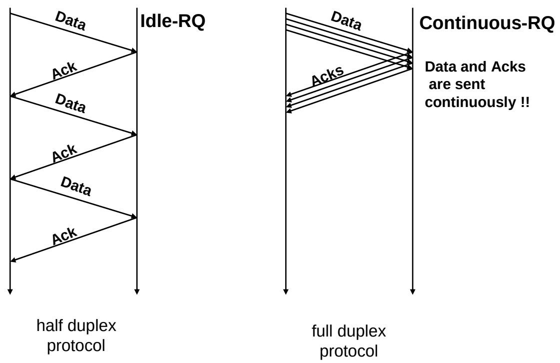
- **correct receipt of each transmitted data frame is acknowledged by the receiver**
  - special control message (ACK) in opposite direction
- **each data frame transmitted is stored in a retransmission buffer until receipt of corresponding acknowledgement**
- **if acknowledgement is not received, data frame will be retransmitted after a timeout**
- **identifiers (N, N+1, ...) are necessary to mark the sequence of data frames and to recognize duplicate frames**

ARQ Variants

Idle-RQ

Continuous-RQ
- **Selective ACK (SACK)**
- **GoBackN**
- **Positive ACK**
- **Selective Reject (SREJ)**

Idle-RQ versus Continuous-RQ



Idle-RQ and Continuous-RQ Facts

- **Idle-RQ**
  - old and slow method
    - but small code and only little resources necessary
    - even today used e.g. TFTP (Trivial File Transfer Protocol)
  - half duplex protocol
- **Continuous-RQ**
  - requires *dramatically* more resources than Idle-RQ or connectionless protocols !!!
    - Retransmission Timers
    - Retransmission Buffers
    - Receive Buffers
  - might result in high CPU loads !!!
  - full duplex protocol

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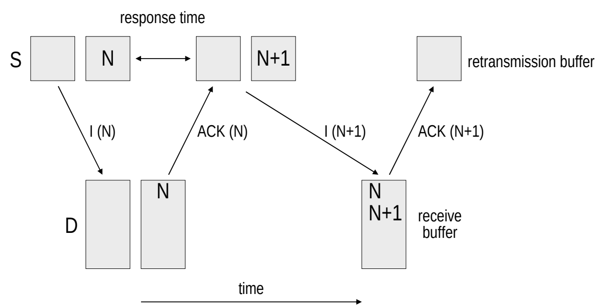
Idle-RQ

- **simple ARQ implementation**
  - stop & wait protocol
  - device waits for the acknowledgement (ACK) before sending the next data frame
  - basic method can be improved by NACK
- **two identifiers are necessary (0, 1)**
  - distinction between new data frame or duplicate frame
- **numbering of data frames**
  - modulo 2
- **half duplex protocol**
- **full duplex lines can not be efficiently used**

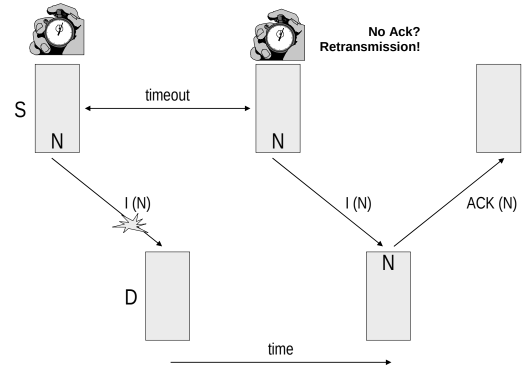
Basic Sequence of Idle-RQ



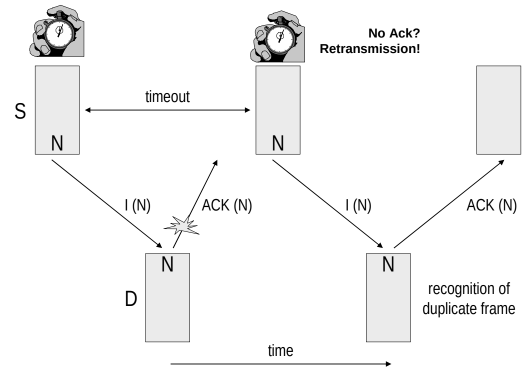
S ... Source of I (N)
D ... Destination I (N)

I (N) ... Information Frame containing Data
ACK (N) ... Acknowledgment Frame

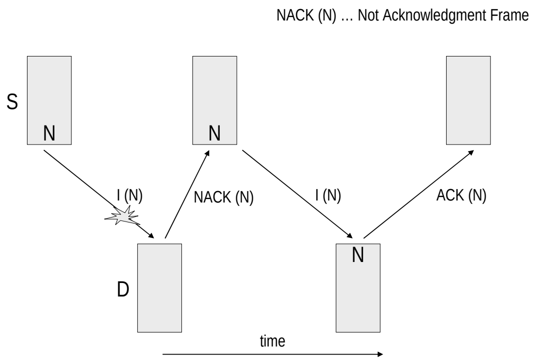
Idle-RQ Retransmission 1



Idle-RQ Retransmission 2



Idle-RQ Retransmission with optional NACK



Agenda

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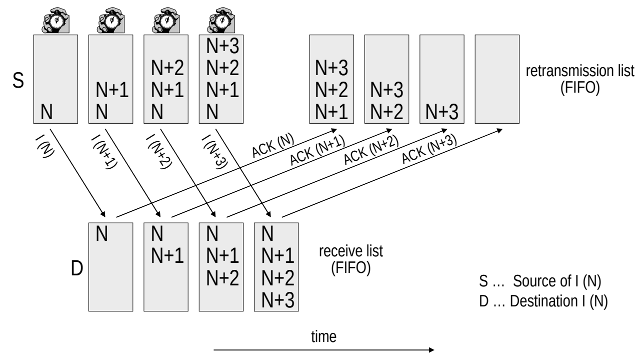
L02 - Protocol Principles

Continuous-RQ

- **in order to use full duplex lines more efficiently, device does not wait for acknowledgements for frames already sent**
  - Continuous Repeat reQuest (C-RQ) protocols
- **full duplex protocol**
- **until receipt of acknowledgments, data frames are buffered in a retransmission list**
- **each incoming acknowledgment removes the corresponding data frame from that list**
- **receiver stores data frames in receive list**
  - to detect duplicates
  - to reorder the sequence

Sequence of Continuous-RQ



Error Control Variants with Continuous-RQ

- **several methods for error control**
  - based on selective acknowledgement
    - selective retransmission done implicitly
    - order of frames is not maintained by the procedure
    - e.g. TCP (Transmission Control Protocol) SACK option
  - based on multiple and negative acknowledgement
    - also known as GoBackN
    - order of frames is maintained by the procedure
    - e.g. HDLC (High Level Data Link Control) check pointing technique and REJ option
    - e.g. DDCMP (Digital Data Link Control Management Protocol)

Error Control Variants with Continuous-RQ

- **several methods for error control (cont.)**
  - based on timeout and positive acknowledgement
    - order of frames is not maintained by the procedure
    - e.g. TCP´s original procedure (early TCP)
    - note: today's TCP uses additionally duplicate ACK´s to signal the rate of frames leaving the network to the sender
  - based on selective reject
    - selective retransmission done explicitly
    - order of frames is not maintained by the procedure
    - e.g. HDLC´s SREJ option

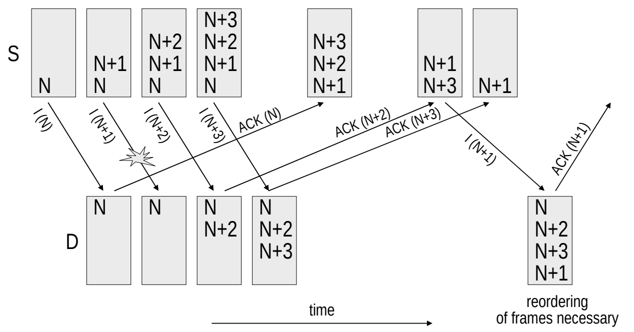
Agenda

Selective Acknowledgement

- **principle**
  - every data frame is exclusively confirmed
  - if acknowledgment is not received, corresponding data frame will be sent again and stored at the end of the retransmission list
  - in case of retransmission
    - data frames may not remain in sequence (scenario 1)
    - receiver must recognize duplicate frames and discard them (scenario 2)
  - each transmitted data frame starts an individual timer
    - which will be reset, if acknowledgement is received
    - if timeout occurs data frame is sent once again (scenario 3)

Selective Acknowledgement 1

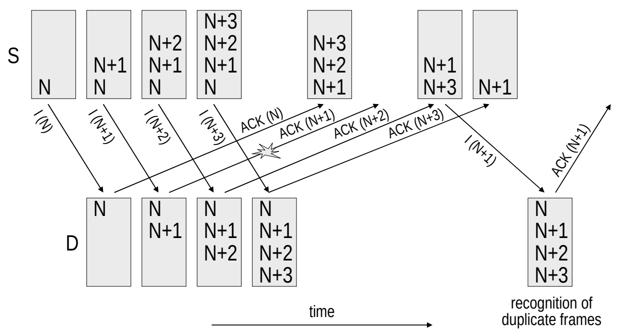
ACK (N+2) triggers implicitly retransmission of I (N+1) at S



 Protocol Principles, v4.6 29

Selective Acknowledgement 2

ACK (N+2) triggers implicitly retransmission of I (N+1) at S



 Protocol Principles, v4.6 30

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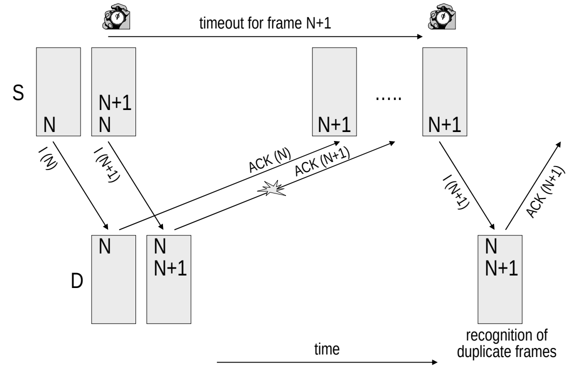
L02 - Protocol Principles

Selective Acknowledgement 3



 Protocol Principles, v4.6 31

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  - Idle RQ
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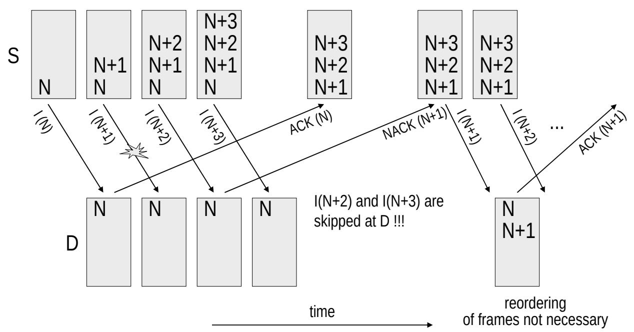
 Protocol Principles, v4.6 32

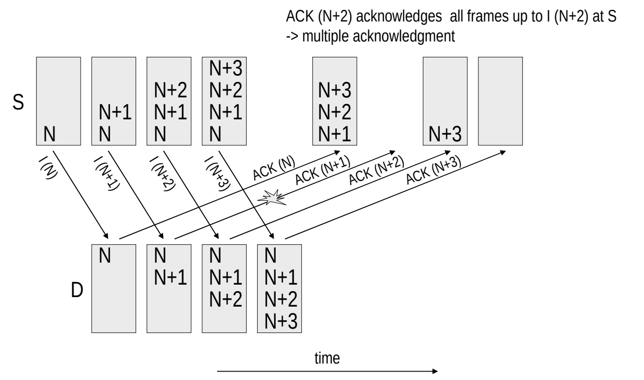
GoBackN

- **principle**
  - in case of errors, all data frames since “N” will be requested again by NACK(N) (Negative Ack.)
  - all following frames are discarded by receiver until frame with correct sequence number arrives
    - reordering is not necessary in this case
    - SW at receiver could be kept more simple
  - a single acknowledgments could confirm multiple data frames (multiple acknowledgement)
    - often use to spare number of Ack´s in opposite direction
  - each transmitted data frame starts an individual timer
    - which will be reset, if acknowledgement is received
    - if timeout occurs data frame is sent once again (scenario 3)

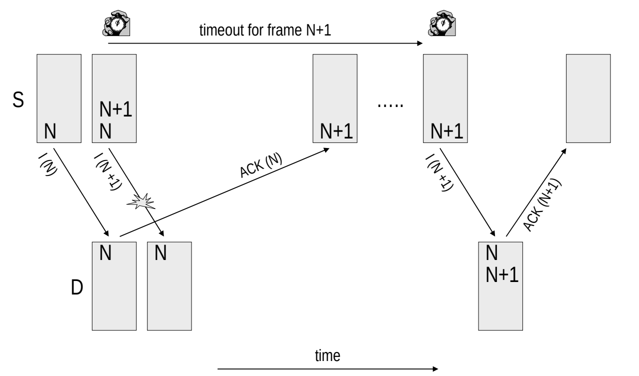
GoBackN 1



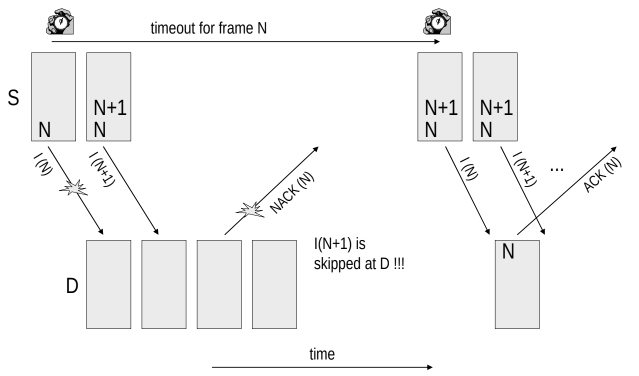
GoBackN 2



GoBackN 3



GoBackN 4



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  - Continuous RQ
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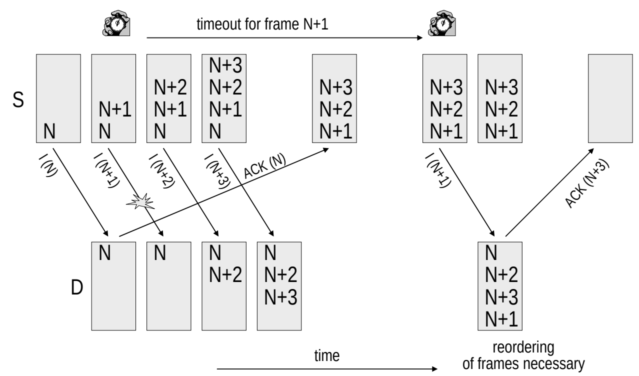
L02 - Protocol Principles

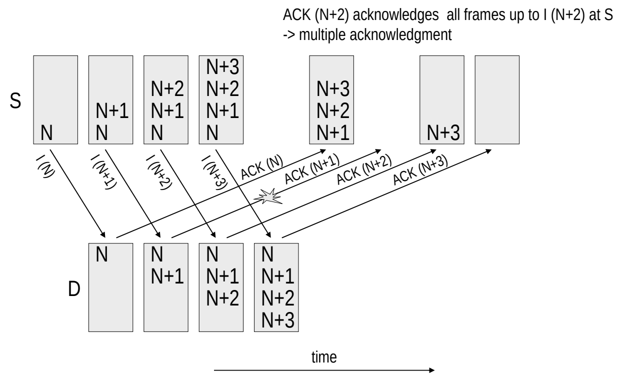
Positive Acknowledgement

- **principle**
  - data frames will be confirmed as long as frames arrives in sequence
    - multiple acknowledgement can be used by receiver
  - if data frames get out of sequence, confirmation is stopped
  - nevertheless, all following data frames will be stored
  - each transmitted data frame starts an individual timer
    - which will be reset, if acknowledgement is received
    - if timeout occurs data frame is sent once again (scenario 1)
  - data frames which are already stored in the receiver
    - can be confirmed with multiple acknowledgements when missing data frame arrives (scenario 1)

Positive Acknowledgement 1



Positive Acknowledgement 2



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  - Introduction
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L02 - Protocol Principles

Sequence Number

- **identifiers of data frames are implemented by increasing numbers**
  - sequence numbers
  - the number used in I-frames
    - send sequence number N(S)
  - the number used in ACK/NACK/SREJ-frames
    - receive sequence number N(R)
  - register variables are necessary
    - V(S), V(R)
    - must be initialized (set to 0) by connection setup
  - handling of V(S), V(R), N(S), and N(R) will be explained in next slides for GoBackN

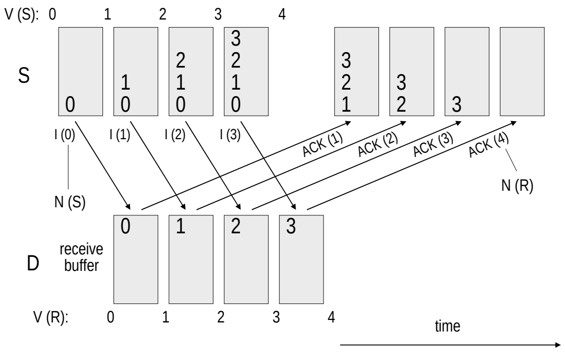
V(S), V(R) with GoBackN

- **V(S) indicates the sequence number of the next I-frame that will be sent**
- **V(R) indicates the expected sequence number of the next in-sequence I-frame to be received**
  - this value will be seen in N(R)
- **prior to sending an I-frame, the value of N(S) is set to the value of V(S)**
  - afterwards V(S) is increased by one

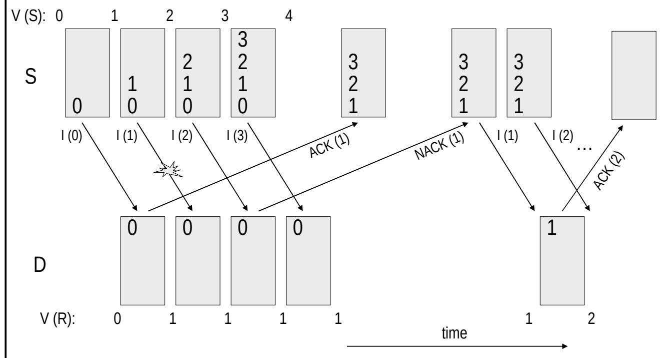
V(S), V(R) with GoBackN

- **receiver only accepts I-frames with N(S) = V(R)**
  - after successful receipt of a frame V(R) will first be increased by one and then acknowledgment with N(R) = V(R) will be sent
- **therefore receipt of ACK with N(R) = x means**
  - that all I-frames until x-1 are confirmed

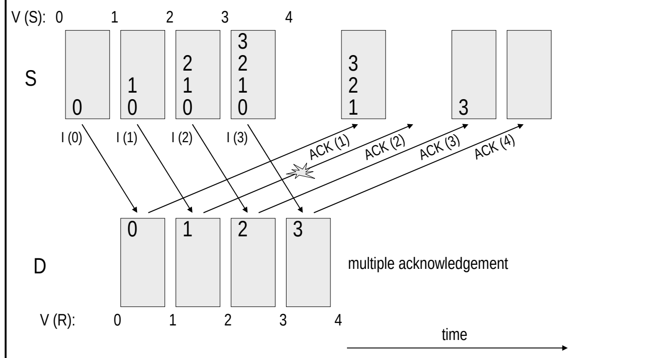
GoBackN 1



GoBackN 2



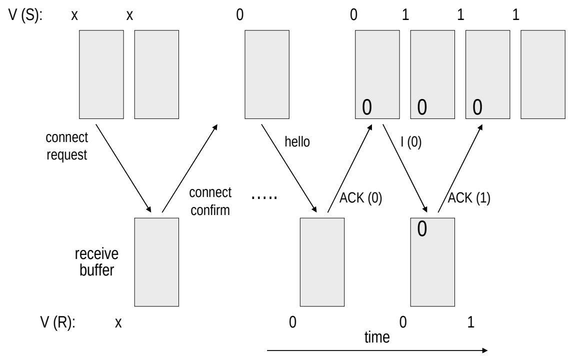
GoBackN 3



Initializing / Transmission Pause

- **connection establishment initializes V(S) and V(R)**
- **after connection establishment**
  - connection is maintained by keepalive messages during transmission pauses
- **example for keepalive technique**
  - exchange of HELLO (request / poll) and ACK (response)
  - ACK is used for acknowledgment as well as for connection maintenance
  - because of this an ACK(N) only confirms all frames up to N-1 and not up to N
    - sender can distinguish between a keepalive response and acknowledgement of a new data frame

Initializing / Keepalive



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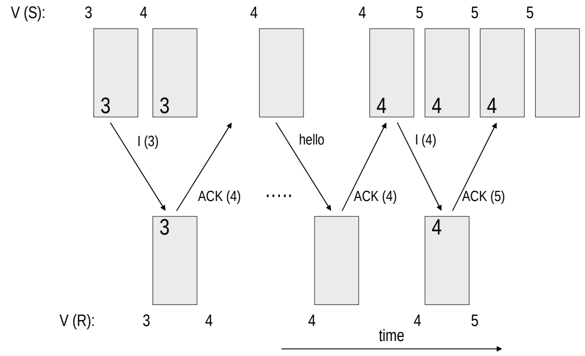
L02 - Protocol Principles

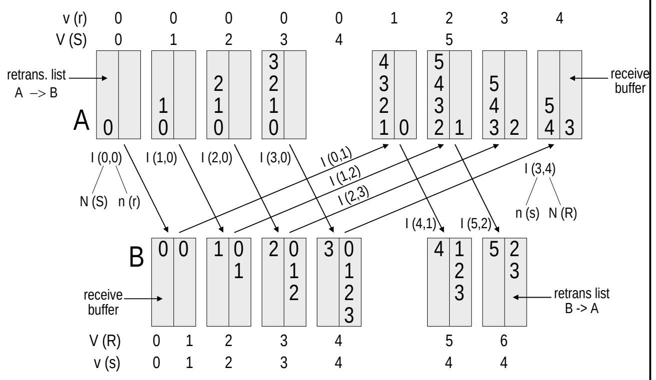
Keepalive



Piggyback Acknowledgement

- **confirmation of every data frame is only appropriate for data flow in one direction**
- **acknowledgment frames produce unnecessary overhead with full duplex data traffic**
- **acknowledgments contained in data frames in opposite direction can avoid that overhead**
  - <u>piggyback acknowledgement</u>
- **if no backward data frame is waiting for transmission**
  - ACK frame will be sent still

Piggyback Acknowledgement



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Data Flow in both Directions

- **data frames contain both send sequence number and receive sequence number of backward direction**
- **now I-frames and ACK/NACK-frames can arise in both directions**
- **communication devices must contain both V(S)- and V(R)-registers, retransmission and receive lists**
- **N(S), N(R), V(S) und V(R) control data transfer from A to B**
- **n(s), n(r), v(s) und v(r) control data transfer from B to A**

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Windowing

- **without a restriction of the number of unconfirmed data frames, continuos-RQ would require infinite number of identifiers and buffer memory**
- **for that reason, the amount W of data frames stored for retransmission must be limited**
  - W = send window
- **if limit is reached, sending of additional data frames is stopped until receipt of acknowledgement indicates that window is opened again**
  - windowing

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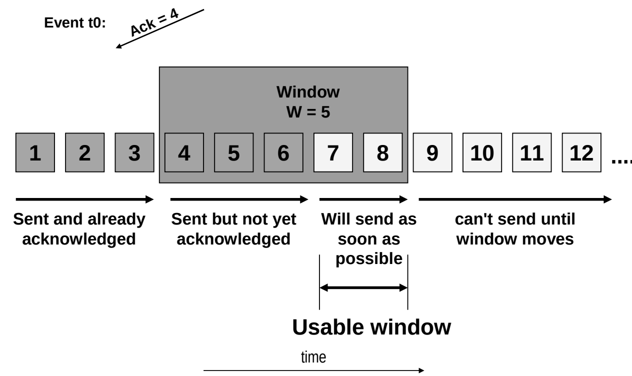
Principle of Windowing



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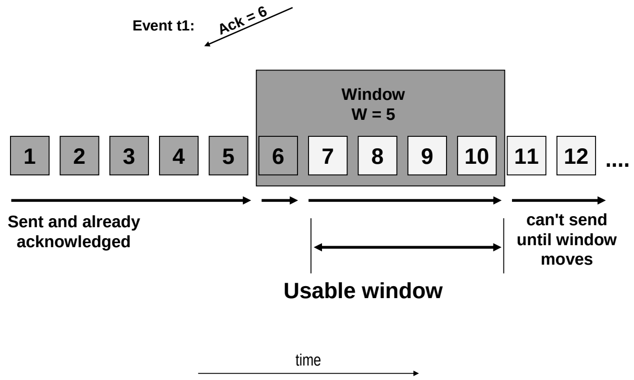
Sliding Windowing

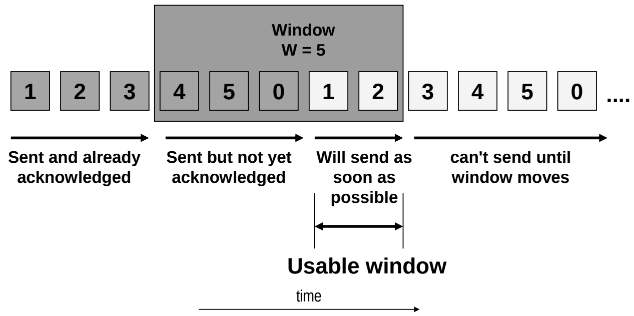


Consequences of Windowing

- **windowing reduces the buffer memory for retransmission buffer and receive-list**
  - buffer size of retransmission buffer = W * maximum frame size
- **windowing reduces the number of identifiers**
  - numbering of data frames can be done by a modulo operation
  - e.g. GoBackN with <u>send window = W</u>
    - needs W+1 identifiers because of worst case scenario next slide
    - <u>data frames can be numbered modulo W+1</u>
  - e.g. Selective Acknowledgement with send window = W
    - needs 2W identifiers because of worst case scenario
    - data frames can be numbered modulo 2W

Windowing with Numbering Modulo W+1

GoBackN and send-window W means W+1 Identifier and numbering with modulo W+1



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Time to Transmit a given Number of Bytes

Serialization Delay (in ms) = [(Number of Bytes * 8) / (Bitrate in sec)] * 1000

	Bitrate		9,6 kbit/s	48 kbit/s	128 kbit/s	2,048 Mbit/s	10 Mbit/s	100 Mbit/s	155 Mbit/s	622 Mbit/s	1 Gigabit/s
	Number of Byte		Delay in msec (10^{-3})	Delay in msec (10^{-3})	Delay in msec (10^{-3})	Delay in msec (10^{-3})	Delay in msec (10^{-3})	Delay in msec (10^{-3})	Delay in msec (10^{-3})	Delay in msec (10^{-3})	Delay in msec (10^{-3})
Bit	0,125		0,104167	0,020833	0,007813	0,000488	0,000100	0,000010	0,000006	0,000002	0,000001
Byte	1		0,833333	0,166667	0,062500	0,003906	0,000800	0,000080	0,000052	0,000013	0,000008
PCM-30	32		26,666667	5,333333	2,000000	0,125000	0,025600	0,002560	0,001652	0,000412	0,000256
ATM cell	53		44,166667	8,833333	3,312500	0,207031	0,042400	0,004240	0,002735	0,000682	0,000424
Ethernet	64		53,333333	10,666667	4,000000	0,250000	0,051200	0,005120	0,003303	0,000823	0,000512
X.25	256		213,333333	42,666667	16,000000	1,000000	0,204800	0,020480	0,013213	0,003293	0,002048
IP	576		480,000000	96,000000	36,000000	2,250000	0,460800	0,046080	0,029729	0,007408	0,004608
Ethernet	1.518		1.265,000000	253,000000	94,875000	5,929688	1,214400	0,121440	0,078348	0,019524	0,012144
FR	8.192		6.826,666667	1.365,333333	512,000000	32,000000	6,553600	0,655360	0,422813	0,105363	0,065536
TCP	65.534		54.611,666667	10.922,333333	4.095,875000	255,992188	52,427200	5,242720	3,382400	0,842881	0,524272

1kbit/s = 1000 bit/s !!!
1KByte = 1024 Byte !!!

Propagation (Signal) Delay

Tp = Propagation Delay (in ms) = [(Distance in m) / (velocity in m/sec)] * 1000

			v=200.000km/s	v=300.000km/s
	Distance		Delay in msec (10^{-3})	Delay in msec (10^{-3})
CPU Bus	10 cm		0,0000005	0,0000003
	1 m		0,0000050	0,0000033
RS232, V24/V.28	15 m		0,0000750	0,0000500
LAN, Copper, RJ45	100 m		0,0005000	0,0003333
LAN, FO, X.21/V.11-V.10	1 km		0,0050000	0,0033333
Local Subscriber Line	2,5 km		0,0125000	0,0083333
WAN Link Repeater	10 km		0,0500000	0,0333333
WAN Link Repeater	100 km		0,5000000	0,3333333
WAN FO Link Repeater	1.000 km		5,0000000	3,3333333
WAN FO Link Repeater	10.000 km		50,0000000	33,3333333
Satellite Link	40.000 km		200,0000000	133,3333333
Satellite Link	50.000 km		250,0000000	166,6666667
	100.000 km		500,0000000	333,3333333
	300.000 km		1500,0000000	1000,0000000

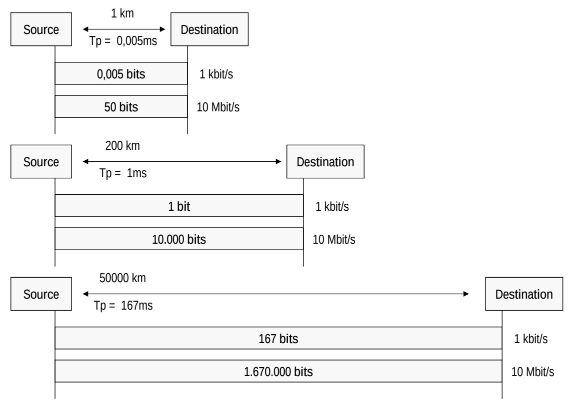
Total Delay = Serialization Delay + Propagation Delay + (Switching Delay)

How Long is a Bit?

Length (in m) = [(1 / (bitrate per sec)] * [(velocity in m/sec)]

	Bitrate		Bit Length in meter	Bit Length in meter
Analogue Modem	9,6 kbit/s		20833,33	31250,00
Analogue Modem	48 kbit/s		4166,67	6250,00
DS0	64 kbit/s		3125,00	4687,50
ISDN (2B)	128 kbit/s		1562,50	2343,75
PCM-30, E1	2,048 Mbit/s		97,66	146,48
Token Ring 4	4 Mbit/s		50,00	75,00
Ethernet	10 Mbit/s		20,00	30,00
Token Ring16	16 Mbit/s		12,50	18,75
Fast Ethernet, FDDI	100 Mbit/s		2,00	3,00
ATM STM1, OC-3	155 Mbit/s		1,29	1,94
ATM STM4, OC-12	622 Mbit/s		0,32	0,48
Gigabit Ethernet	1 Gigabit/s		0,20	0,30
OC-48	2,5 Gigabit/s		0,08	0,12
10 Gigabit Ethernet	10 Gigabit/s		0,02	0,03
			Copper	LWL - Free Space
			200.000 km /sec	300.000 km / sec

Propagation Delay and Number of Bits on a given Link



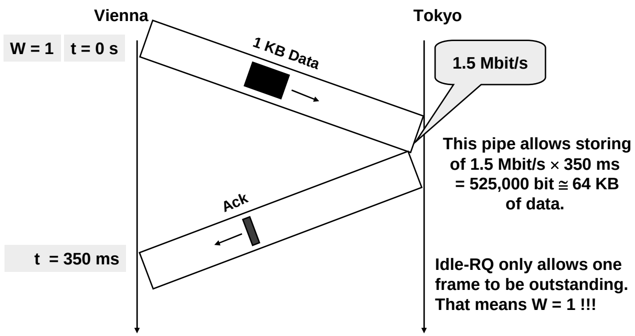
How Large should be the Window Size?

- **choice of window size is determined by**
  - response time (= round trip time RTT)
    - 2 x (propagation + serialization) delay plus response delay of partner
  - bandwidth (bit rate) of communication channel
  - [available buffer size transmitter/receiver]
- **principle to achieve the optimum:**
  - the sender´s window must be big enough so that the sender can fully utilize the channel volume
  - the channel volume can be expressed by the

<u>Delay-Bandwidth Product</u>

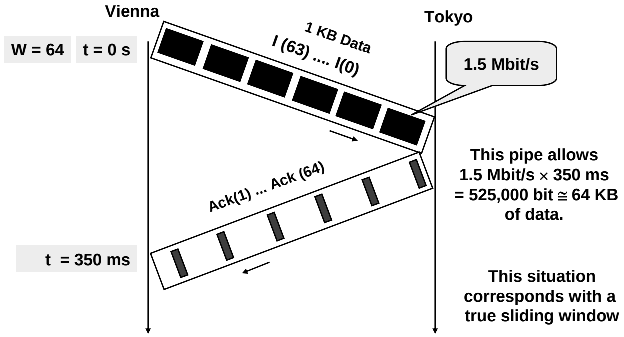
  - window size W in bytes = RTT x BW

Nearly Empty Pipe with Idle-RQ and W = 1



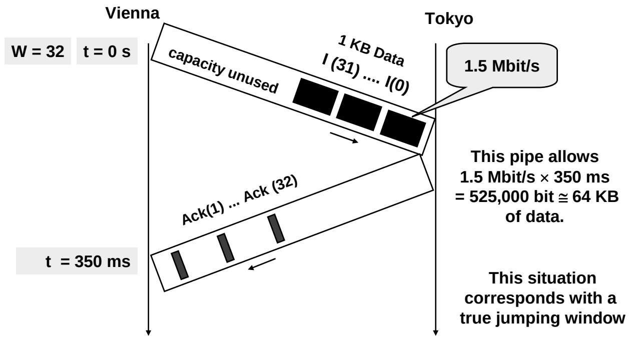
Assume 1 KByte (1024 byte) maximum frame size, then the maximal achievable rate is (1024 × 8) bit / 0.35 s ≅ 23 kbit/s

Full Pipe with Continous-RQ and W = 64



**Continous-RQ (C-RQ) allows several frames to be outstanding.
With 1 KByte maximum Frame Size optimum would be W = 64 !!!**

Only Half Pipe Used with C-RQ and W = 32



**With 1 KByte maximum Frame Size and W = 32
the pipe could be used only half the time !!!**

Optimal Window Size - Sliding Window

- **optimal window size (Continuous-RQ)**
  - acknowledgments arrive just in time to keep the window always open
    - sliding window
  - requirement for optimum
    - window size W in bytes in minimum equal to RTT x BW
- **if window size is smaller than RTT x BW**
  - transmission will be stopped until acknowledgments arrive
    - jumping window
  - Idle RQ behaviour in worst case with W = 1
- **if window size is too large**
  - in case of errors many good frames must be retransmitted (see Go Back N)

Timers - Retransmission Timeout

- **the value for retransmission timeouts with line protocols can be easily calculated using the following parameters**
  - bitrate
  - maximum data frame size
  - worst case time at receiver to generate an acknowledgment
  - size of acknowledgment frame
- **calculation for network protocols with varying transmission delays is more complex**
  - adaptive process is necessary

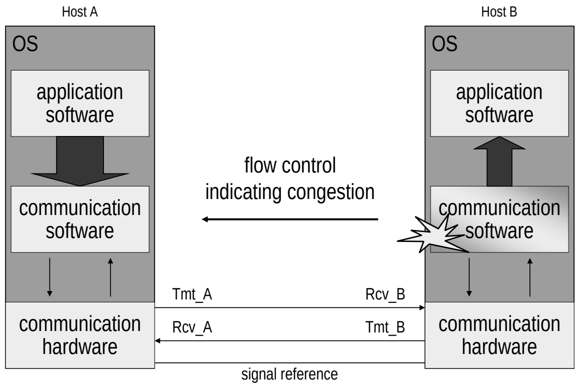
Agenda

- **Introduction**
  - 3 Layer Model and Service Types
- **ARQ Techniques**
  - Introduction
  - Idle RQ
  - Continuous RQ
    - Selective Acknowledgement
    - GoBackN
    - Positive Acknowledgement
  - Sequence Numbers and Windowing
  - Delay Bandwidth Product
  - Flow Control
  - HDLC Overview

Flow Control

- **if data frames arrive faster than application is able to process,**
  - receiver runs out of available buffer storage and good frames must be discarded by the receiver
  - discarded data frames will cause retransmission but they will be still discarded because of lack of buffers
- **therefore receiver should control the rate of transmission of data frames**
  - flow control
  - overload/congestion situation indicated to the sender using flow control messages
  - sender stops and waits until receiver is able to process frames again

Flow Control



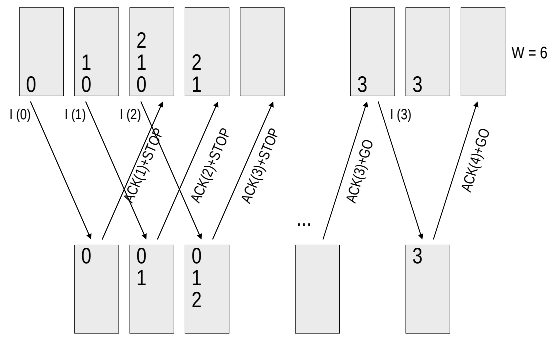
Flow Control

- **windowing could be used to implement flow control**
  - receiver does not generate acknowledgements in case of congestion
  - sender will stop transmission if send window is closed
- **problem with windowing**
  - after timeout unconfirmed frames will be retransmitted
  - after a defined amount of unsuccessful retransmissions, the connection is considered to be broken
- **therefore flow control is based on**
  - separate flow control frames
  - and windowing

Flow Control

- **typically used flow control messages**
  - STOP, e.g. HDLC´s Receiver Not Ready (RNR)
  - GO, e.g. HDLC´s Receiver Ready (RR)
- **in case of congestion**
  - receiver signals STOP
  - on receipt of STOP sender will suspend transmitting
  - in the worst case, sender will use the send window before stopping transmission
  - receiver signals GO when data flow can resume
  - STOP and GO may contain N(R) and hence be used for acknowledgement

Flow Control



Flow Control / Keepalive

- **in case of full duplex data communication**
  - STOP and GO control frames are used for flow control in both directions
- **in some cases STOP and GO frames are further used for connection management**
  - keepalive procedure
  - if no data frames are waiting for transmission a GO frame can signal keepalive to the partner
  - if traffic was suspended by STOP a periodic repetition of STOP can signal keepalive to the partner
  - in both cases keepalives maintain the connection

Flow Control / Adaptive Windowing

- **window size could be**
  - constant or dynamic during lifetime of a connection
    - constant window size is used e.g. by HDLC, X.25
- **if window size is dynamic**
  - a start value is negotiated during connection establishment
  - actual window size will be dynamically adjusted to an optimal value
    - receiver continuously advertises optimal value (e.g. based on availability free buffer memory)
    - advertised window size = 0 -> STOP
    - advertised window size > 0 -> GO
  - adaptive windowing
    - e.g used by TCP

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L02 - Protocol Principles

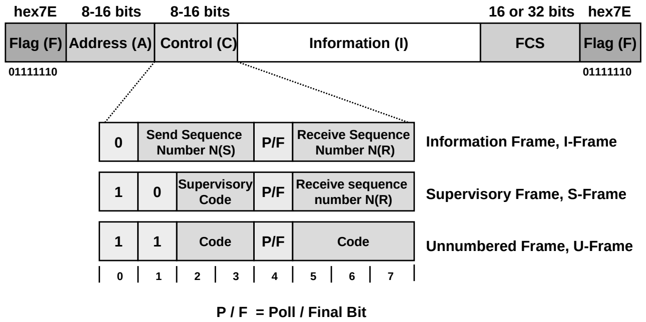
Agenda

- **Introduction**
  - 3 Layer Model and Service Types
- **ARQ Techniques**
  - Introduction
  - Idle RQ
  - Continuous RQ
    - Selective Acknowledgement
    - GoBackN
    - Positive Acknowledgement
  - Sequence Numbers and Windowing
  - Delay Bandwidth Product
  - Flow Control
  - HDLC Overview

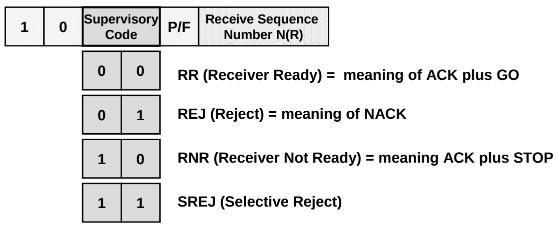
HDLC

- **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 (see appendix chapter for details)
- **provides many options**
  - half-duplex and full-duplex transmission (see appendix chapter for details)
  - point-to-point and multipoint configuration (see appendix chapter for details)
  - switched or non-switched channels

HDLC Frame Format



Supervisory Frames



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L02 - Protocol Principles

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

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

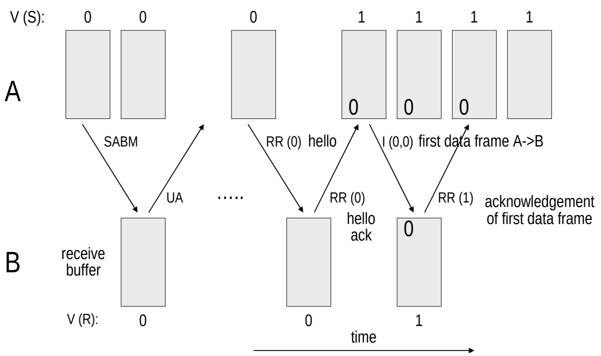
Miscellaneous

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

Unnumbered Frames

1	1	Code		P/F	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	

HDLC Example: Initializing / Keepalive / First Data Frame A -> B



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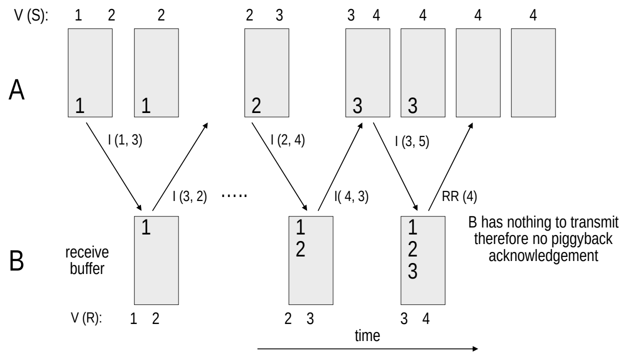
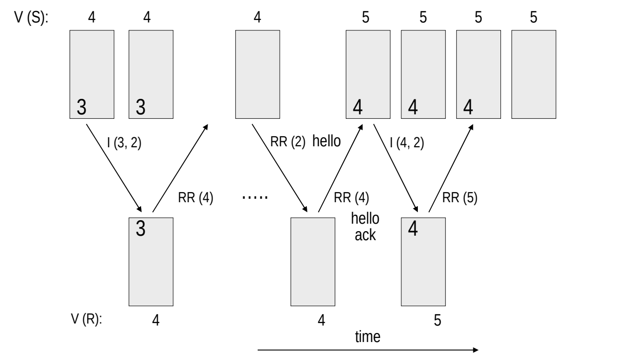
L02 - Protocol Principles

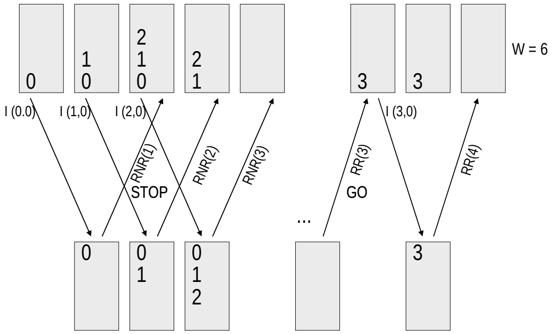
HDLC Example: Data Frames A->B , B->A with piggyback ACK



HDLC Example: Keepalive



HDLC Example: Flow Control



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)**