Computer Networks I

Data Link Layer

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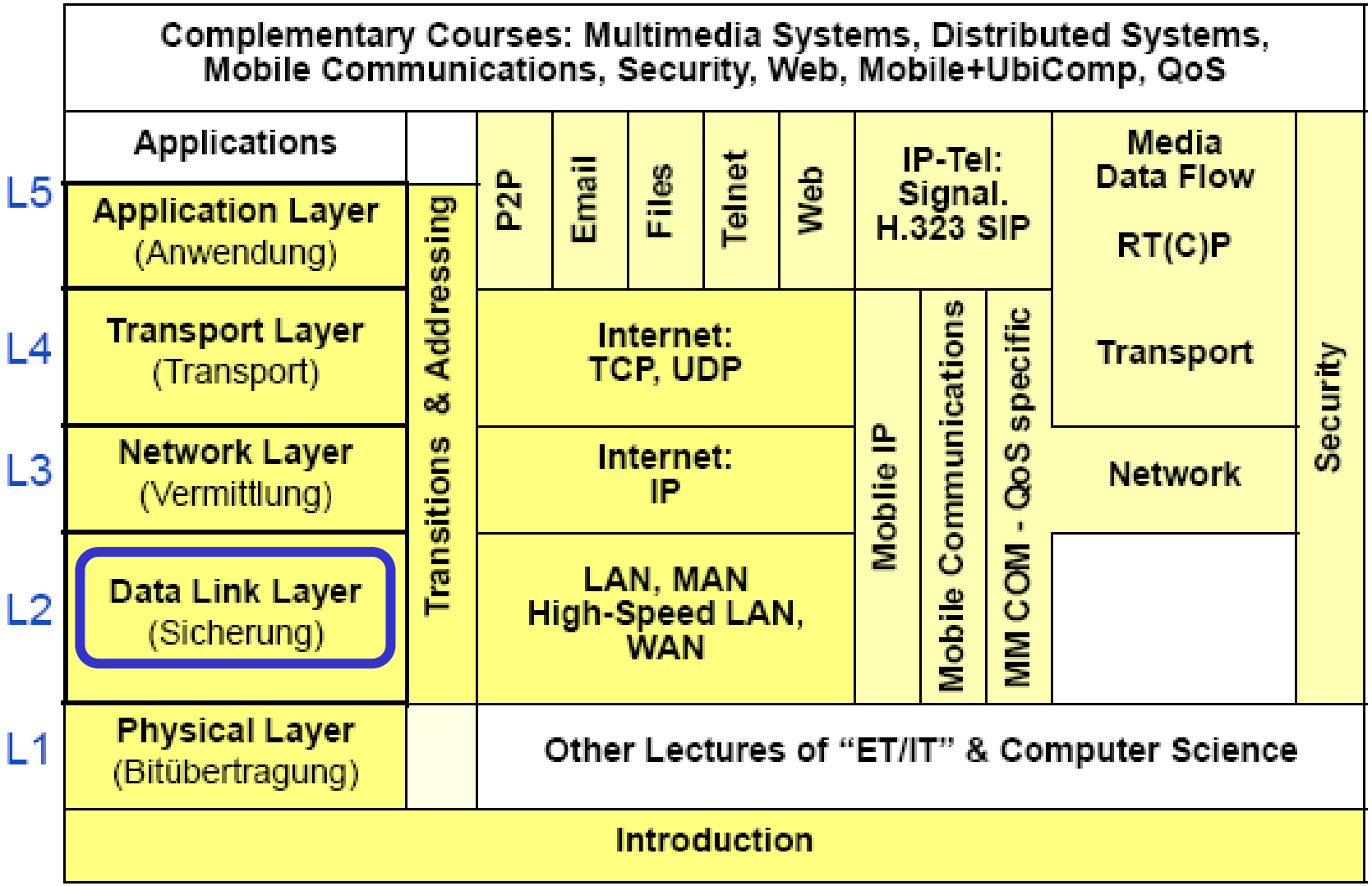
Scope


Complementary Courses: Multimedia Systems, Distributed Systems, Mobile Communications, Security, Web, Mobile+UbiComp, QoS
Applications
L5
Application Layer (Anwendung)
L4
Transport Layer (Transport)
L3
Network Layer (Vermittlung)
L2
Data Link Layer (Sicherung)
L1
Physical Layer (Bitübertragung)
Transitions & Addressing
P2P
Email
Files
Telnet
Web
IP-Tel: Signal. H.323 SIP
Media Data Flow
RT(C)P
Transport
Internet: TCP, UDP
Internet: IP
Network
LAN, MAN High-Speed LAN, WAN
Moblie IP
Mobile Communications
MM COM - QoS specific
Security
Other Lectures of "ET/IT" & Computer Science
Introduction

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  1.3 Connection Management

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Overview

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1 Function, Services and Connection Management

L1 Service:

- transmission of a bit stream (“unreliable bit pipe")
  - without sequence errors
- ’malign’ features of the L1 service (& the communication channel)
  - finite propagation speed
    - between sending and receiving operations at L2
  - limited data rate

➔ i. e. loss, insertion and changing of bits possible

L2 Service:

- (reliable), efficient data transfer between ADJACENT stations
  - may be between more than 2 stations
  - adjacent = connected by one physical channel
    - wireless, coax, optical fiber,...

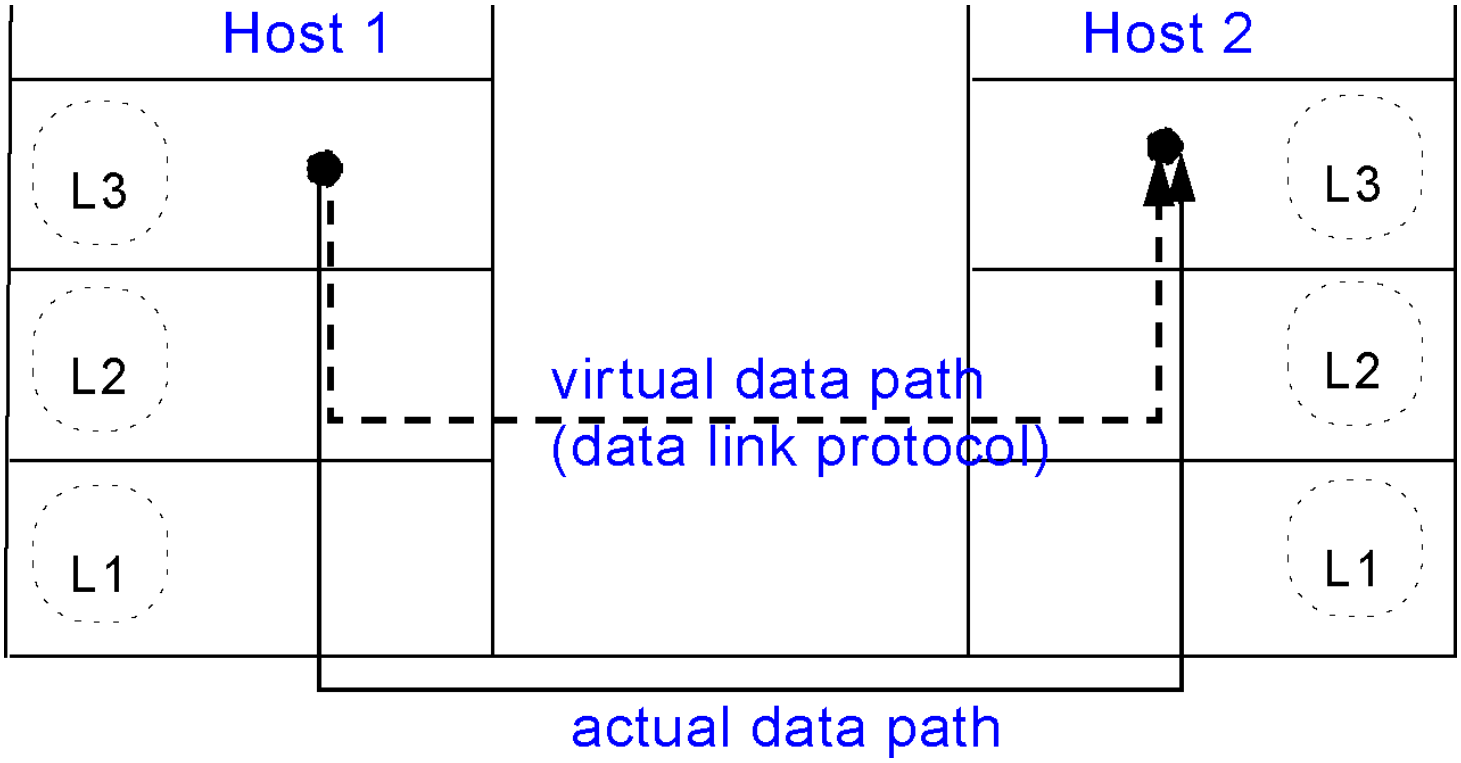
L2 Functions:

- data transmission as FRAMES

- ERROR control and correction
- FLOW CONTROL of the frames
- configuration management

Services

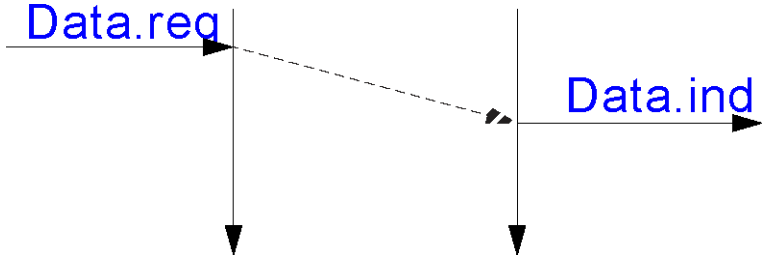
Actual data path and virtual data path:



L2 service classes:

- unconfirmed connection-less service
- confirmed connection-less service
- connection-oriented service

1.1 L2 Service Class "Unconfirmed Connection-less Service"



Transmission of isolated, independent units (frames)

- loss of data units possible
  - L2 does not try to correct this
  - L2 transmits only correct frames

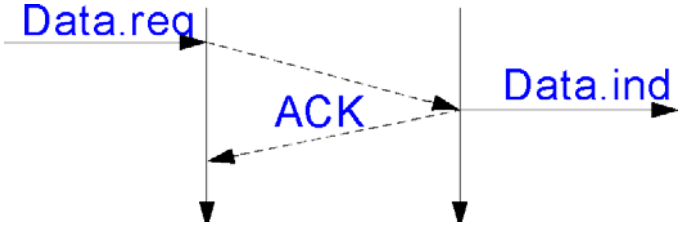
Features

- no flow control
- no connect or disconnect

Applications

- on L1 communication channels with VERY LOW ERROR RATE
  - corrections will possibly be done at a higher level
- possibly during real time data transfer like interactive voice communication
  - timing errors probably more critical than errors in the voice data
- often used in LANs

1.2 L2 Service Class “Confirmed Connection-less Service”



Receipt of data units (implicitly) acknowledged

- no loss (each single frame is acknowledged)
- timeout and retransmit (if sender does not receive an acknowledgement within a certain time frame)

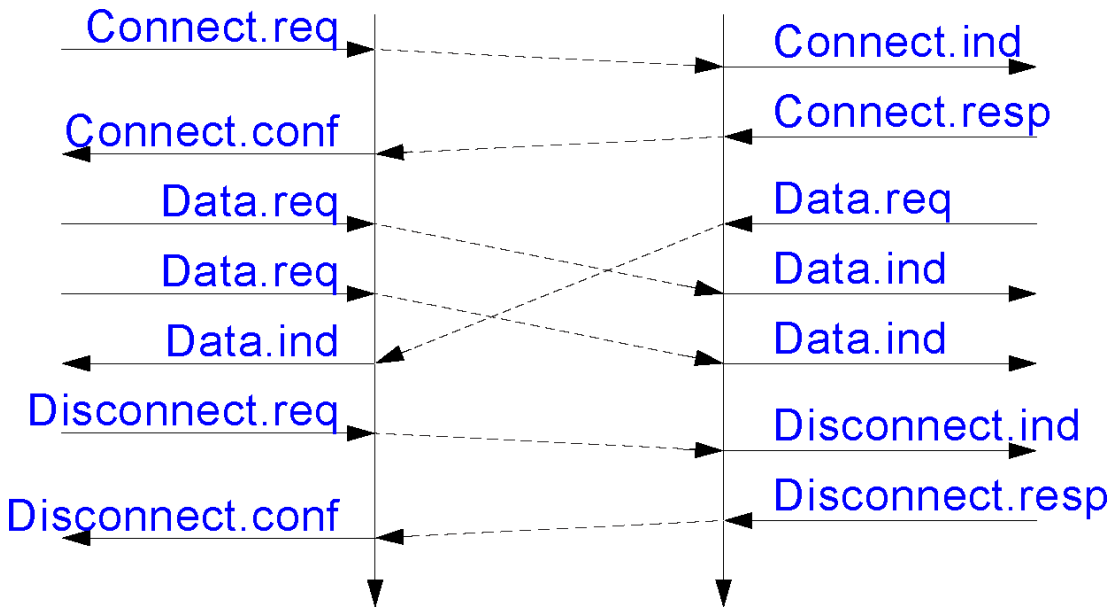
Features

- no flow control, no connect, no disconnect
- duplicates and sequence errors may happen due to “retransmit”

Application

- L1 communication channel with high error rate e.g. mobile communication

L2 Service Class “Connection-Oriented Service”



Connection: idea is to offer error free channel with

- no loss, no duplication, no sequencing error
- flow control

3-phased communication

1. connect
   - initializing the counters/variables of the sender and receiver
2. transfer data
3. disconnect

L2 Services: Comments

Acknowledging on L2:

- is only for optimization but is not indispensable
- because this can also be done at a higher level (L4)

however

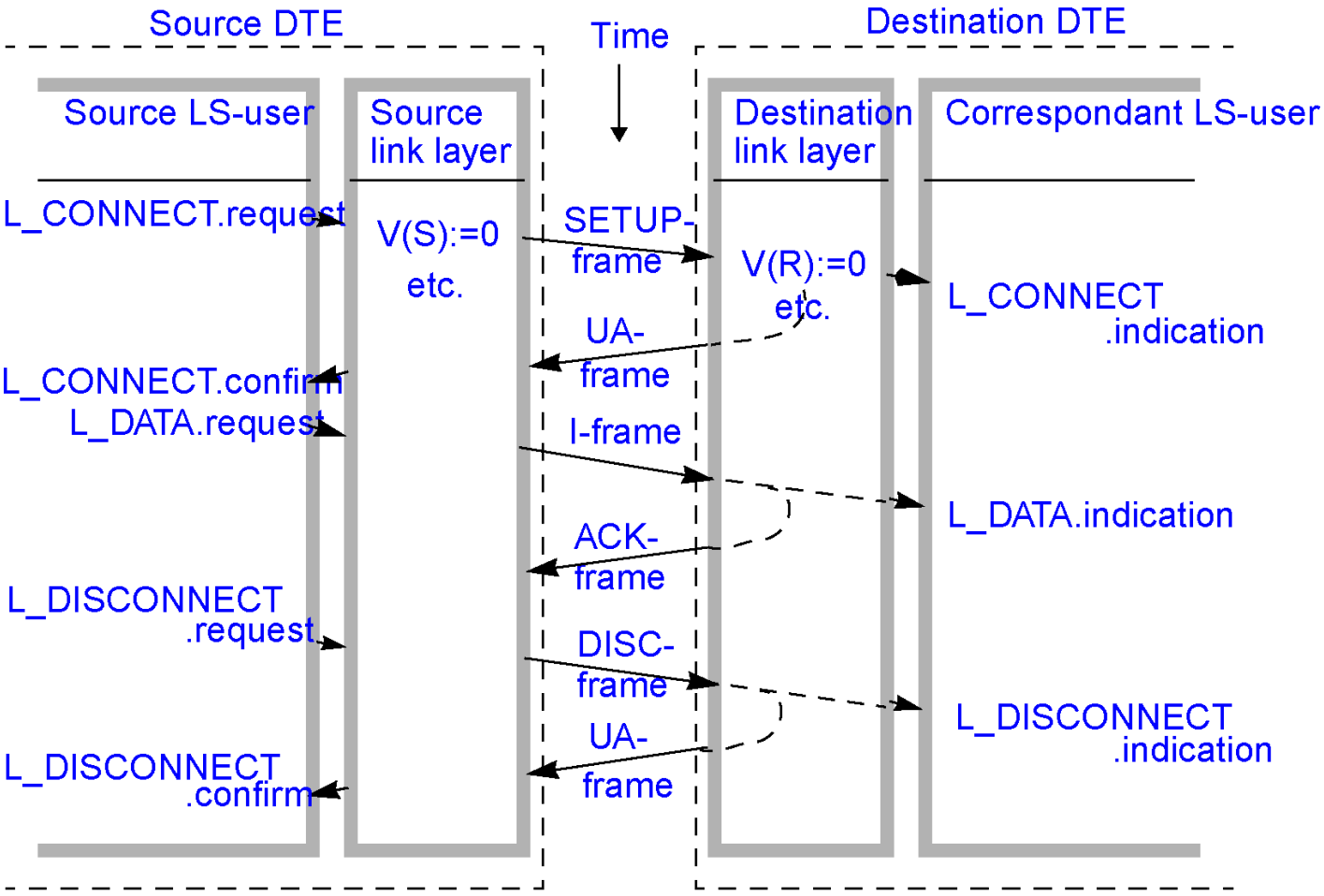
- L4 message usually consists out of n (e.g. 20) L2 frames
  - if there is an error in a frame => the whole message will be retransmitted
  - that means loss of time and efficiency

End-to-end argument:

- *J.H. Saltzer, D.P. Reed, D.D. Clark: "End-to-End Arguments in System Design", ACM Transactions on Computer Systems, Vol. 2, No. 4, November 1984, pp. 277-288*

1.3 Connection Management

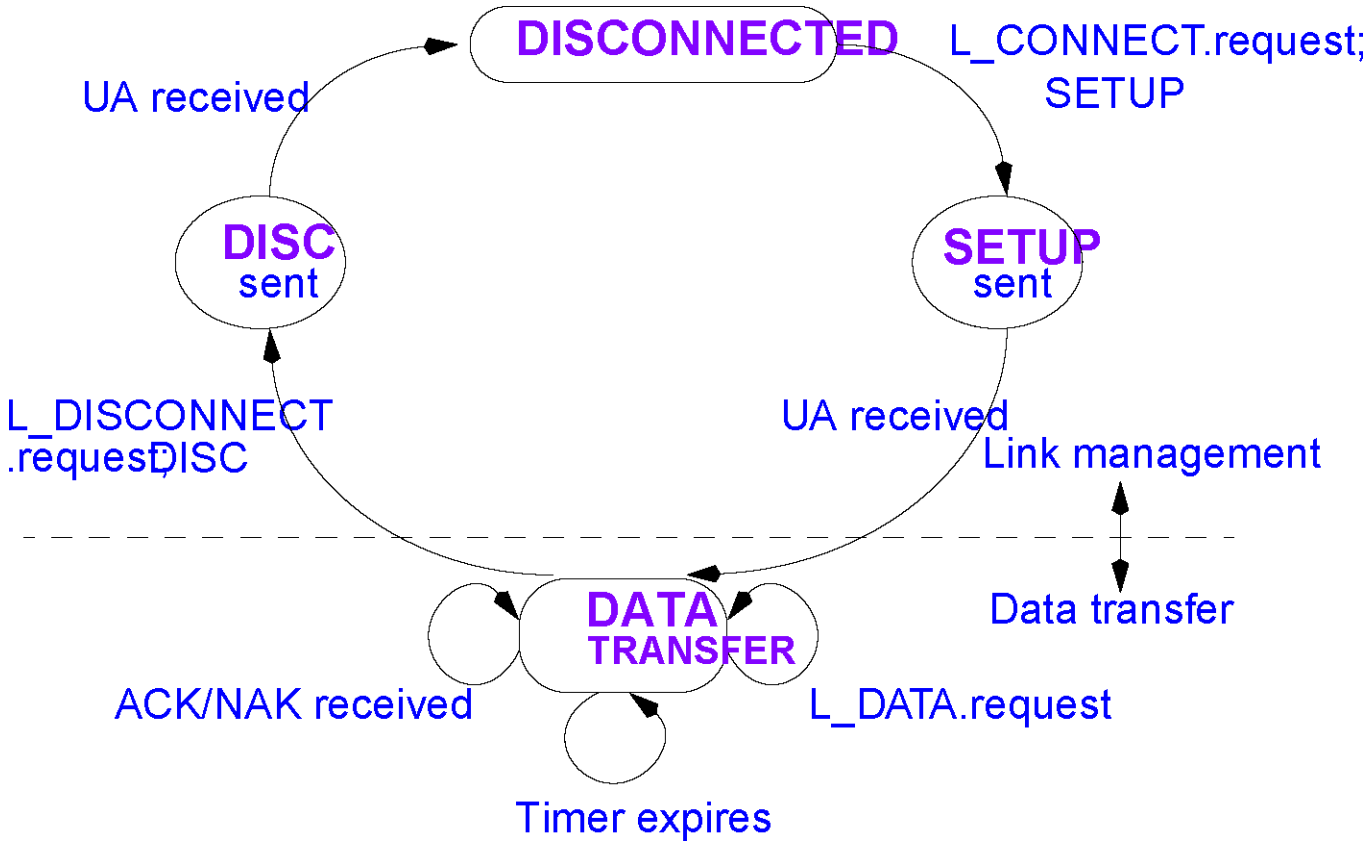
Presentation of the transmitted frame sequences, an example



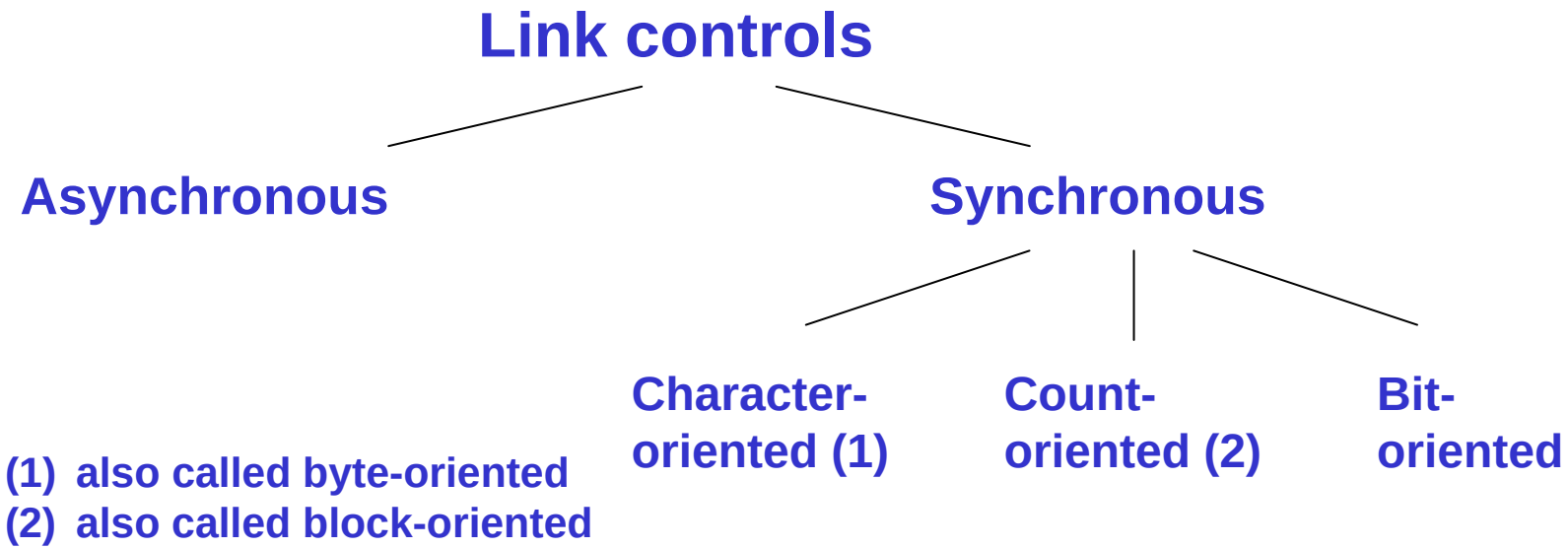
- UA: Unnumbered Acknowledgement

Connection Management

State presentation



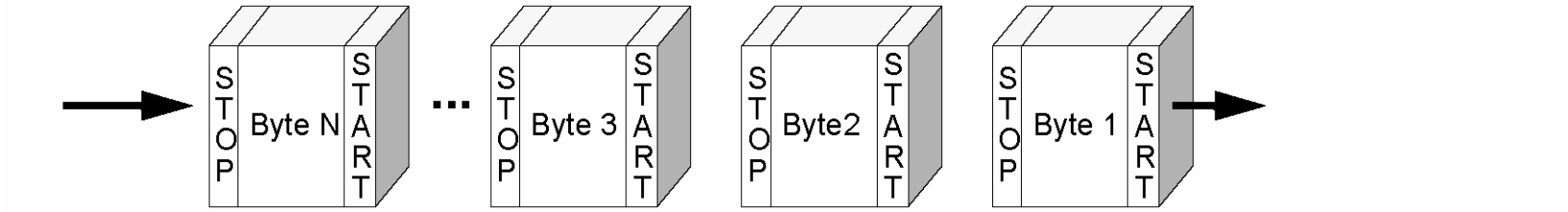
2 Operating Mode: Asynchronous and Synchronous



(1) also called byte-oriented
(2) also called block-oriented

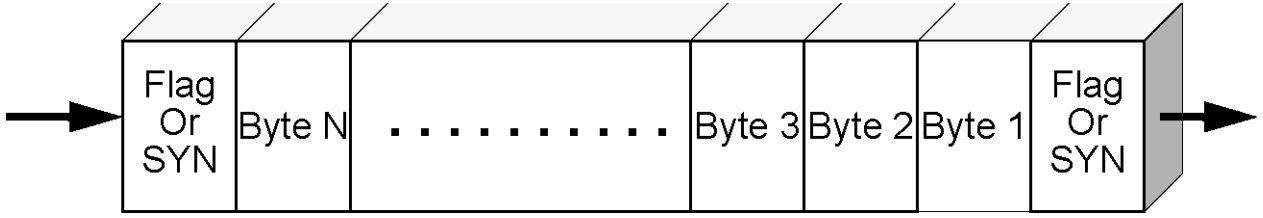
Asynchronous and Synchronous

Asynchronous transmission



- each character is bound by a start bit and a stop bit
- simple + inexpensive, but low transmission rates, often up to 200 bit/sec

Synchronous transmission (to be discussed in more detail in the following)



- several characters pooled to frames
- frames defined by SYN or flag
- more complex, but higher transmission rates

Synchronous Data Transmission: Framing

L2 forms a frame from the L1-bits

- which (as a unit) undergoes error correction

Possibilities for definition and recognition of frames boundaries

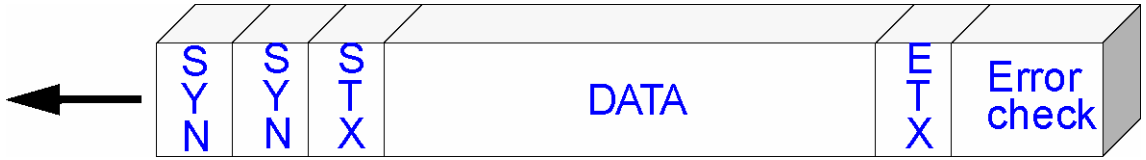
- bound frames by idle times
  - problems
    - networks (L1) usually have no suitable notion of time
    - possibly loss of efficiency

1. character oriented
2. count oriented
3. bit oriented
4. using invalid characters of the physical layer

Comment

- Combinations may be used in L2:
  - e.g.
    - count oriented and bit oriented
    - the transmission is error free only if both match

2.1 Character Oriented Protocols



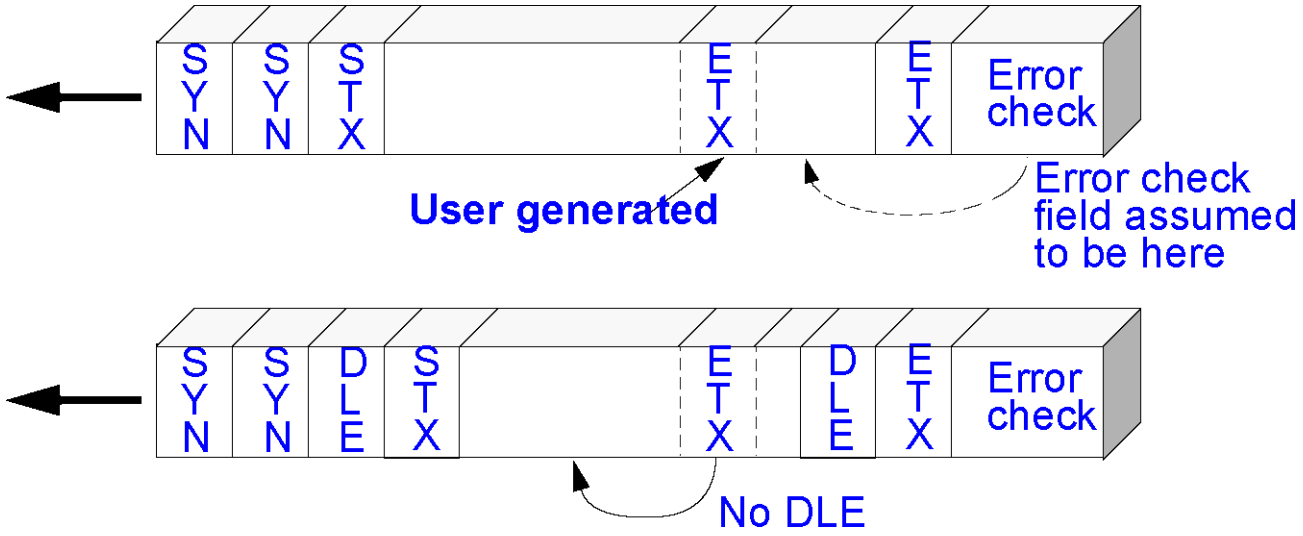
Control Fields

- flag frame areas
- depend on encoding (e.g. ASCII, EBCDIC)

Character Oriented Protocols

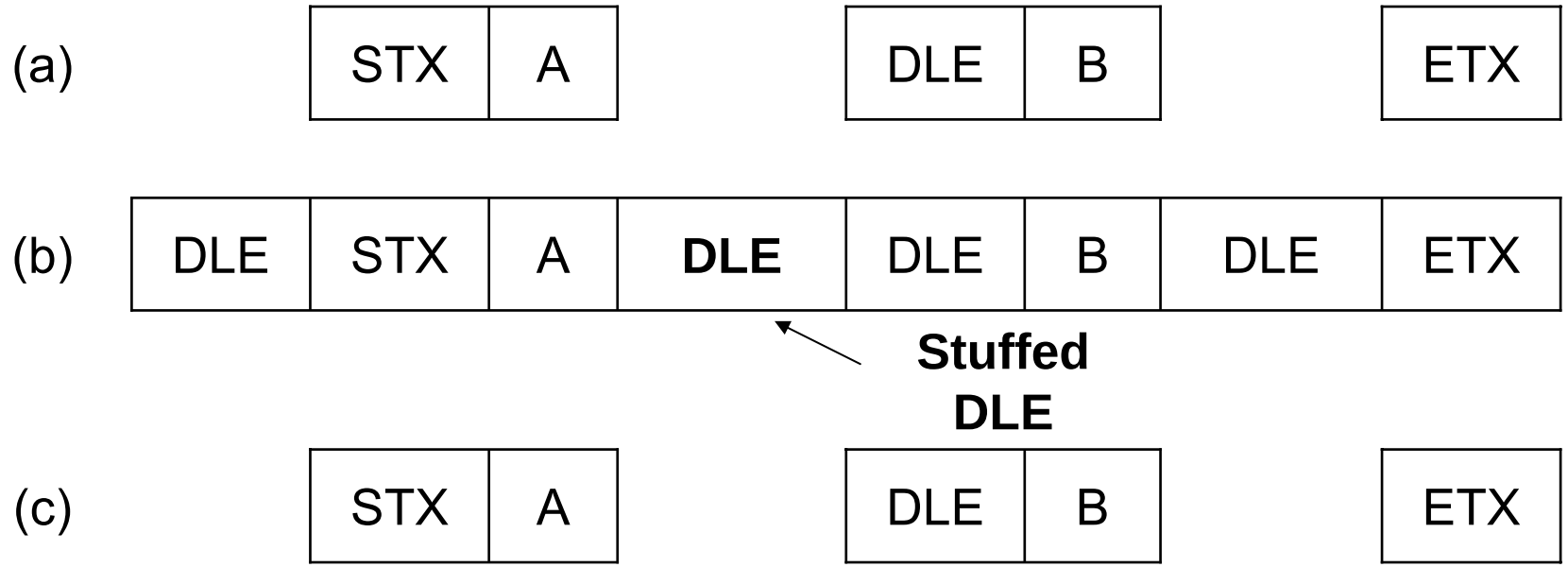
Problem: user data may contain “control characters”

Solution: CHARACTER STUFFING



- SENDER: each control character is preceded by a DLE (Data Link Escape), (but not in user generated data)
- RECEIVER: only control characters preceded by DLEs are interpreted as such

Character Oriented Protocols



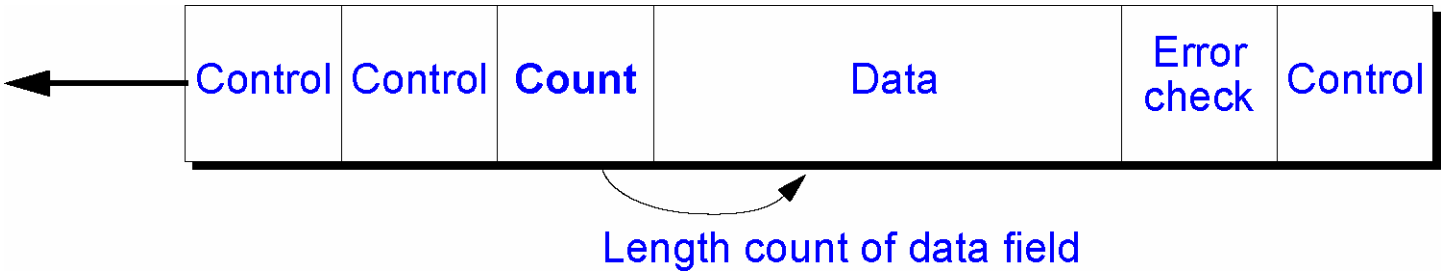
Problem: user generated date contain DLE
Solution:

- the sender inserts an additional DLE before the DLE in the user's data
- the receiver ignores the first of two back-to-back DLEs

Disadvantages:

- DLE insertion requires additional effort/time
- usually a derivation of an ASCII 8 bit encoding used
  - i.e. conversion required (if codes are different)

2.2 Count Oriented Protocol



Frame contains LENGTH COUNT FIELD

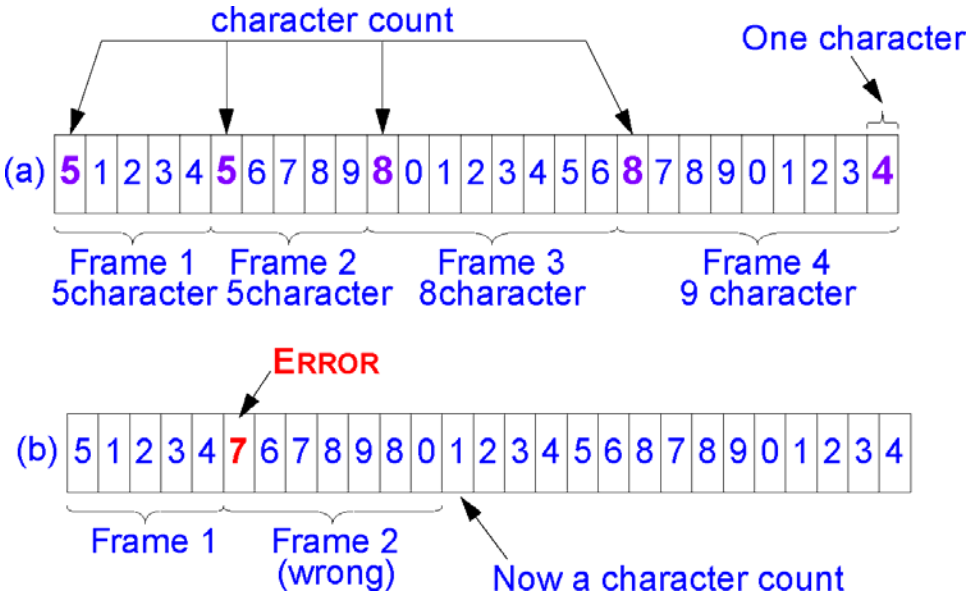
PROBLEM: Transmission error destroys length count

- sender and receiver are not synchronized anymore

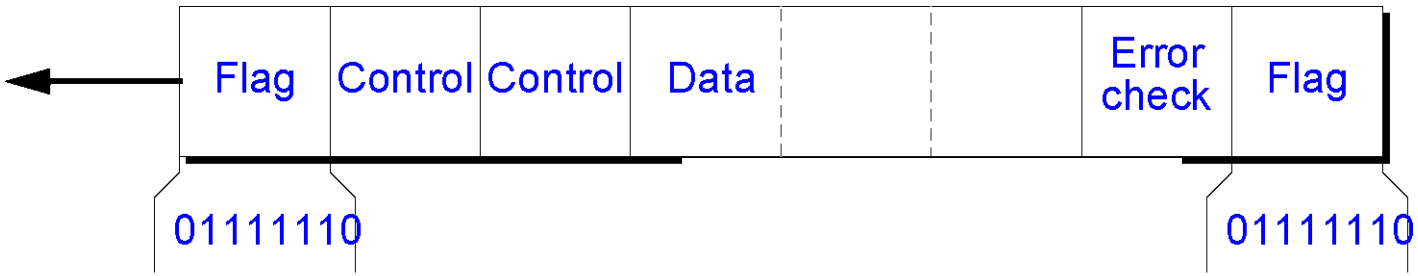
that means

- where does the next frame start?
- Where do retransmitted frames start?

➔ Therefore not widely spread!



2.3 Bit Oriented Protocols



Most of today's protocols use such an approach

- independent from encoding
- block definition

```
flag (01111110)
```

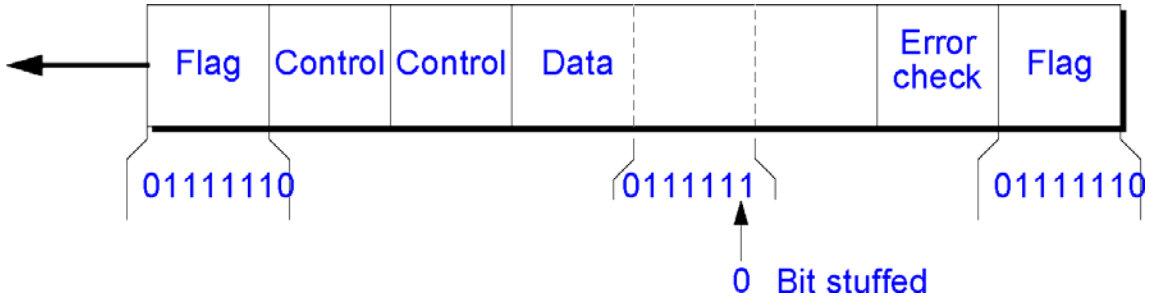
Start / end

- may be different flags
- are typically identical

Bit Oriented Protocols

PROBLEM:

- ”flag” in user data
  (e.g. 01111110)



SOLUTION:

- bit stuffing

(a) 0 1 1 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0 1 0

(b) 0 1 1 0 1 1 1 1 1 **0** 1 1 1 1 1 **0** 1 1 1 1 1 **0** 1 0 0 1 0

Stuffed Bits

(c) 0 1 1 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0 1 0

SENDER

- inserts a "0" bit after 5 successive "1“
  (only in the user data stream)

RECEIVER

- suppresses “0” after 5 successive “1”

2.4 Protocol with Invalid Characters

Invalid

- with regard to the layer in consideration:
- in this case the physical layer

Method

- L1 defines digital encoding

Example

- Return to Zero (RZ)
  - 1: clock pulse (double frequency) during the interval
  - 0: low level
- there is always a combination of “high-low” or a sequence of “low”
- there is never a “high-high” combination (invalid symbol)
  - i. e. define an invalid symbol in L2 as the bit boundary

Comment

- effective
- but, actually inconsistent with the layer model

3 Error Detection and Correction

BIT ERROR: Modification of single bits

BURST ERROR: Modification of a sequence of bits

Causes for errors:
- thermic noise:
  - electron movement generates background noise
- impulse disruptions (often last for 10 msec):
  - cause: glitches in electric lines, thunderstorms, switching arcs in relais, etc.
  - most common cause for errors
- crosstalk in adjacent wires
- echo
- signal distortion (dampening is dependent on frequency)

➔ errors usually occur in bundles: BURST ERROR

Error detection:
- inserting redundancies so that receiver is able to **detect** an error
- no error correction: usage of separate method, if needed
  - e.g., retransmission

Error correction:
- inserting redundancies
  - so that receiver is able to **detect and correct** an error

3.1 Basics: Code Word, Hamming Distance

Frame (= code word) contains
- data
- checking information

Code = set of all valid code words

Hamming distance of two words w1 and w2:
- number of bit positions by which w1 and w2 differ
- example:

```
      w1 10001001
XOR   w2 10110001
      =   00111000 i.e. d = 3
```

Hamming distance of a code:
- minimum Hamming distance between two words of a code
- example:

```
w1 10001001
w2 10110001
w3 10110011
```

the Hamming distance w2 XOR w3 = 1 is the smallest, therefore, the Hamming distance of the code is d = 1

3.2 Detection and Correction (according to Hamming)

Hamming Distance determines

- a code's error detection and correction properties

1. DETECTION of f 1-bit errors:

- example 1-dimensional

parity bit p

0	0	0
0	1	1

- 2-dimensional

parity bits last column and last row

0	0	1	1	0	0
1	1	1	1	1	1
1	0	0	0	0	1
1	1	0	0	0	0
0	0	0	0	1	1
1	0	0	0	0	1

- 2-dimensional
- allows to detect 1,2 and 3 bit errors
- (example from page 92 "Peterson Davie", german book)

Detection and Correction (according to Hamming)

DETECTION of f 1-bit errors:

- if the Hamming distance of code d

  $d \geq f + 1$

- i.e. f and less errors generate an invalid code word
- example:

```
    parity bit
    p
0 0 0
0 1 1
1 0 1
1 1 0
  d = 2:
  i.e. maximum value for f: f=1
  detection of a (i.e. one) 1-bit error
```

Detection and Correction (according to Hamming)

2. CORRECTION of f 1-bit errors:
   - if the Hamming distance of code d
     $$d \geq 2*f + 1$$
   - f and less errors transcribe word w into an invalid word,
     - which is "closer" to w than to any other word

   - example: d=5 ➔ f = 0,1 or 2

     0 0 0 0 0 0 0 0 0 0
     0 0 0 0 0 1 1 1 1 1
     1 1 1 1 1 0 0 0 0 0
     1 1 1 1 1 1 1 1 1 1

   - correction of two 1-bit errors (f=2) in the following word:

     0 0 0 0 0 0 0 1 1 1 ➔

   - result
     - because the NEXT POSSIBLE WORD the following is

     0 0 0 0 0 1 1 1 1 1

Detection and Correction (according to Hamming)

CORRECTION of f 1-bit errors:

- if the Hamming distance of code d

  $d \geq ...*f + ...$

- f and less errors transcribe word w into an invalid word, which is "closer" to w than to any other word

- example: d=5 ➔ f = 0,1 or 2 ??

  0 0 0 0 0 0 0 0 0 0
  0 0 0 0 0 1 1 1 1 1
  1 1 1 1 1 0 0 0 0 0
  1 1 1 1 1 1 1 1 1 1

- correction of two 1-bit errors (f=2) in the following word:

  0 0 0 0 0 ***0 0*** 1 1 1 ➔

- result
  - the NEXT POSSIBLE WORD the following is ..

    0 0 0 0 0 ***1 1*** 1 1 1

3.3 Error Correction

CORRECTION of f 1-bit errors:

- if Hamming distance of code is given by $d \geq 2f + 1$

Lower bound for the number of check-bits for correcting 1-bit errors: $(m + r + 1) \leq 2^r$

(m is # data bits; r is # check-bits

e. g.

m = 8 ➔ r = 4

m = 1000 ➔ r = 10

Procedure:

- according to Hamming, 1950
- according to Trellis

Correction of burst errors (up to length k)

- treat k consecutive codewords as matrix
- transmission by columns

Properties:

- only possibility for simplex operation
- but high redundancy in each block

➔ usually less efficient than error detection

3.4 Error Detection

CYCLIC REDUNDANCY CODE (CRC) is one of the error detection procedures
see e.g. http://de.wikipedia.org/wiki/Cyclic_Redundancy_Check

Basic idea:

- bit strings are treated as polynomials

n-bit string: $k_{n-1} \cdot x^{n-1} + k_{n-2} \cdot x^{n-2} + \ldots + k_1 \cdot x + k_0$
whereas ki = [0,1]

Example:
1 1 0 0 0 1 ➔ x5 + x4 + 1

Polynomial arithmetics: modulo 2 ("algebraic field theory")

```
Sender                                  Receiver
          /*sends block B*/
       B(x)/G(x) = Q(x)+ R(x);
            (B, R)
send ------------------------> receive;
                               (B(x)-R(x))/G(x)
 =Q(x)+R'(x)
                               if R'(x) = 0
                               then Accept B
                               else Reject B
```

Error Detection

Algorithm
B(x) ... Block polynomial

G(x) ... Generator polynomial of degree r
- r < degree of B(x)
- highest and lowest order bit = 1

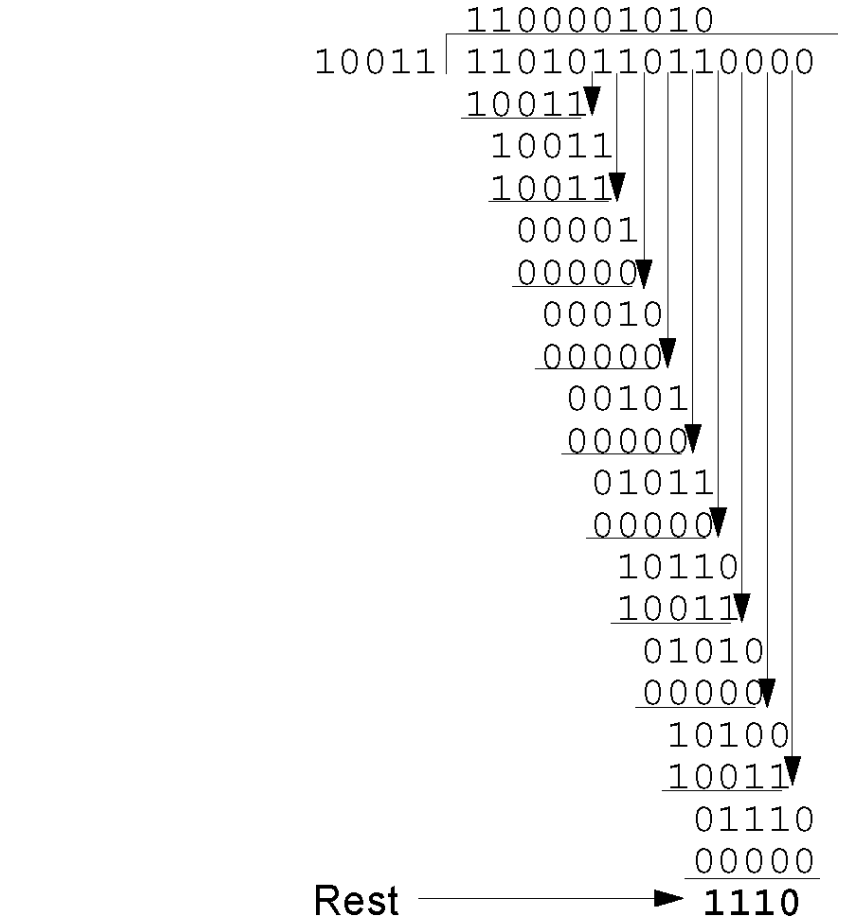
1. Add r 0-bits at the lower order end of B.
Let result be B^E and corresponds to: $x^r * B(x)$

2. Divide $B^E(x)$ by G(x)
- modulo 2: subtraction and addition correlate to XOR
- result: Q(x) + R(x)

3. Subtract R(x) from B^E(modulo 2)
Transmit the result.

Error Detection

Example: frame: 1101011011
Generator G(x), degree 4: 10011
Frame with 4 attached 0-bits: 11010110110000



Transfered frame: 11010110111110
Transfered frame: 11010110111110

Error Detection

Standardized polynomials:

```
CRC - 12 = x12 + x11 + x3 + x2 + x1 + 1
CRC - 16 = x16 + x15 + x2 + 1
CRC - CCITT= x16 + x12 + x5 + 1
```

CRC - CCITT recognizes

- all simplex and duplicate errors
- all errors with odd bit numbers
- all burst errors up to a length of 16
- 99,99 % of all burst errors of a length of 17 and more

Implementation

- looks complicated but can be done using simple shift register in HW
- virtually all LANs use it

Assumptions & analyses

- have been made for long time assuming frames contain random bits
- recent work inspecting real data showed this to be wrong
  - undetected errors are more common than previously assumed

4 Flow Control and Error Treatment

Basics, problems statement:

- sender can send faster than receiver can receive

WITHOUT FLOW CONTROL:

- sender can send faster than receiver can receive
- that means that the receiver loses frames despite error-free transmission

WITH FLOW CONTROL:

- sender can adapt to receiver's abilities by feedback

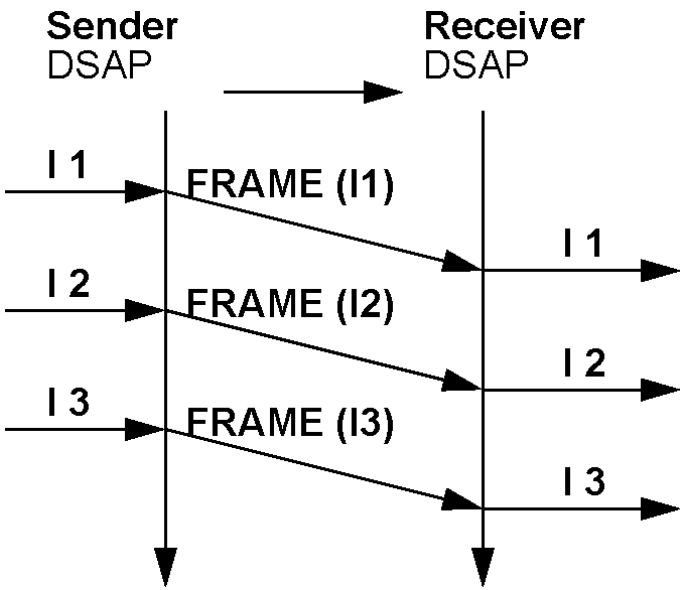
Comment:

- error control and flow control are usually interlinked
- rate control (in contrast to flow control)
  - reference to frame sequencing (not single frames)
  - used with continuous-media data (audio, video)

4.1 Protocol 1: Utopia

Assumptions:

- error-free communication channel
- receiving buffer infinitely large
- receiving process infinitely fast



DSAP: Data link (layer) Service Access Point

- but: finite buffer, finite processor output
  ...

- sender floods receiver with data faster than the latter is able to process

4.2 Protocol 2: Stop-and-Wait

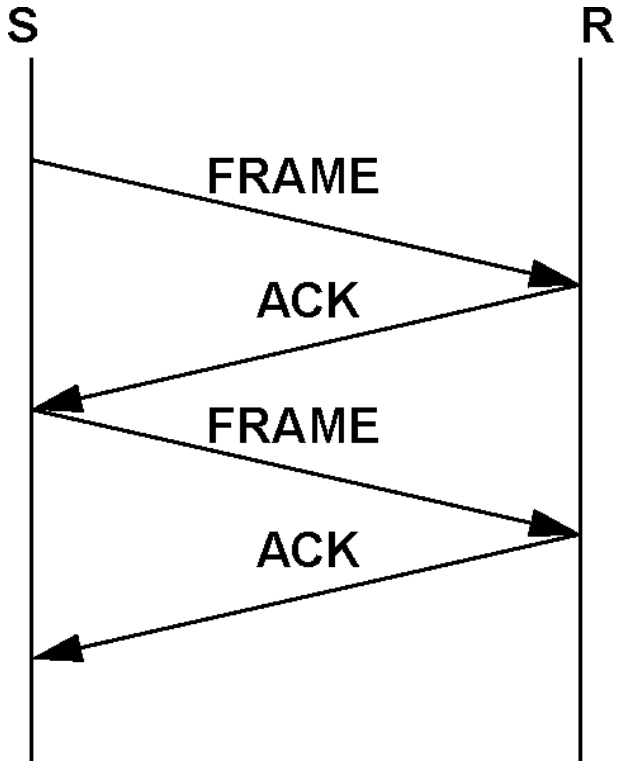
Assumptions:

- error-free communication channel
- NOT [infinitely large receiving buffer]
- NOT [receiving process infinitely fast]
  - but always fast enough for processing one (1) frame

Further

- simplex mode for actual data transfer
  - acknowledgement requires at least semi-duplex mode

Flow control necessary: STOP-AND-WAIT



- receiving buffer for a frame
- communication in both directions (frames, ACKs)

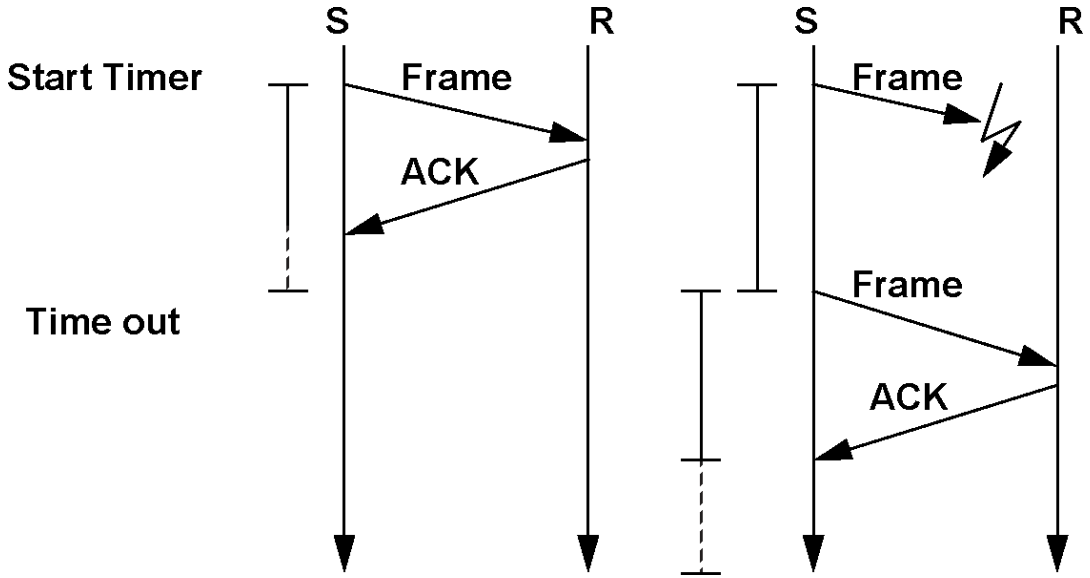
but: additionally, noisy communication channel (loss of frames)...

4.3 Protocol 3a: Stop-and-Wait / PAR

Assumptions:
- NOT [error-free communication channel]
- NOT [infinitely large receiving buffer]
- NOT [receiving process infinitely fast]

Problem: protocol 2 locks down during loss of both frames and ACKs

Solution:
- PAR (Positive-Acknowledgement with Retransmit)
- also called ARQ (Automatic Repeat reQuest)



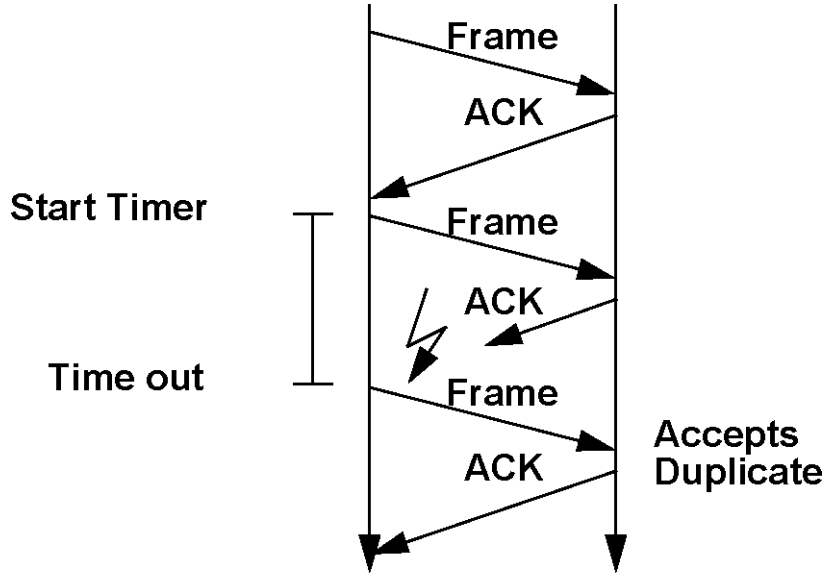
Timeout interval:
- TOO SHORT:
  - unnecessary sending of frames
- TOO LONG:
  - unnecessary long wait in case of error

but: in addition if ACK is lost
...

4.4 Protocol 3b: Stop-and-Wait / PAR / SeqNo

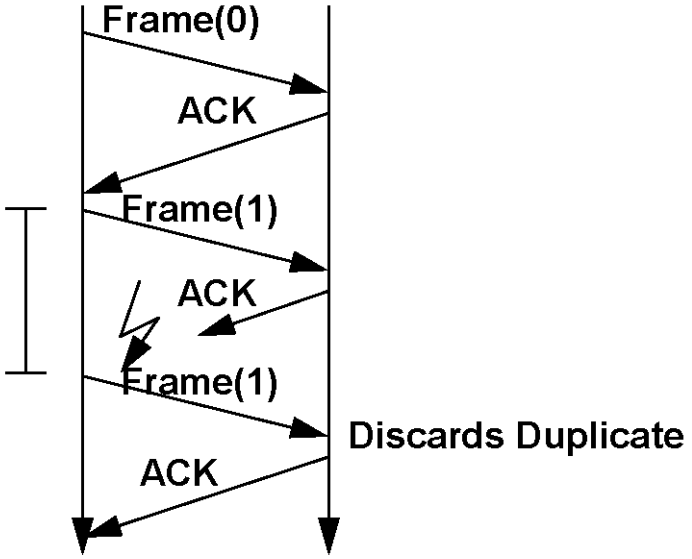
Problem:

- loss of ACKs leads to block duplication



Solution: sequence numbers

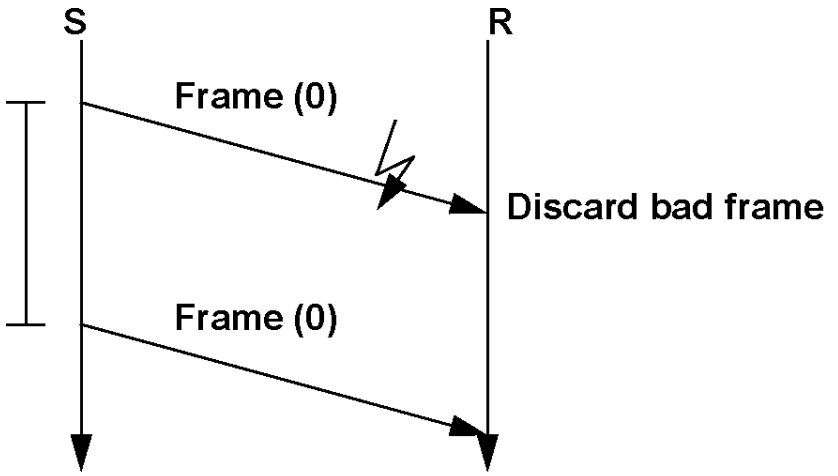
- each block contains a sequence number
- sequence number is kept during retransmissions
- range
  - in general: [0, …, k], $k=2^n-1$
  - Stop-and-Wait: 0,1
  - n: window size



4.5 Protocol 3c: Stop-and-Wait / NAC+ACK / SeqNo

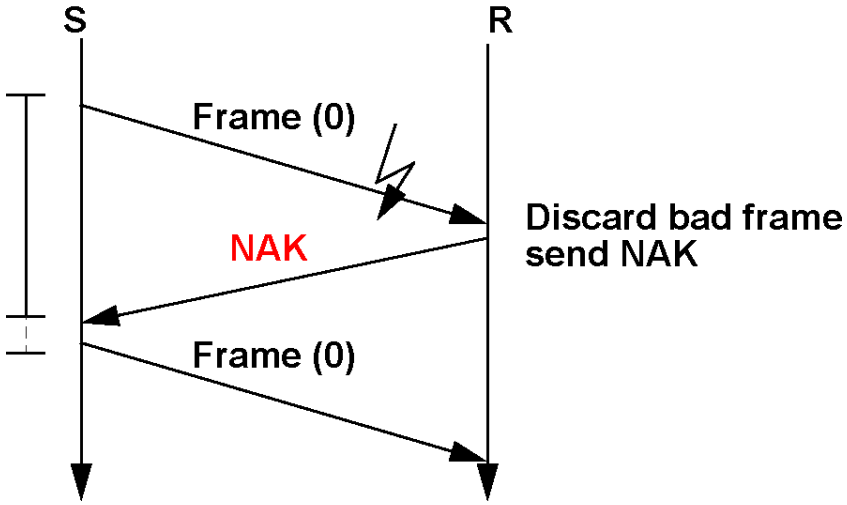
Until now passive error control

- no differentiation between
  - missing and
  - faulty frames
- even if receiver knows the error, it has to wait for the timer
  - time consuming



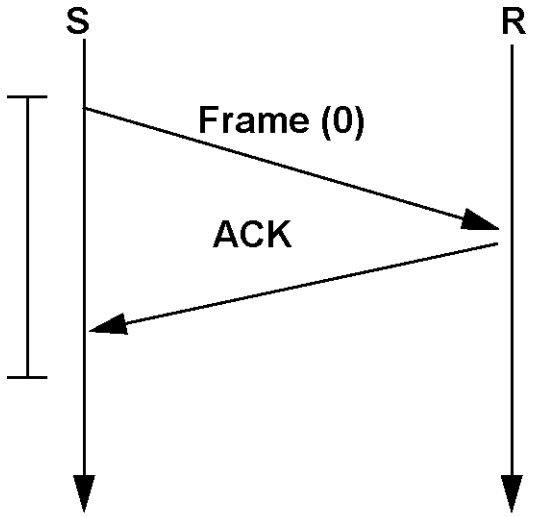
Alternative: Active error control

- include negative ACK (NAK)
- in addition to ACK

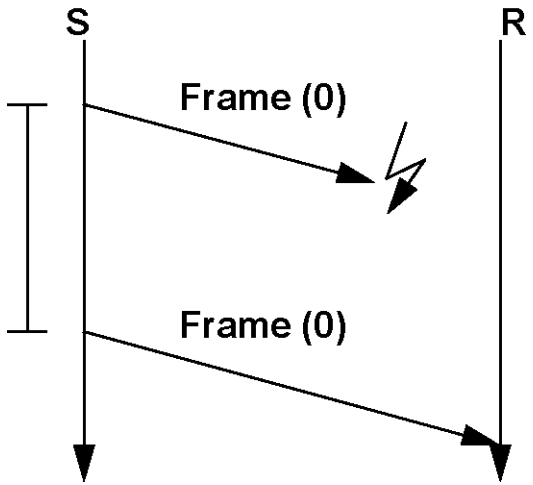


Protocol 3c: Stop-and-Wait / NAC+ACK / SeqNo

1. Situation: OK
Frame correctly transmitted
➔ ACK sent



2. Situation:
Break
on path sender to receiver
• frame did not arrive
➔ timer issues retransmit



Protocol 3c: Stop-and-Wait / NAC+ACK / SeqNo

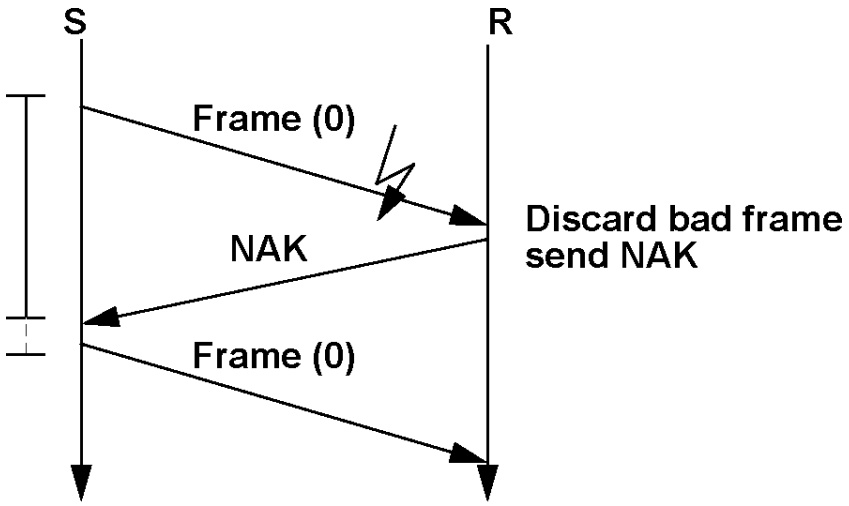
3. Situation:

Break

on path sender to receiver

- faulty frame arrives

➔ NAK issued



4. Situation:

on path receiver to sender

- NAK issued

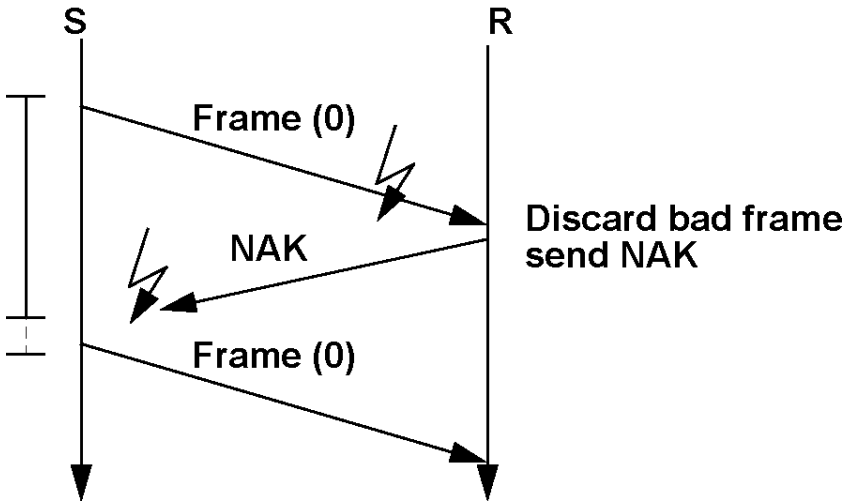
but,

- NAK does not arrive

or

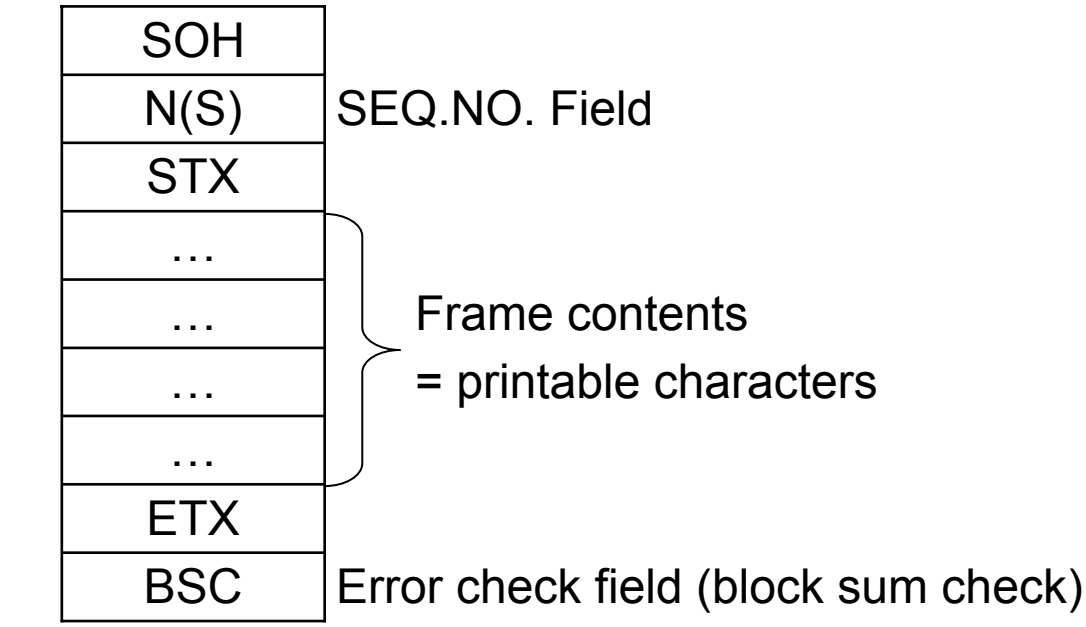
- NAK arrives damaged

➔ timer issues retransmit

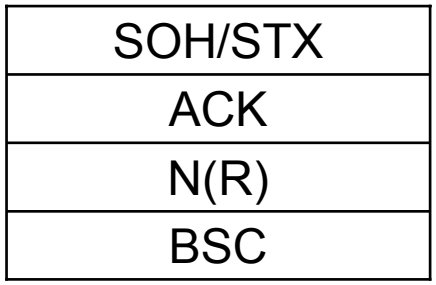


4.6 Example of Matching Frame Formats, Seq.No.

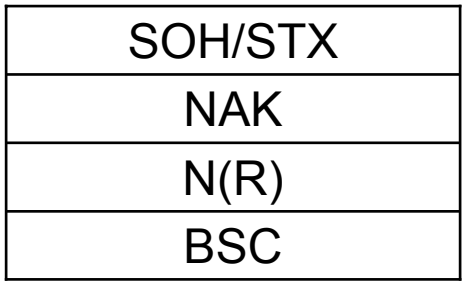
Example: using a character oriented protocol



I-frame format (information, data frame)



ACK-frame format



NAK-frame format

5 Sliding Window – Flow Control & Error Treatment

5.1 Channel Utilization and Propagation Delay
5.2 Sliding Window: Concept

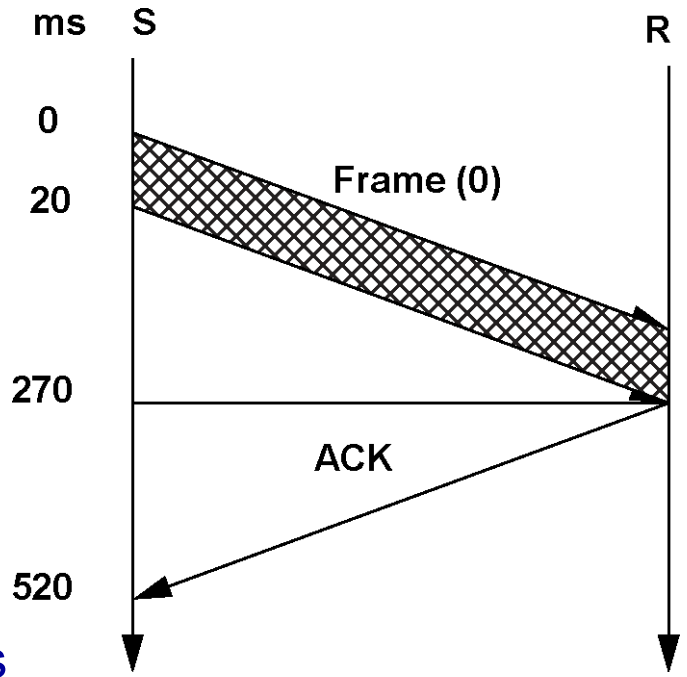
5.1 Channel Utilization and Propagation Delay

Stop-and-Wait:

- un-defined state (parallelism) with simultaneous
  - lost frames, modified frames and
  - premature time-out
- poor utilization of the channel

Example: satellite channel

- transmission rate: 50 kbps
- roundtrip delay 500 ms (2*250 ms)
- frame size: 1000 bit
- in comparison; ACK is short and negligible

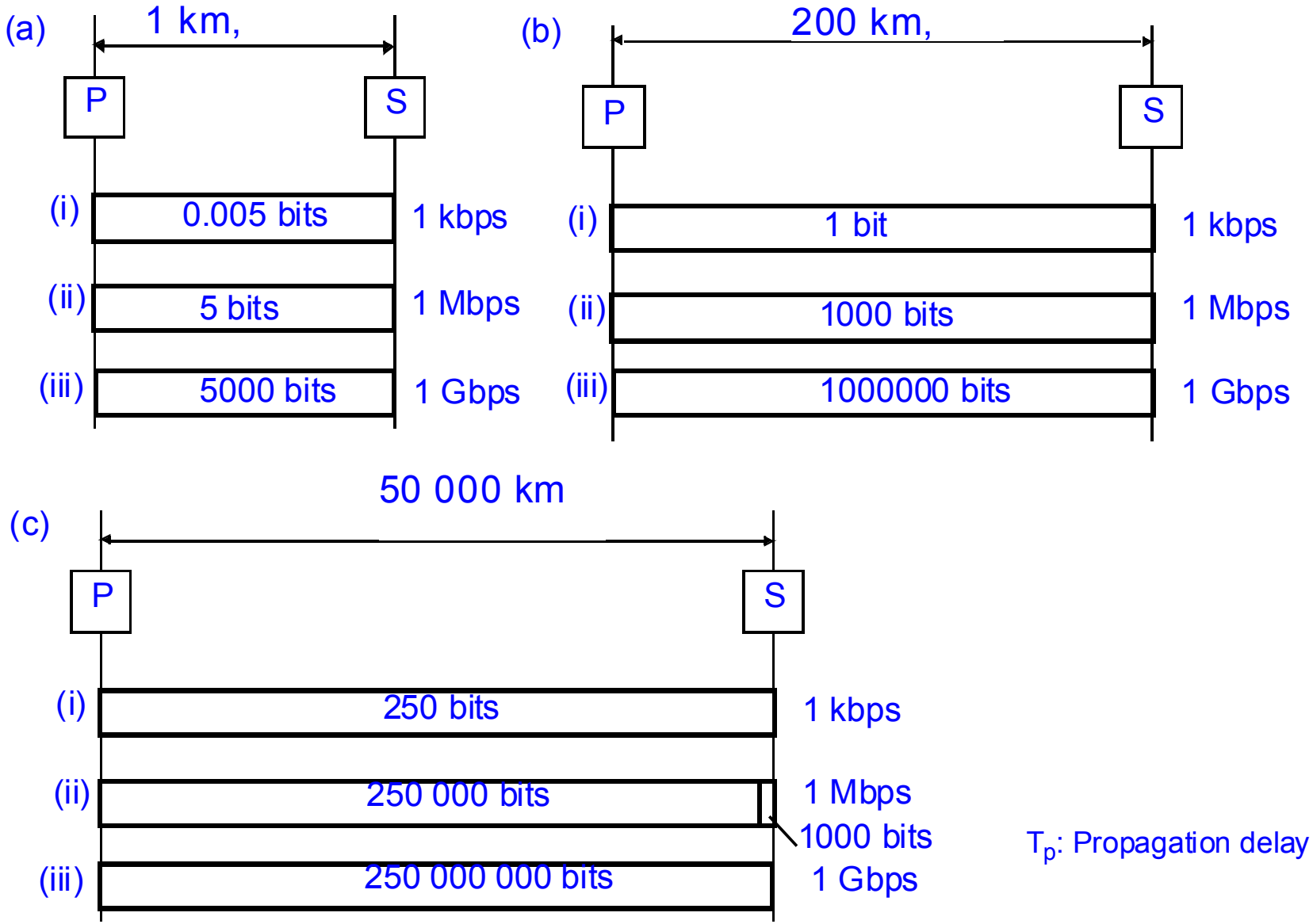


this means

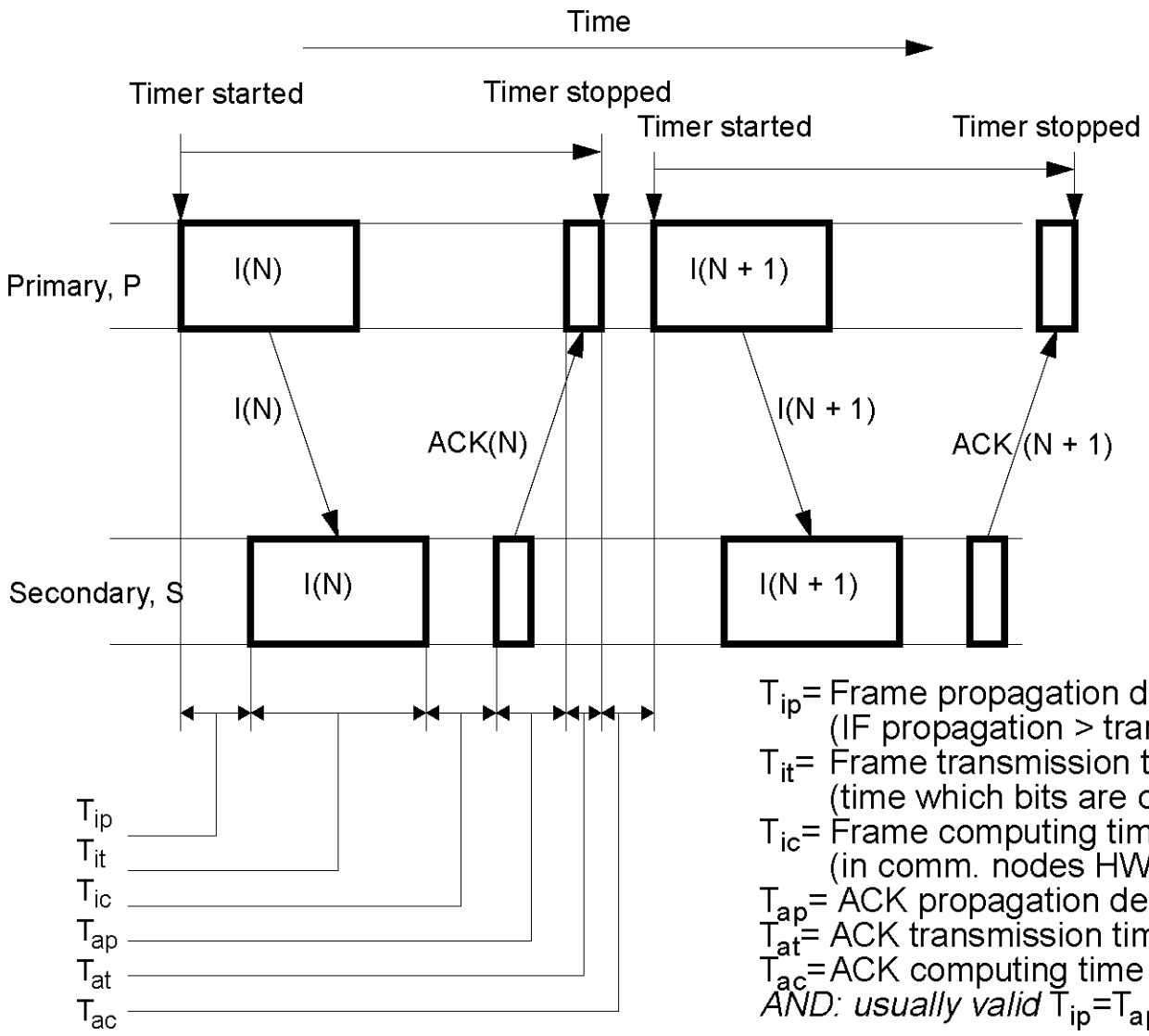
- sending needs 1000 bit / 50.000 bps = 20 ms
- sender is blocked for 500 ms of 520 ms

➔ Channel utilization < 4%

Channel Utilization and Propagation Delay



Channel Utilization and Propagation Delay



T_{ip}= Frame propagation delay (**P** → **S**)
(IF propagation > transmission)
T_{it}= Frame transmission time (**P** → **S**)
(time which bits are on channel)
T_{ic}= Frame computing time in *S*
(in comm. nodes HW & SW)
T_{ap}= ACK propagation delay(**S** → **P**)
T_{at}= ACK transmission time(**S** → **P**)
T_{ac}=ACK computing time in *P*
AND: usually valid $T_{ip}=T_{ap} = T_p$

Channel Utilization and Propagation Delay

exact formula (note: some values based on assumptions):

$$U = \frac{T_{it}}{\sum T_{\text{information} + \text{acknowledgement}}} = \frac{T_{it}}{T_{ip} + T_{it} + T_{ic} + T_{ap} + T_{at} + T_{ac}}$$

approximated formula:

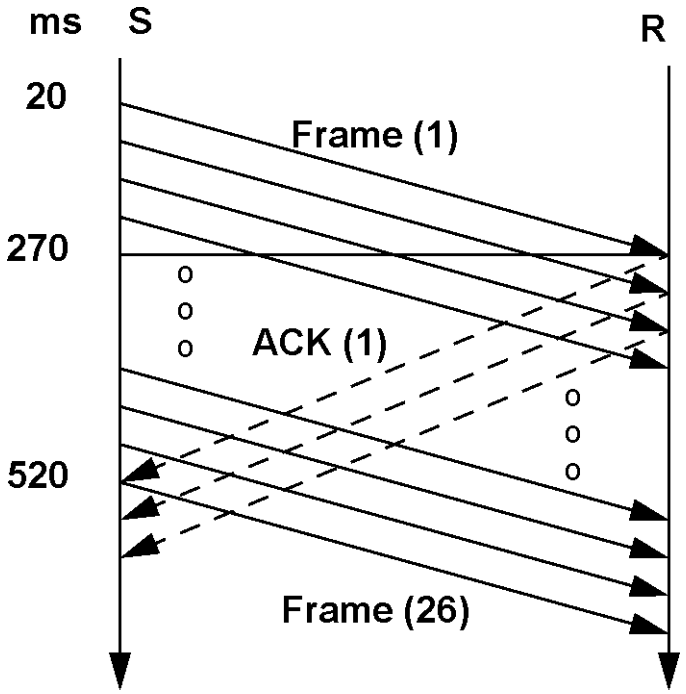
$$U = \frac{T_{it}}{T_{it} + 2T_{ip}} = \frac{1}{1 + 2\frac{T_{ip}}{T_{it}}}$$

- with the assumption
  $T_{ip} = T_{ap} = T_p$
  T_{ic}, ac computing << $T_{ip, ap}$ propagation delay
  T_{it} information frame transm. >> T_{at} ack information frame transm.

T_{ip} = Frame propagation delay
(IF propagation > transmission)
T_{it} = Frame transmission time
(time which bits are on channel)
T_{ic} = Frame computing time in S
(in comm. nodes HW & SW)
T_{ap} = ACK propagation delay
T_{at} = ACK transmission time
T_{ac} = ACK computing time in P

better: Pipeline ... Sliding Window

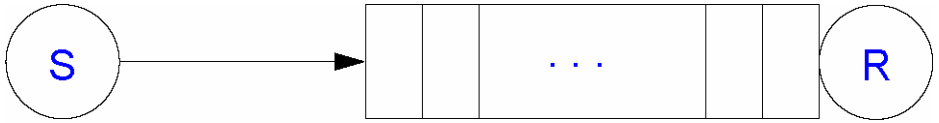
Solution: pipelining



Flow control: sliding window mechanism

5.2 Sliding Window: Concept

Flow control: receiving buffer must not be flooded



Sender and receiver window per connection (communication relationship)

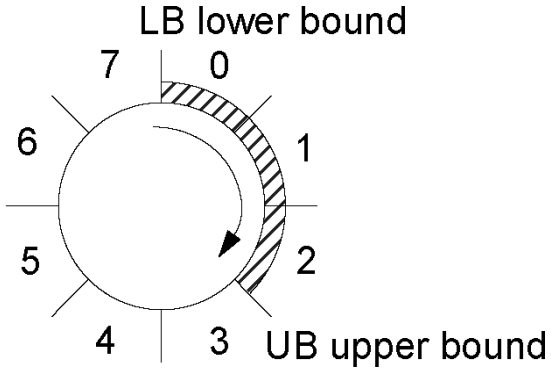
R-WINDOW:

- sequence numbers, which can be accepted

S-WINDOW:

- sequence numbers, which were sent but not yet acknowledged

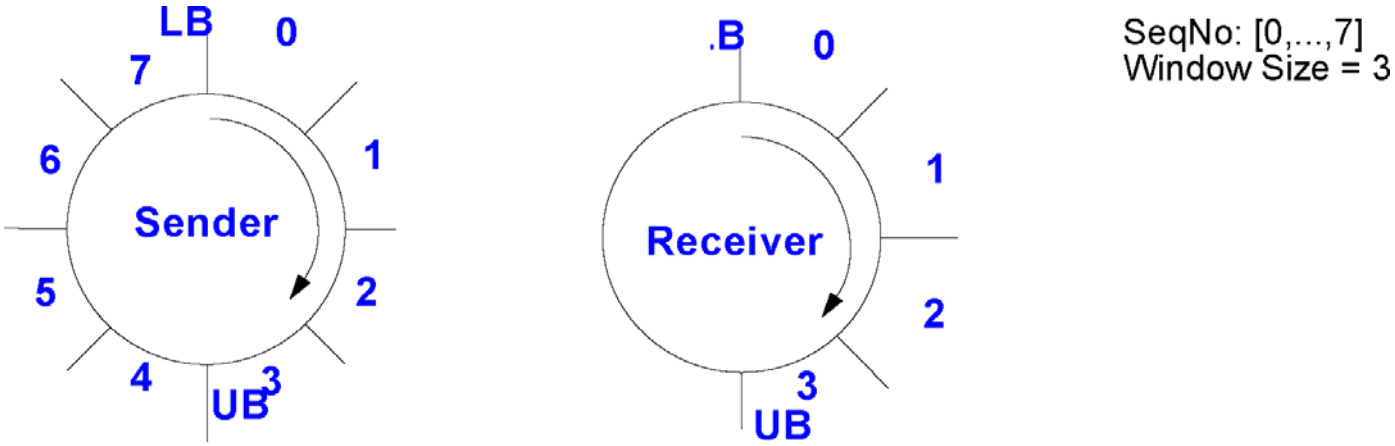
SeqNo: [0,...,7]
Window Size = 3



Initial window size:

- R-Window: number of buffers reserved
- S-Window: maximum number of blocks, which may still be open for acknowledgement

Sliding Window: Concept



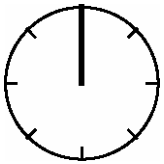
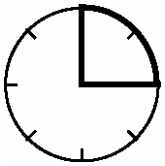
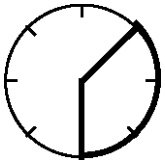
Lower Bound & Upper Bound

	Sender	Receiver
LB	oldest not yet confirmed seqno.	next, to be expected seqno.
UB	next seqno. to be send	highest seqno. to be accepted

Manipulation: increment(LB), increment(UB), if

	Sender	Receiver
LB	on reception of an ACK	on reception of a frame
UB	when sending of a frame	when sending of an ACK

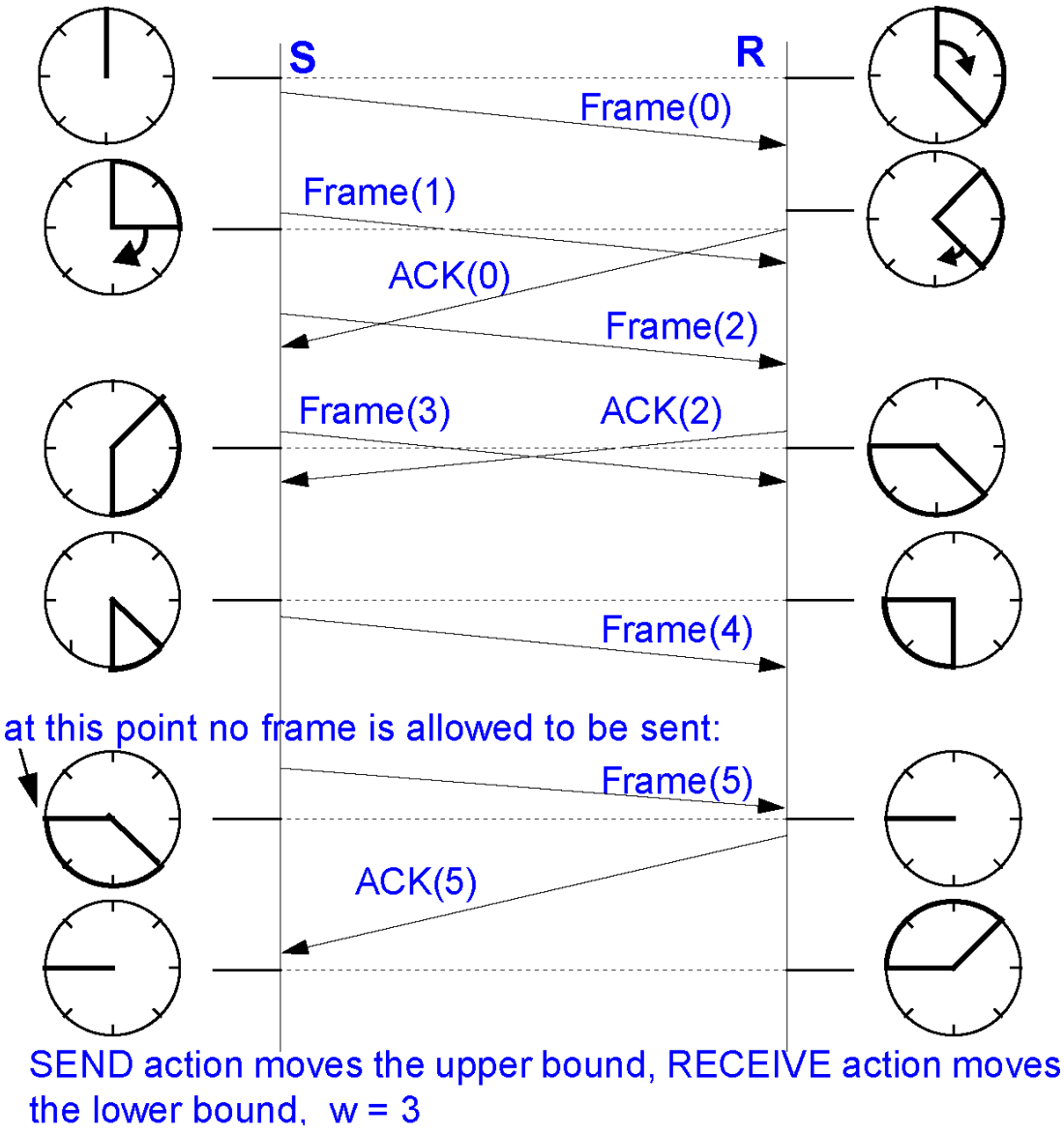
Sliding Window: Examples

Sender: Sliding Window	Stored Frames	Situation
	0	in this case sender may send up to 3 frames
	2	in this case sender may send 1 frame
	3	sender is not permitted to send anything, sender's L3 must not transmit further data to L2

Example Including Acknowledgement

Including Acknowledgement

- ACKs contain SeqNo
- that means ACK(SeqNo) confirms all frames(SeqNo') with
  - SeqNo' = SeqNo
  - and
  - SeqNo' before SeqNo



Example: Description

Stored frames at the sender

- maximum number defined by sender's window size (here 3)
- the frames not yet acknowledged by the receiver

Stored frames at the receiver

- maximum number determined by receiver's window size (here 3)
- the frames not yet acknowledged to the sender

ACK sent by receiver if frame

- has been identified as being correct
- has been transmitted correctly to the network layer (or a corresponding buffer)

APPLET

http://www.kom.e-technik.tu-darmstadt.de/Teaching/Visualization/visualization.html

- initialization (additionally!) different
  - send window LB=UB=0 (as described here)
  - receiving window LB=UB=0 (different)

6 Sliding Window: Remarks & Refinement

- Sliding Window: Influence of the Window Size
- Sliding Window: Piggybacking
- Sliding Window: Go-Back-N (Error Treatment)
- Sliding Window: Selective Repeat (Error Treatment)
- Channel Utilization
- Comparing Protocols

6.1 Sliding Window: Influence of the Window Size

Expected order

- if window size 1
  - sequence always correct
- if window size n (n>1)
  - no requirement to comply with the sequence
  - but, size limited by the window size

efficiency depends on (among other things)

- type and amount of errors on L1
- amount of data (in one packet) and rate of data
- end-to-end delay on L1
  - e.g. satellite
- window size

Operating resources and quality of service

- if the window size is small
  - generally shorter end-to-end delays at the L2 service interface
  - less memory needs to be kept available
    - per L2 communication relation

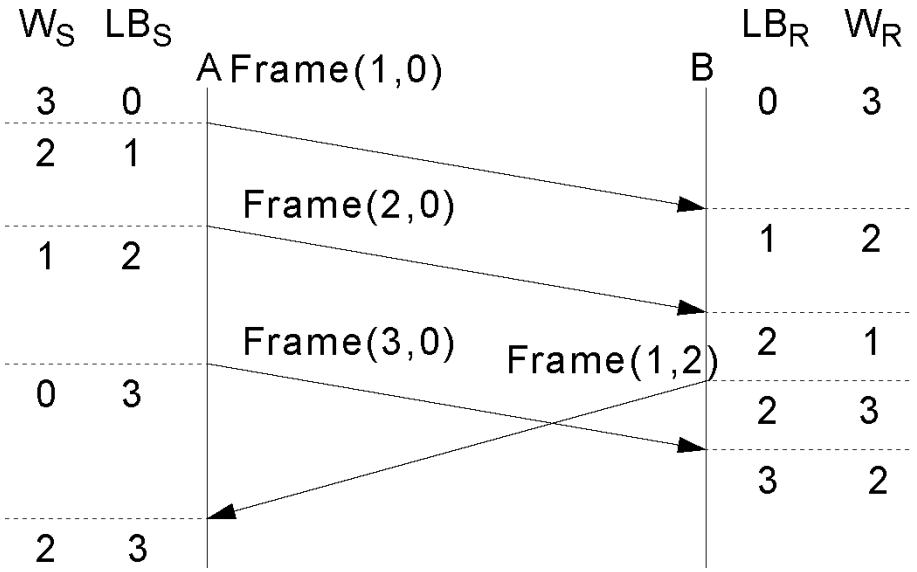
6.2 Sliding Window: Piggybacking

Frames may contain implicit ACKs

- duplex operation

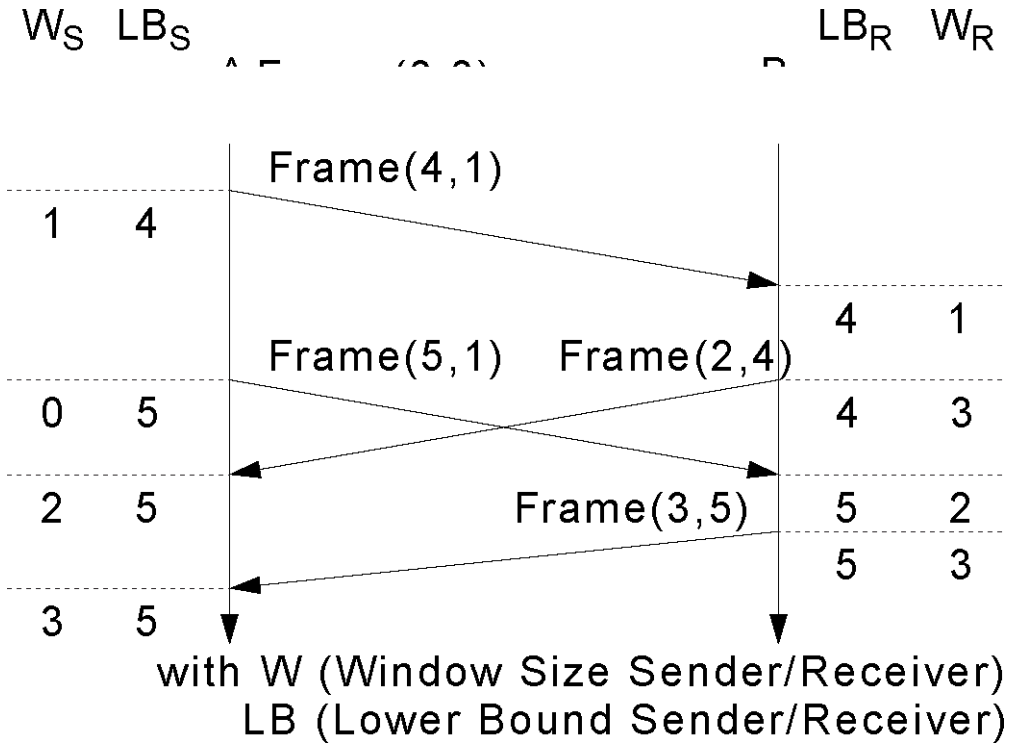
  `Frame(SeqNo, ACK-SeqNo,...Data...)`

- assumptions in this example
  - the initial SeqNo. is 0
  - the next SeqNo. and the next ACK-SeqNo to be expected is given



with W (Window Size Sender/Receiver)
LB (Lower Bound Sender/Receiver)

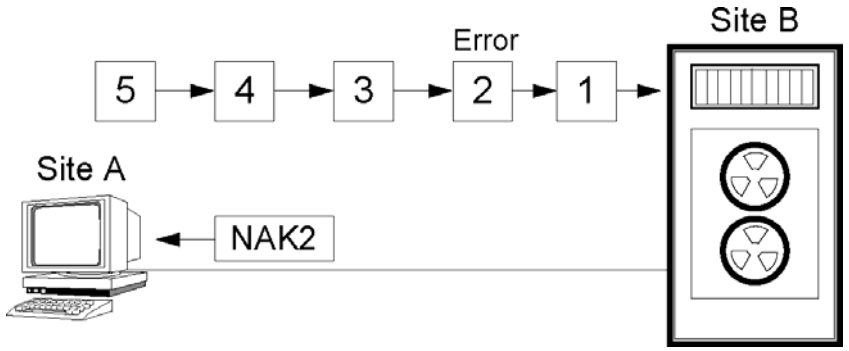
Sliding Window: Piggybacking



6.3 Sliding Window: Go-Back-N (Error Treatment)

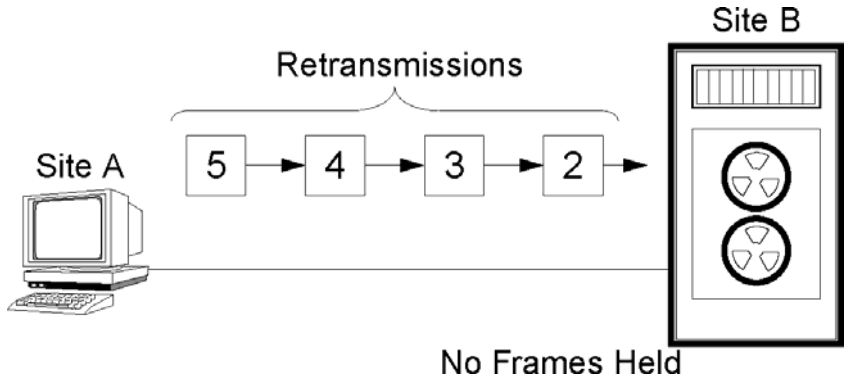
Procedure

- after a FAULTY FRAME has been received
  - receiver DROPS all FURTHER FRAMES until
    - correct frame has been received



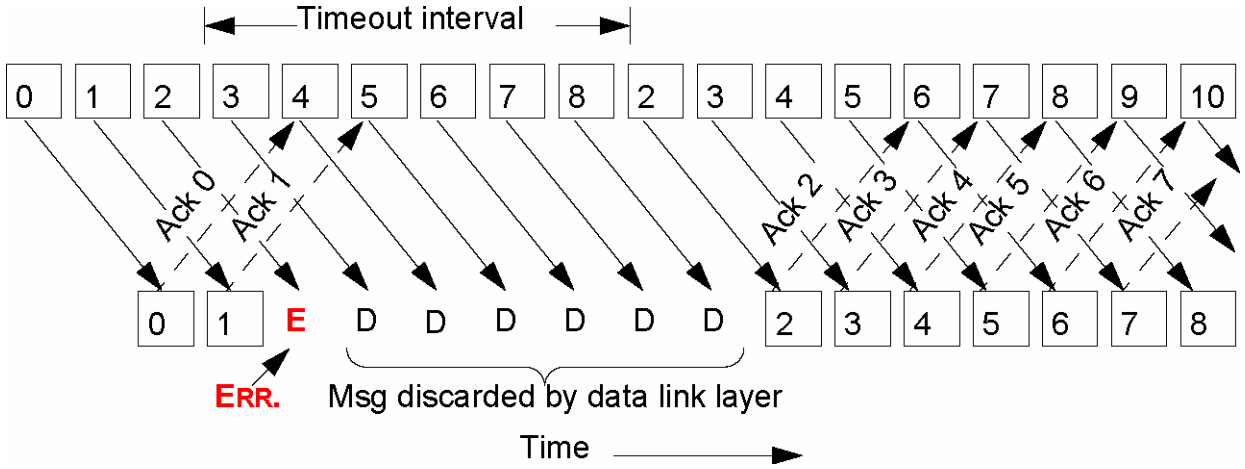
Evaluation

- simple
- no buffering of
  - “out-of sequence” frames necessary
    - (only for optimization purposes)
- poor throughput

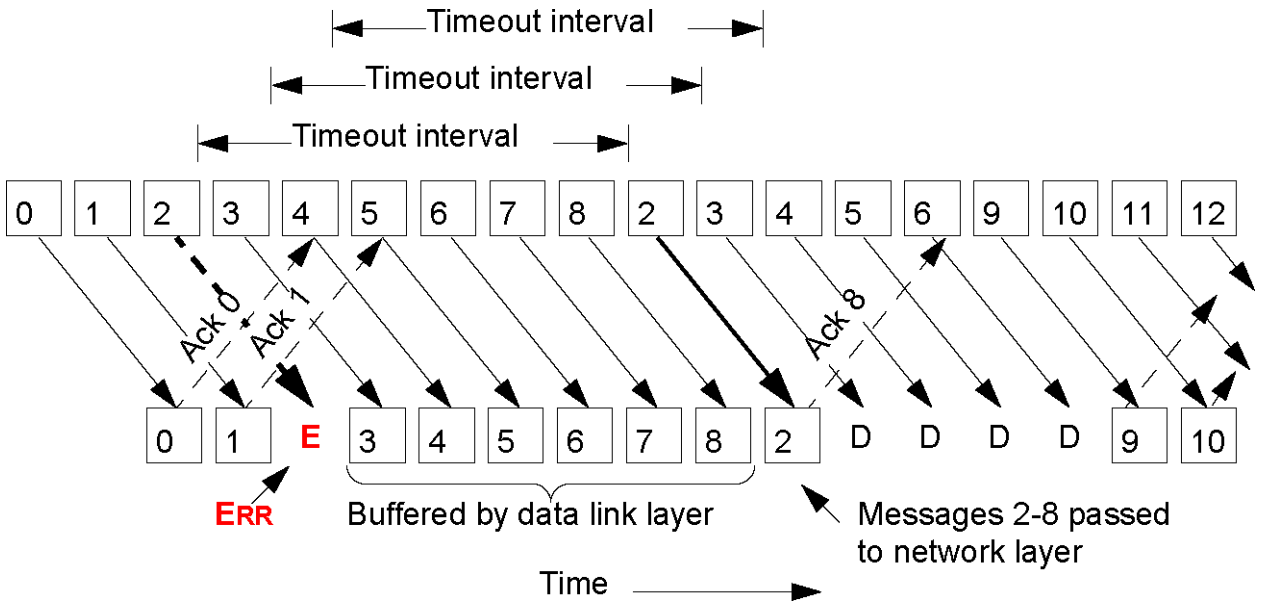


Sliding Window: Go-Back-N (Error Treatment)

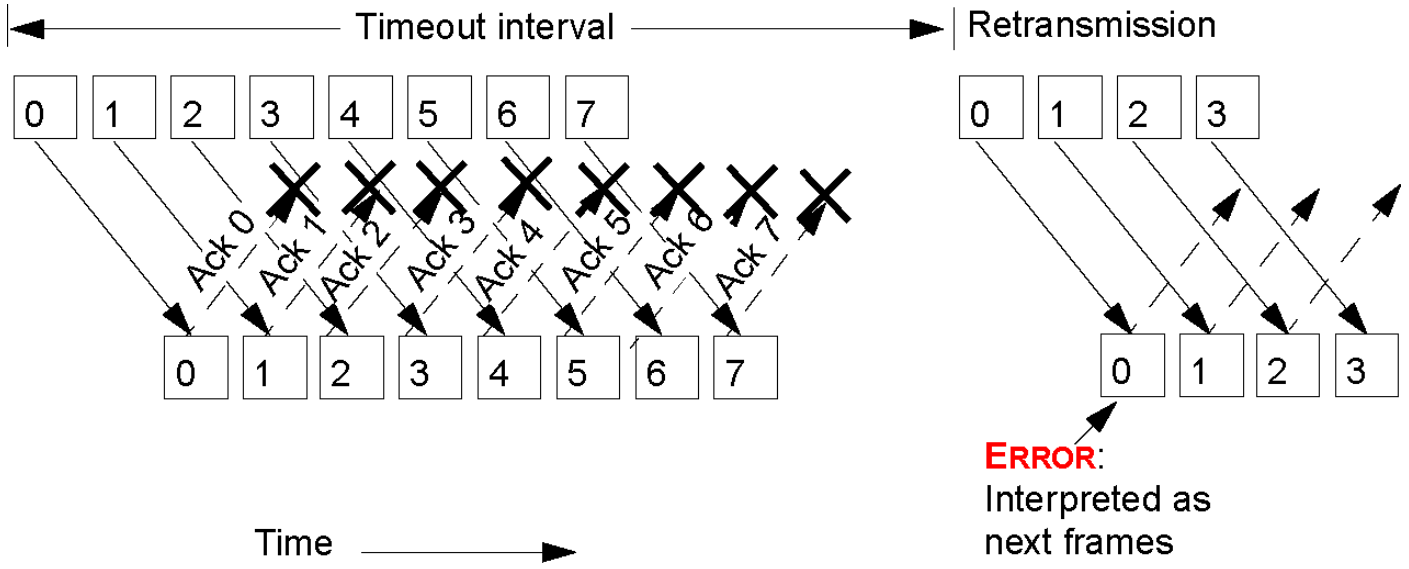
Example: sender: error detection by timeout



Optimization



Sliding Window: Maximum Window Size



Example:

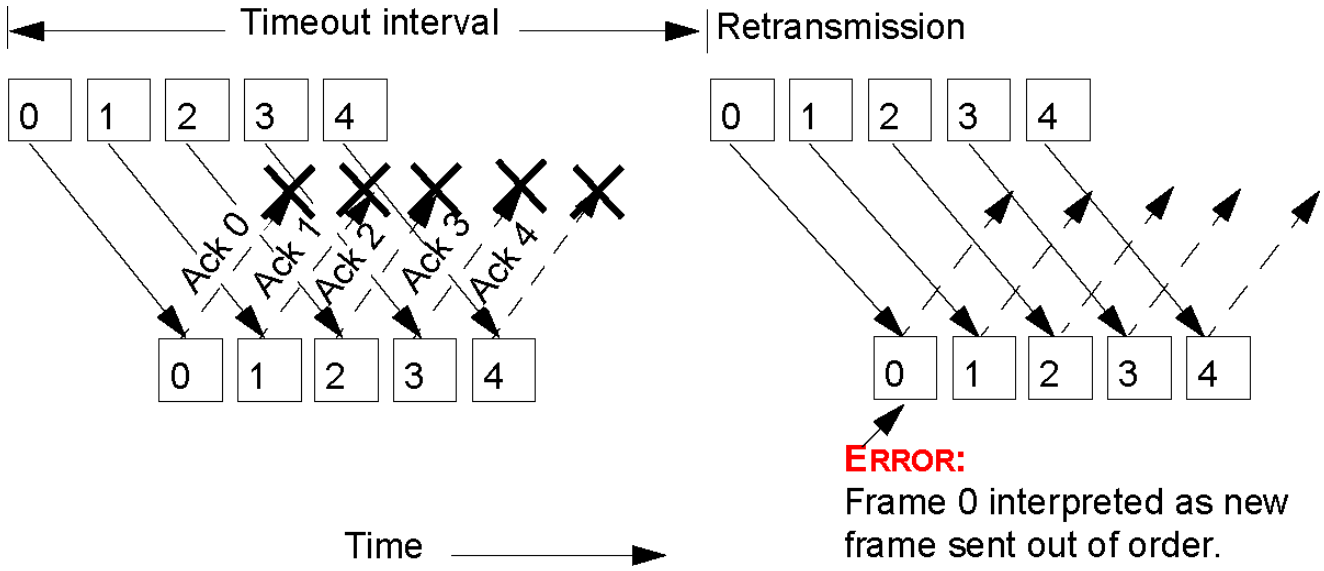
- amount of sequence numbers 8
- window size 8
- all ACKs lost

Correlation between

- window size and
- number of possible sequence numbers:

➔ at least max. window size <= range of sequence numbers

Sliding Window: Maximum Window Size and Frame Sequence



If the sequence is arbitrary
the following situation may occur, for example:

- amount of sequence numbers = 8
- window size = 5
- all ACKs are lost, and the frame that has been lost last is the first one to arrive at the receiver again

Correlation between window size and number of possible sequence numbers:

➔ max. window size <= 1/2 range of sequence numbers

- if Sender Window Size = Receiver Window Size
- during Go back N (otherwise possibly different)

6.4 Sliding Window: Selective Repeat (Error Treatment)

Procedure

- receiver stores all correct frames following a faulty one
- if sender is notified about an error
  - it retransmits only the faulty frame
  - (i.e. not all the following ones, too)
- if received properly
  - receiver has a lot of frames in its buffer
  - and transfers frames in correct sequence from L2 to L3

Comments

- corresponds to window size > 1
- occurrence of bursts at data link service interface

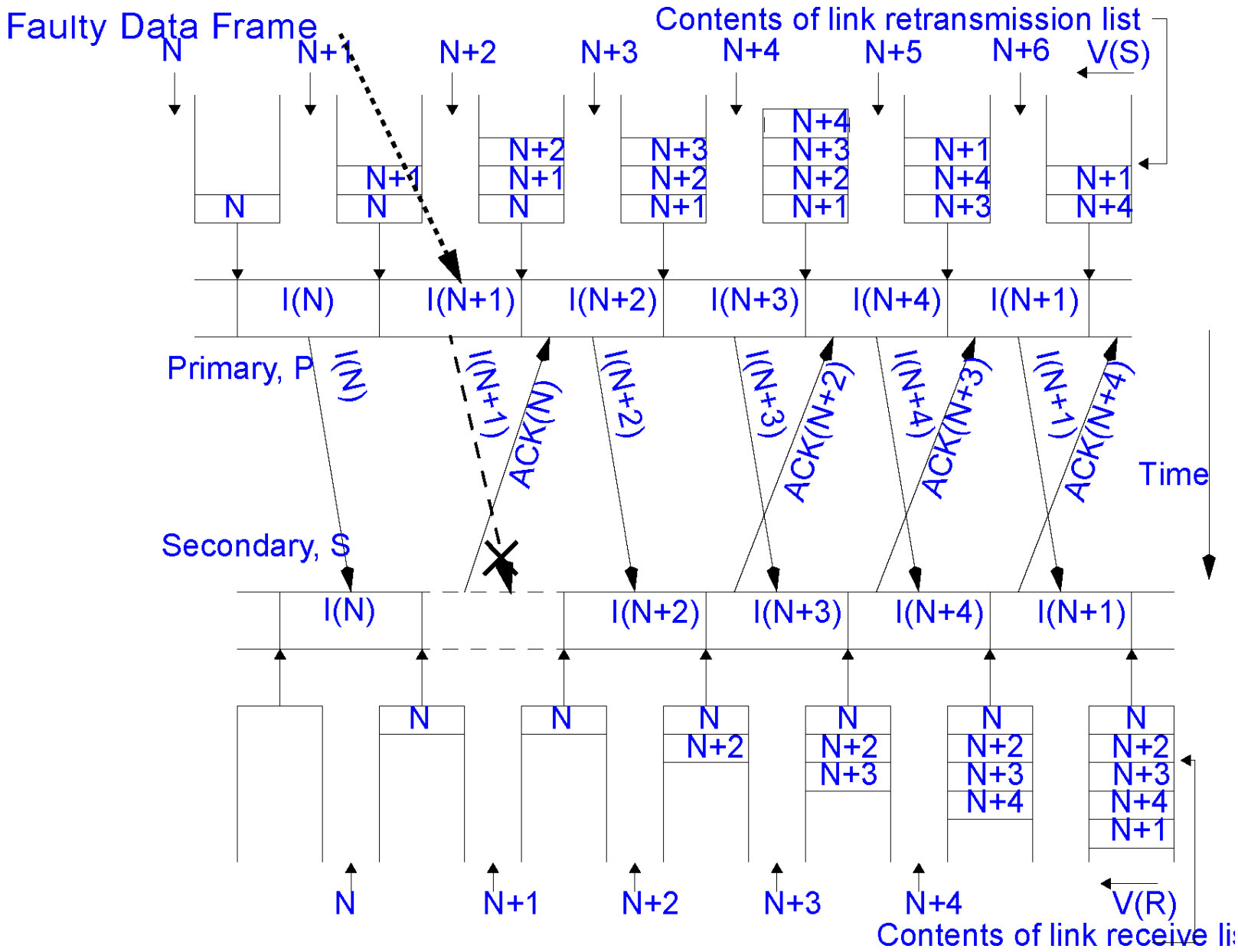
Sliding Window: Selective Repeat

Features

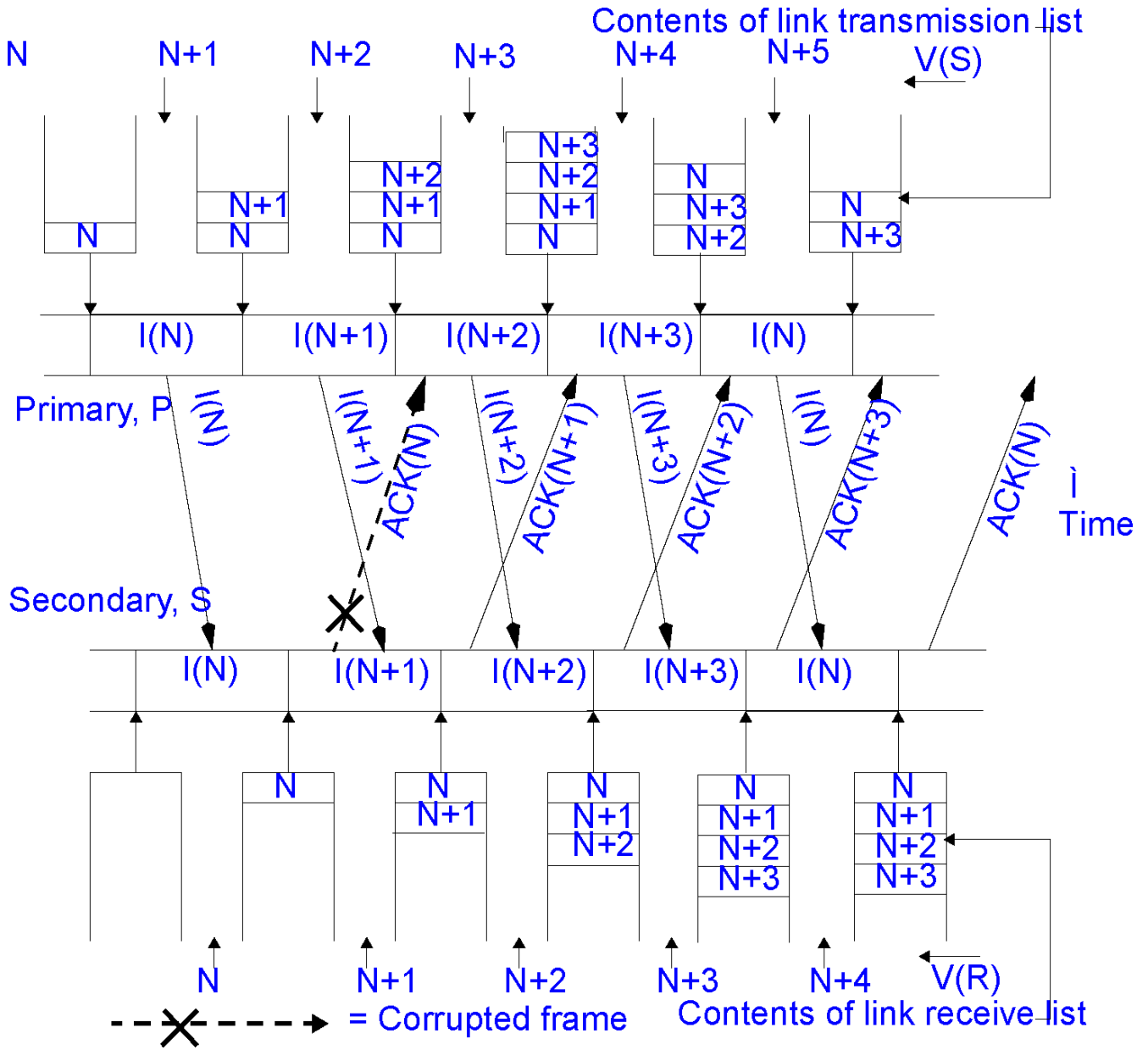
- more complex
- buffering of “out of sequence” frames
- increased throughput
- no cumulative acknowledgements

Example: ....

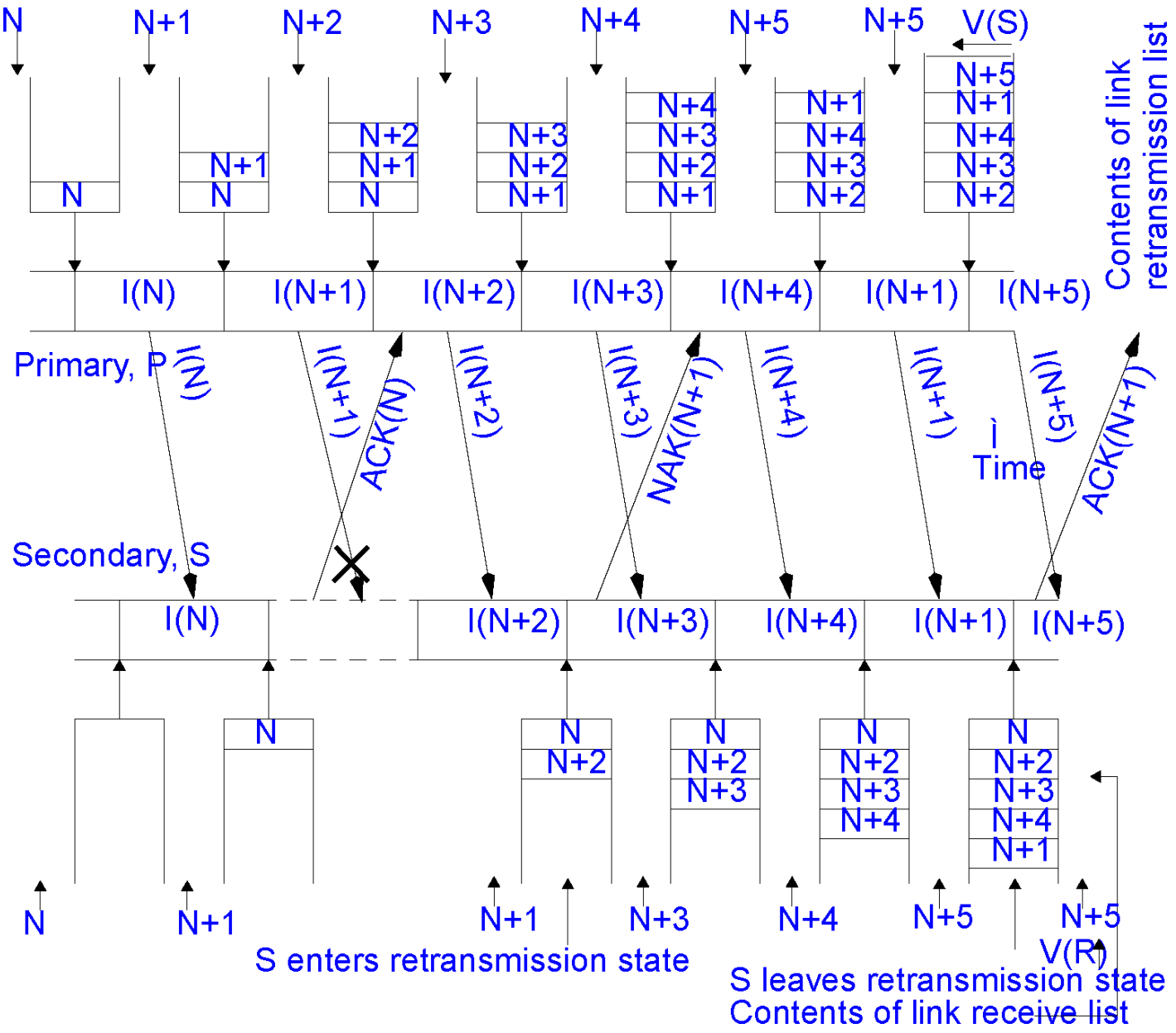
Faulty Data Frame



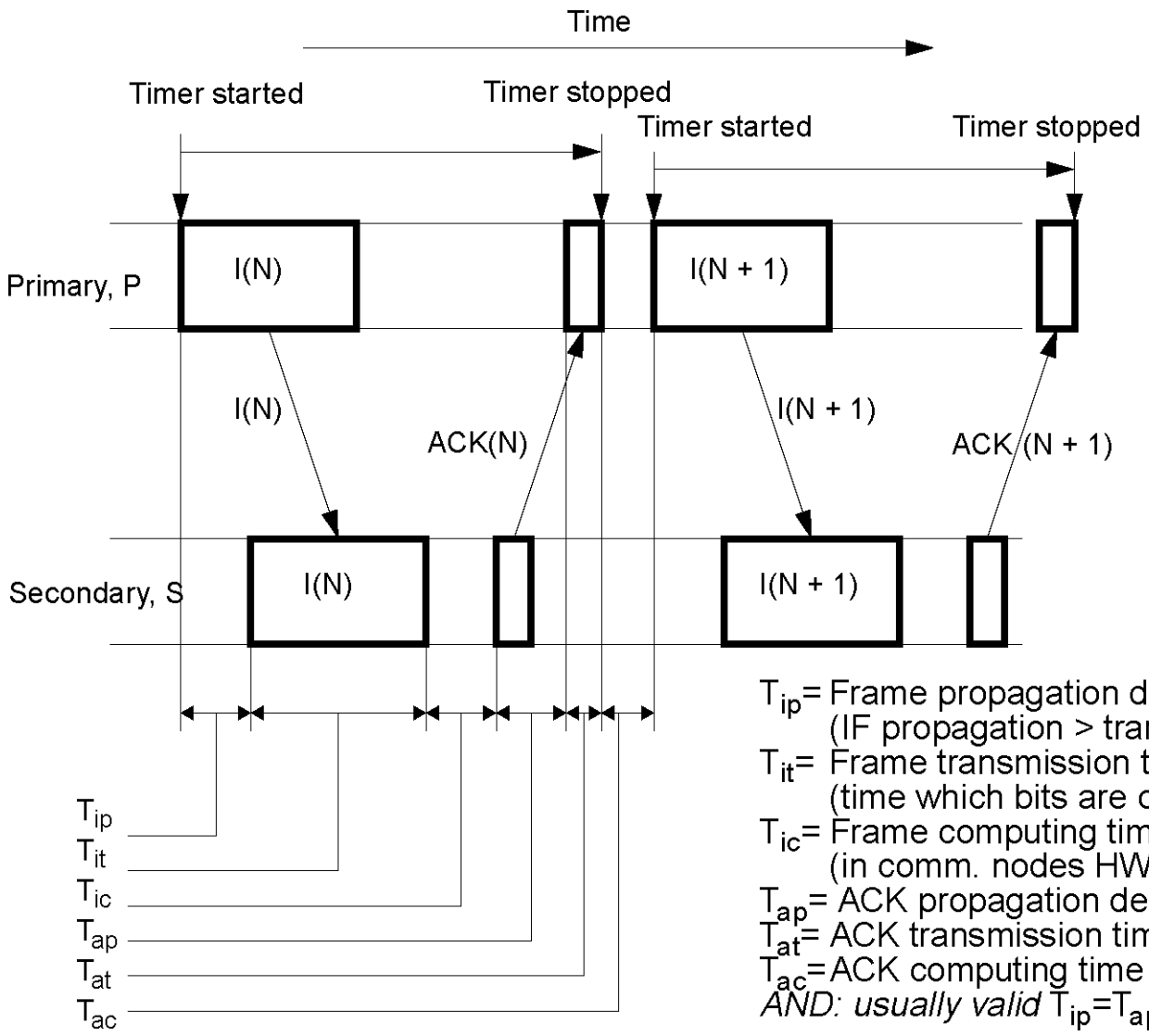
Faulty Acknowledge Frame



Active Error Control



6.5 Channel Utilization



T_{ip}= Frame propagation delay (**P** → **S**)
(IF propagation > transmission)
T_{it}= Frame transmission time (**P** → **S**)
(time which bits are on channel)
T_{ic}= Frame computing time in *S*
(in comm. nodes HW & SW)
T_{ap}= ACK propagation delay(**S** → **P**)
T_{at}= ACK transmission time(**S** → **P**)
T_{ac}=ACK computing time in *P*
AND: usually valid T_{ip}=T_{ap} = T_p

Channel Utilization and Propagation Delay: Recapitulation without Sliding Window

exact formula (note: some values based on assumptions):

$$U = \frac{T_{it}}{\sum T_{\text{information} + \text{acknowledgement}}} = \frac{T_{it}}{T_{ip} + T_{it} + T_{ic} + T_{ap} + T_{at} + T_{ac}}$$

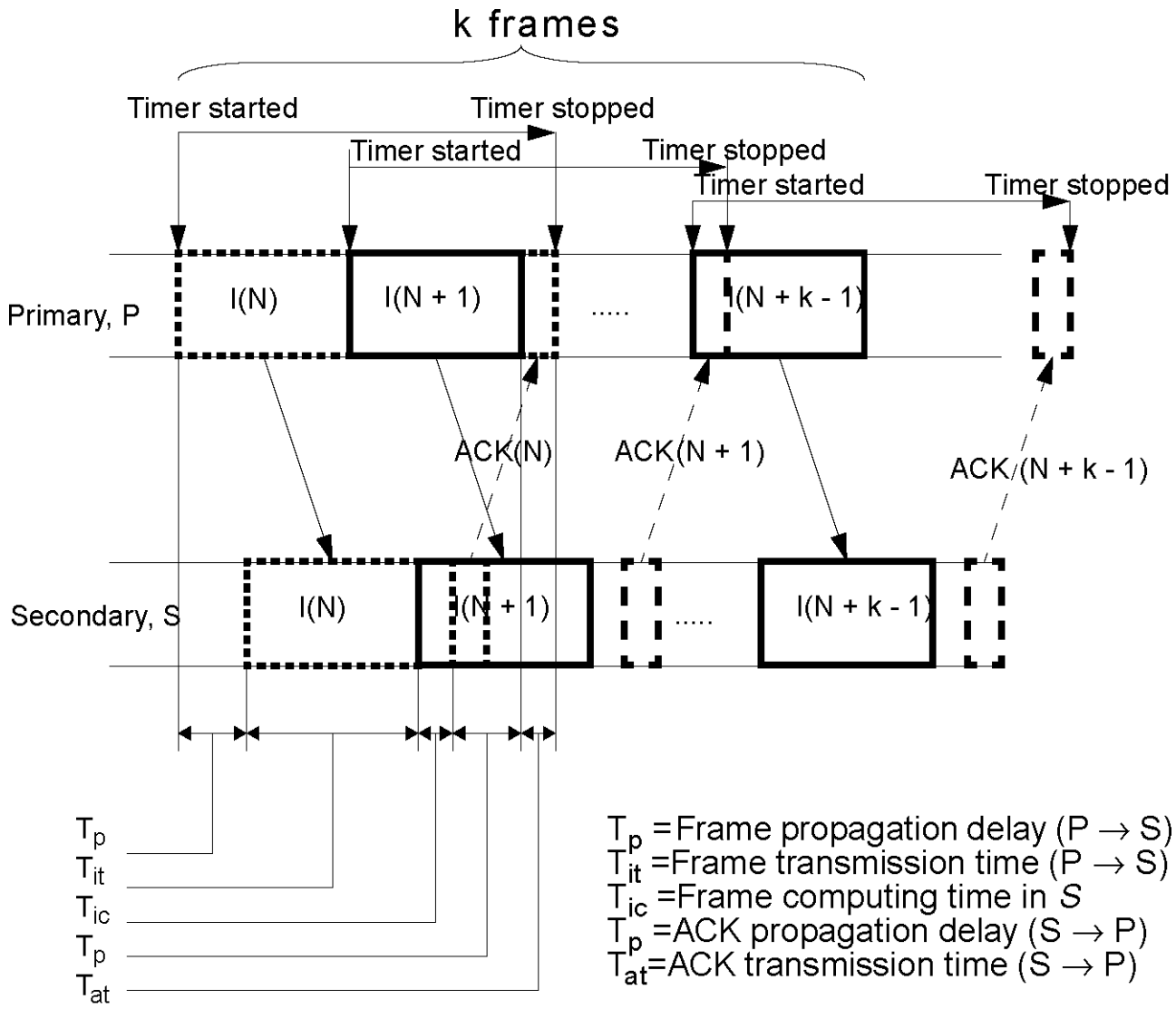
approximated formula:

$$U = \frac{T_{it}}{T_{it} + 2T_{ip}} = \frac{1}{1 + 2\frac{T_{ip}}{T_{it}}}$$

- with the assumption
  $T_{ip} = T_{ap} = T_p$
  T_{ic}, ac computing << $T_{ip, ap}$ propagation delay
  T_{it} information frame transm. >> T_{at} ack information frame transm.

T_{ip} = Frame propagation delay
(IF propagation > transmission)
T_{it} = Frame transmission time
(time which bits are on channel)
T_{ic} = Frame computing time in S
(in comm. nodes HW & SW)
T_{ap} = ACK propagation delay
T_{at} = ACK transmission time
T_{ac} = ACK computing time in P

Channel Utilization with Sliding Window



T_p = Frame propagation delay (P → S)
T_{it} = Frame transmission time (P → S)
T_{ic} = Frame computing time in *S*
T_p = ACK propagation delay (S → P)
T_{at} = ACK transmission time (S → P)

T_{ac} may be neglected
if window size > 1

Channel Utilization

$$U = \begin{cases} \dfrac{kT_{it}}{T_{it} + 2T_p} = \dfrac{k}{1 + 2\dfrac{T_p}{T_{it}}} & \text{if } \left(k < 1 + 2\dfrac{T_p}{T_{it}} \right) \\ 1 & \text{otherwise} \end{cases}$$

Comment

- k specifies
  - how many frames are transmitted simultaneously (sequentially) on the L1 channel
  - i.e. k is the window size

6.6 Comparing Protocols

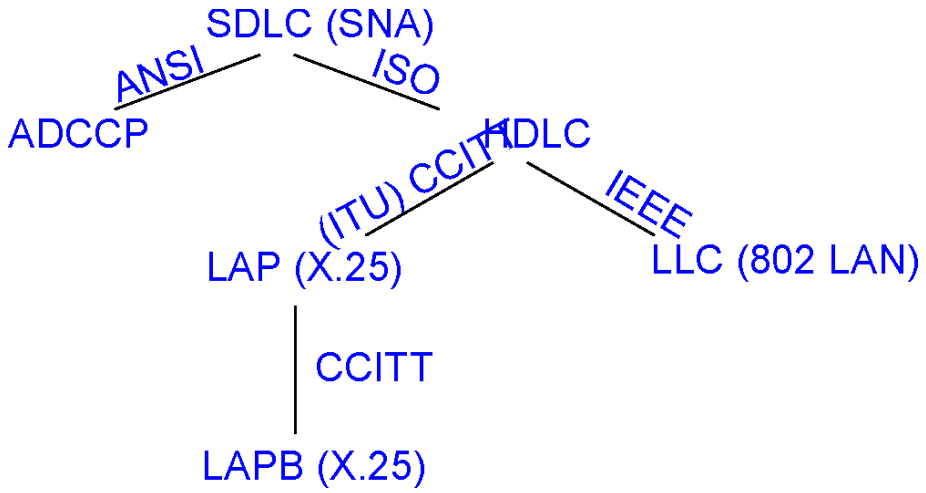
Stop-and-Wait

+ little demand for buffering
+ well-suited for less complex end devices
- poor channel utilization
- low throughput

Sliding Window

+ good channel utilization
+ good throughput
+ consideration of the current system state by adjusting the window size
- increased buffer demand
- more complex protocol

7 Protocols: HDLC Family



SDLC:	Synchronous Data Link Control (derived from IBM System Network Architecture SNA)
ADCCP:	Advanced Data Communication Control Procedure
HDLC:	High-Level Data Link Control
LAP:	Link Access Procedure
LAPB:	Link Access Procedure, Balanced, exple.L2 from OSI L3: X.25
LLC:	Logical Link Control
others:	Kermit, XMODEM (for modems between PCs)

➔ “The nice thing about standards is that you have so many to choose from" [Tanenbaum]

7.1 HDLC: Principle

Detailed description: standards, [black]
- a.o. ISO 3309 HDLC Procedures - Frame Structure

Protocol: bit oriented, full duplex

Data transparency: bit stuffing (5* “1” always followed by “0”)

Frame format (L2-PDU):
- address: addressing of stations:
  - important if several nodes on level L1
  - if point-to-point - L1:
    - sometimes used to differentiate between command and response
- control: sequence numbers, ACKs, ... (see below)
- data: any user data of any length
- checksum: Frame Check Sequence FCS variation of CRC

Bits	8	8	8	#(n*8)	16	8
	01111110	Address	Control	Data	Checksum	01111110

7.2 Three Types of frames: (differ in control field)

Information for data transmission

Supervisory for control management during data transfer

Unnumbered for connection management

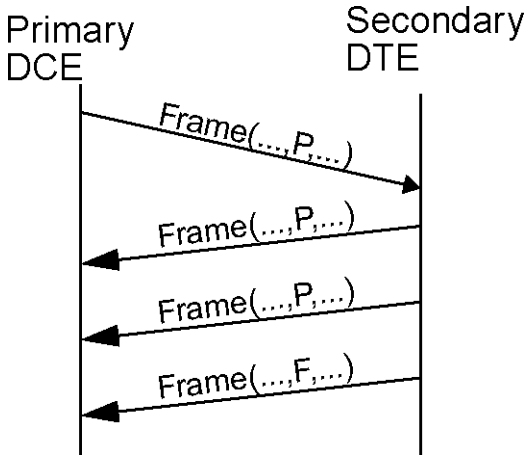
HDLC: Information Frame

Control field:

Bits	1	3	1	3
	0	Seq	P/F	Next

Sliding window, 3-bit sequence number

- Seq: sequence number of the frame
- Next: sequence number of the frame to be expected next (instead of the last correctly received frame as described earlier)
  - in form of “Piggybacking”
- P/F: Poll/Final, mainly used for polling
  - DCE (computer) requests DTEs to transmit data
  - DTE transmits (P-bit setting, last frame with F-bit)



HDLC: Supervisory Frame

Control field:

1	0	TYPE	P/F	Next

TYPES:

- Type 00: RECEIVE READY (actually ACK)
  - explicit acknowledgement
  - NEXT: next expected frame
- Type 01: REJECT (actually NAK)
  - negative acknowledgement if transmission error
  - NEXT: first frame to be retransmitted
  - “Go-back-N” method (retransmit all up to faulty frame)
- Type 10: RECEIVE NOT READY (actually ACK & STOP)
  - reports that receiver has a temporary problem
  - cease acknowledgement and transmission
  - next: frame to be expected
  - re-activate transmission: RECEIVE READY, REJECT,...
- Type 11: SELECTIVE REJECT
  - retransmission of a frame (but not all previous frames)
  - next: frame to be retransmitted
  - “Selective Repeat” method

HDLC: Unnumbered Frame

Control field:

1	1	TYPE	P/F	MODIFIER

Application:

- control data
- unsecured connectionless service

TYPES (type, modifier) a.o.

- DISC (Disconnect):
  - reports inavailability (e.g. during preventive maintenance)
- SNRM (Set Normal Response Mode):
  - reports availability (Set SeqNo. = 0)
    (Seq.No's. are reset to 0)
    unbalanced (primary/secondary master/slave) from "old" times
- SABM (Set Asynchronous Balanced Mode):
  - reports availability (Set SeqNo. = 0) balanced (peer-to-peer) from "more recent" times
- FRMR (Frame Reject):
  - frame drop if protocol infraction
    e.g. frame < 32 bit, ACK from frames with invalid SeqNo's
- UA (Unnumbered Acknowledgement):
  - safeguards against loss/error of unnumbered frames
  - ACK, acknowledgement for unnumbered frames

Differences HDLC, SDLC, LAPB

Supervisory Frames

- HDLC and ADCCP
  - know SELECTIVE REJECT
  - are more effective on L1 if many bit errors occur
- SDLC and LAPB
  - SELECTIVE REJECT not defined
  - i.e. only Go-Back-N

Unnumbered Frames

- HDLC and LAPB
  - know SABM (SET ASYNCHRONOUS BALANCED MODE)
  - know SABME and SNRME (... extended) with 7 bit SeqNo. (instead of 3 bit)
- other
  - actually do not have this frame specified

HDLC and OSI Service Elements

Connect
- OSI SDU use of
  - Connect Request
  - Connect Response

HDLC PDU Unnumbered Frame:
SABM (Set Asynchronous Balanced Mode)
UA (Unnumbered Acknowledgement)

Data transfer phase
- OSI SDU use of
  - Data Request itself

HDLC PDU Information Frame:
Information Frame

Disconnect
- OSI SDU use of
  - Disconnect Request

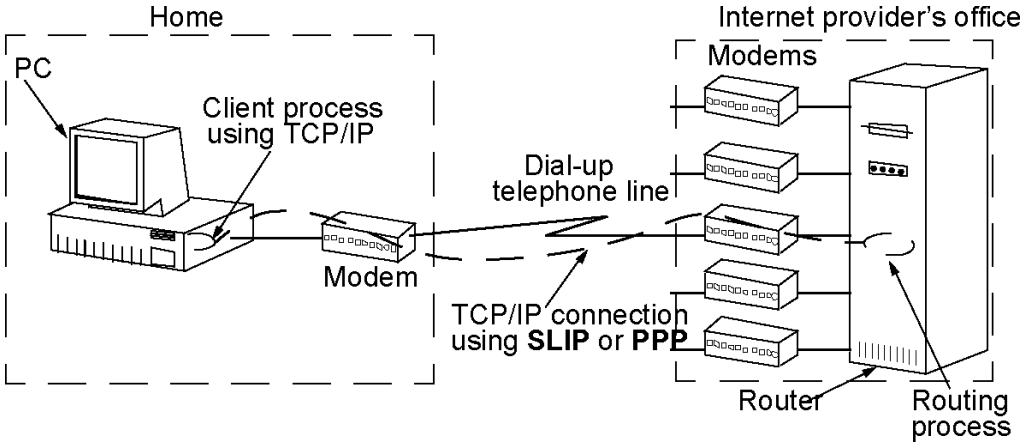
HDLC PDU Unnumbered Frame:
DISC (Disconnect)

Exemption treatment
- OSI SDU use of
  - Abort Indication

HDLC PDU Unnumbered Frame:
FRMR (Frame Reject)

other HDLC PDUs
- are exchanged within L2
- do not have a direct effect onto L3- or L2-SDUs respectively

8 Protocols: at Internet Layer 2



Internet Connections

- end devices to "network"
  - approx. 10m - 10 km: LAN & MAN: many connected to each other
  - more than approx. 10-100 km: WAN
    - point-to-point (considered here)
    - an Internet provider (AOL, T-Online, Univ.,...)
    - usually via phone line and modem
    - usually TCP/IP over SLIP or PPP
- connection between network nodes
  - point-to-point: (reviewed herein)
  - usually over dedicated line with router or bridge
  - often IP over SLIP or PPP

8.1 Internet: Serial Line IP (SLIP)

History

- 1984: Rick Adams connects Sun computers via modem to the Internet
- description in RFC 1055

Protocol (very simple)

- data (payload)
  - L3 packets (here only IP packets)
- framing:
  - add flag byte (0xC0) at the end of the packet
  - character stuffing: if 0xC0 part of the data, replace this by 0xDB, 0xDC, etc.
  - note: some implementations insert these also as headers

Internet: Serial Line IP (SLIP)

Properties

- no error detection or error correction
- only IP is supported
  - IP addresses of communicating entities have to be known in advance
  - (i.e. cannot be allocated dynamically)
  - i.e. each user would have to have his own IP address on the host -> too many addresses
- no authentification
  - (problem for switched line, not dedicated line)
- many different implementations exist because no Internet standard
- widely used

Optimizations:

- RFC 1144
- properties:
  - successive packets often have the same header
- use:
  - header compression, if successive packets are the same

8.2 Internet: Point-To-Point Protocol (PPP)

History

- IETF initiated group to
  - replace SLIP (not a standard) by the Internet standard
  - improve the data link protocol
- application: login connections and dedicated lines
- RFC 1661 (others: RFC 1662, RFC 1663)
- will replace SLIP

Protocol: character oriented (SLIP bit oriented) with

- FRAMING: frame identification and error treatment
- Link Control Protocol LCP (PHASE 1)
  - establish, test, release L2 connection
  - authentification: L2 entities can determine each other's identities
  - negotiate options with L2 partner entity (e.g. coordinate payload size, select NCP protocol)
- Network Control Protocol NCP (PHASE 2)
  - one NCP per each L3 protocol
  - NCP for IP: selects for example IP address
- actual data transfer (PHASE 3)

Internet: Point-To-Point Protocol (PPP)

Bits (of SDLC to compare)

8	8	8	no	≥0	16	8

Bytes PPP here:

1	1	1	1 or 2	≥0	2 or 4	1
Flag 01111110	Addr. 11111111	Ctrl. 00000011	Protocol	Payload	Checksum	Flag 01111110

Frame Format (similar to or derived from HDLC):

- (HDLC) flag: identifying characters for L2 frame
- address: always addressing of all stations
- control: default: unnumbered frame (see above) without ACK, without error treatment
- otherwise: numbered mode

(Commt.: Address & Control fields can be left out depending on the setup)

- protocol: designates the protocol, usually 2 byte
  - L2: LCP, NCP
  - L3: IP, OSI CLNP, Appletalk, ..
- payload/data: any user data
  - length: negotiated, otherwise max. 1500 byte
- checksum: CRC variation, usually 2 byte
- (HDLC) flag: bound of the L2 frame

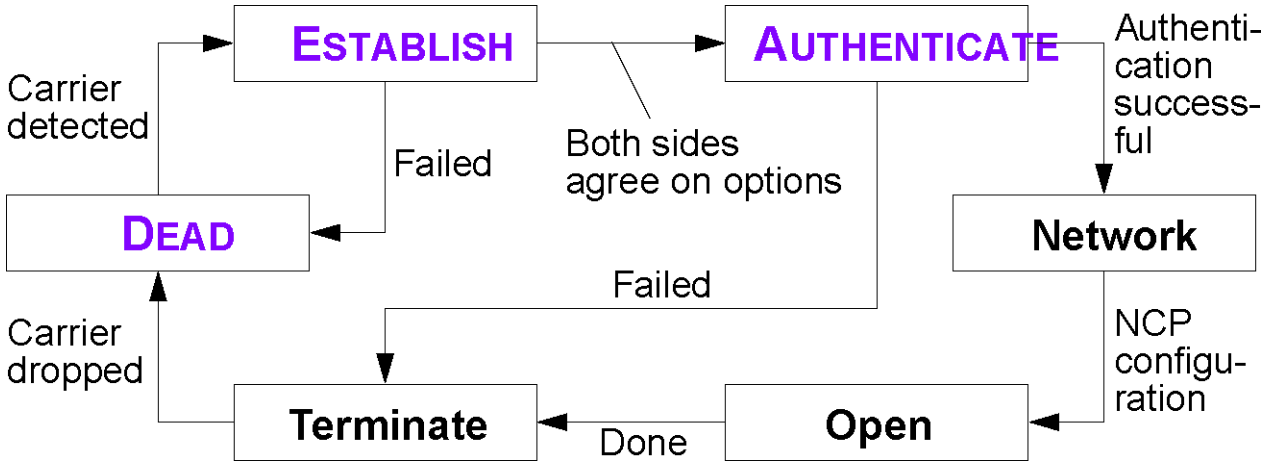
Internet: Point-To-Point Protocol (PPP)

Features

- error treatment
- supports several L3 protocols/services
- IP addresses are determined dynamically
- authentification

Example: ....

Internet: Point-To-Point Protocol (PPP)



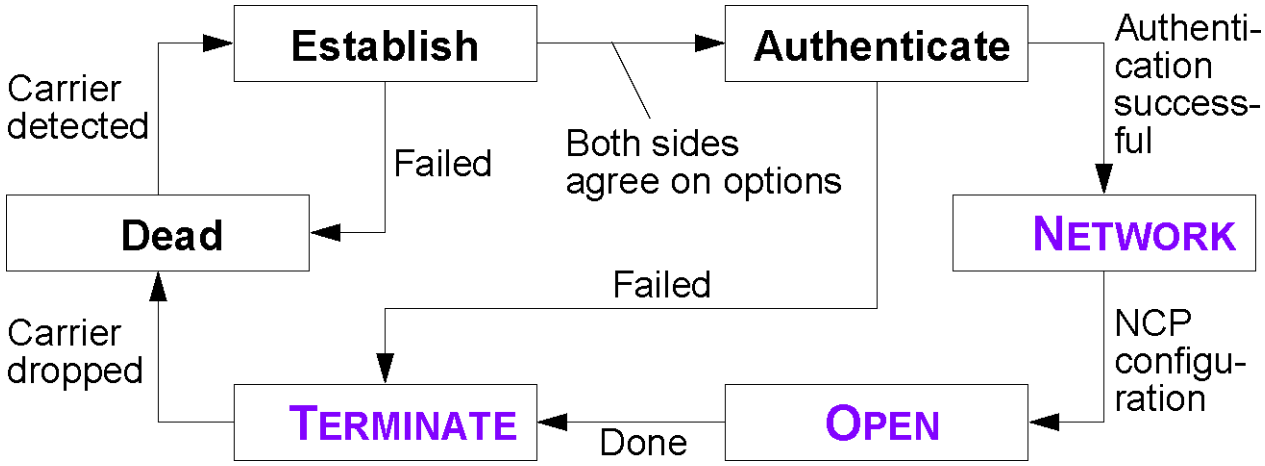
Dead
- L1 connection does not existent

Establish
- after L1 connect
- negotiation of LCP options

Authenticate
- authentification of both parties

...

Internet: Point-To-Point Protocol (PPP)



...

Network

- call of the desired NCP protocol
- configuration of the network layer

Open

- data transfer may begin
- e.g. transmission of IP packets in the payload field of PPP frames

Terminate

- disconnect

9 Protocols: Perspective – L2 Communication Design Tasks

Service and protocol design include among others questions about:
Specification method

- type (Petri-Net, SDL, ESTELLE, LOTOS,..)
- utilization range (up to generating programs)
- deadlocks may be recognized (depending on method)

Implementation

- HW vs. SW
- SW environment (C, C++, class library,...)
- buffer management (logical copying)
- process segmentation

Service selection

- connection oriented vs. confirmed connectionless vs. connectionless

Configuration/parameter selection

- sliding window size (among others depends on L1 error properties, L1 transmission time)
- error correction procedure