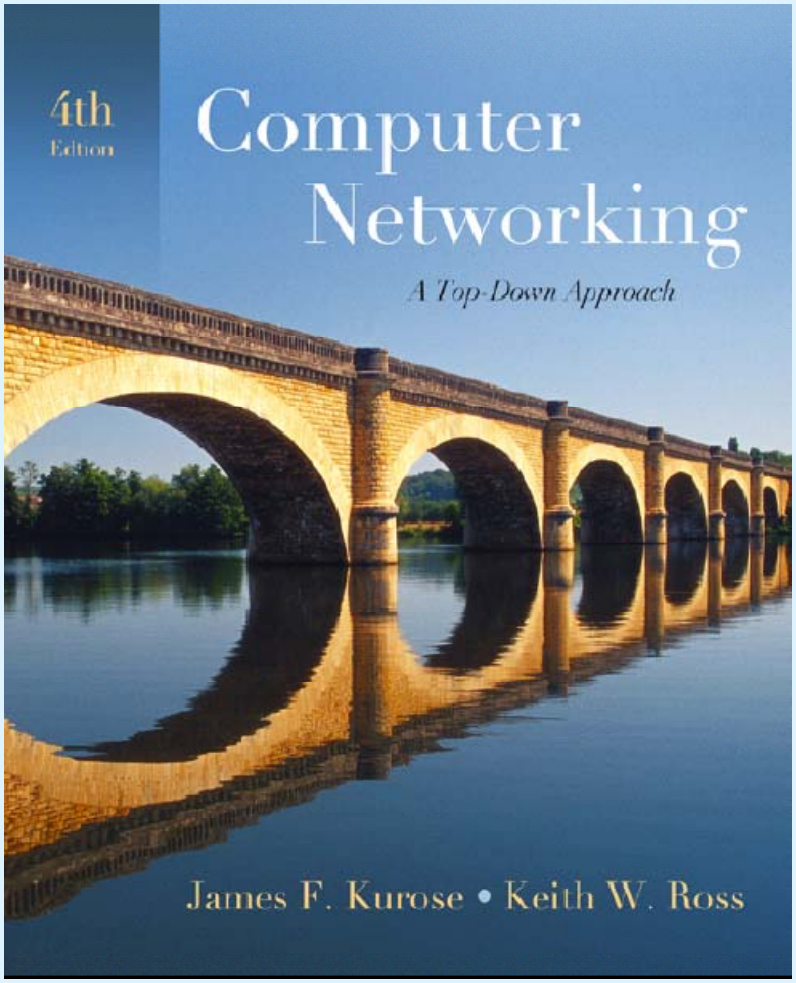
Transport Layer

Felövervakning

Övningar på Internet-checksumman

- UDP
  - Förbindelselöst
  - "Best effort"
- TCP
  - Förbindelseorientat
  - Tillförlitligt
  - Flödesreglering
  - Trafikstockningsreglering

Bildspelet omfattar till stor del bilder som hör till följande bok:



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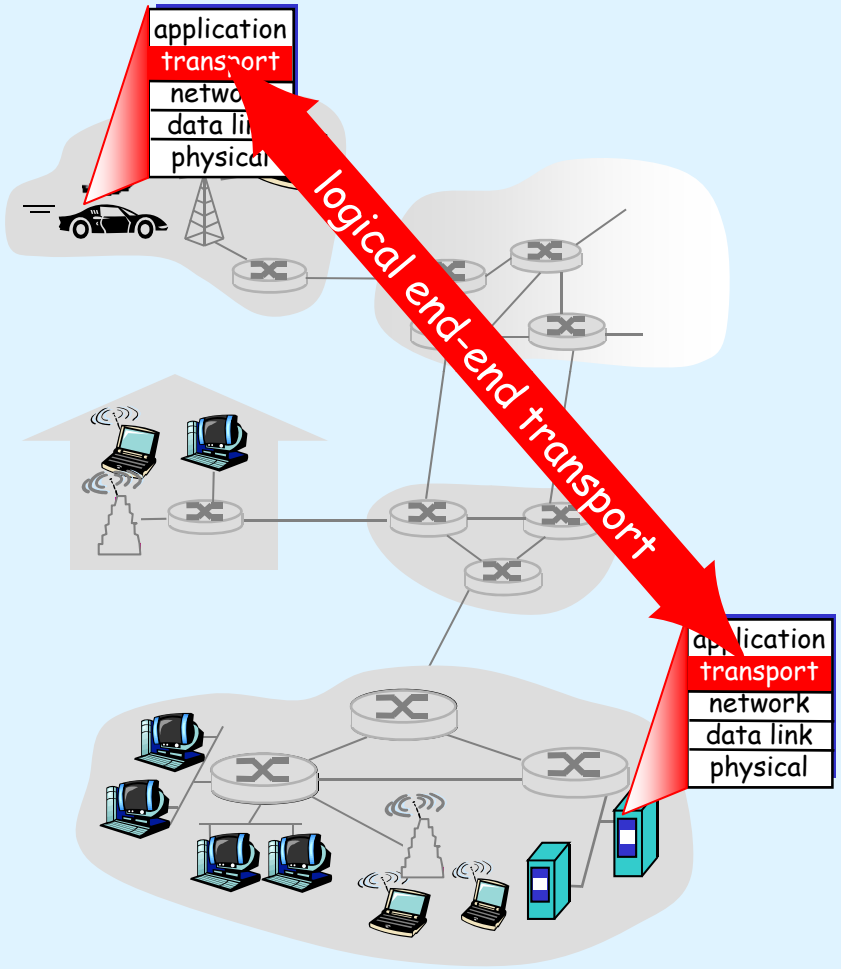
Thanks and enjoy! JFK/KWR

Computer Networking: A Top Down Approach, 4th edition.
Jim Kurose, Keith Ross, Addison-Wesley, July 2007.

Transport services and protocols

- provide *logical communication* between app processes running on different hosts
- transport protocols run in end systems
  - send side: breaks app messages into segments, passes to network layer
  - receiver side: reassembles segments into messages, passes to app layer



Transport vs. network layer

- *Transport layer:*

  logical communication between processes

  - relies on, enhances, network layer services

- *Network layer:*

  logical communication between hosts

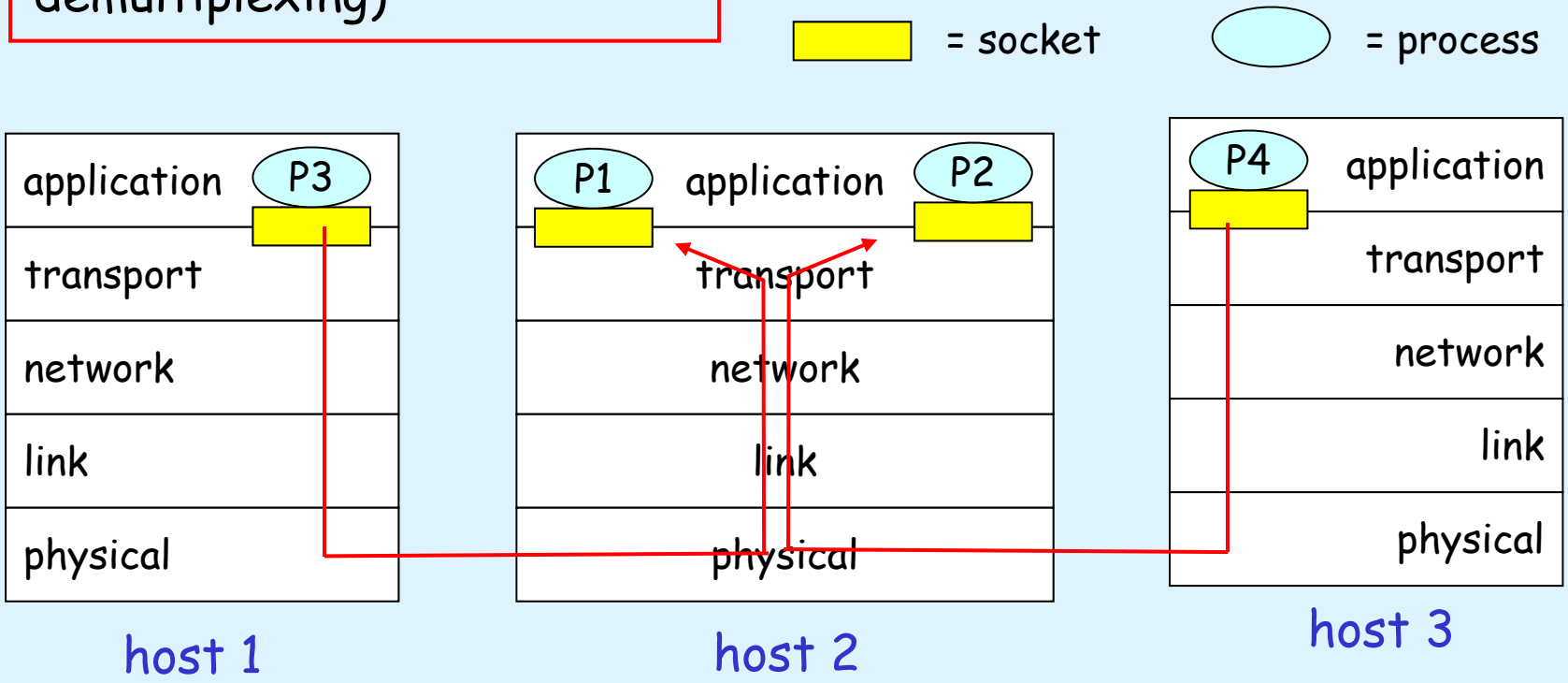
Multiplexing/demultiplexing

Multiplexing at send host:

gathering data from multiple sockets, enveloping data with header (later used for demultiplexing)

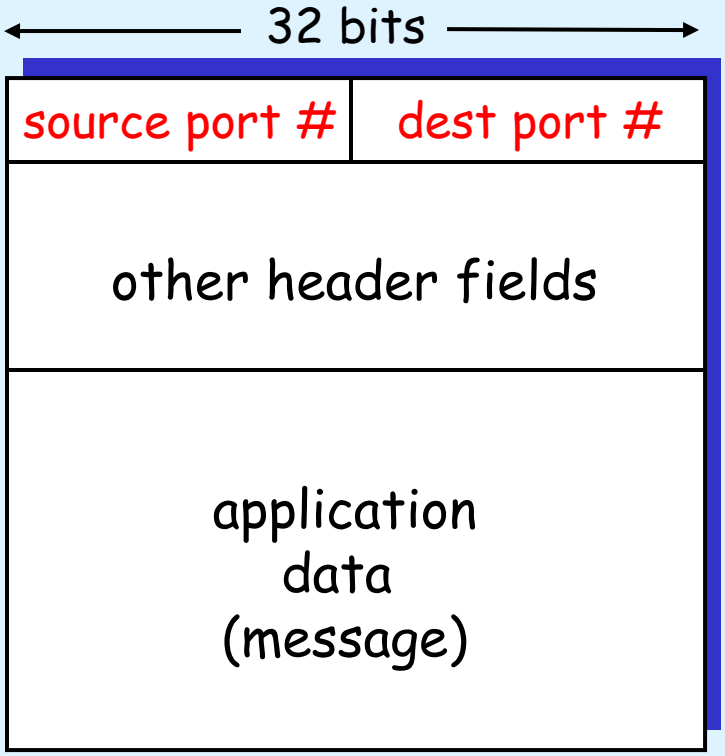
Demultiplexing at rcv host:

delivering received segments to correct socket



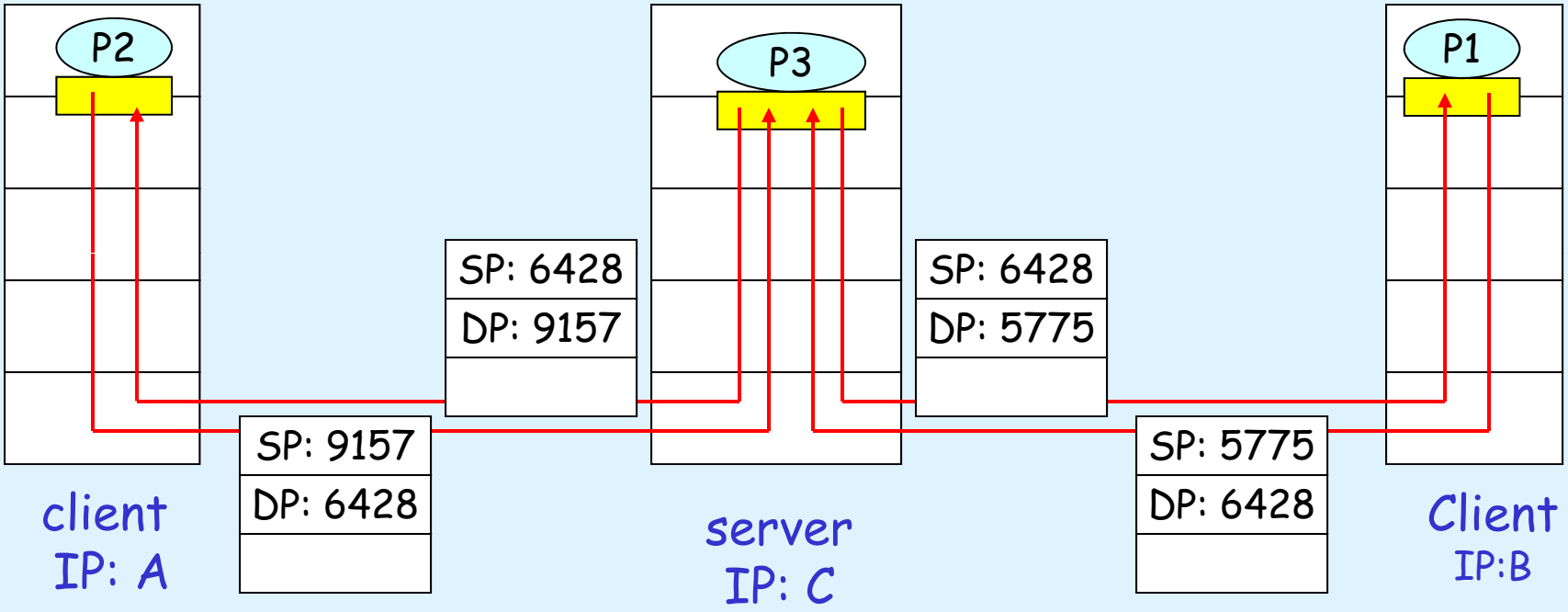
How demultiplexing works

- host receives IP datagrams
  - each datagram has source IP address, destination IP address
  - each datagram carries 1 transport-layer segment
  - each segment has source, destination port number
- host uses IP addresses & port numbers to direct segment to appropriate socket



TCP/UDP segment format

Connectionless demux (cont)

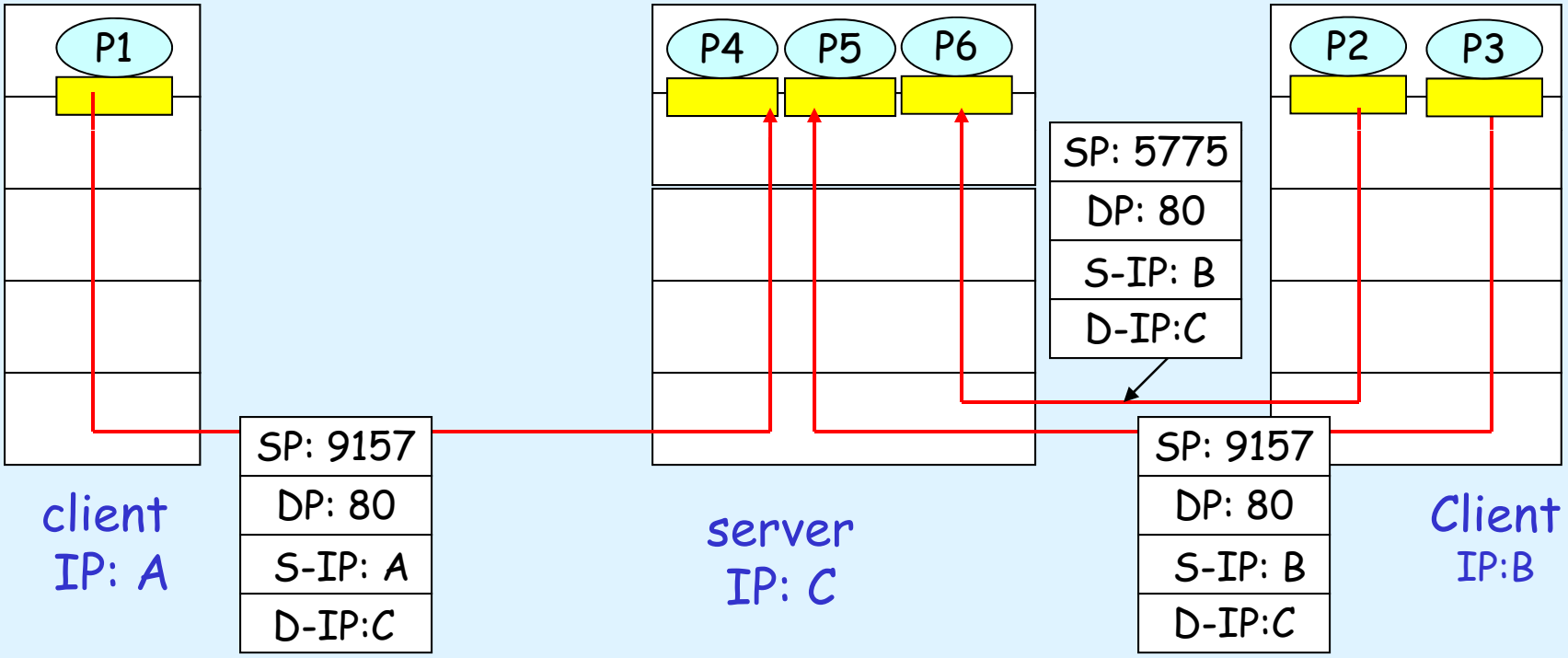


SP provides "return address"

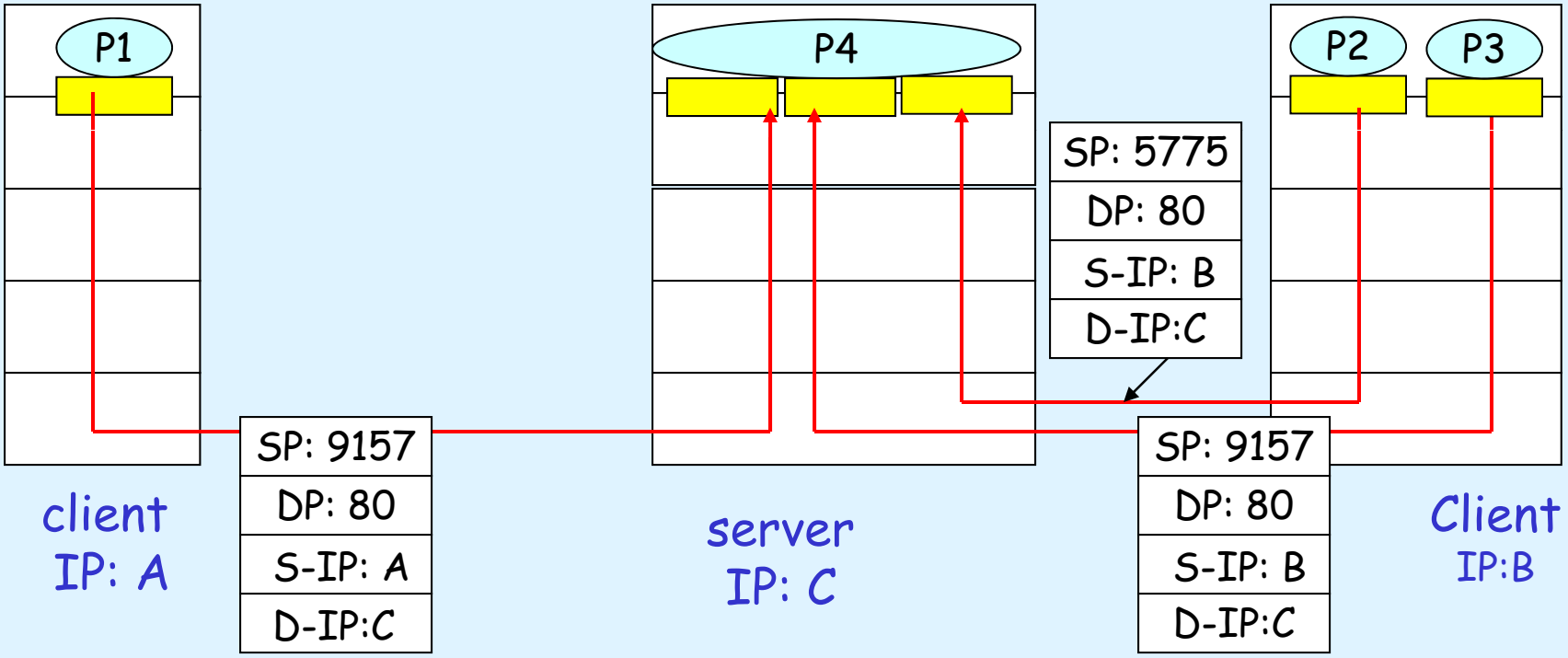
Connection-oriented demux

- TCP socket identified by 4-tuple:
  - source IP address
  - source port number
  - dest IP address
  - dest port number
- recv host uses all four values to direct segment to appropriate socket
- Server host may support many simultaneous TCP sockets:
  - each socket identified by its own 4-tuple
- Web servers have different sockets for each connecting client
  - non-persistent HTTP will have different socket for each request

Connection-oriented demux (cont)



Connection-oriented demux: Threaded Web Server



Felövervakning (1)

- Sekvensnummer
- Checksumma
- Omsändningsmetod

Felövervakning (2)

- Manuell

  Exempelvis Echo checking.

- Automatisk
  (Automatic Repeat Request, ARQ)

  Upptäcka bitfel (feedback error control)

  Korrigera bitfel (forward error control)

Kvittenser för ARQ

- Positiva kvittenser

  (Acknowledgement, ACK)

- Negativa kvittenser

  (Negative Acknowledgement, NAK)

Idle repeat request

- Implicit retransmission

  Endast ACK.

- Explicit request

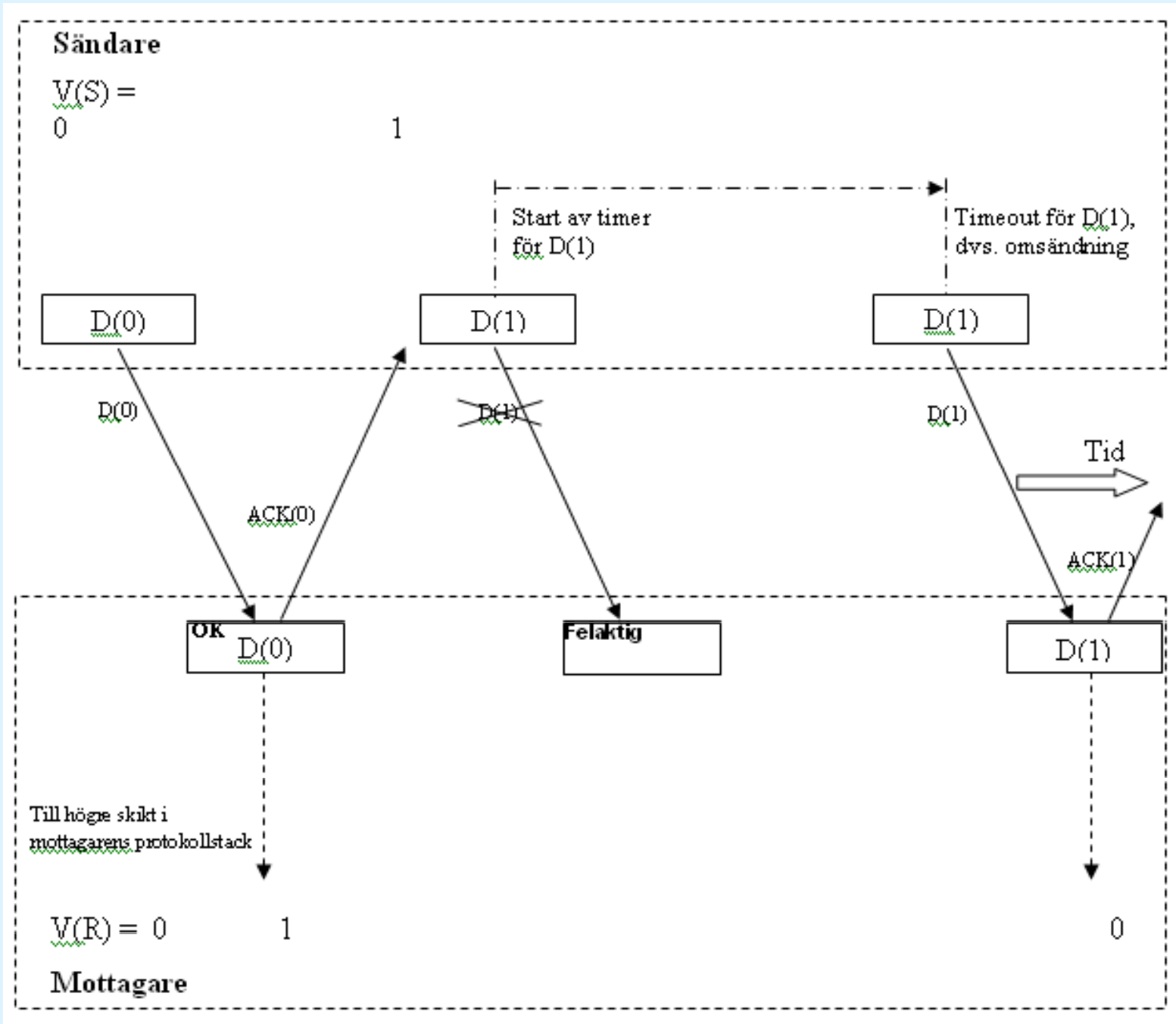
  ACK och NAK.

Implicit retransmission

- Sänd – vänta på ACK eller timeout

  Om ACK, sänd nästa – ...

  Om timeout, repetera föregående – ...


Sändare
V(S) =
0
1
Start av timer
för D(1)
Timeout för D(1),
dvs. omsändning
D(0)
D(1)
D(1)
D(0)
D(1)
D(1)
Tid
ACK(0)
ACK(1)
OK
D(0)
Felaktig
D(1)
Till högre skikt i
mottagarens protokollstack
V(R) = 0
1
0
Mottagare

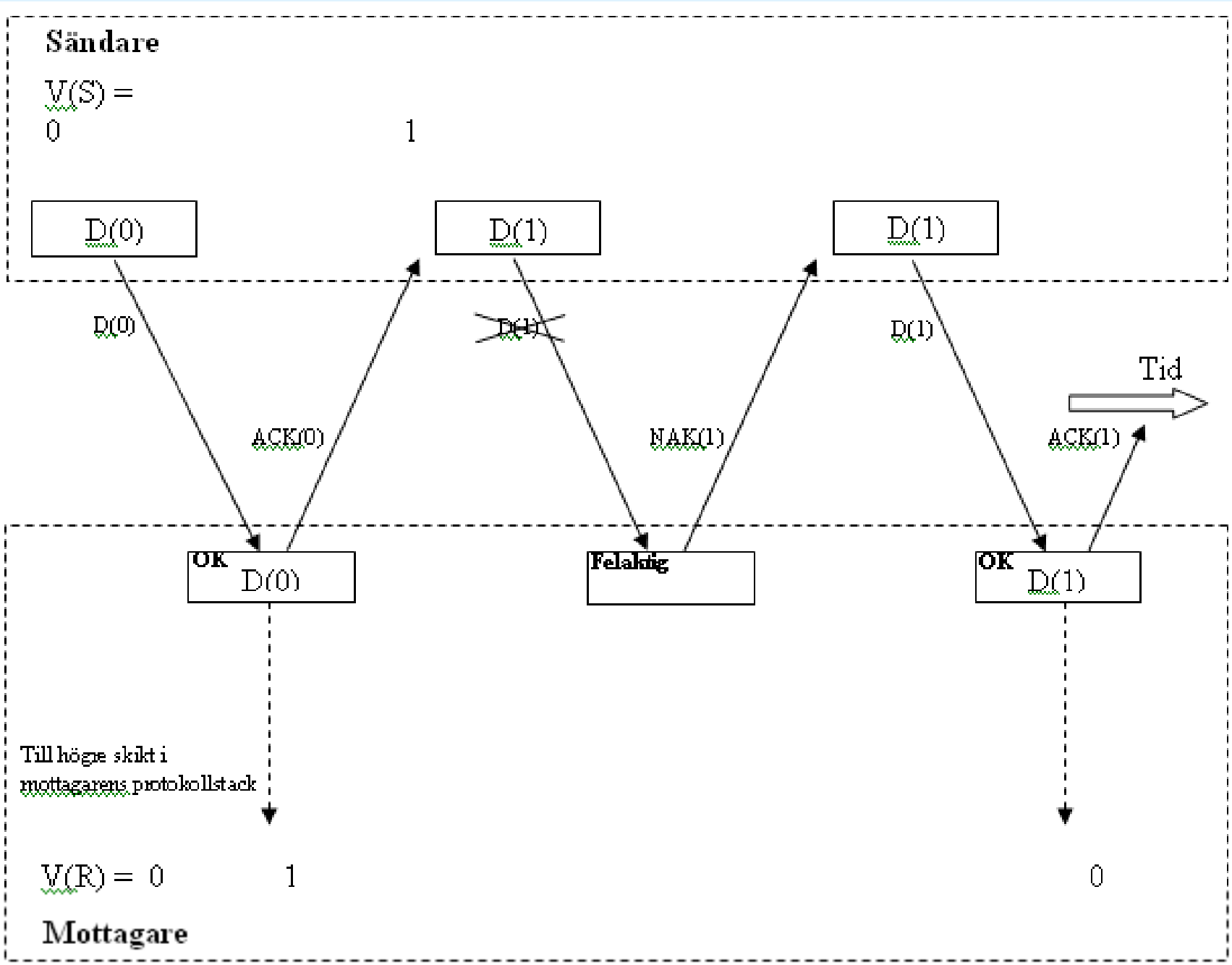
Explicit request

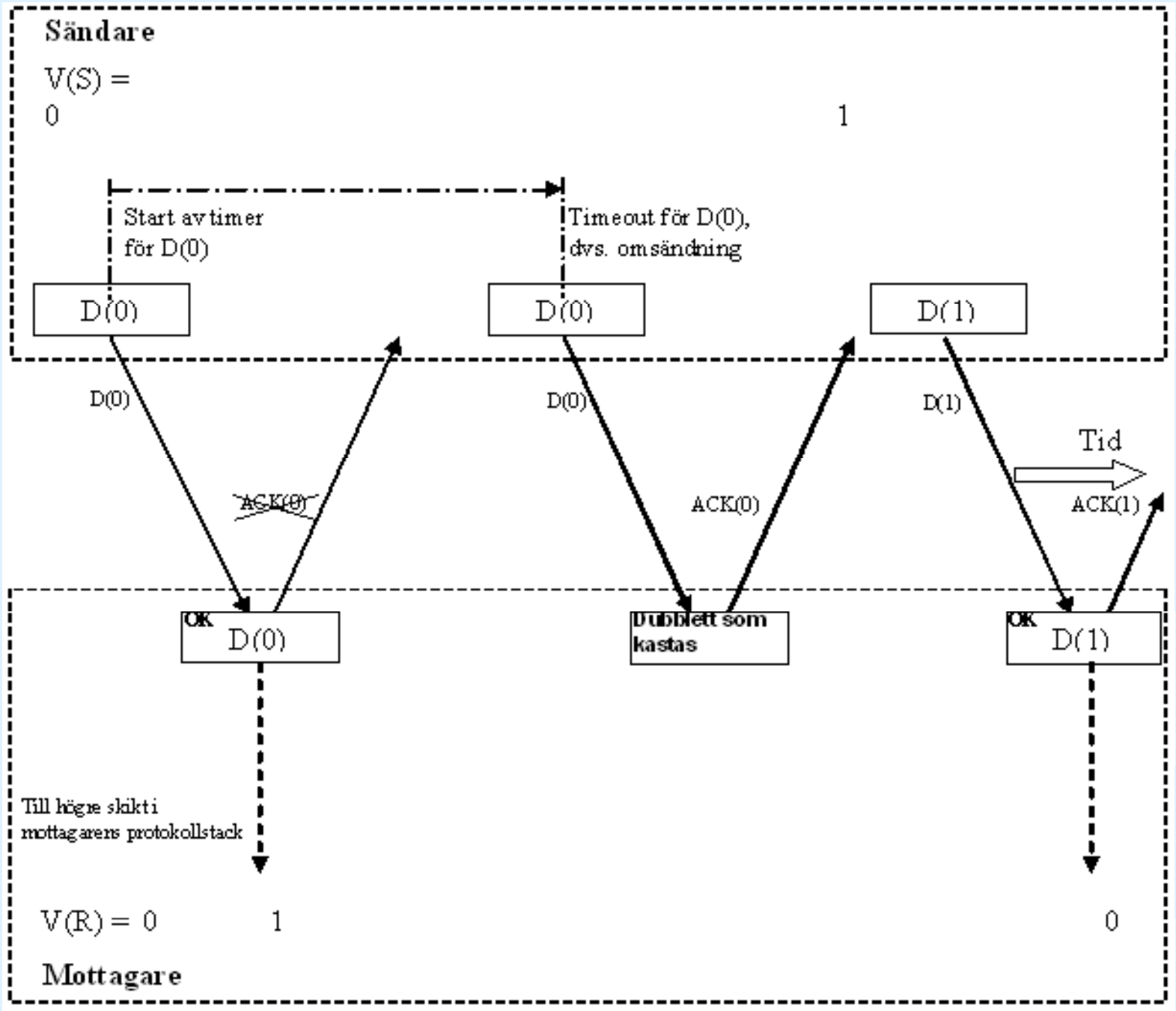
- Sänd – vänta på ACK, NAK eller timeout

  Om ACK, sänd nästa – ...

  Om NAK eller timeout, repetera föregående – ...

- NAK används av mottagaren för att snabbt få ett meddelande (ram, paket, segment etc.) repeterat.


Sändare
V(S) =
0
1
D(0)
D(1)
D(1)
D(0)
D(1)
D(1)
Tid
ACK(0)
NAK(1)
ACK(1)
OK
D(0)
Felaktig
OK
D(1)
Till högre skikt i
mottagarens protokollstack
V(R) = 0
1
0
Mottagare


Sändare
V(S) =
0
1
Start av timer
för D(0)
Timeout för D(0),
dvs. omsändning
D(0)
D(0)
D(1)
D(0)
D(0)
D(1)
Tid
ACK(0)
ACK(0)
ACK(1)
OK
D(0)
Dubblett som
kastas
OK
D(1)
Till högre skikt i
mottagarens protokollstack
V(R) = 0
1
0
Mottagare

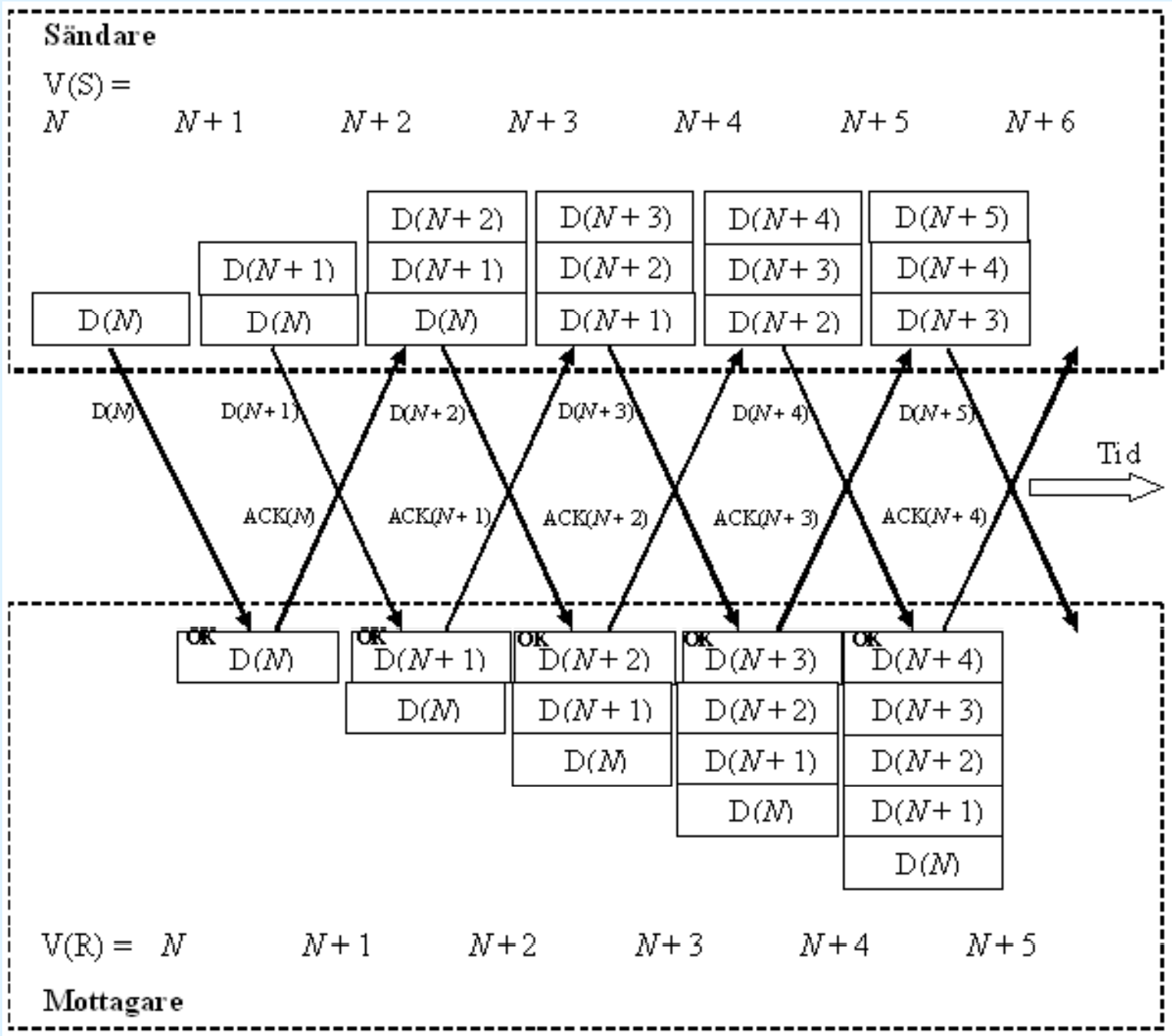
Continous repeat request (1)

- Omsändningsmetoderna med stora sändnings- och mottagningsbuffertar

- Skicka meddelanden (ramar, paket, segment etc.) som i strömmar utan att behöva invänta varje ACK, NAK eller timeout.

Continous repeat request (2)

- Selective repeat with implicit retransmission
- Selective repeat with explicit request
- Go-back-N


Sändare
V(S) =
N
N+1
N+2
N+3
N+4
N+5
N+6
D(N)
D(N+1)
D(N+2)
D(N+3)
D(N+4)
D(N+5)
Tid
ACK(N)
ACK(N+1)
ACK(N+2)
ACK(N+3)
ACK(N+4)
OK
V(R) =
Mottagare

Selective repeat with implicit retransmission (1)

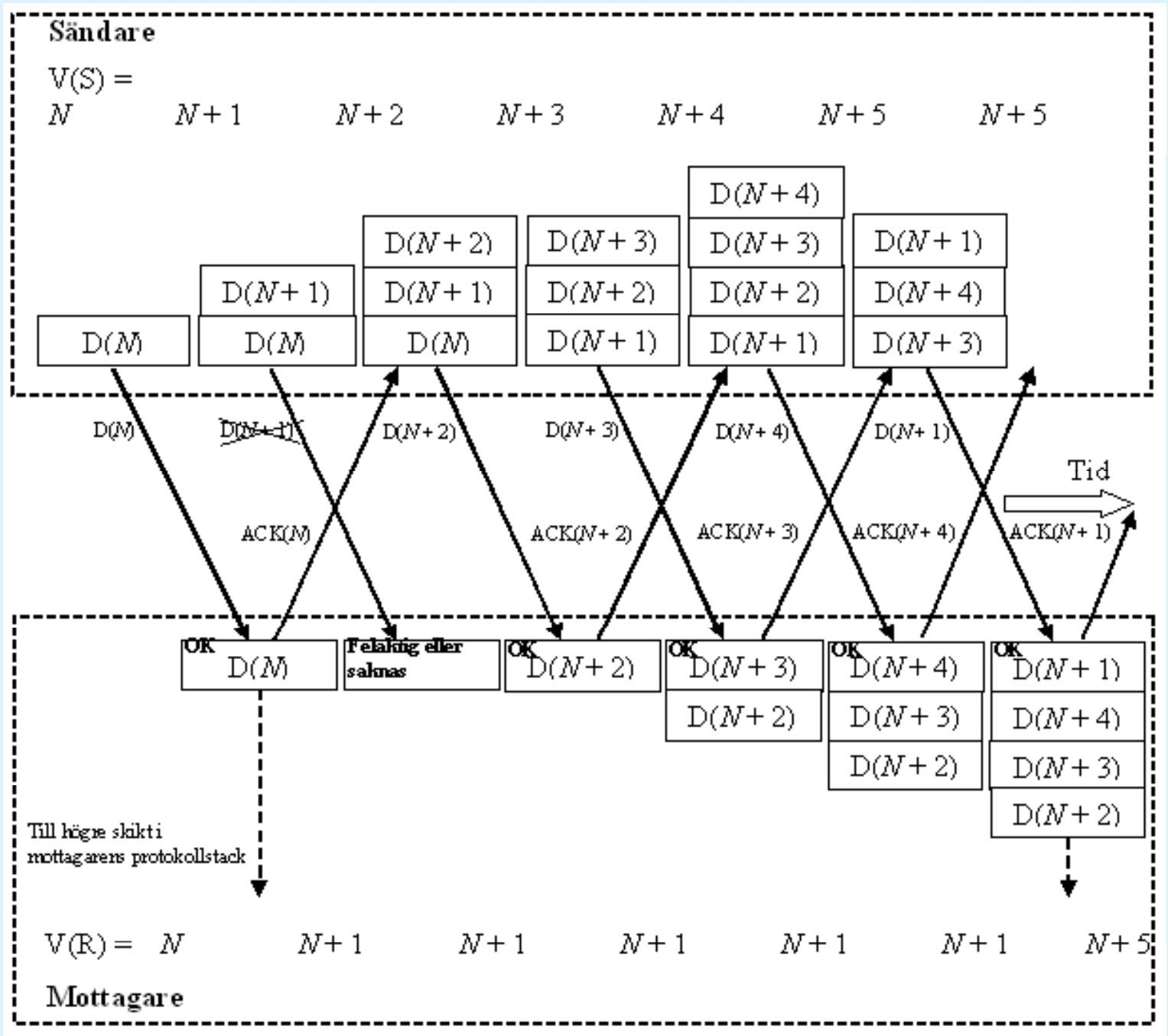
- Enbart felaktiga meddelanden (ramar, paket, segment etc.) sänds om vid begäran.
- Implicit retransmission betyder att NAK inte används.

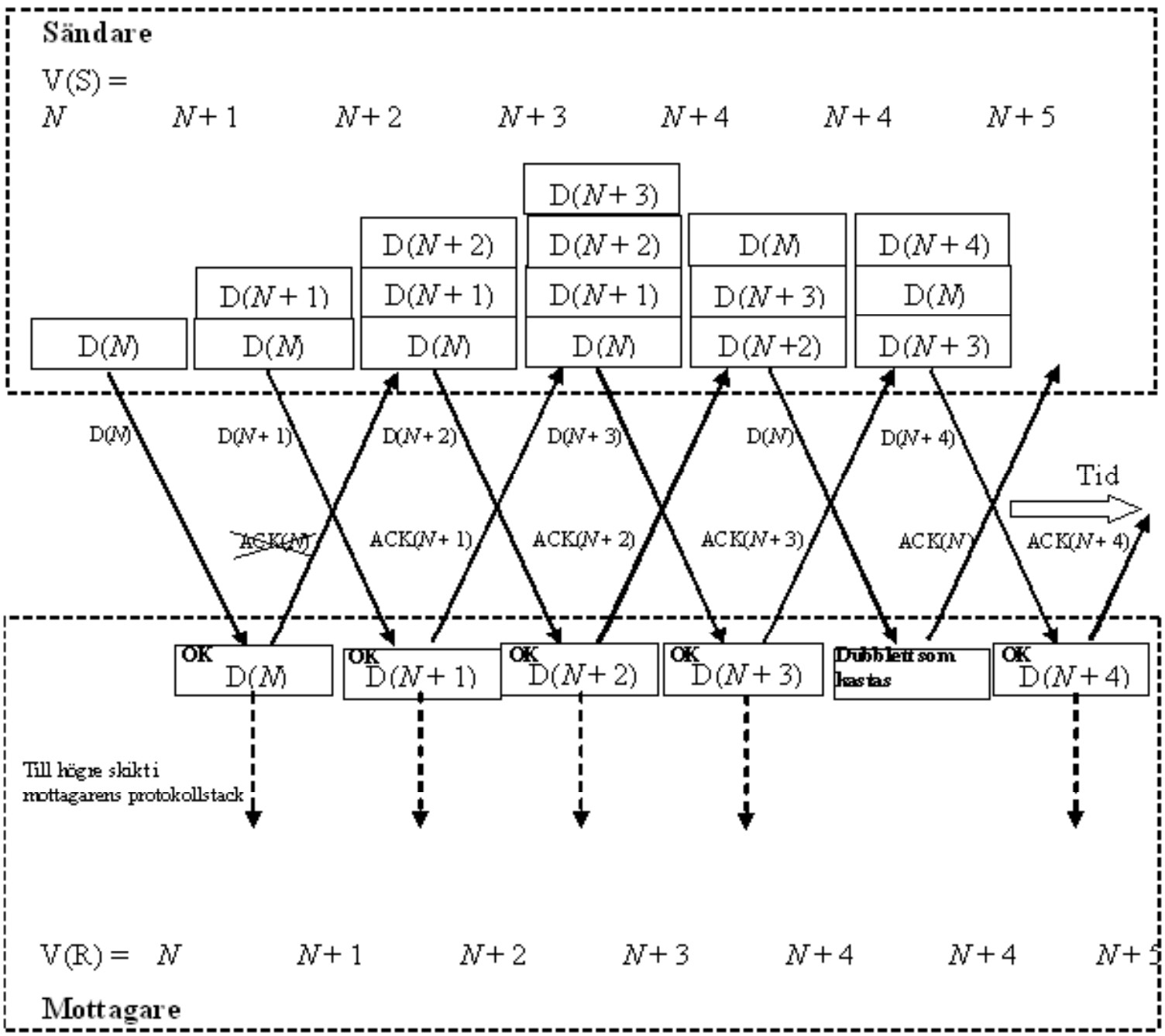
Selective repeat with implicit retransmission (2)

Speciella egenskaper:

- Om meddelande *N* + 1 kvitteras innan meddelande *N*, sänds meddelande *N* på nytt.
- Fel på ACK uppfattas av sändaren som ingen ACK.
- Dubbla försändelser kan hanteras av mottagaren.
- Det behövs inga timers för att kontrollera ACK:ar.

  (Däremot kan timers användas för kunna att upptäcka avbrutna sändningar.)


Sändare
V(S) =
N
N+1
N+2
N+3
N+4
N+5
N+5
D(M)
D(N+1)
D(N+2)
D(N+3)
D(N+4)
D(N+3)
D(N+1)
D(N+2)
D(N+4)
D(N+1)
D(N+2)
D(N+3)
D(M)
D(N+1)
D(N+2)
D(N+3)
D(N+4)
D(N+1)
Tid
ACK(M)
ACK(N+2)
ACK(N+3)
ACK(N+4)
ACK(N+1)
OK
D(M)
Felaktig eller saknas
OK
D(N+2)
OK
D(N+3)
D(N+2)
OK
D(N+4)
D(N+3)
D(N+2)
OK
D(N+1)
D(N+4)
D(N+3)
D(N+2)
Till högre skikt i mottagarens protokollstack
V(R) = N
N+1
N+1
N+1
N+1
N+1
N+5
Mottagare


Sändare
V(S) =
N
N+1
N+2
N+3
N+4
N+4
N+5
D(N+3)
D(N+2)
D(N+2)
D(M)
D(N+4)
D(N+1)
D(N+1)
D(N+1)
D(N+3)
D(M)
D(M)
D(M)
D(M)
D(M)
D(N+2)
D(N+3)
D(M)
D(N+1)
D(N+2)
D(N+3)
D(M)
D(N+4)
Tid
ACK(M)
ACK(N+1)
ACK(N+2)
ACK(N+3)
ACK(N)
ACK(N+4)
OK
D(M)
OK
D(N+1)
OK
D(N+2)
OK
D(N+3)
Dubblett som kastas
OK
D(N+4)
Till högre skikt i mottagarens protokollstack
V(R) = N
N+1
N+2
N+3
N+4
N+4
N+5
Mottagare

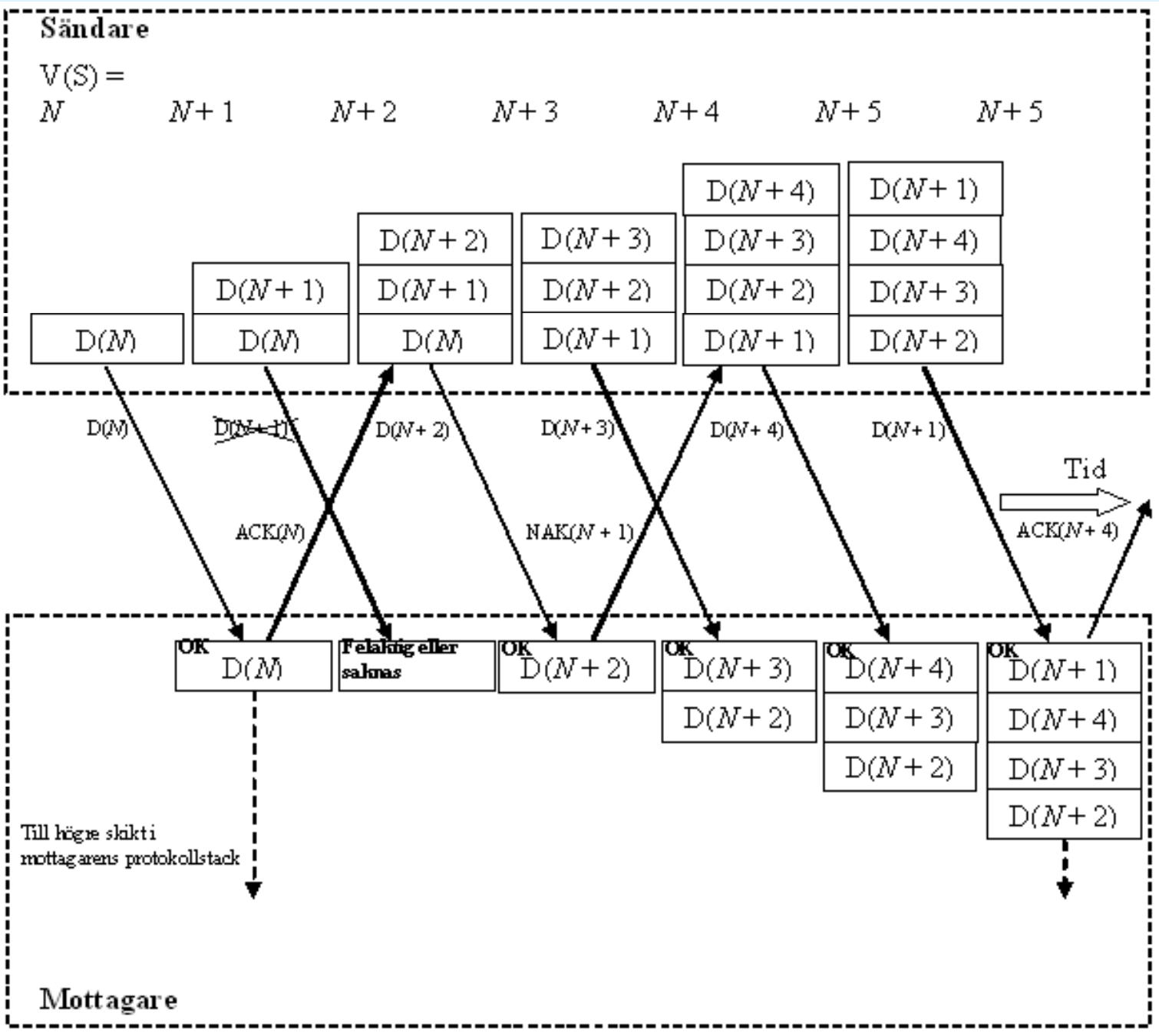
Selective repeat with explicit request (1)

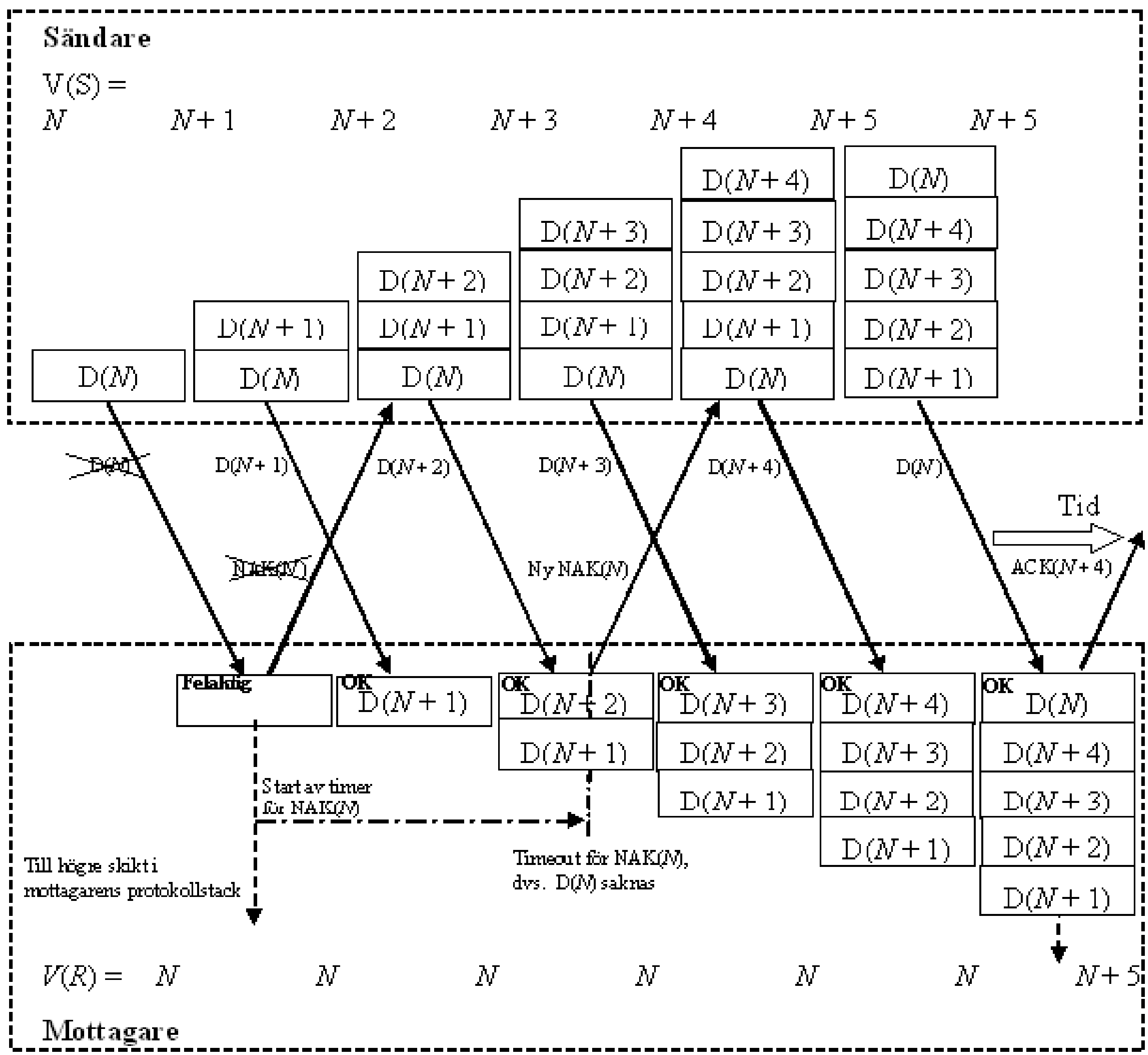
- Enbart felaktiga meddelanden (ramar, paket, segment etc.) sänds om vid begäran.
- Explicit request betyder att NAK används.

Selective repeat with explicit request (2)

Speciella egenskaper:

- ACK(N) kvitterar samtliga meddelanden till och med meddelande N.
- Mottagaren har timer för att förhindra uteblivet meddelande vid ev. fel på NAK.


Sändare
V(S) =
N
N+1
N+2
N+3
N+4
N+5
N+5
D(N)
D(N+1)
D(N+2)
D(N+3)
D(N+4)
D(N+1)
D(N+2)
D(N+3)
D(N+4)
D(N+1)
D(N+2)
D(N+3)
D(N+1)
D(N)
D(N)
D(N)
D(N+1)
D(N+2)
D(N+3)
D(N+4)
D(N+1)
ACK(N)
NAK(N+1)
ACK(N+4)
Tid
OK
D(N)
Felaktig eller saknas
OK
D(N+2)
OK
D(N+3)
D(N+2)
OK
D(N+4)
D(N+3)
D(N+2)
OK
D(N+1)
D(N+4)
D(N+3)
D(N+2)
Till högre skikt i mottagarens protokollstack
Mottagare

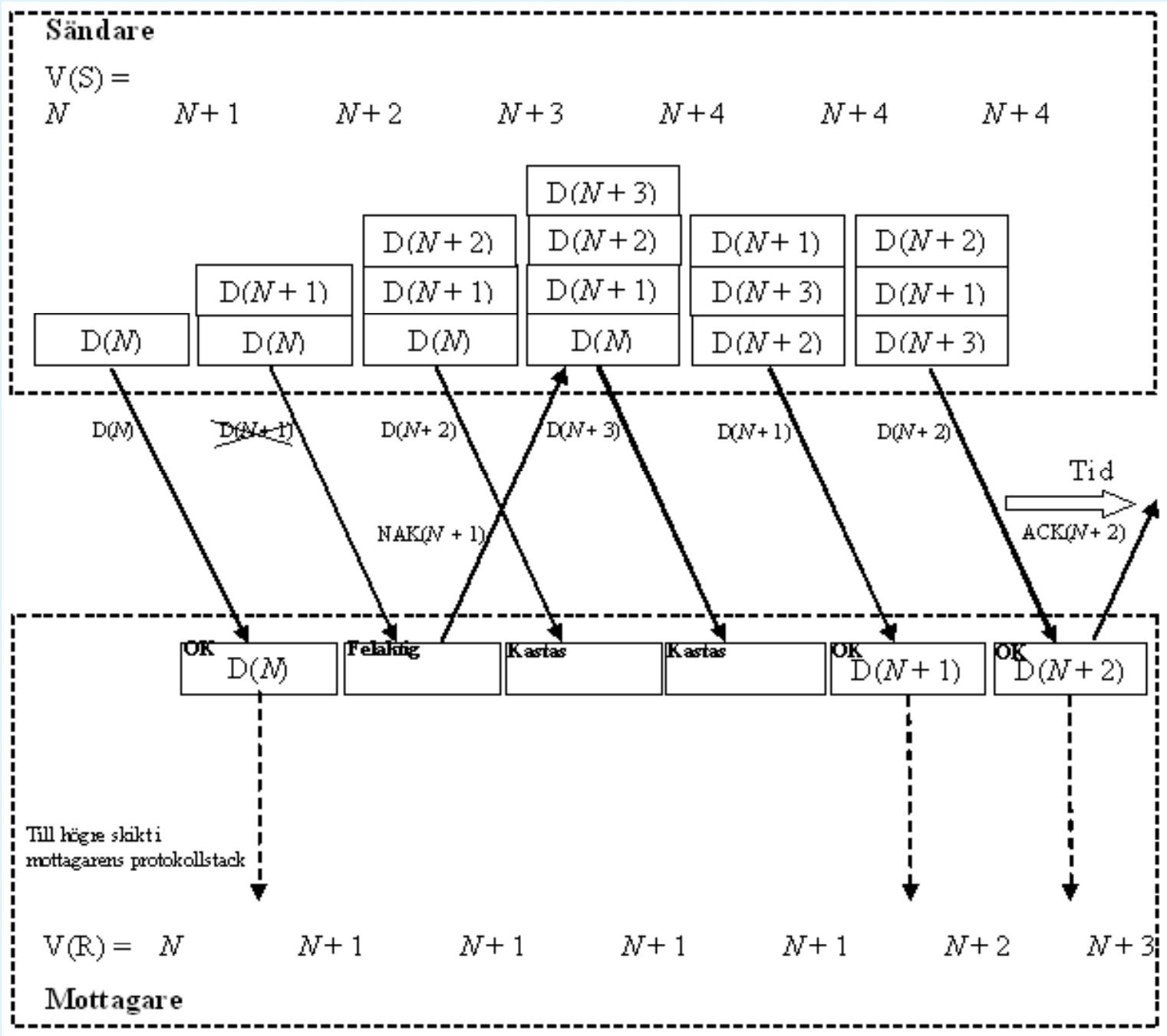

Sändare
V(S) =
N
N+1
N+2
N+3
N+4
N+5
N+5
D(N)
D(N+1)
D(N+2)
D(N+3)
D(N+4)
D(N)
D(N+1)
D(N+2)
D(N+3)
D(N+4)
NAK(N)
Ny NAK(N)
ACK(N+4)
Tid
Felaktig
OK
Start av timer
för NAK(N)
Timeout för NAK(N),
dvs. D(N) saknas
Till högre skikt i
mottagarens protokollstack
V(R) = N N N N N N N+5
Mottagare

Go-back-N (1)

- Repeterar samtliga meddelanden från och med ett felaktigt.
- Fördel: mottagningsbufferten behöver plats för ett enda meddelande.

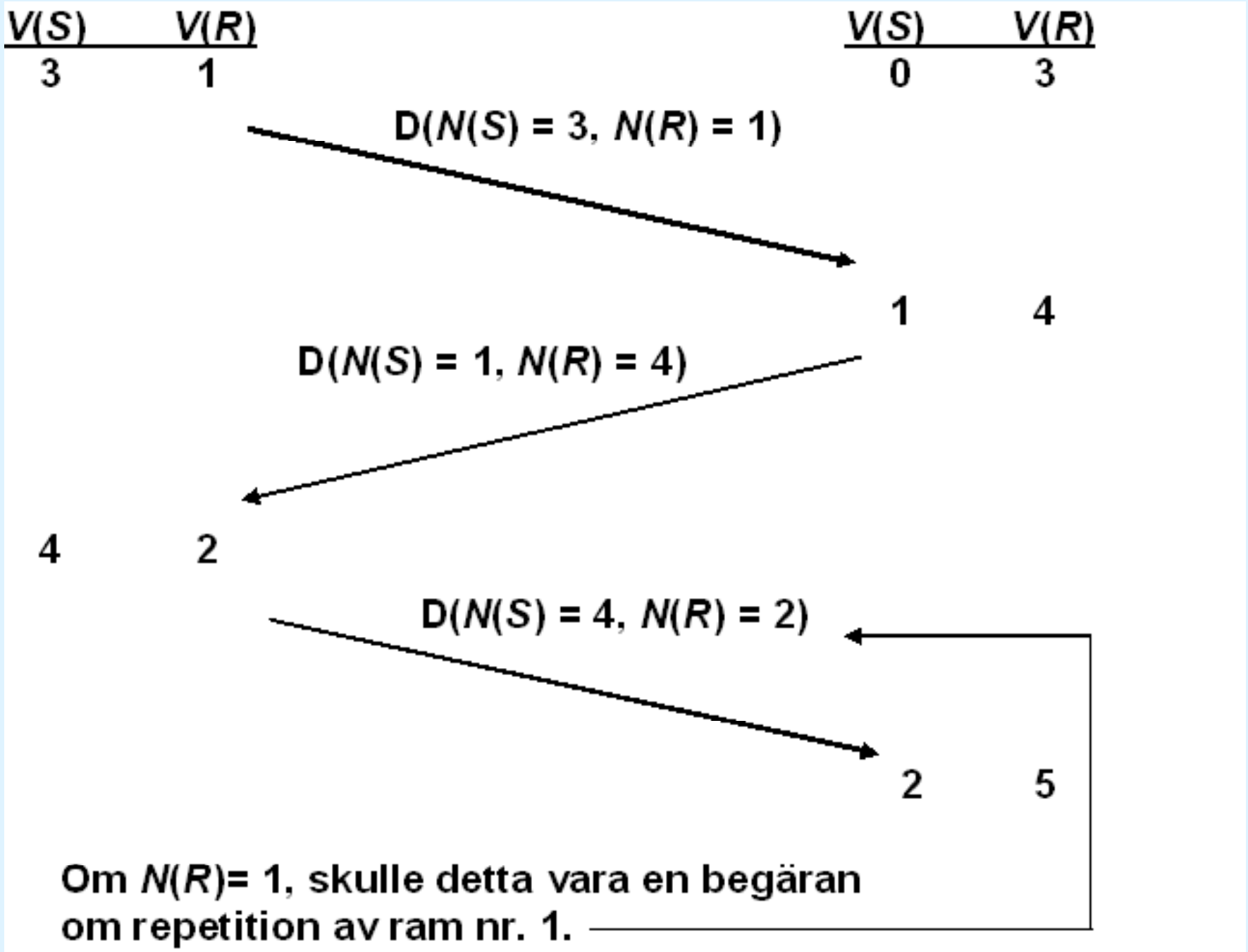
Go-back-N (2)

- Både ACK och NAK används.
- NAK(*N*) medför omsändning från och med meddelande *N*.
- ACK(*N*) och NAK(*N* + *1*) ger implicit kvittering för alla meddelanden till och med meddelande *N*.
- Varje meddelande som sänds har en timer hos sändaren så att utebliven ACK/NAK ger omsändning.


Sändare
V(S) =
N
N+1
N+2
N+3
N+4
N+4
N+4
D(N)
D(N+1)
D(N+2)
D(N+3)
D(N+1)
D(N+2)
D(N+2)
D(N+3)
D(N+1)
D(N+3)
D(N+2)
D(N+2)
D(N+1)
D(N+3)
D(N)
D(N+1)
D(N+2)
D(N+3)
D(N+2)
NAK(N+1)
Tid
ACK(N+2)
OK
D(N)
Felaktig
Kastas
Kastas
OK
D(N+1)
OK
D(N+2)
Till högre skikt i
mottagarens protokollstack
V(R) =
N
N+1
N+1
N+1
N+1
N+2
N+3
Mottagare

Piggyback acknowledgement

- Kvittenser inbäddade i nyttomeddelanden
- Onödig trafik reduceras


V(S) V(R)
3 1
V(S) V(R)
0 3
D(N(S) = 3, N(R) = 1)
1 4
D(N(S) = 1, N(R) = 4)
4 2
D(N(S) = 4, N(R) = 2)
2 5
Om N(R)= 1, skulle detta vara en begäran
om repetition av ram nr. 1.

Hammingavstånd

- *HD* = min(alla avstånd i en mängd av kodord)

- Om *HD* = *u* + 1,

  kan *u* st. bitfel upptäckas i ett felaktigt kodord.

- Om *HD* = 2*r* + 1,

  kan *r* st. bitfel korrigeras i ett felaktigt kodord.

Exempel på blockparitet (blocksumma)

	00000010	= STX
	10101000	1:a tecknet
	00100000	2:a tecknet
	10101101	3:e tecknet
	11100011	4:e tecknet
⊕	**1**0000011	= ETX
BCC =	**1**1000111	

Cyclic Redundancy Check (CRC)

- Används i många typer av LAN

  Exempelvis i Ethernet.

- Felsökning

- Felrättning

  CRC integrerad med felrättande kod

Generatorpolynom

- Bestämmer checksummans tillförlitlighet
- CRC-12: $G = x^{12} + x^{11} + x^3 + x^2 + 1$
- CRC-16: $G = x^{16} + x^{15} + x^2 + 1$
- CRC-CCITT: $G = x^{16} + x^{12} + x^5 + 1$
- CRC-32: $G = x^{32} + x^{26} + x^{23} + x^{16} + x^{12} + x^{11} + x^{10} + x^8 + x^7 + x^5 + x^4 + x^2 + x + 1$

CRC-beräkningar

$$\frac{D \cdot 2^n}{G} = Q \oplus \frac{R}{G} \qquad \frac{13}{4} = 3 + \frac{1}{4}$$

Sändaren skickar

$$T = D \cdot 2^n \oplus R$$

Mottagaren testar

$$\frac{T'}{G} = Q \oplus \frac{E}{G}$$

Om $E = 0$, felfri övering.

Feltyper med CRC

Med ett bra val av generatorpolynom kan mottagaren upptäcka följande:

- alla en-bits fel
- alla två-bitars fel
- alla udda antal bitar fel
- alla felskurar < $n + 1$ bitar
- de flesta felskurar ≥ $n + 1$ bitar

Reed-Solomon (RS) (1)

- Används för datakommunikation och lagringsmedia

  Det gör CRC också!

- Felsökning

- Felrättning

Reed-Solomon (RS) (2)

- RS(n, k)

  Antal data (s-bitars symboler): k

  Antal data inklusive checksummorna: n

  Antal checksummor (s-bitars symboler): $n - k$

Reed-Solomon (RS) (3)

- Maximalt antal data som kan rättas (t)

  $2t = n - k$

  dvs.

  $t = (n - k)/2$

Flödesreglering

- Programstyrd
- Hårdvarustyrd
- Fönsterteknik

Fönsterteknik

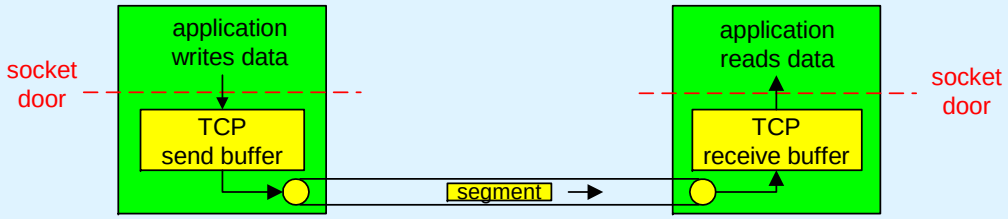
Omsändningsmetod	Sändningsfönster	Mottagningsfönster
Idle repeat request	1	1
Selective repeat	$k/2$	$k/2$
Go-back-N	$k-1$	1

Antal sekvensnummer: $k = 2^n$

TCP: Overview

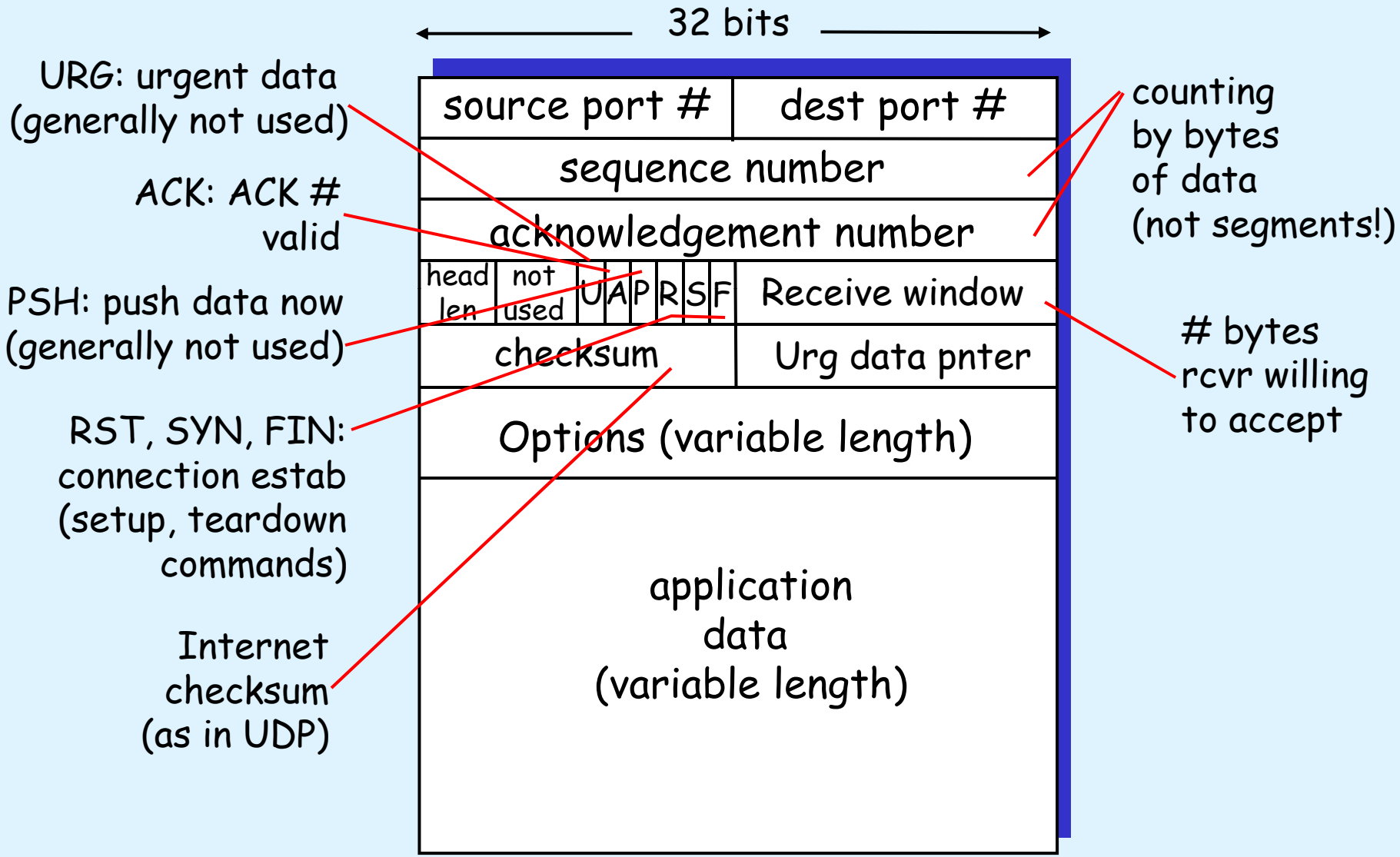
RFCs: 793, 1122, 1323, 2018, 2581

- point-to-point:
  - one sender, one receiver
- reliable, in-order *byte steam:*
  - no "message boundaries"
- pipelined:
  - TCP congestion and flow control set window size
- *send & receive buffers*



- full duplex data:
  - bi-directional data flow in same connection
  - MSS: maximum segment size
- connection-oriented:
  - handshaking (exchange of control msgs) init's sender, receiver state before data exchange
- flow controlled:
  - sender will not overwhelm receiver

TCP segment structure



TCP Connection Management

Recall: TCP sender, receiver establish "connection" before exchanging data segments

- initialize TCP variables:
  - seq. #s
  - buffers, flow control info (e.g. **`RcvWindow`**)

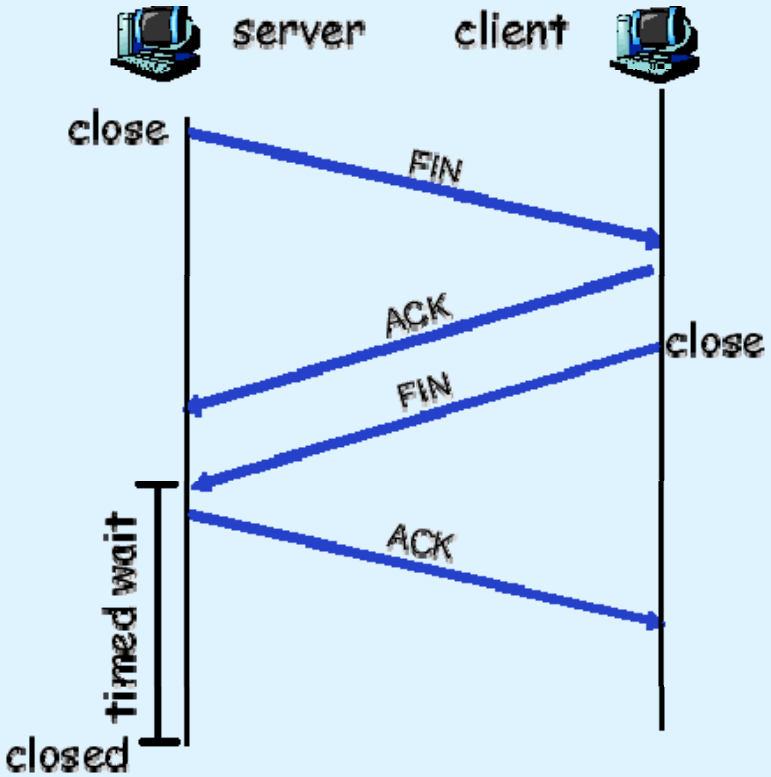
Three way handshake:

Step 1: client host sends TCP SYN segment to server
- specifies initial seq #
- no data

Step 2: server host receives SYN, replies with SYNACK segment
- server allocates buffers
- specifies server initial seq. #

Step 3: client receives SYNACK, replies with ACK segment, which may contain data

TCP Connection Management (cont.)



Step 1: server end system sends TCP FIN control segment to client

Step 2: client receives FIN, replies with ACK. Closes connection, sends FIN.

Step 3: server receives FIN, replies with ACK.

- Enters "timed wait" - will respond with ACK to received FINs

Step 4: client, receives ACK. Connection closed.

TCP Round Trip Time and Timeout

Q: how to set TCP timeout value?

- longer than RTT
  - but RTT varies
- too short: premature timeout
  - unnecessary retransmissions
- too long: slow reaction to segment loss

Q: how to estimate RTT?

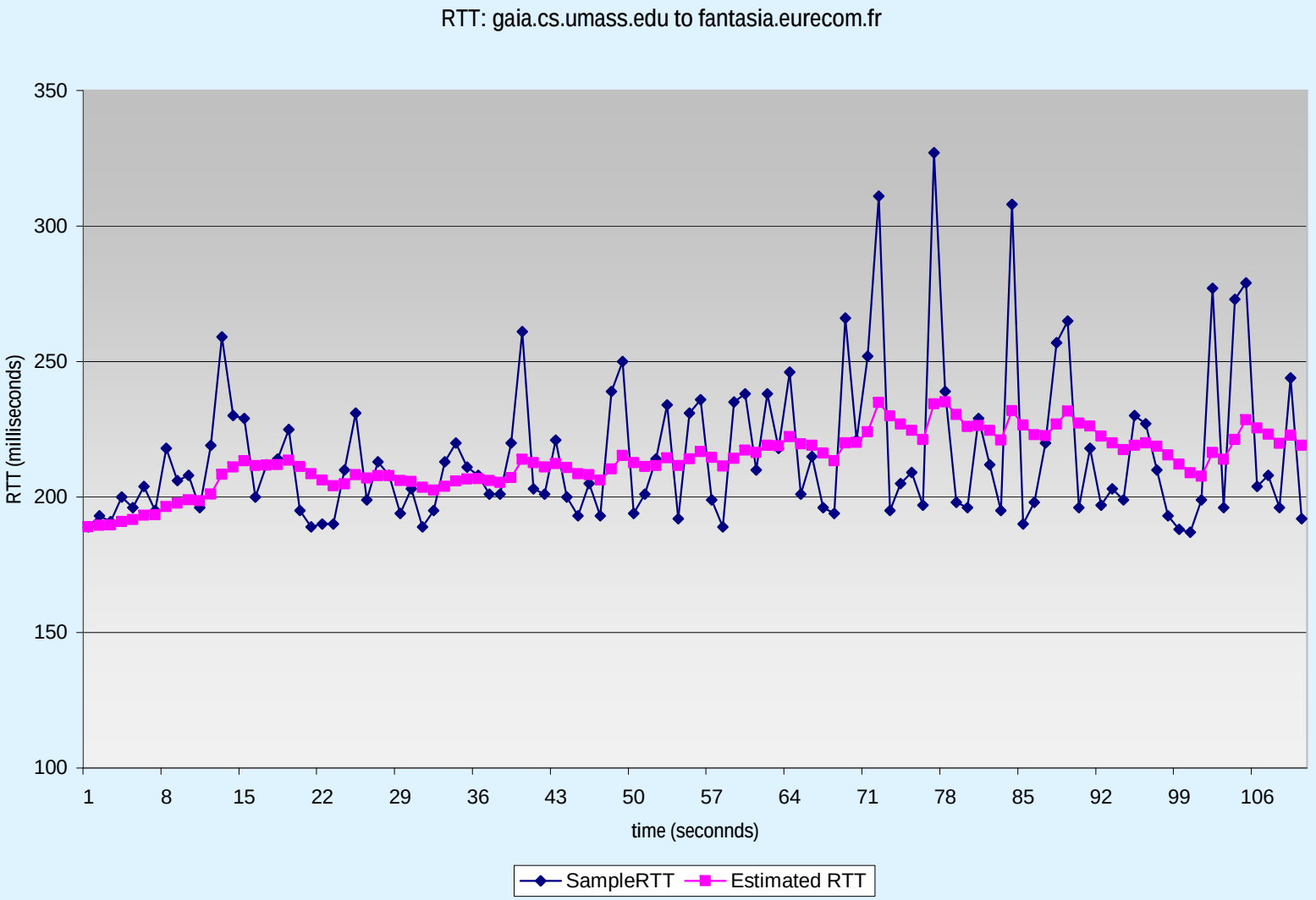
- **SampleRTT**: measured time from segment transmission until *ACK* receipt
- **SampleRTT** will vary, want estimated RTT "smoother"
  - average several recent measurements, not just current **SampleRTT**

TCP Round Trip Time and Timeout

$$\mathbf{EstimatedRTT_{new} = (1-\alpha)\cdot EstimatedRTT_{old} + \alpha\cdot SampleRTT}$$

- Exponential weighted moving average
- influence of past sample decreases exponentially fast
- typical value: $\alpha = 0.125$

Example RTT estimation:



TCP Round Trip Time and Timeout

Setting the timeout

- **EstimtedRTT** plus "safety margin"
  - large variation in **EstimatedRTT** -> larger safety margin
- first estimate of how much SampleRTT deviates from EstimatedRTT:

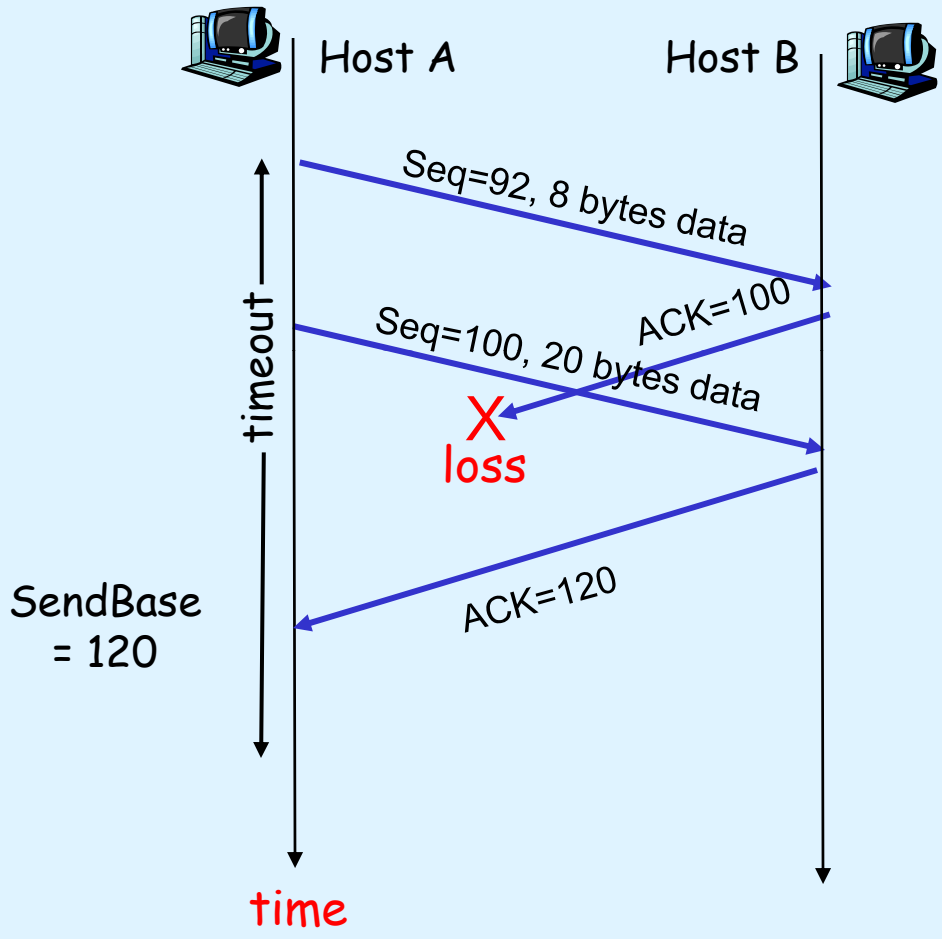
$$\mathbf{DevRTT_{new} = (1-\beta)\cdot DevRTT_{old} + \beta \cdot |SampleRTT-EstimatedRTT|}$$

(typically, β = 0.25)

Then set timeout interval:

$$\mathbf{TimeoutInterval = EstimatedRTT + 4\cdot DevRTT}$$

TCP retransmission scenarios (more)

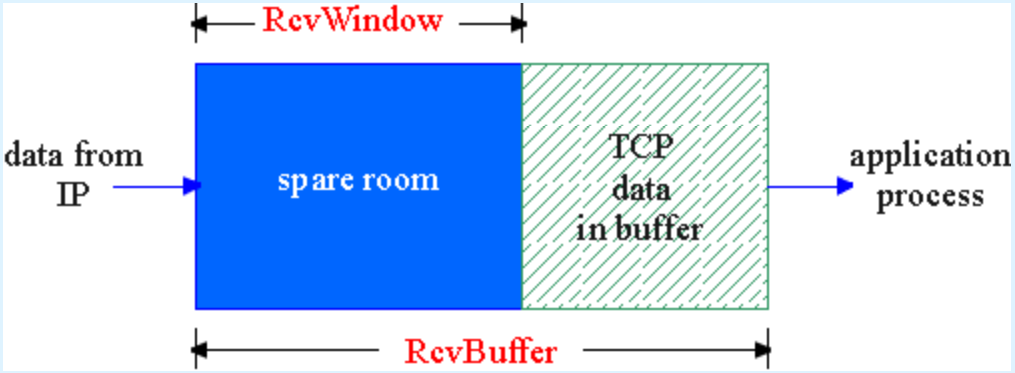


Cumulative ACK scenario

Fast Retransmit

- Time-out period often relatively long:
  - long delay before resending lost packet
- Detect lost segments via duplicate ACKs.
  - Sender often sends many segments back-to-back
  - If segment is lost, there will likely be many duplicate ACKs.
- If sender receives 3 ACKs for the same data, it supposes that segment after ACKed data was lost:
  - fast retransmit: resend segment before timer expires

TCP Flow control: how it works



- Rcvr advertises spare room by including value of **RcvWindow** in segments
- Sender limits unACKed data to **RcvWindow**
  - guarantees receive buffer doesn't overflow

- spare room in buffer

= RcvWindow

= RcvBuffer-[LastByteRcvd - LastByteRead]

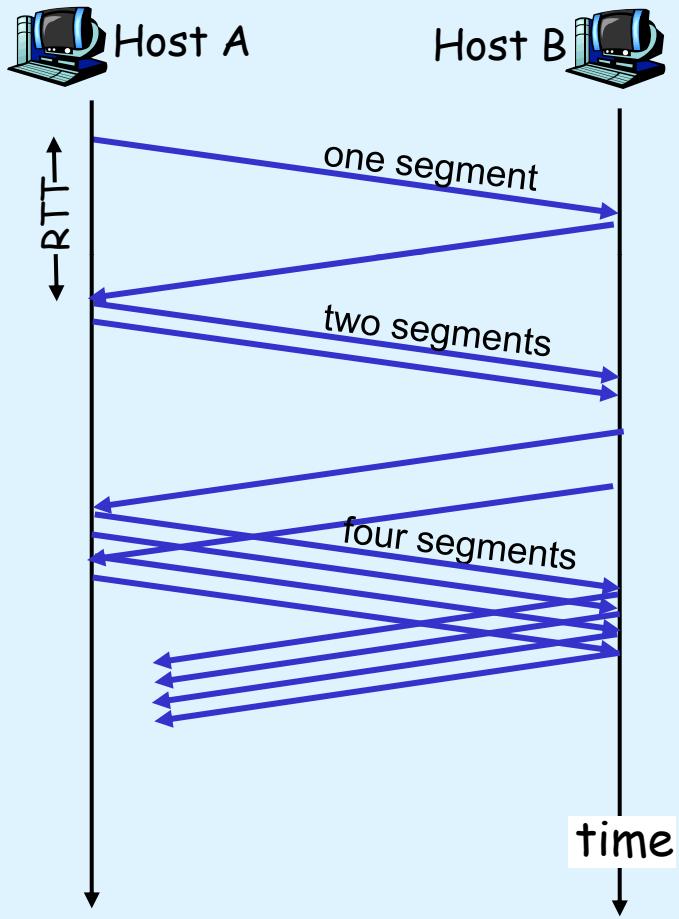
Principles of Congestion Control

Congestion:

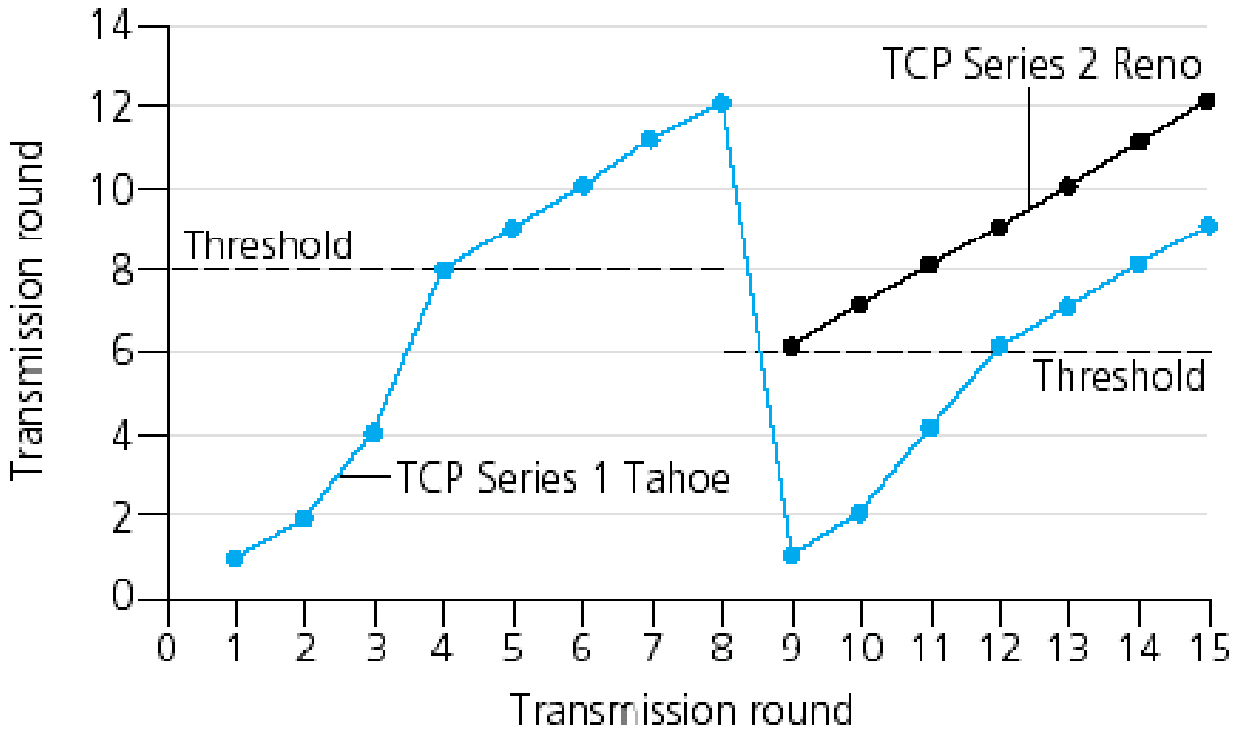
- informally: "too many sources sending too much data too fast for *network* to handle"
- different from flow control!
- manifestations:
  - lost packets (buffer overflow at routers)
  - long delays (queueing in router buffers)
- a top-10 problem!

TCP Slow Start (more)

- When connection begins, increase rate exponentially until first loss event:
  - double **CongWin** every RTT
  - done by incrementing **CongWin** for every ACK received
- Summary: initial rate is slow but ramps up exponentially fast



Refinement


14
12
10
8
6
4
2
0
Transmission round
Threshold
TCP Series 2 Reno
Threshold
TCP Series 1 Tahoe
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
Transmission round

Summary: TCP Congestion Control

- When **CongWin** is below **Threshold**, sender in slow-start phase, window grows exponentially.
- When **CongWin** is above **Threshold**, sender is in congestion-avoidance phase, window grows linearly.
- When a triple duplicate *ACK* occurs, **Threshold** set to **CongWin/2** and **CongWin** set to **Threshold**.
- When timeout occurs, **Threshold** set to **CongWin/2** and **CongWin** is set to 1 MSS.