Primer Data Communication Technology

Pillars of Data Communication:

Framing, Layering, Protocol, Error Recovery, ARQ

TDM, Circuit Switching, Packet Switching

Today's Internet Technologies / Terms

Ethernet Switching PIM-SM SSM IGMP RSTP IP Address SRTP

Carrier Ethernet VLAN LTE RTP Radius SSH ARP

NetFlow WLAN VM POP3 OTV Data Center FTP TCP

SNMP SMTP ISP Address Aggregation

L2TPv3 LISP Pseudowire UDP Autonomous Systems

IP Routing MAC Address

L3-QoS (DSCP) CIDR Firewall NAC LACP IMAP

Multicast

VOIP IPsec-VPN IPv4 Virtualization IDS/IPS MIME ICMP

IPv6 NAT MPLS Trill NHRP

SSL-VPN Anycast IP Mobility ND

AAA

Unicast PPP VIX MPLS-VPN

VPLS SDN IKE

Cloud PPTP

OSPF Segment Routing RSVP

Teredo EIRGP NMS Load Balancer

Shim6 MPLS-TE

HTML MLD HIP BGP IS-IS ISATAP NVF

TLS

HTTP WWW NAT64/DNS64 DNSSEC HSRP/VRRP/GLBP

6PE

Openflow SIP ADSL/VDSL 6VPE 6to4 6rd

L2-CoS

SLAAC LDAP DMVPN NAT444 DNS DS-Lite GetVPN

Yesterday's Technologies / Terms

PSTN Transdata MAN MAP SONET

SDLC Decnet

PAD ATOM PNNI OSI

AppleTalk

ISDN ATM

X.25 B-ISDN CNLP PDH SDH CSMA/CD

HDLC

Frame-Relay Novell-IPX

RIP

Source-Route Bridging

APPN

Token-Ring SNA SMDS L3-QoS (RSVP)

DQDB

VGAnyLan Token-Bus NHRP (ATM)

FDDI

BISYNC/BSC

SR Translational Bridging LANE MPOA

FTAM BUS/LES Terminal-Multiplexer

MARS, MCS

Datex-P Datex-L

ATMR X.500 LAPB

DAP LAPF

VT JTM MHS PABX LAPD

LAPM

Confused ?

Destroyed ?

Frustrated ?

!!! Take the Data Communication Lectures !!!

https://www.ict.tuwien.ac.at/lva/384.081/index.html

Generic Pillars of Data Communication

- Serial Transmission Technology
  - Bit Synchronization
  - Encoding / Decoding
- Framing and Error Detection
  - Frame Synchronization, Checksum
- Layering, Protocols, Services
  - Encapsulation / Decapsulation
  - Connectionless versus Connection-oriented
  - OSI-7 Layer Model
- Error Recovery
  - ARQ Techniques, Sequence Numbers, Windowing
  - Delay-Bandwidth Product
- Flow Control
  - End System to End System
  - End System to Network
- Time Division Multiplexing (TDM)
  - Synchronous TDM
  - Asynchronous (Statistical) TDM
- Network Methods
  - Circuit Switching
  - Packet Switching

Today's Most Important Technologies

- LAN Technology
  - Ethernet, Ethernet Switching
  - Rapid Spanning-Tree, VLAN, LACP
  - WLAN (***)
- IP Network Technology
  - IP Unicast Forwarding (Addressing, ARP, ICMP, PPP, HSRP)
  - IP Routing (RIP, OSPF)
  - Internet Routing, BGP (*), CIDR
- IP End-to-End Transport
  - TCP and UDP
- IP Administration, Standard Applications, Special Topics
  - NAT
  - *BootP, DHCP, TFTP*
  - *DNS*
  - *FTP, Telnet / SSH*
  - *HTTP, WWW*
  - VOIP (*)
  - Firewall (*), (***)
- IP Backbone Technology and VPN
  - *MPLS*
  - *MPLS, MPLS-VPN*
  - IPsec and IPsec VPNs (*)
- IP Advanced Topics
  - IPv4 Multicast (IGMP, PIM-DM, PIM-SM, SSM) (*)
  - I*Pv6 ("The New IP")*
  - LISP (Locator / Identifier Separation Protocol) (**)
- Virtualization, SDN (Software Defined Networks), NFV (Network Function Virtualization),

Agenda

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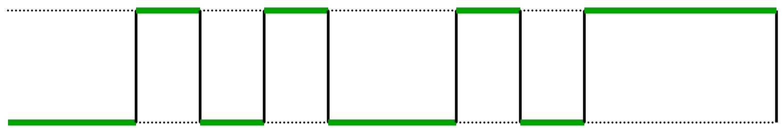
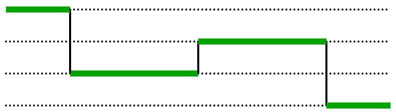
Representation of Symbols for Information Processing, Storage and Exchange

- **In the context of computer systems and data communication**
- **Discrete levels = "Digital"**
  - Resistant against noise
- **How many levels?**
  - Binary (easiest)
    - Bit (binary digit), values 0 and 1
  - M-ary: *More information per time unit!*

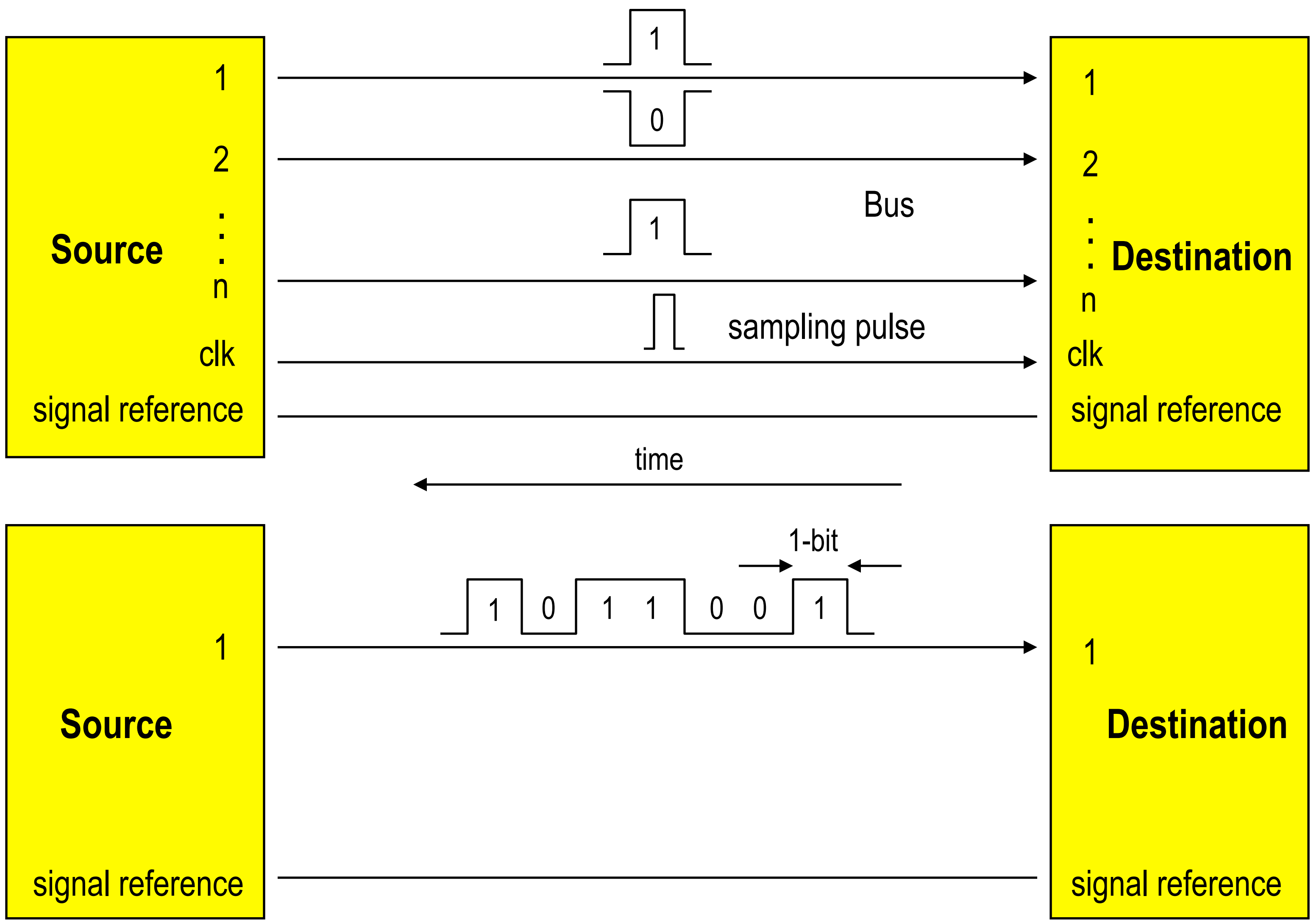


Binary

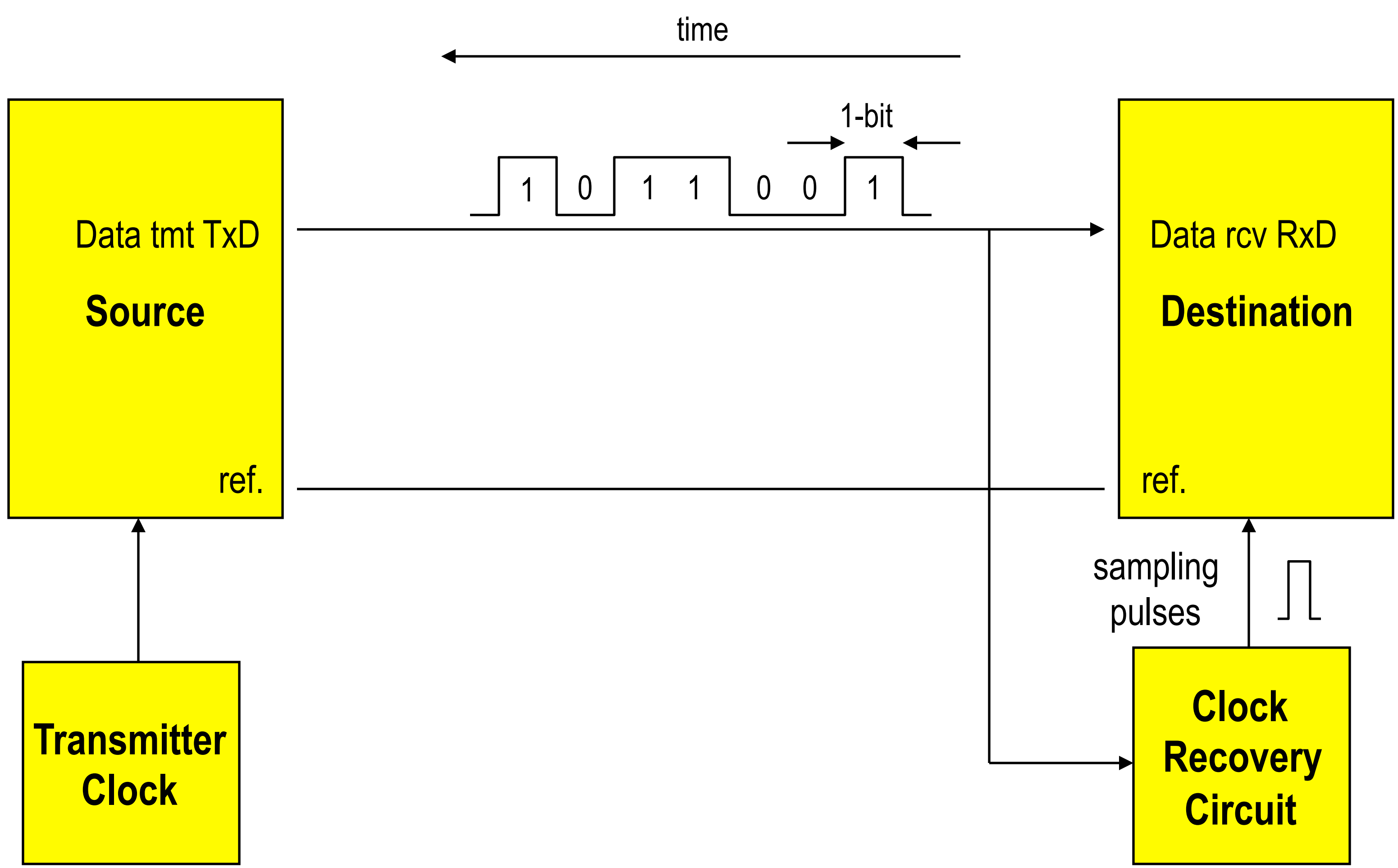


M-ary
(here 4 levels, e. g. ISDN)

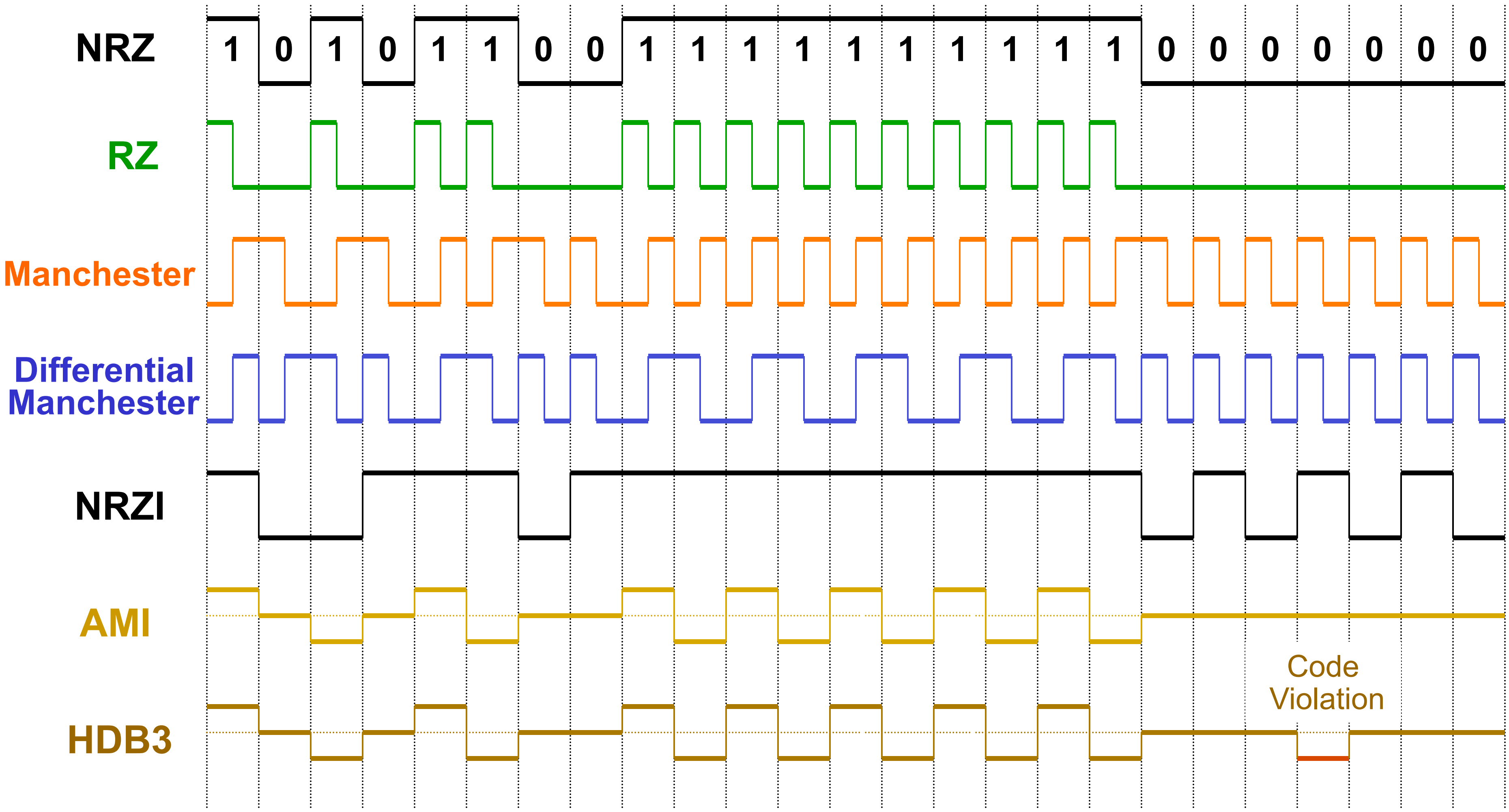
Transmission of Information: Parallel versus Serial



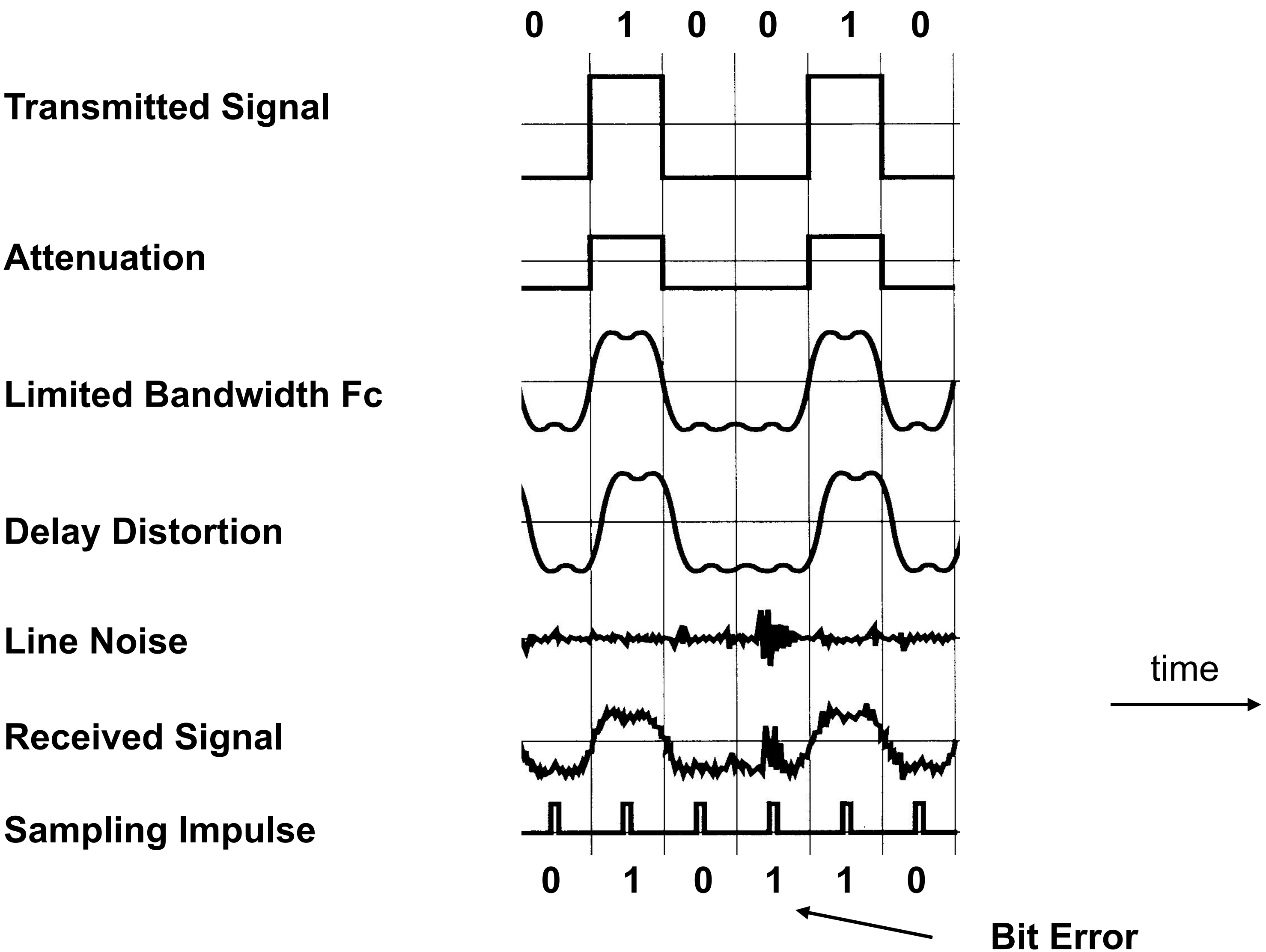
Bit (Clock) Synchronization Receiver Side



Line Coding Examples



That Happens To A Signal !!!



Requirements & Facts
Serial Transmission System

- **Information between systems is exchanged in blocks of bits**
  - Every block is carried in as so called transmission frames
- **The recognition of the beginning and the end of a block in the received bit stream is necessary**
  - Frame synchronization
- **Errors on physical lines may lead to damage of digital information**
  - 0 becomes 1 and vice versa
  - The longer the block the higher the probability for an error
- **Methods necessary for error checking**
  - Frame protection
  - Error detection and recovery

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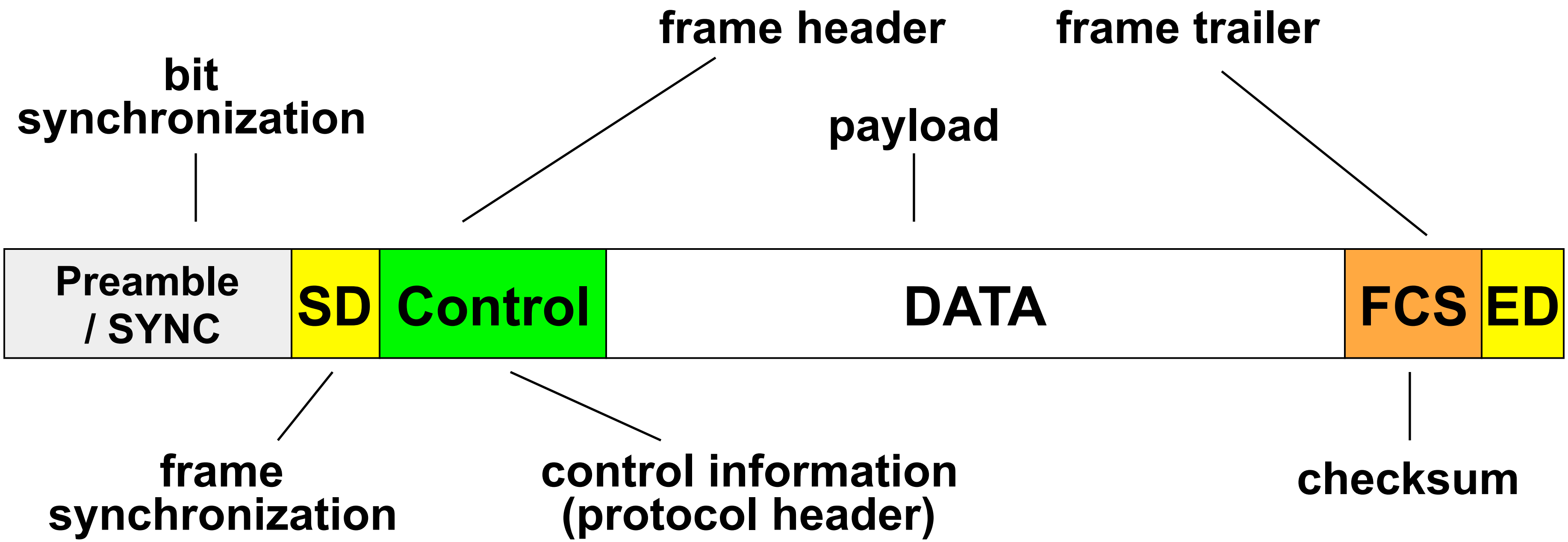
Generic Frame Format



SYNC - Sync Pattern
SD - Starting Delimiter
ED - Ending Delimiter
FCS - Frame Check Sequence

Preamble

- **Preamble / SYNC is a special bit pattern**
  - Used for bit synchronization after an idle period (Preamble)
  - Can be used as fill pattern during idle times to keep the receiver clock synchronized (SYNC)
- **Enables PLL synchronization**
  - Typically a 0101010...-pattern
  - Example: 8 Byte preamble in Ethernet frames

Preamble / SYNC	**SD**	**Control**	**DATA**	**FCS**	**ED**

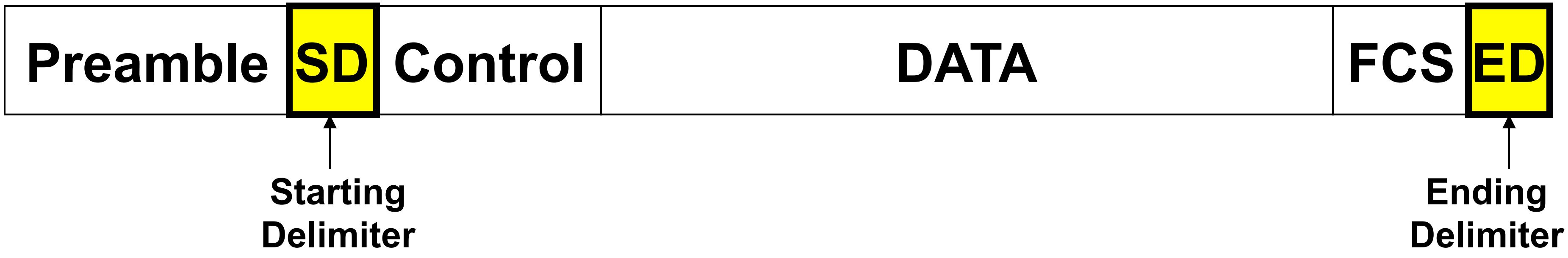
Control Field

- **Is used for implementing protocol procedures**
- **Contains information such as**
  - Frame type, protocol type
    - Data, Ack, Nack, Connect, Disconnect, Reset, etc.
    - IP, IPX, AppleTalk, etc.
  - Sequence numbers for identification of frame sequence
    - Necessary for error recovery and flow control with connection oriented services
  - Address information of source and destination in case of a multipoint line
  - Frame length, etc.

SYNC	**SD**	**Control**	**DATA**	**FCS**	**ED**

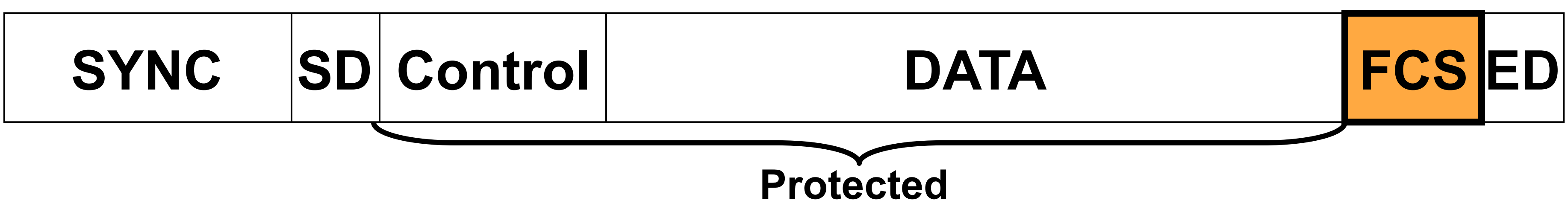
Frame Synchronization

- **Beginning and ending of a frame is indicated by SD and ED symbols**
  - Bit-patterns or code-violations
  - Length-field can replace ED (802.3)
  - Idle-line can replace ED (Ethernet)
- **Also called "Framing"**



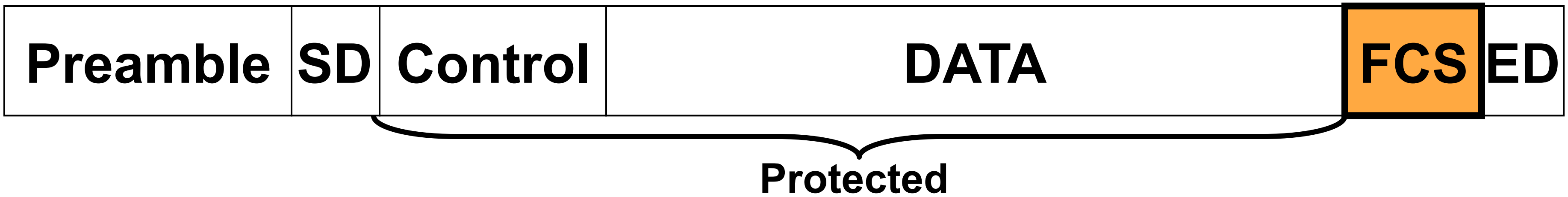
Error Control

- **Focus on error detection**
  - Include enough redundant information with each block of date to enable receiver to detect only errors occurred -> error detecting codes -> Frame Check Sequence
  - After error detection a retransmission of frame is initiated through protocol feedback to the sender
    - Area of ARQ-techniques
    - Feedback Error Control



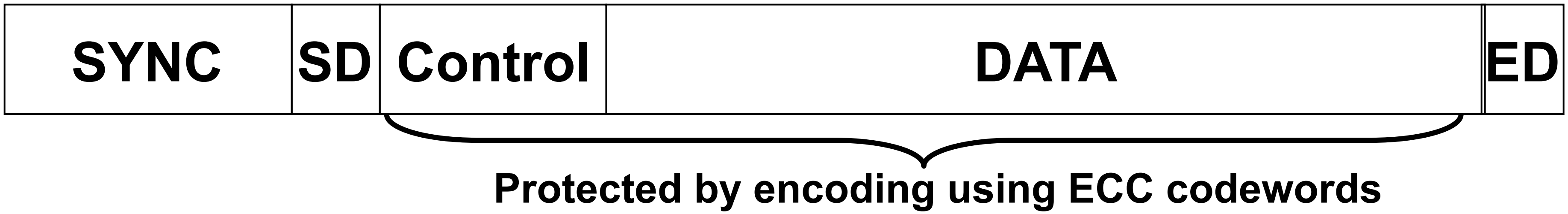
Frame Protection

- **A frame check sequence (FCS) protects the integrity of our frame**
  - From Sunspots, Mobile-Phones, Noise, Heisenberg and others
- **FCS is calculated upon data bits**
  - Different methods based on mathematical efforts: Parity, Checksum, CRC
- **Receiver compares its own calculation with FCS**



Error Control

- **Focus on error correction**
  - Include enough redundant information with to enable receiver to correct errors occurred -> error correcting codes ECC (important -> “Hamming Distance”)
  - Forward Error Control (FEC)
  - Required for "extreme" conditions
    - High BER (Bit Error Rate), EMR
    - Long delays, space links
  - Examples: Reed-Solomon codes, Hamming-codes



Time to Transmit A Given Number Of Bytes

<u>Serialization Delay</u> (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 = <u>Propagation Delay</u> (in ms) = [(Distance in m) / (velocity in m/sec)] * 1000

	Distance		v=200.000km/s Delay in msec (10^{-3})	v=300.000km/s 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

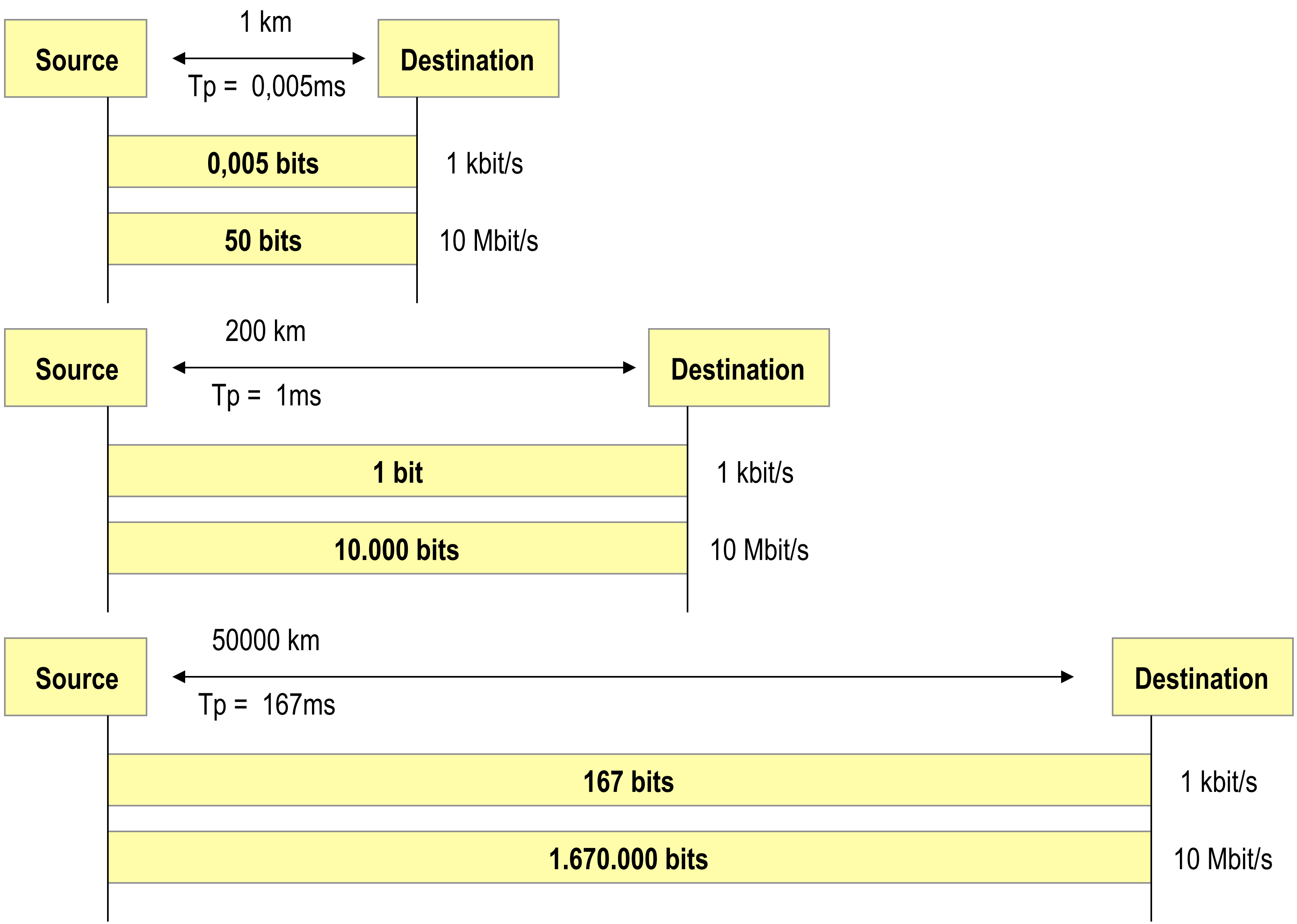
Total Delay (for a block of bits)
= Propagation Delay + Serialization Delay + (Switching Delay)

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



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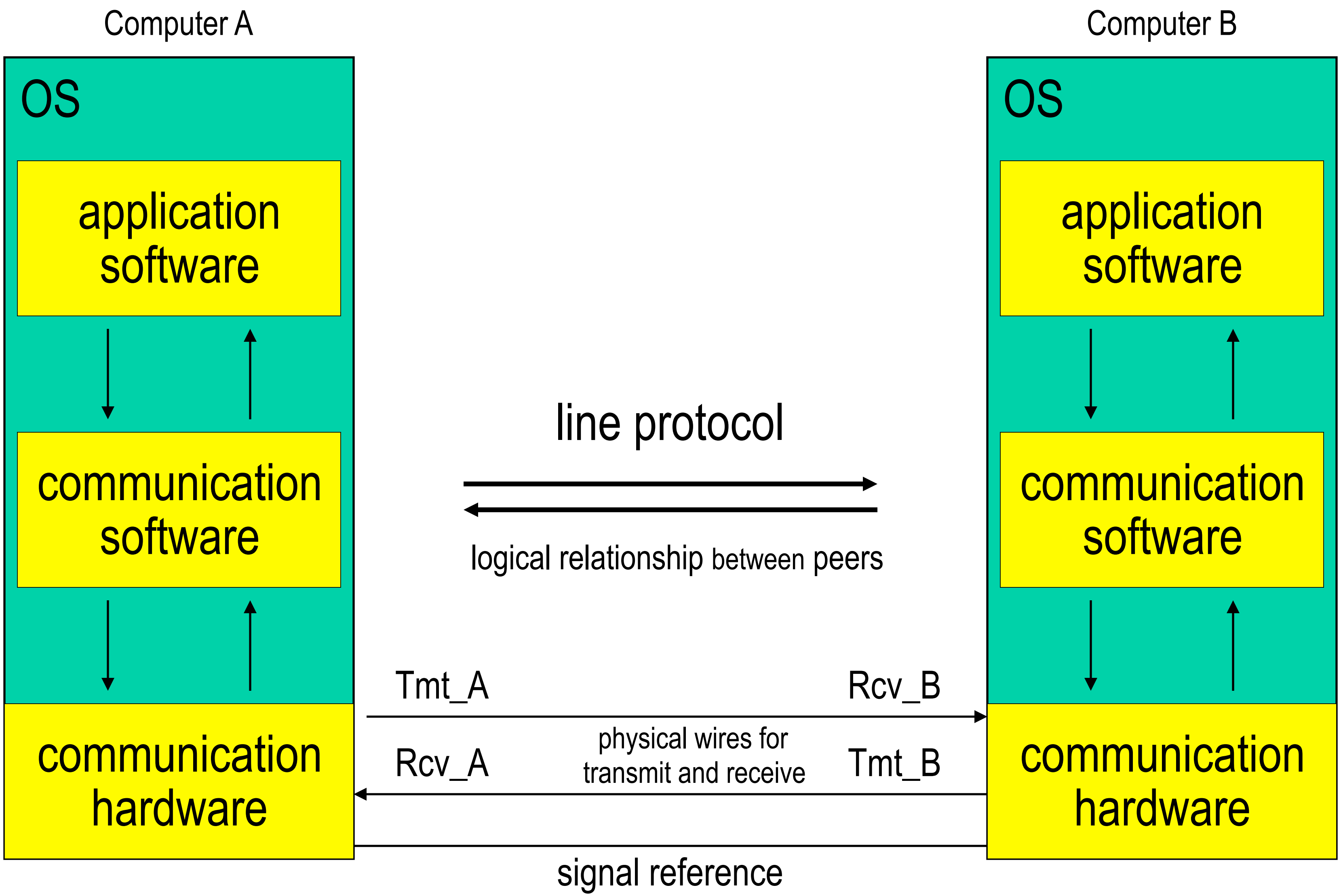
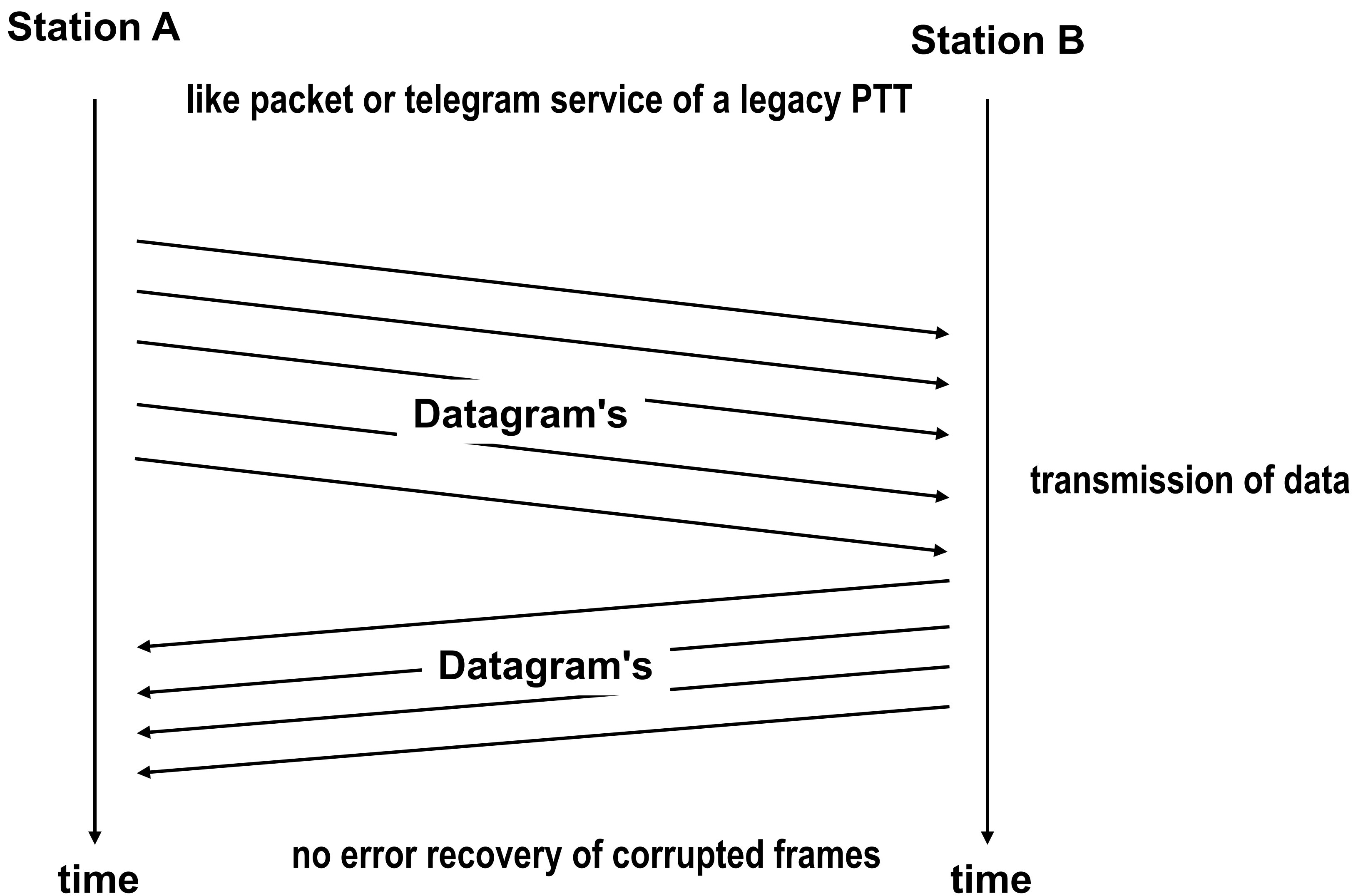
Three Important Principles for Data Communication

- **Layering**
  - Structuring the complex task of data communication into smaller pieces by usage of "layers"
- **Services**
  - Are provided by a layer to the upper layer and describe what is exchanged between layers within a system
    - Implementation-specific
    - World of industry standards created by vendors
- **Protocols**
  - Are used for communication between the systems (peers) within a layer
    - World of communication standards (IEEE, ITU, IETF, ETSI, OSI)

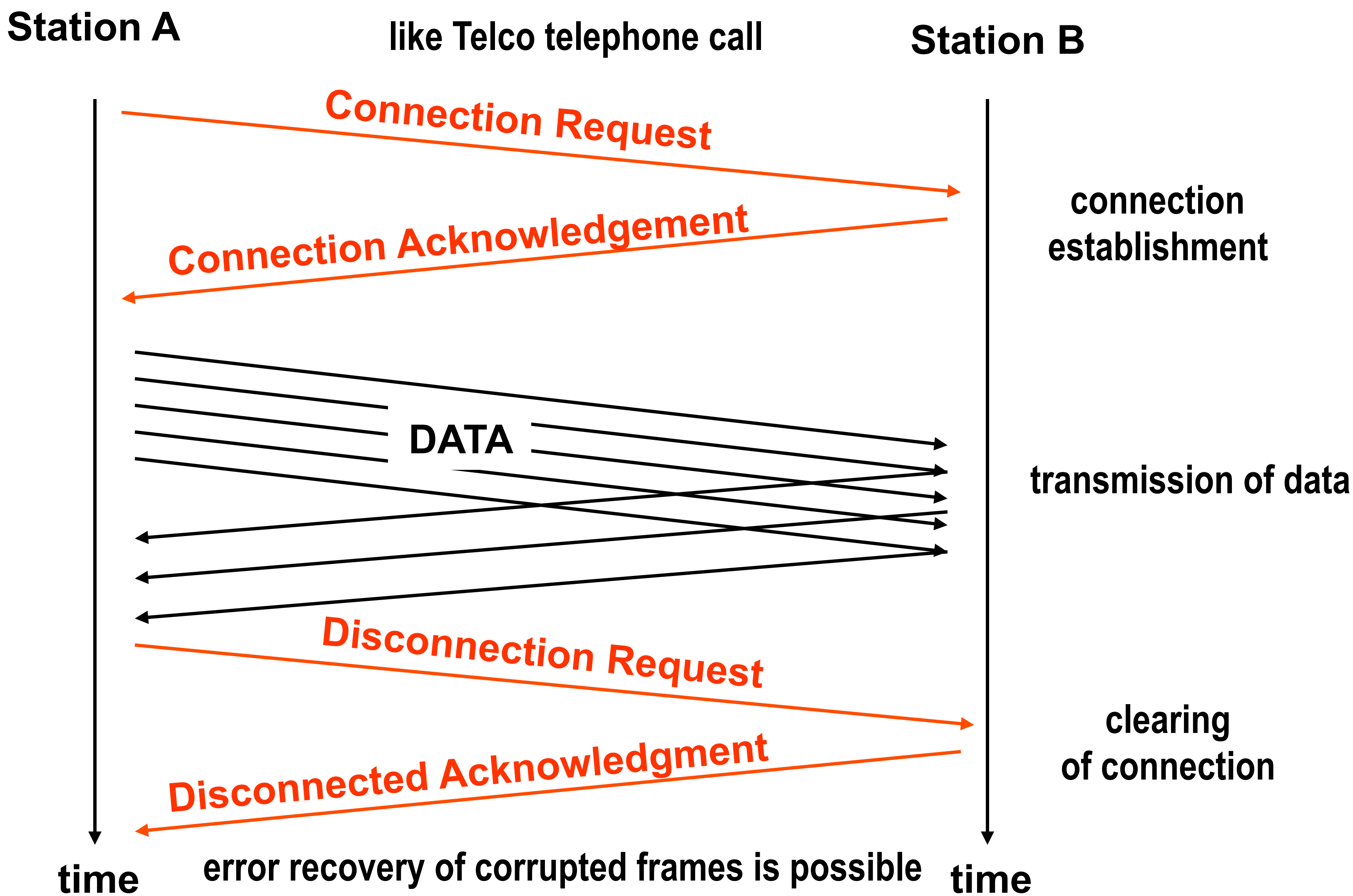
Point-to-Point Communication
3 Layer Model



Best-Effort Service: Connection-less Protocol



Reliable Service: Connection-oriented Protocol



error recovery of corrupted frames is possible by usage of ARQ techniques

Connection-oriented Protocols

- **Different definitions**
  - Some say *"protocols without addressing information"* and think of circuit-switched technologies
  - Some say *"protocols that do error recovery"*

- **Correct: "protocols that require a connection establishment before sending data and a disconnection procedure when finished"**

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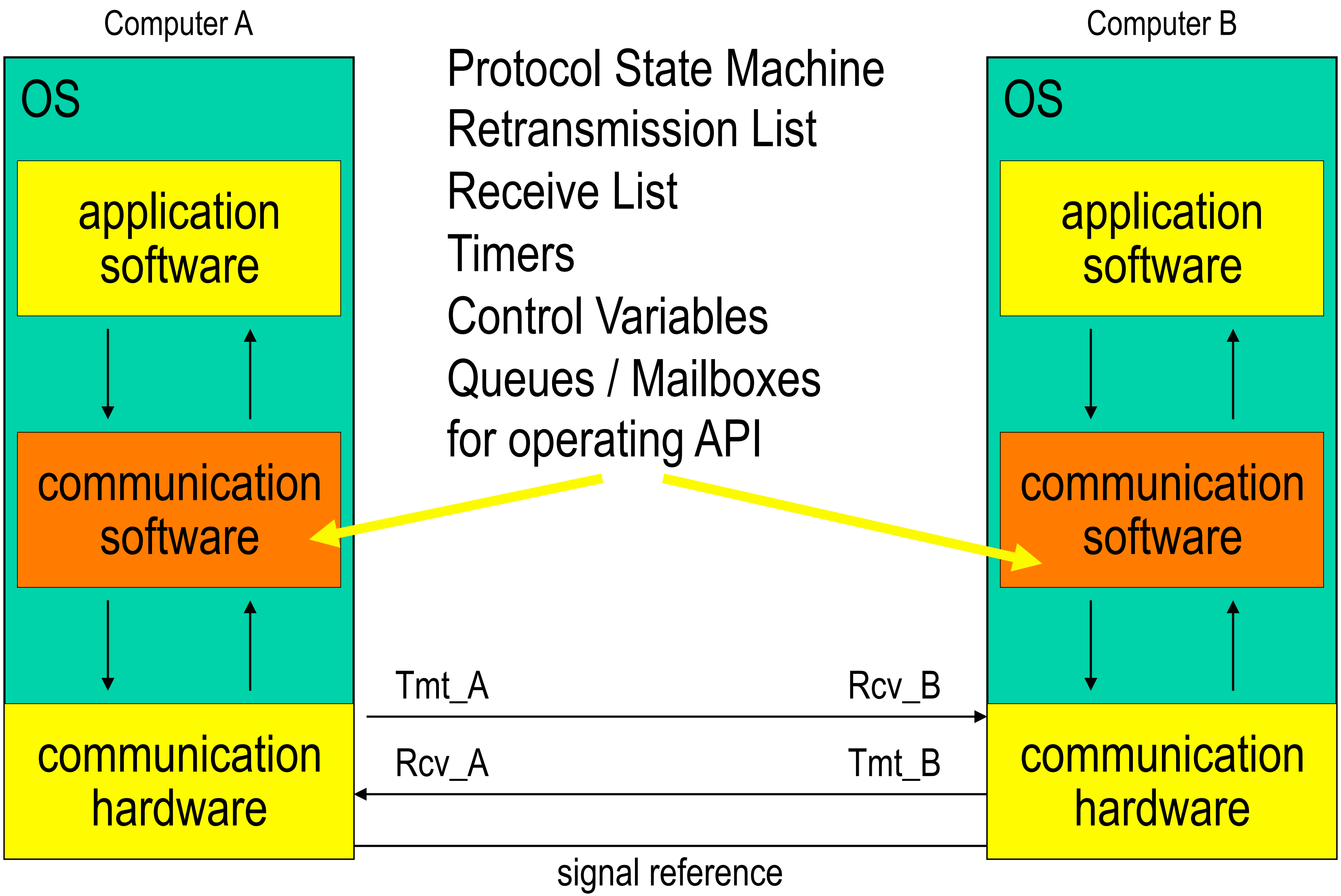
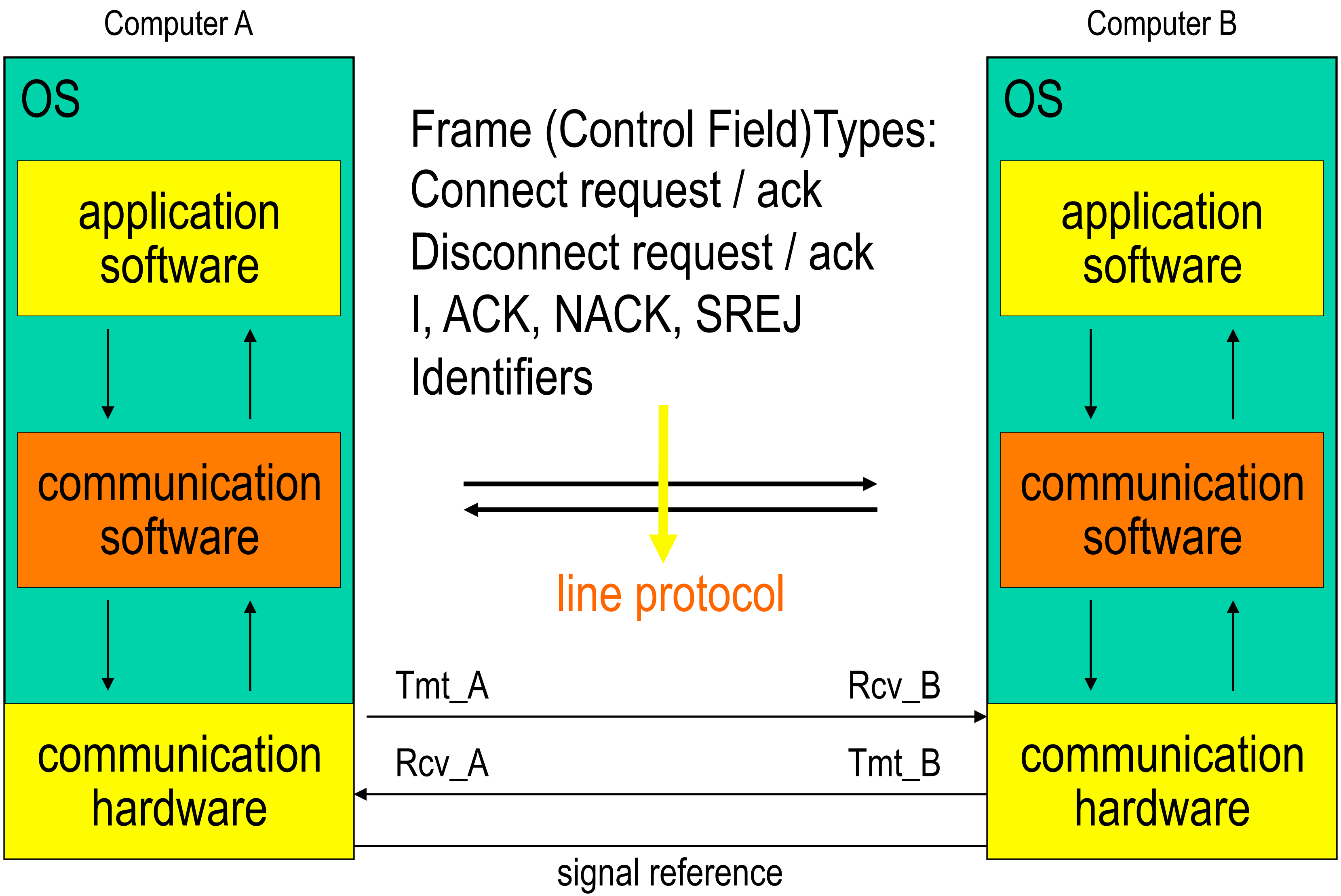
ARQ Techniques Overview

- **ARQ protocols guarantee correct delivery of data**
  - Error recovery by usage of feedback error control
  - Retransmission of data (information) frames after errors are detected by the receiver
- **Basic Method:**
  - Receiver acknowledges correct receipt of data frame by sending special control frames (ACK) in opposite direction
  - Acknowledgements refer to identifiers (sequence numbers) carried in the protocol header of the original data frame (I)

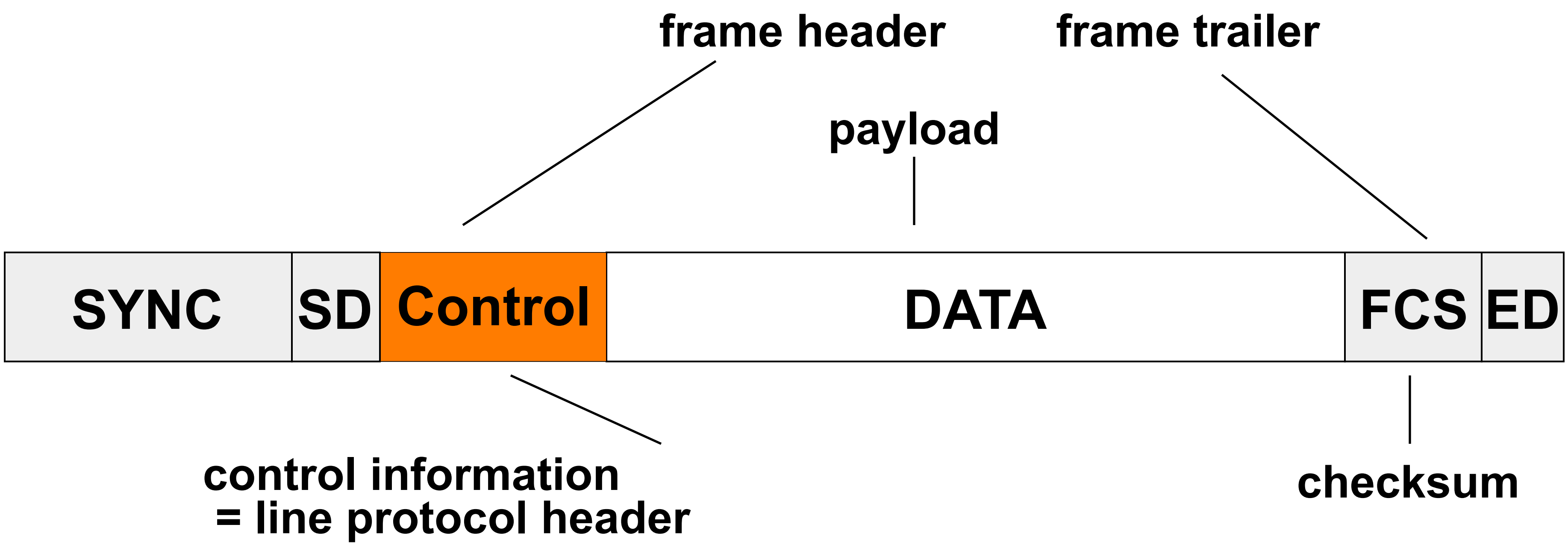
Com-SW Layer Implementation
Necessary Resource Elements



Com-SW Layer Implementation
Necessary Protocol Elements

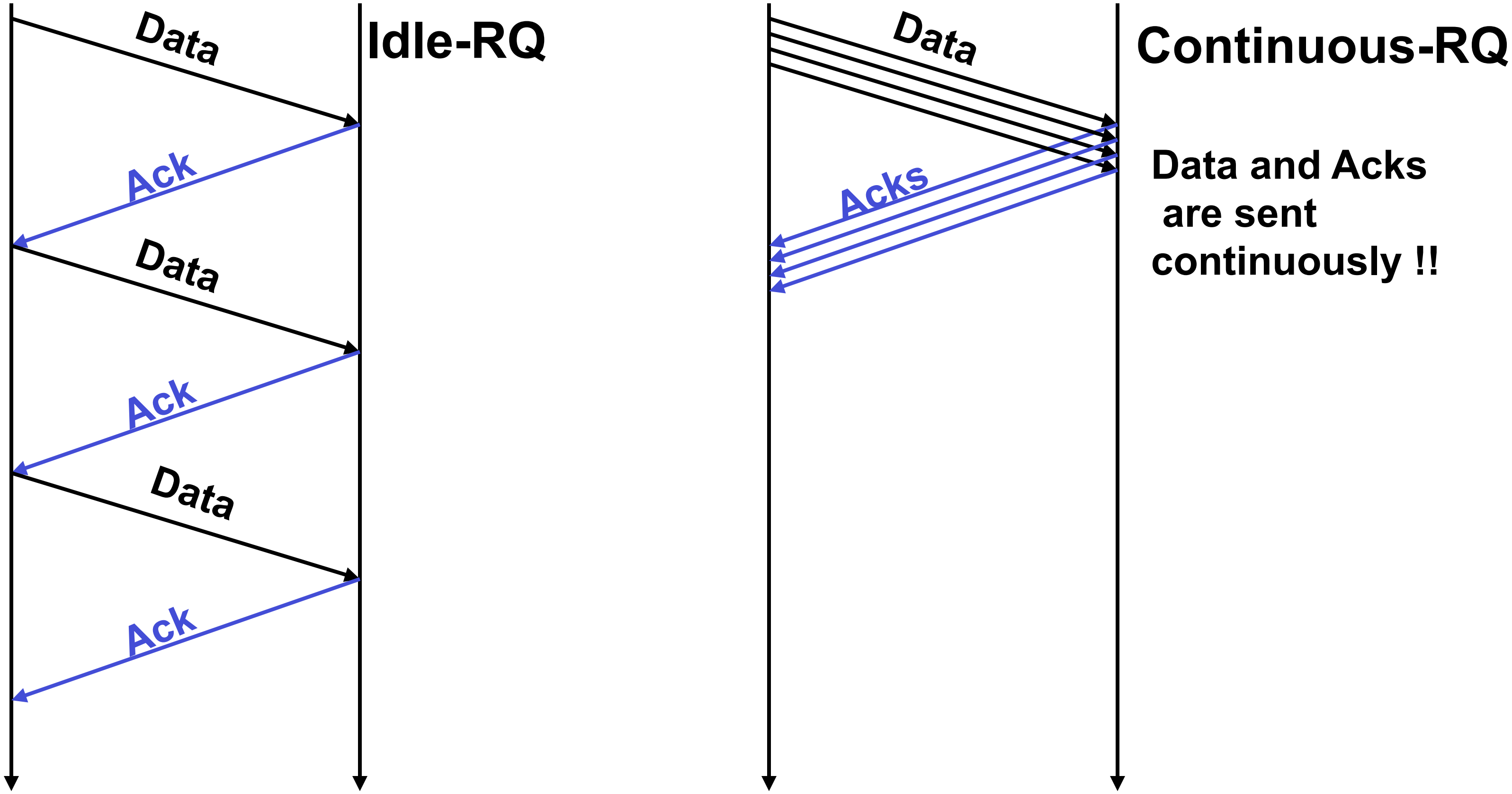


Remember Control Field (Generic Frame Format)



Frame Type Field: Connect Request, I, ACK, NACK, …
Identifier Field: N, N+1, …

Idle-RQ versus Continuous-RQ

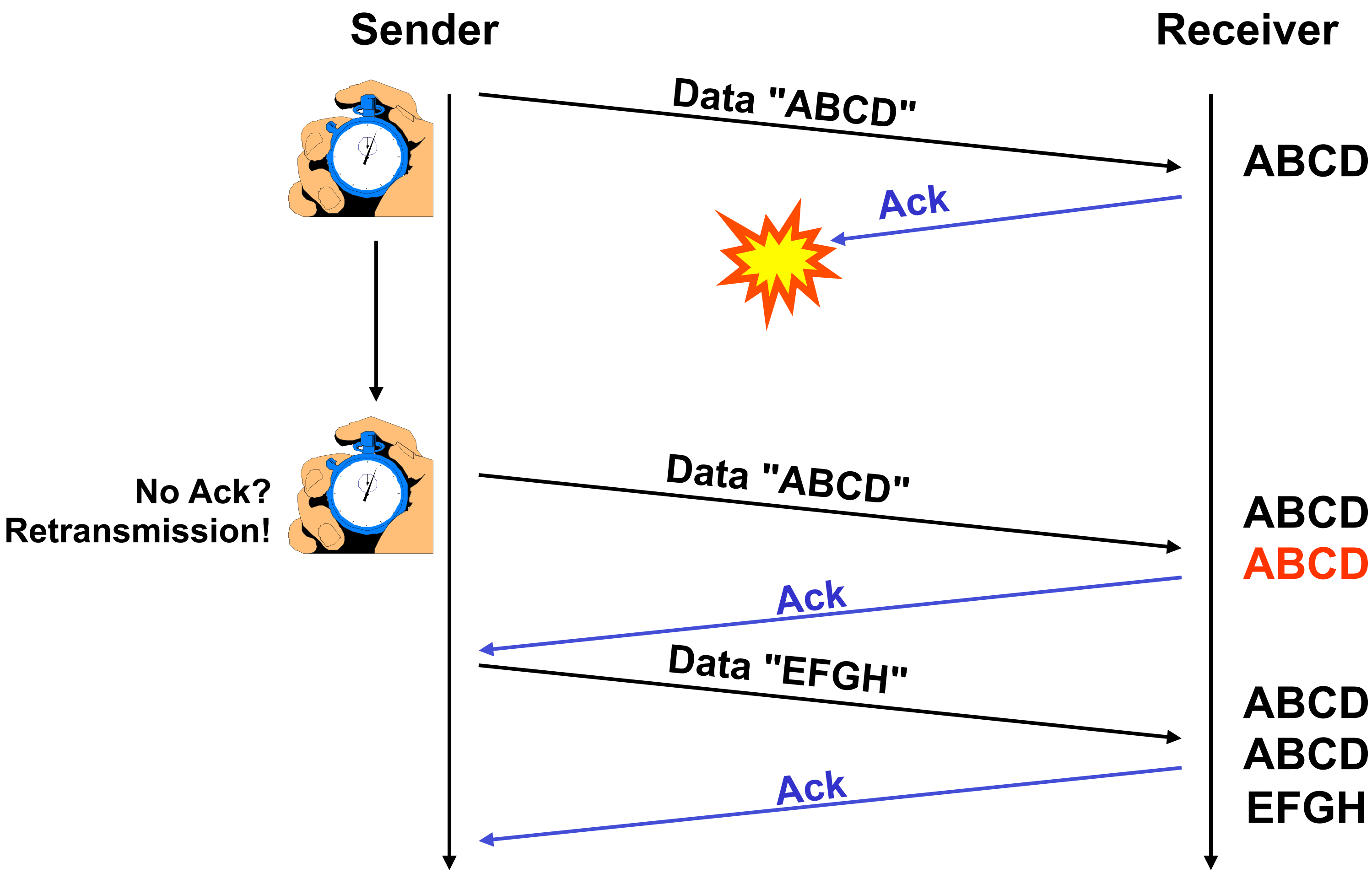


Data and Acks are sent continuously !!

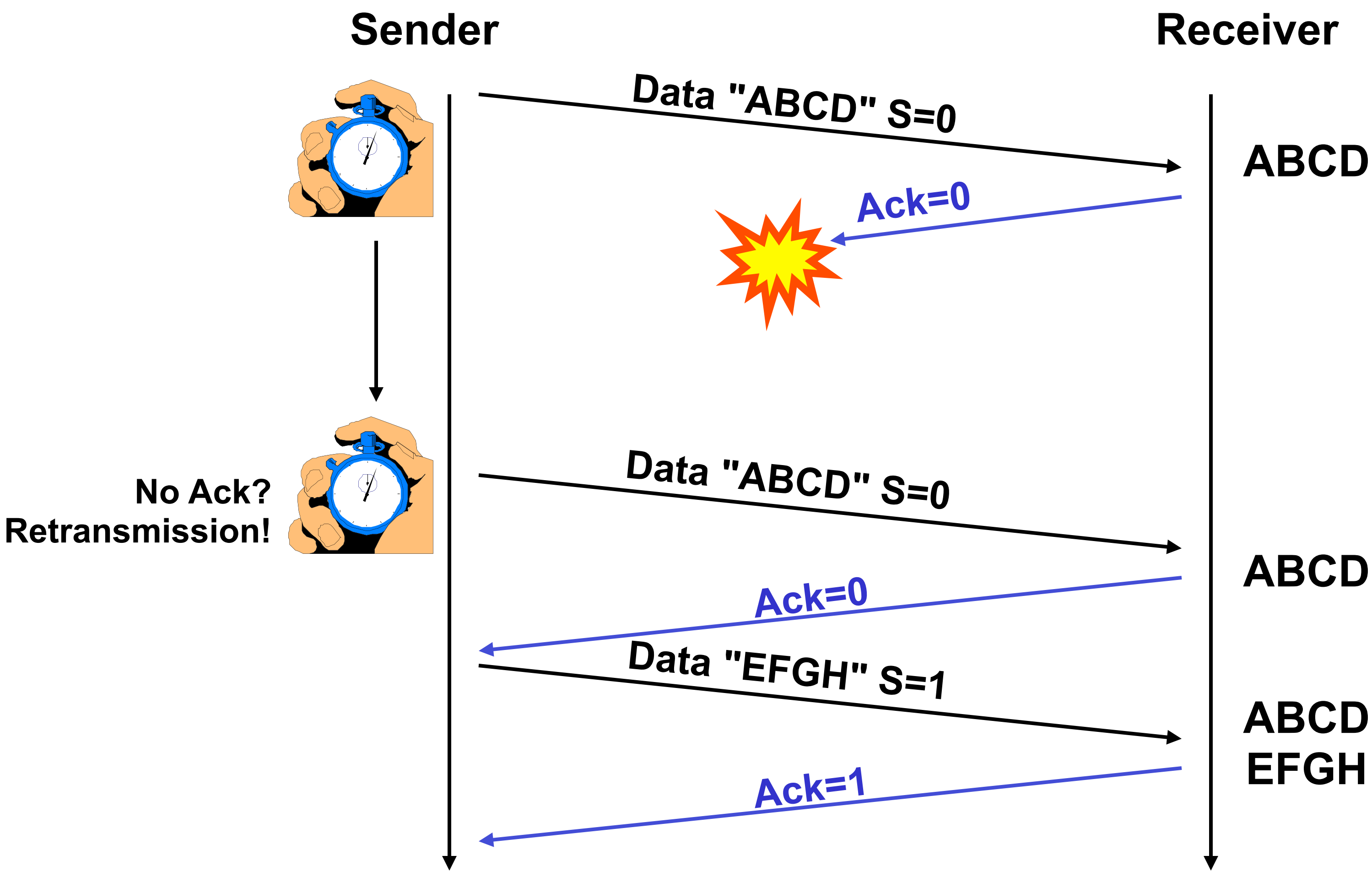
half duplex protocol

full duplex protocol

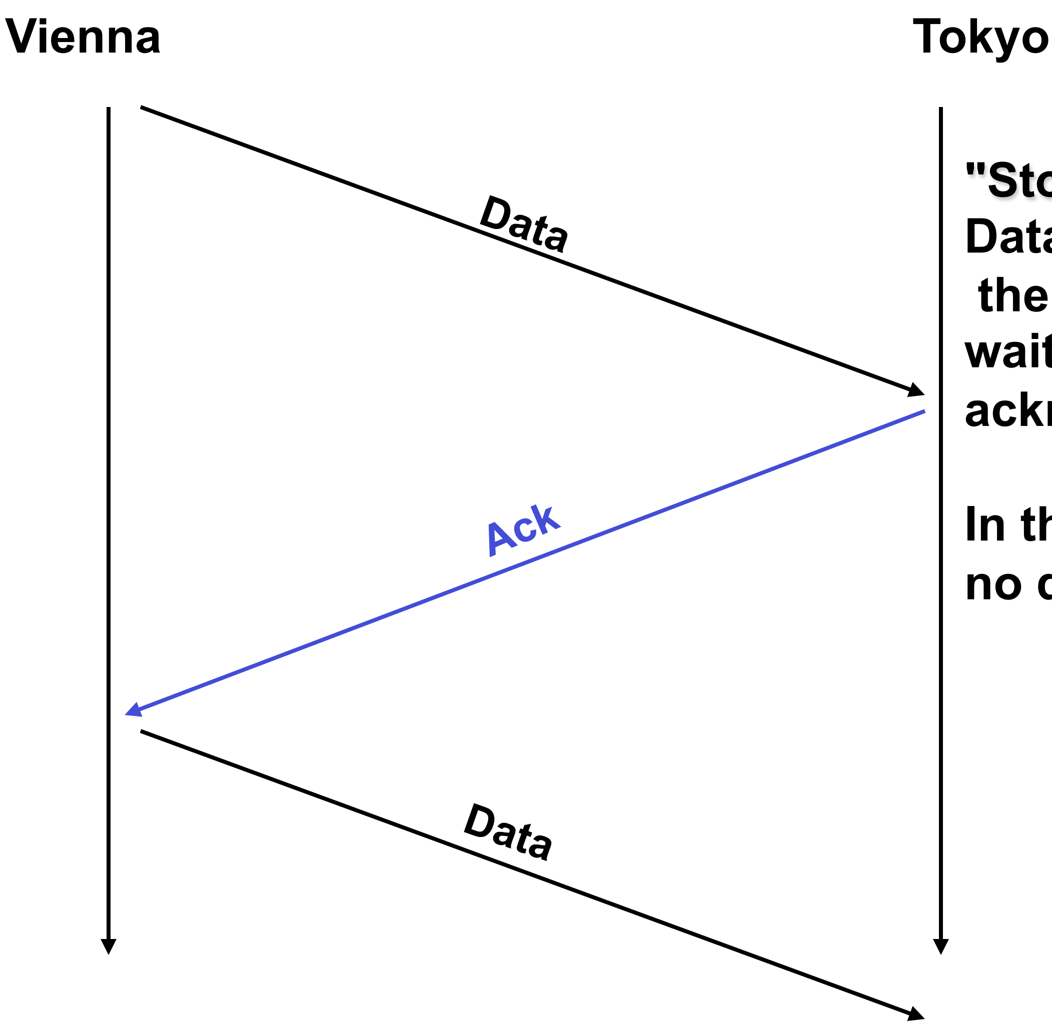
Why Identifiers or Sequence Numbers?



Modulo 2 Numbering for Identifiers Sequence Numbers 0 and 1



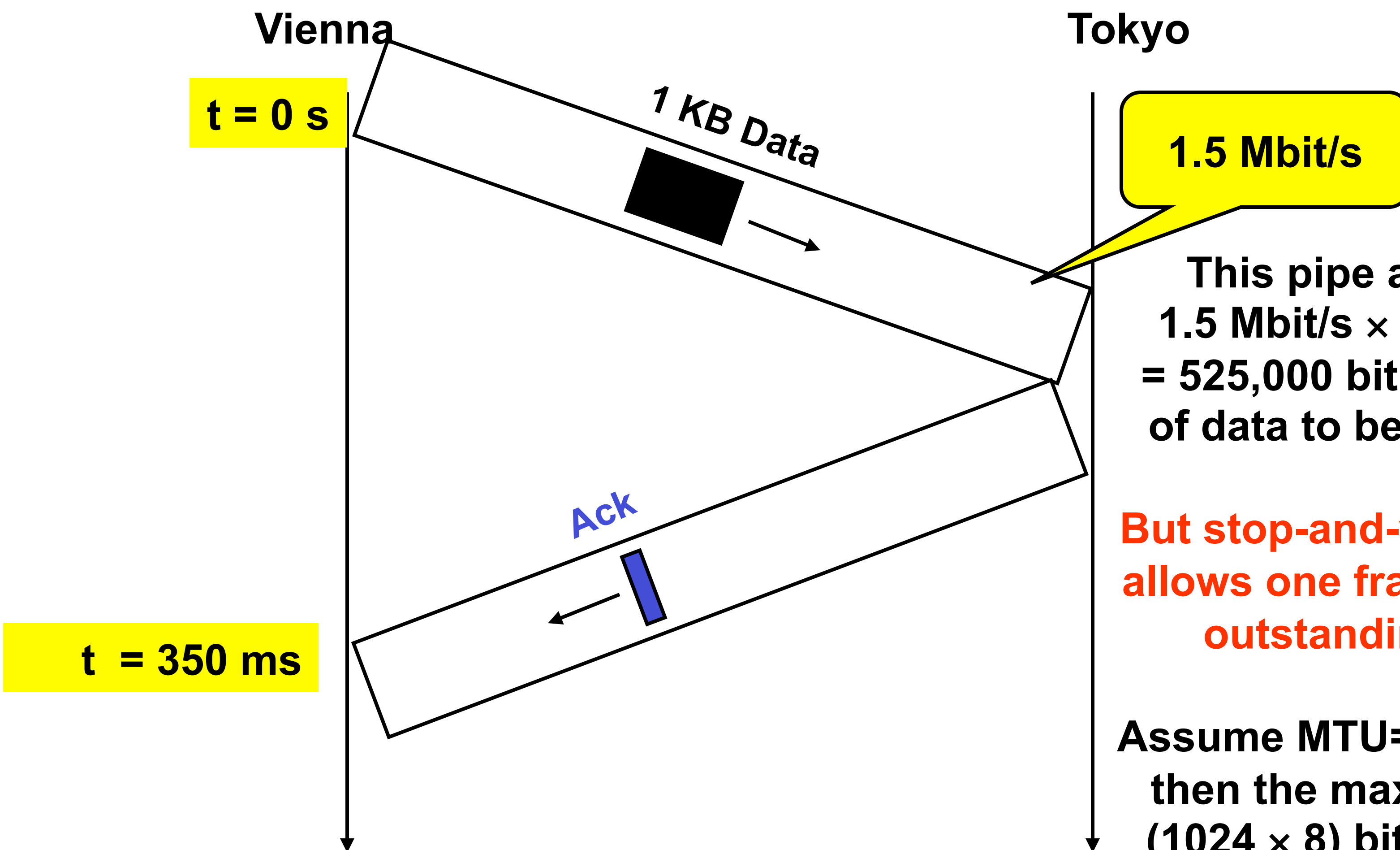
Slow !



"Stop and Wait":
Data is traveling round the earth while sender waits for the acknowledgement.

In the meantime no data can be sent !!

Nearly Empty Pipe !

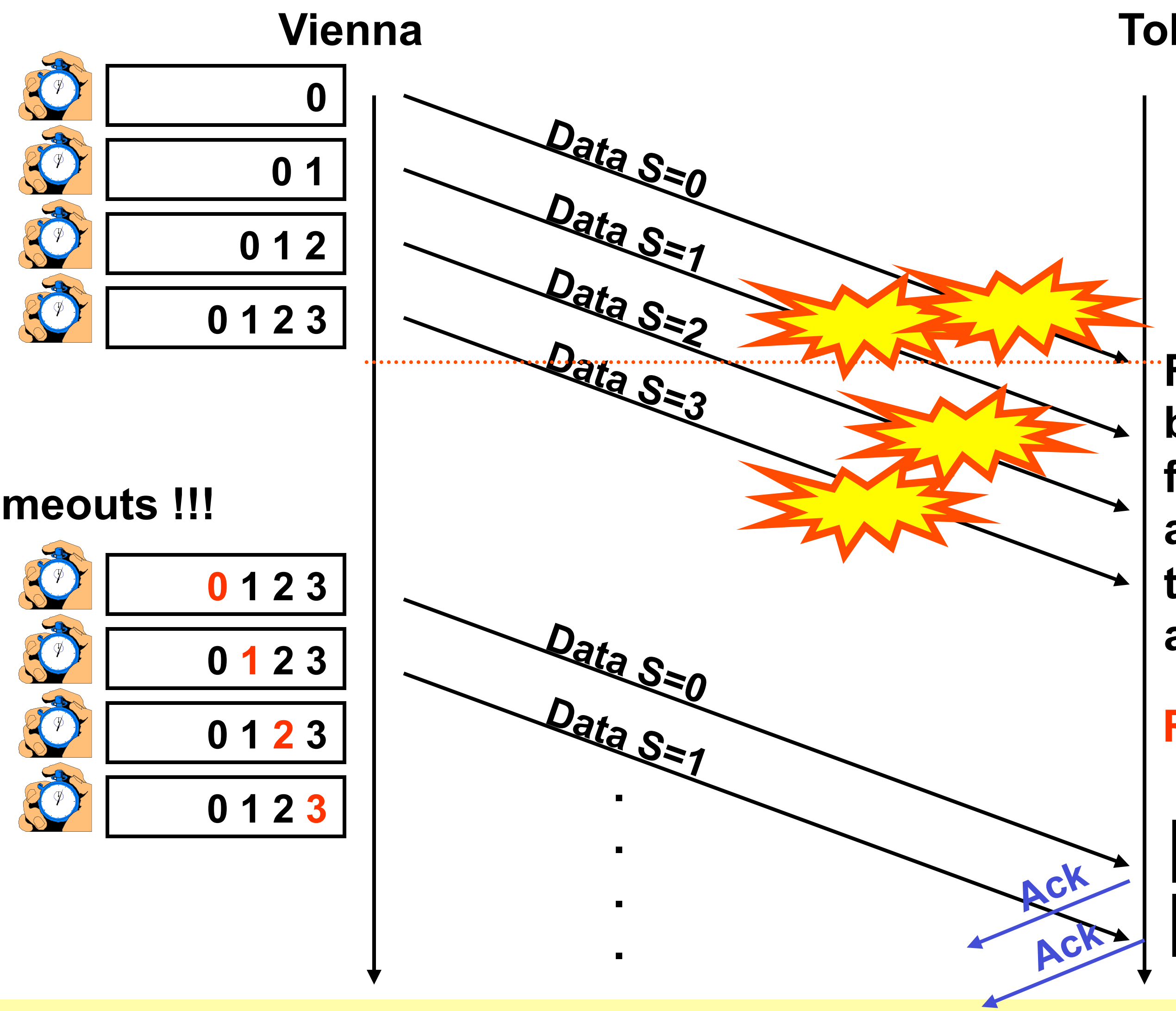


This pipe allows 1.5 Mbit/s × 350 ms = 525,000 bit ≅ 64 KB of data to be stored.

But stop-and-wait only allows one frame to be outstanding !!!

Assume MTU=1 KByte, then the max rate is (1024 × 8) bit / 0.35 s ≅ 23 Kbit/s

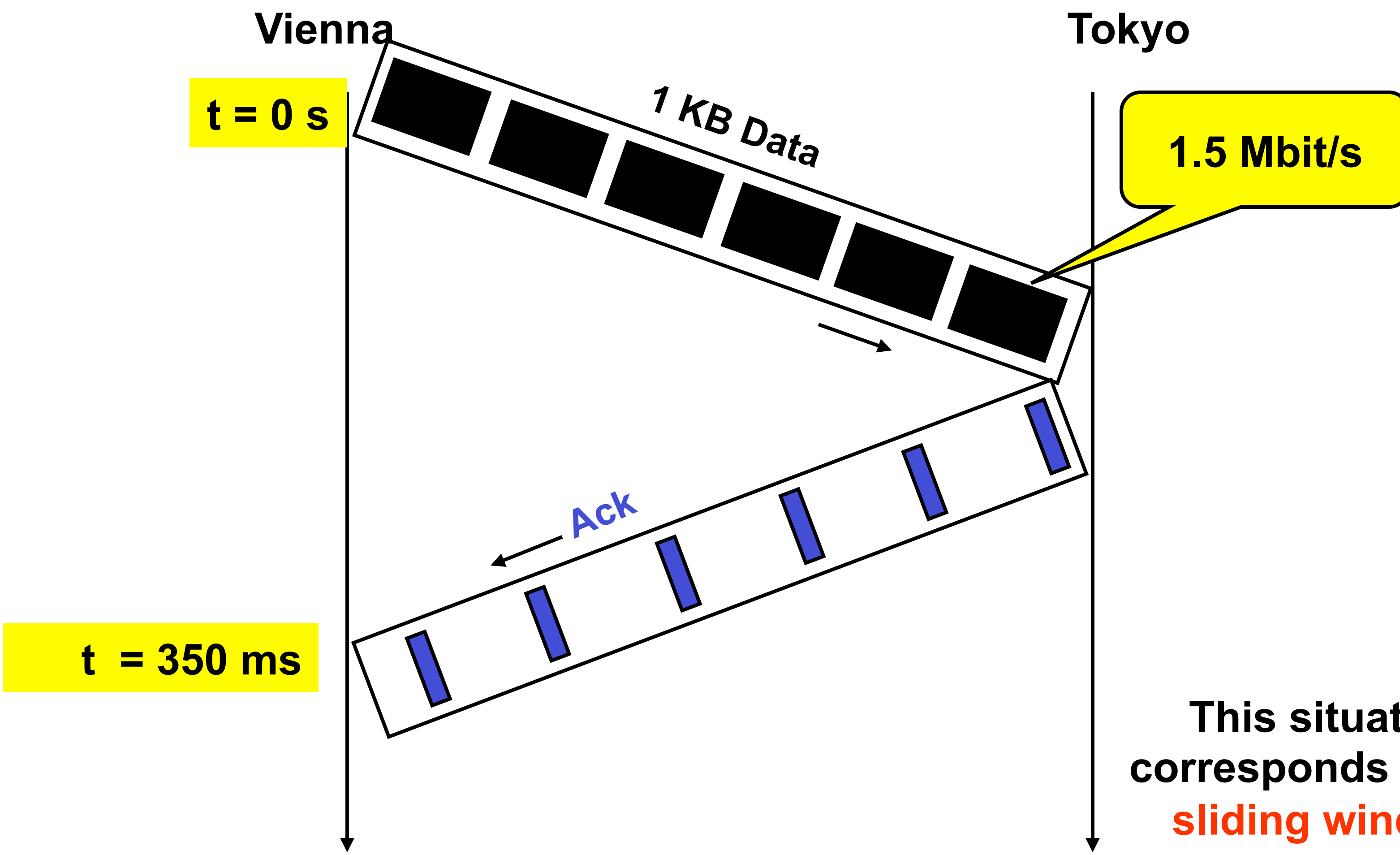
Why we need a Retransmission Buffer?



Four packets are sent, but due to a network failure none of them arrive (or equivalently they do arrive but all the Acks are lost)

Retransmissions

Full Pipe !



This situation corresponds with a **sliding window**

ARQ (Automatic Repeat Requests) Variants

Idle-RQ

Used by TFTP

(Trivial File Transfer Protocol)

Based on UDP

(User Datagram Protocol)

Note:

FTP (File Transfer Protocol)

Based on TCP

(Transmission Control Protocol)

Continuous-RQ

Selective ACK (SACK)

e.g.TCP modern variant

GoBackN

e.g. HDLC, LAPB

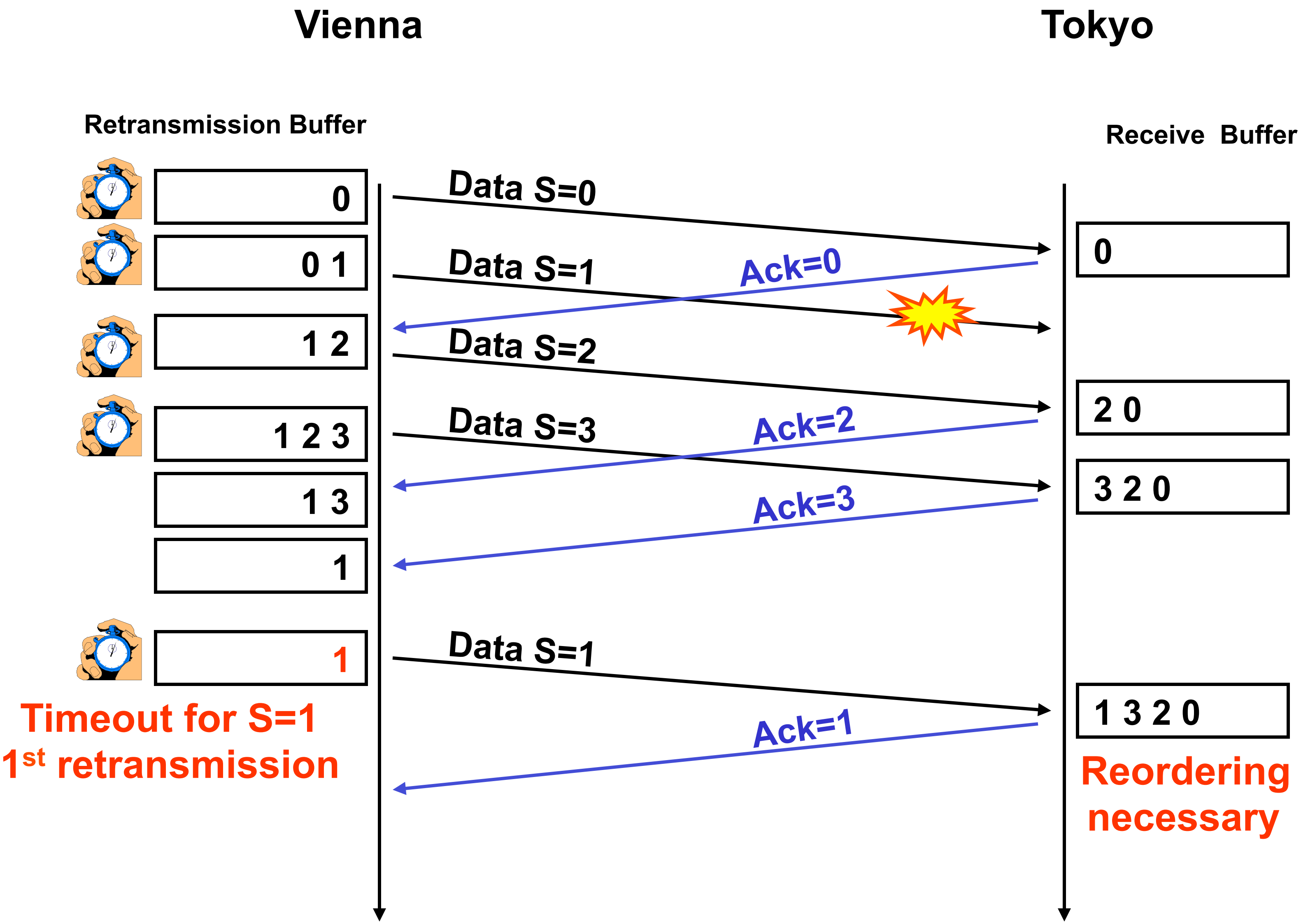
Positive ACK

e.g. TCP base variant

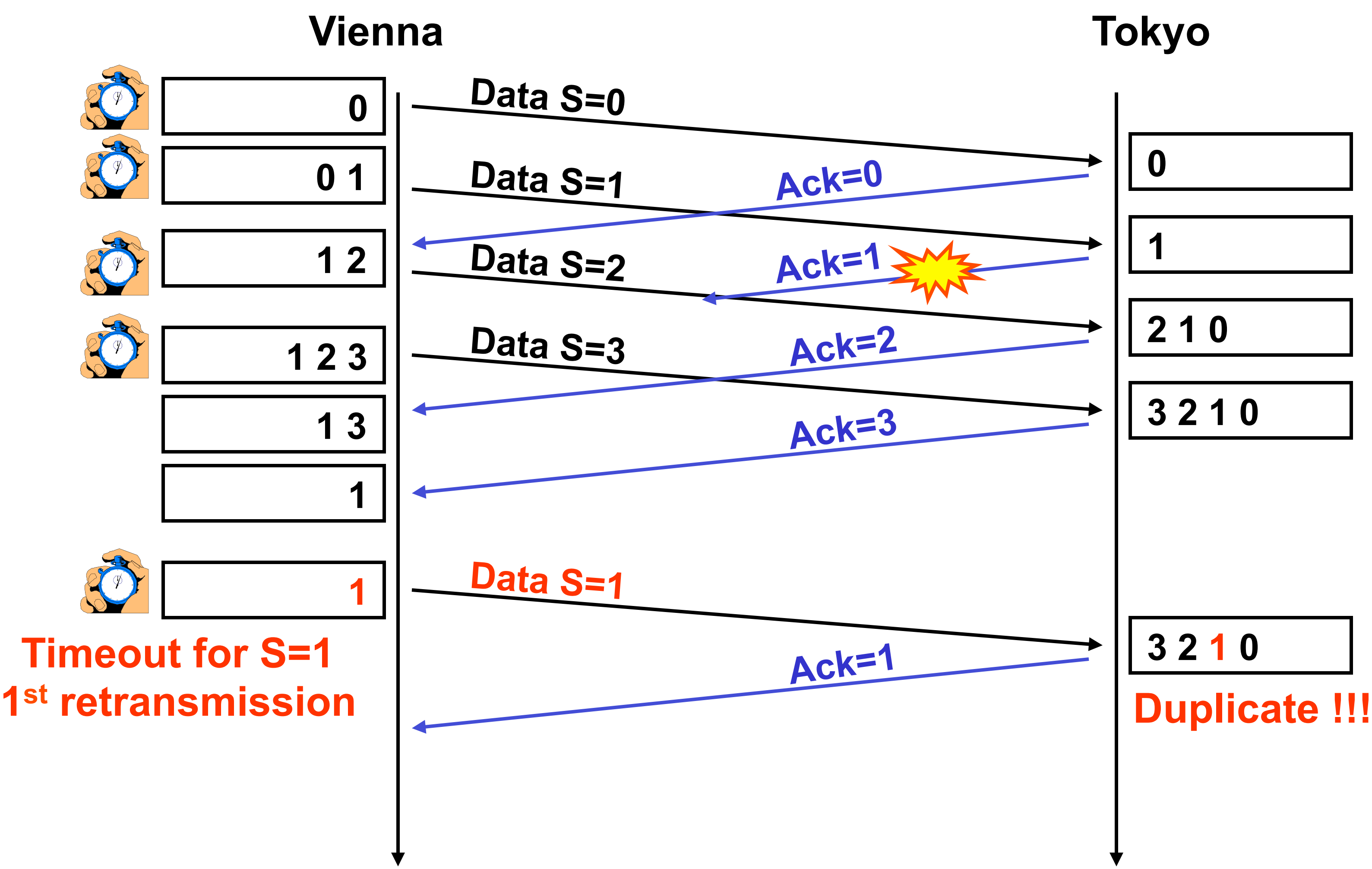
Selective Reject (SREJ)

e.g. HDLC variant

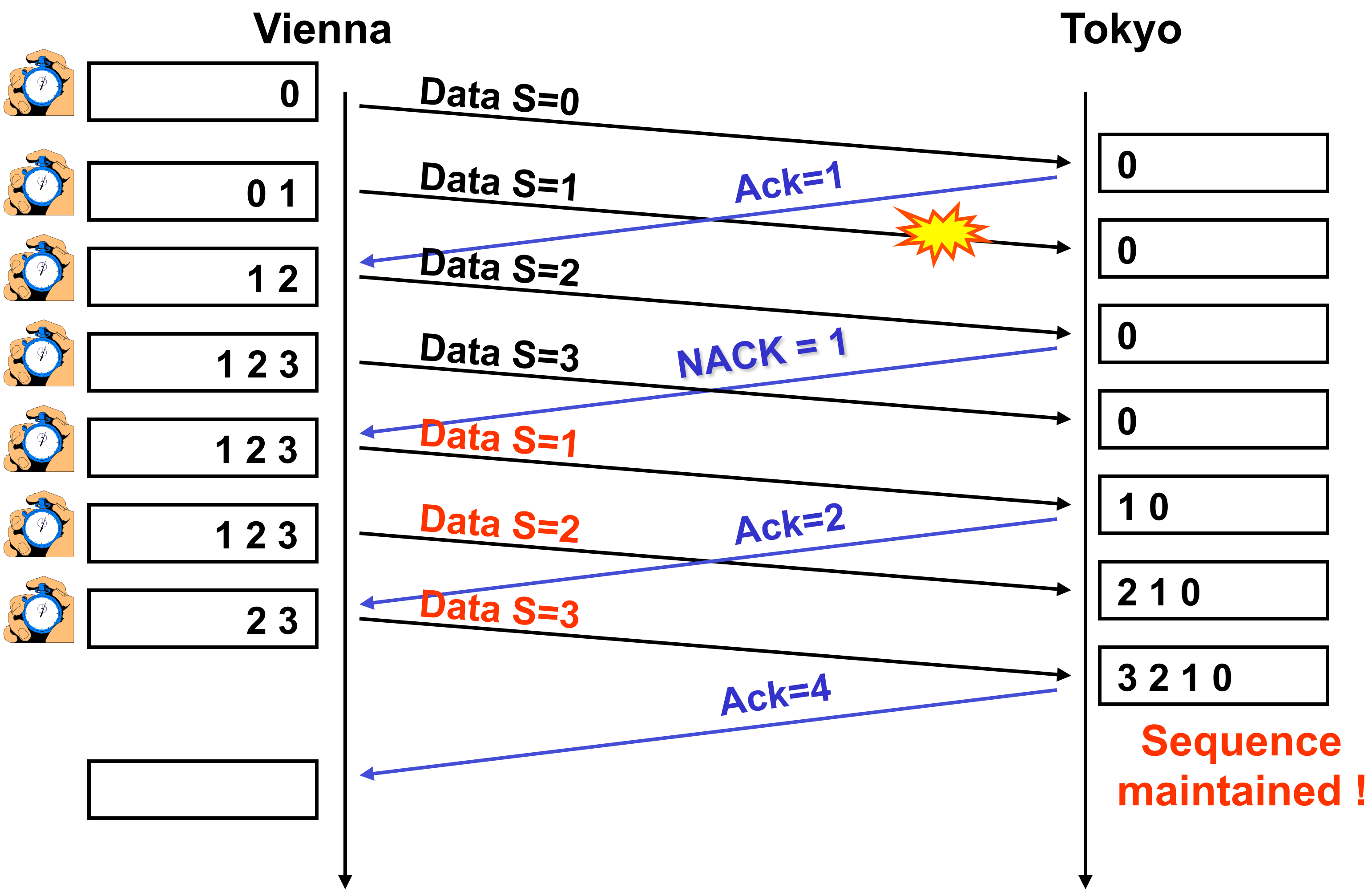
Selective Acknowledgement (1)



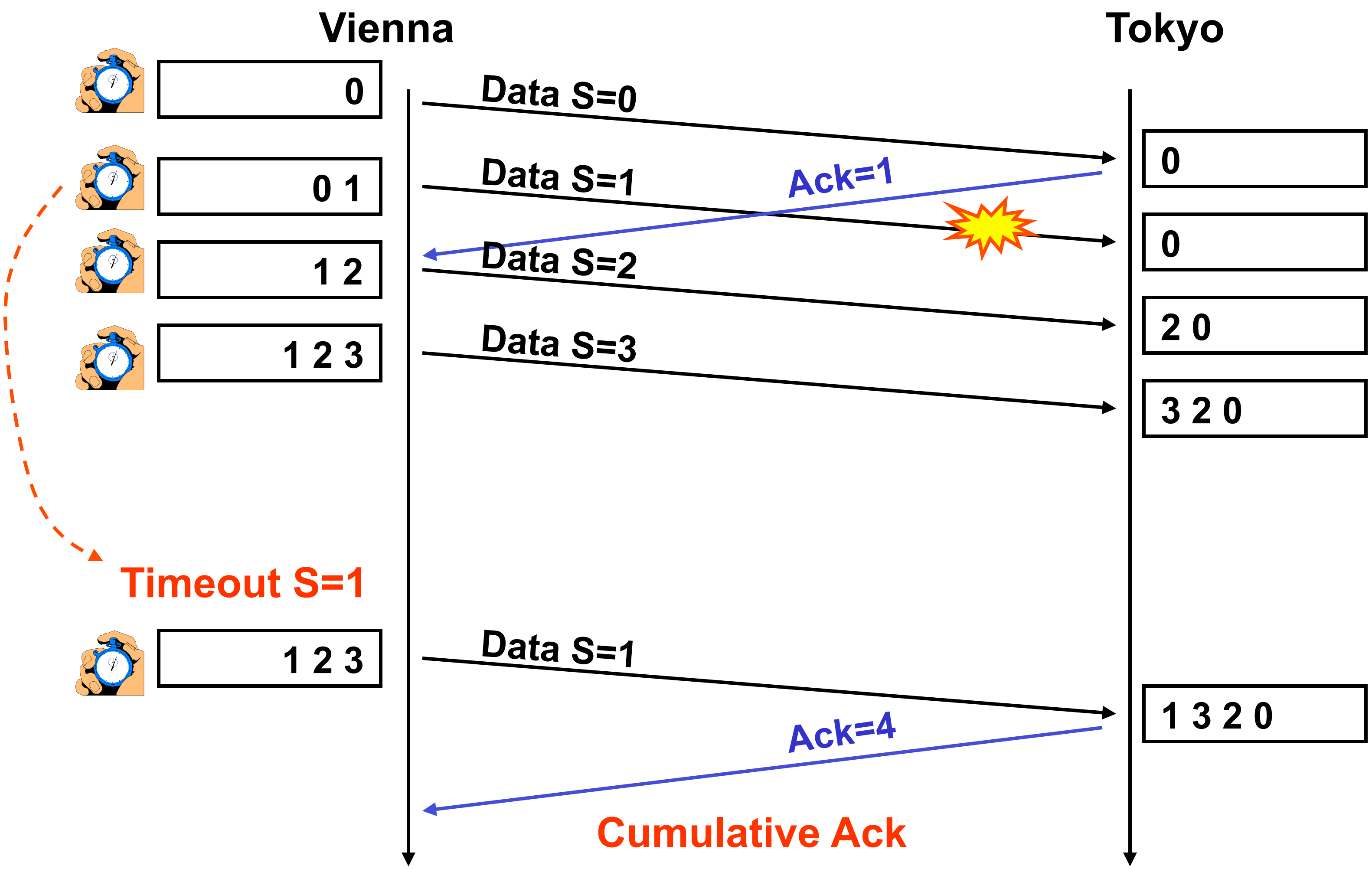
Selective Acknowledgement (2)



GoBackN with Sequence Numbers



Positive ACK with Sequence Numbers



Agenda

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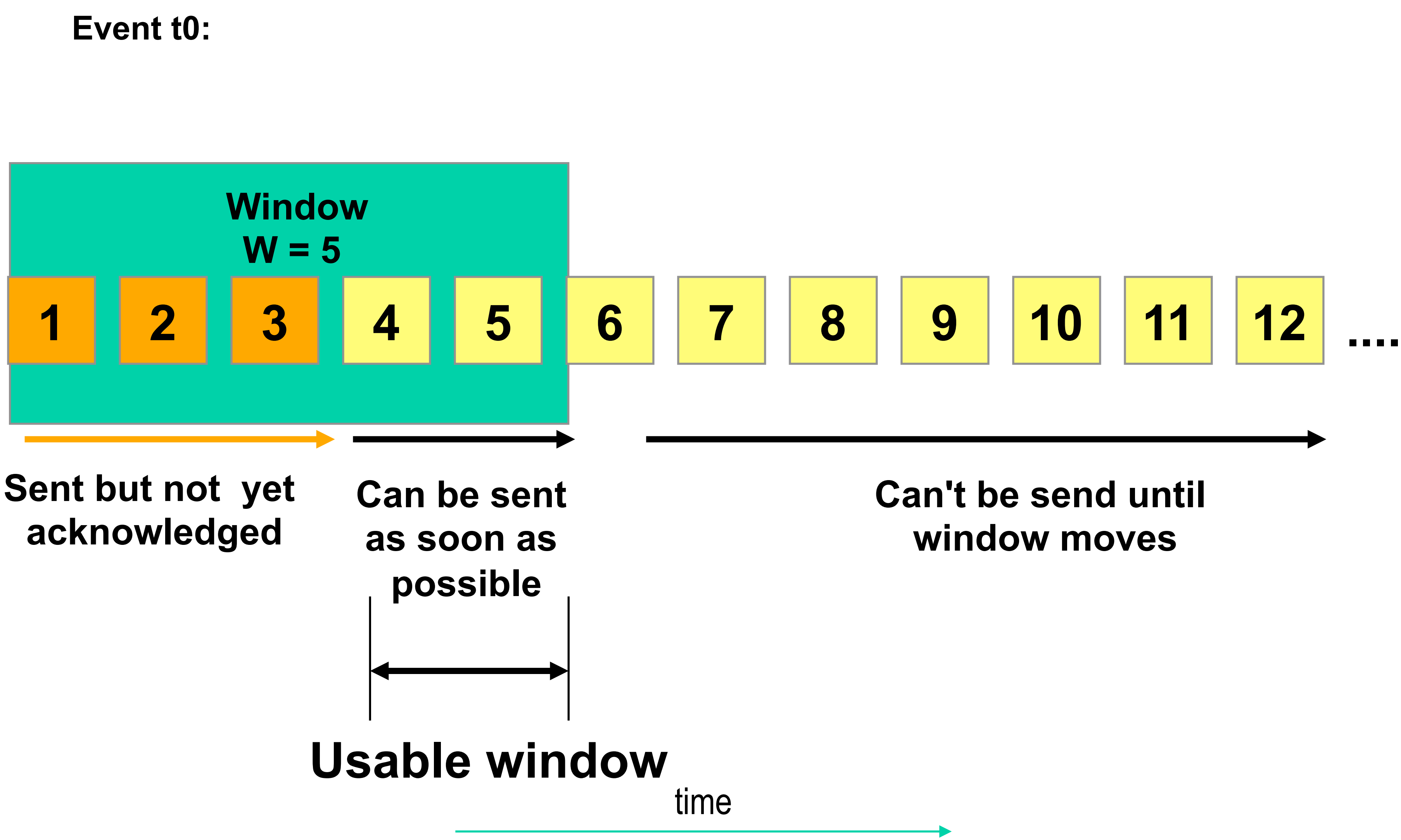
Timers - Retransmission Timeout

- **The value for retransmission timeouts for 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

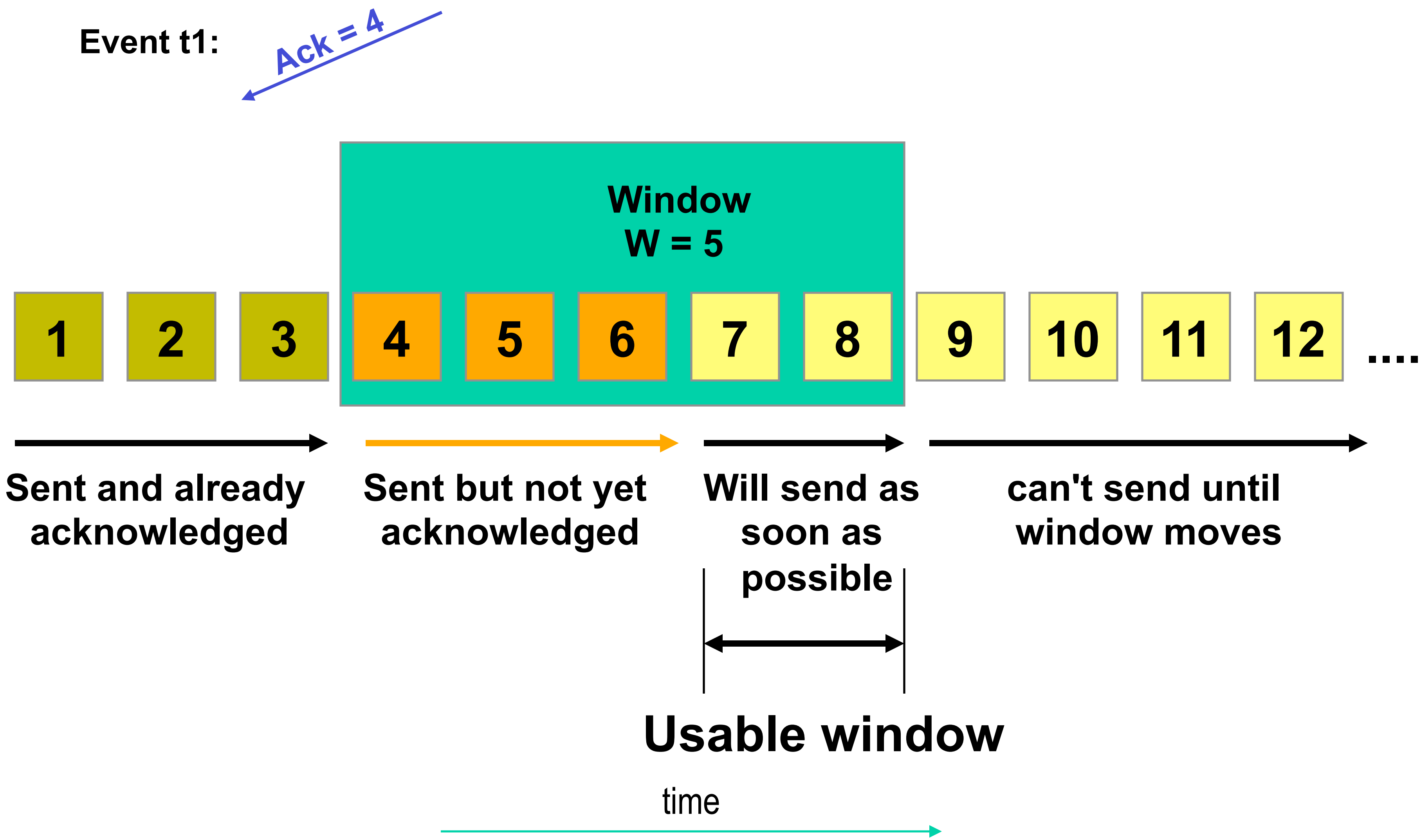
Send Window and Sliding Window

- **Continuous-RQ techniques would require infinite sender/receiver buffer size (also infinite number of identifiers)**
  – If we do not restrict the number of unacknowledged frames
- **Send Window W**
  – Is the maximum allowed number of unacknowledged frames in the retransmission list
- **Necessary sender-buffer size is W * maximum frame size**
  – Also called the **Window Size**
- **Handling procedure**
  – Is called **(Sliding) Windowing**

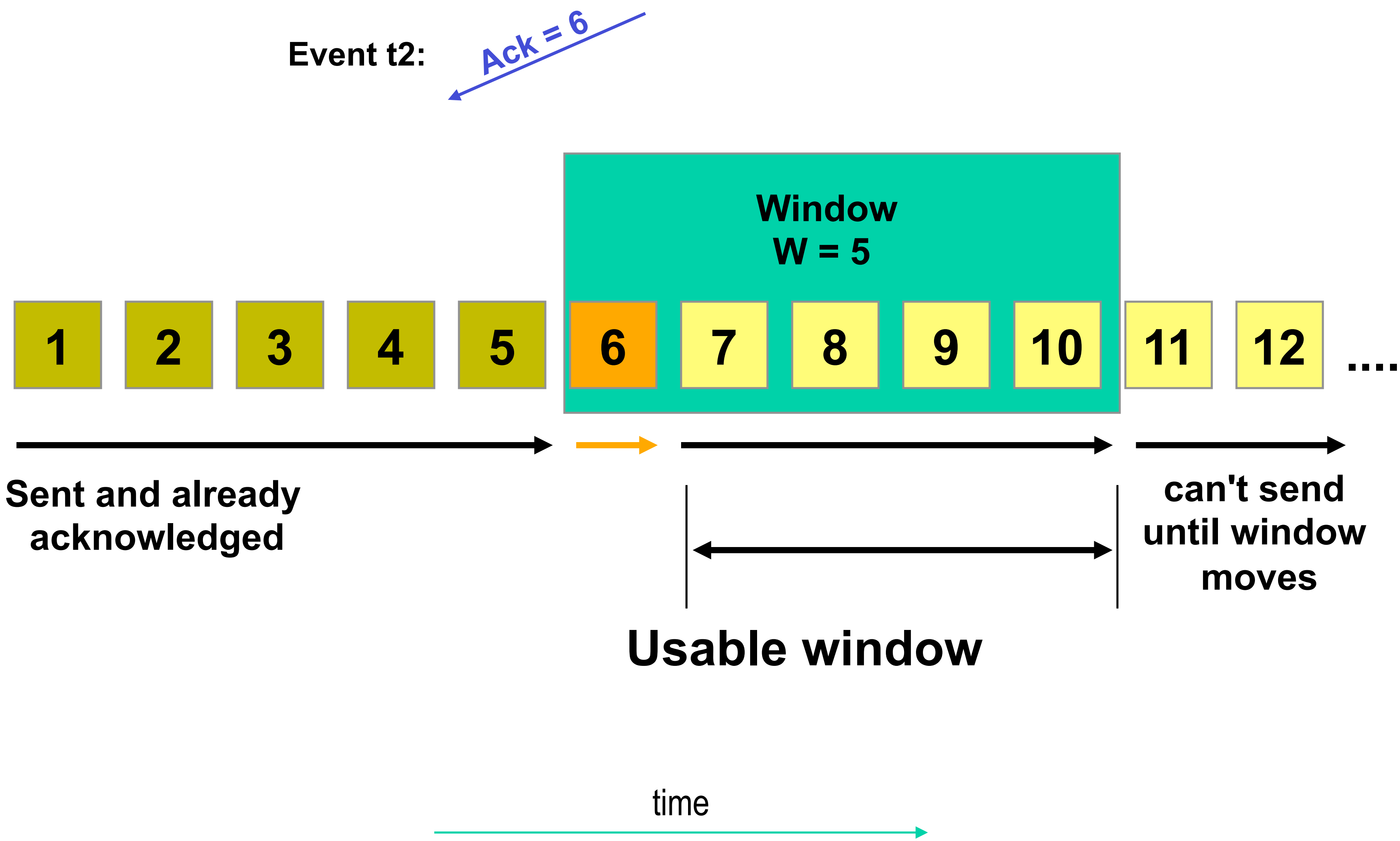
Sliding Window Basics (1)



Sliding Window Basics (2)

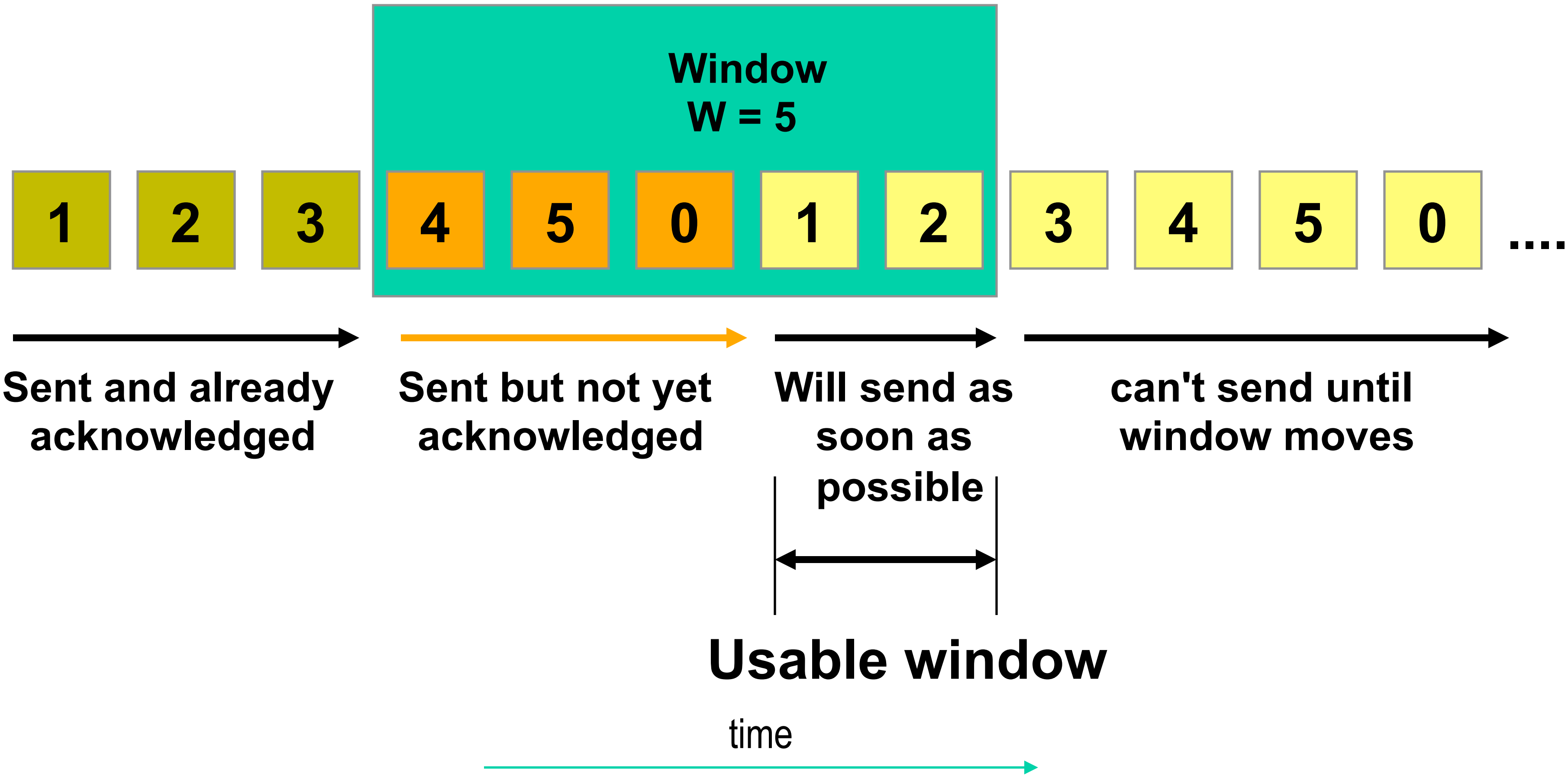


Sliding Window Basics (3)



Windowing with Numbering Modulo W+1

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



How Large should be the Window Size?

- **Window size depends on**
  - Bandwidth (bit rate) of the communication channel
  - Round-Trip-Time (RTT)
    - = 2 x (propagation + serialization) delay plus response delay of partner
  - (Available buffer size transmitter/receiver)
- **The optimum window size**
  - must be big enough so that the sender can fully utilize the channel volume which is given by the

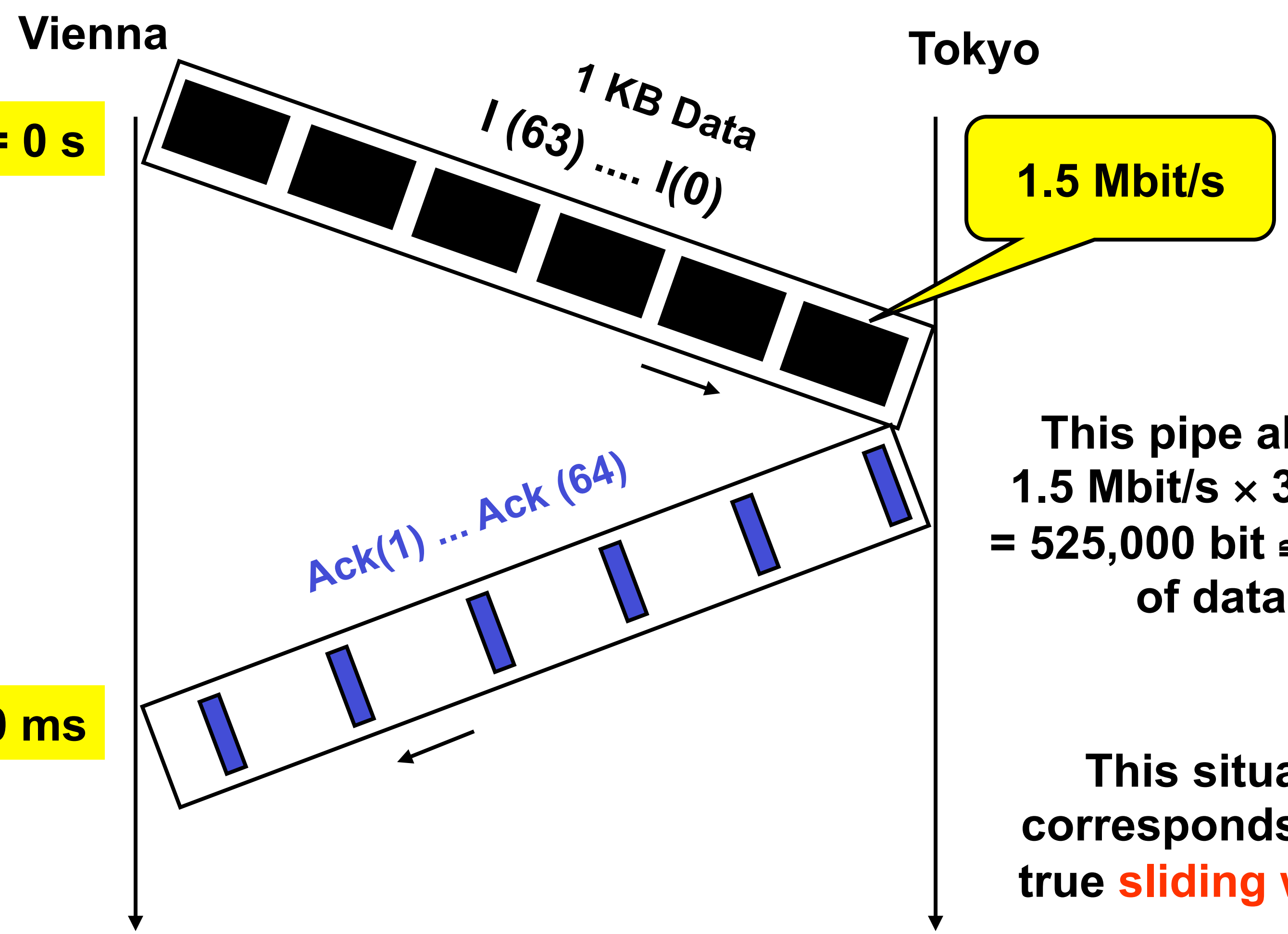
Bandwidth-Delay Product

  - Window size in Bytes >= BW × RTT
  - If smaller: jumping window
  - Extreme case: Idle-RQ with W=1

Full Pipe with Continuous-RQ and W = 64

W = 64 t = 0 s

t = 350 ms

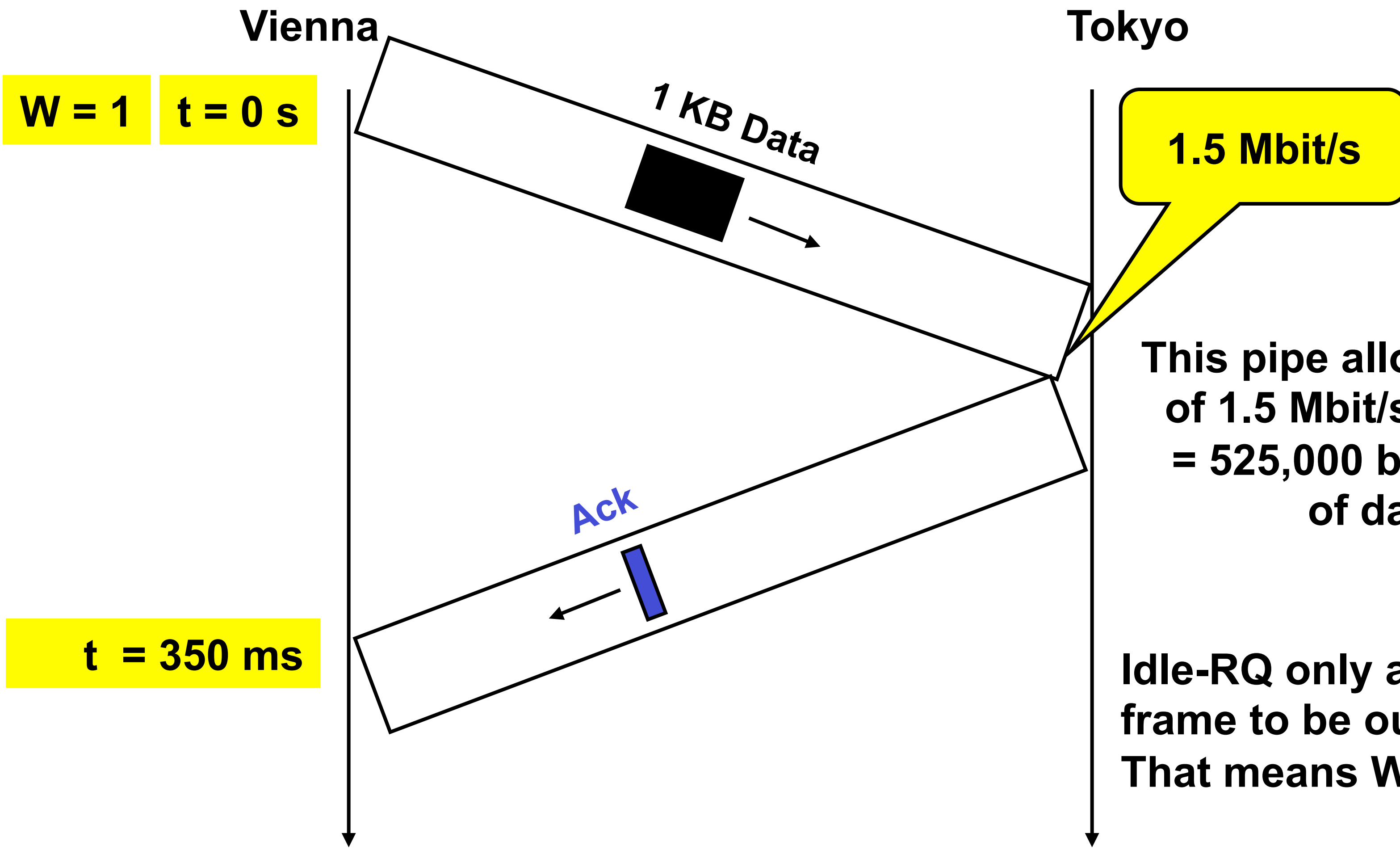


This pipe allows 1.5 Mbit/s × 350 ms = 525,000 bit ≅ 64 KB of data.

This situation corresponds with a true sliding window

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

Nearly Empty Pipe with Idle-RQ and W = 1

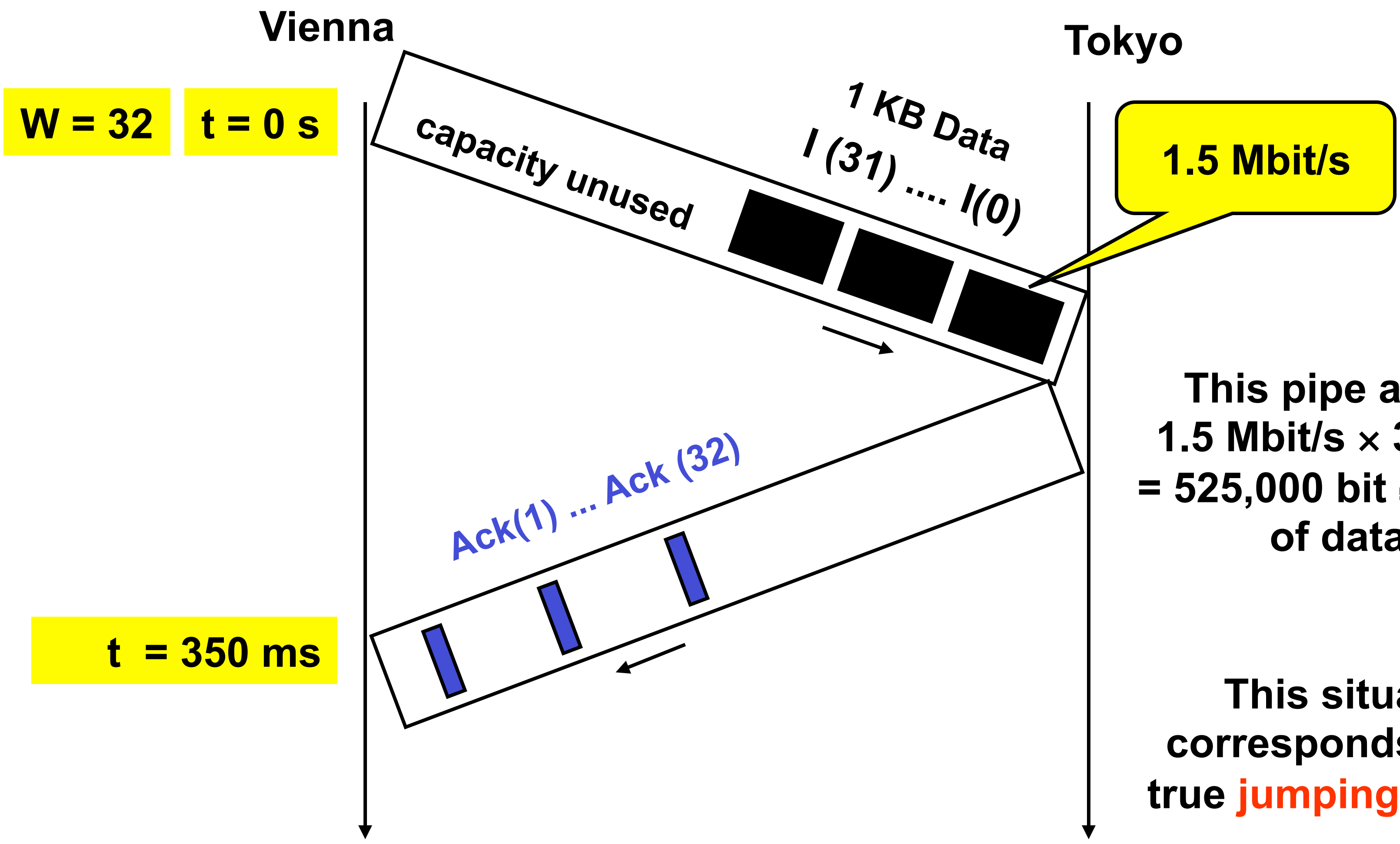


This pipe allows storing of 1.5 Mbit/s × 350 ms = 525,000 bit ≅ 64 KB of data.

Idle-RQ only allows one frame to be outstanding. That means 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

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

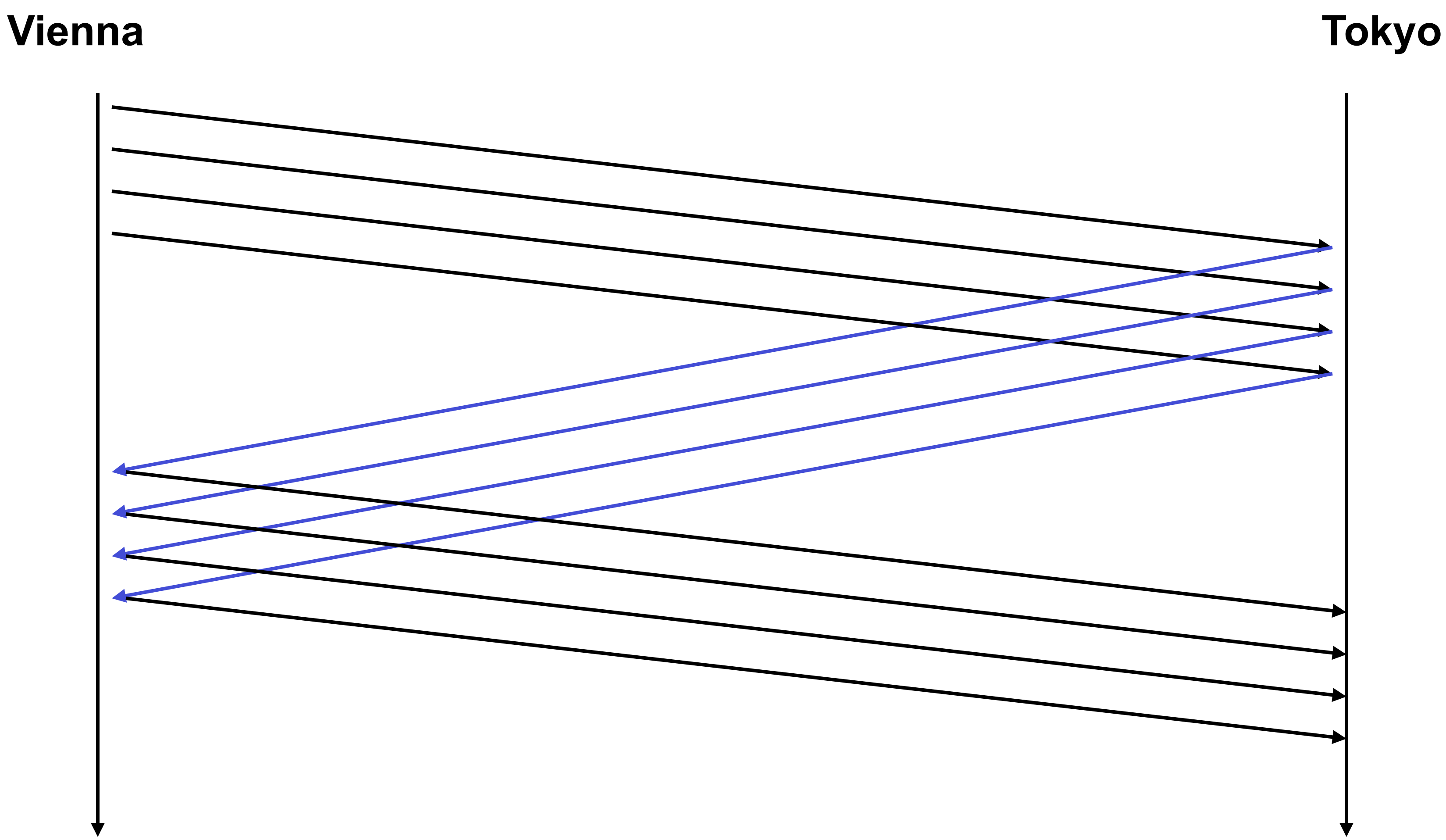


This pipe allows 1.5 Mbit/s × 350 ms = 525,000 bit ≅ 64 KB of data.

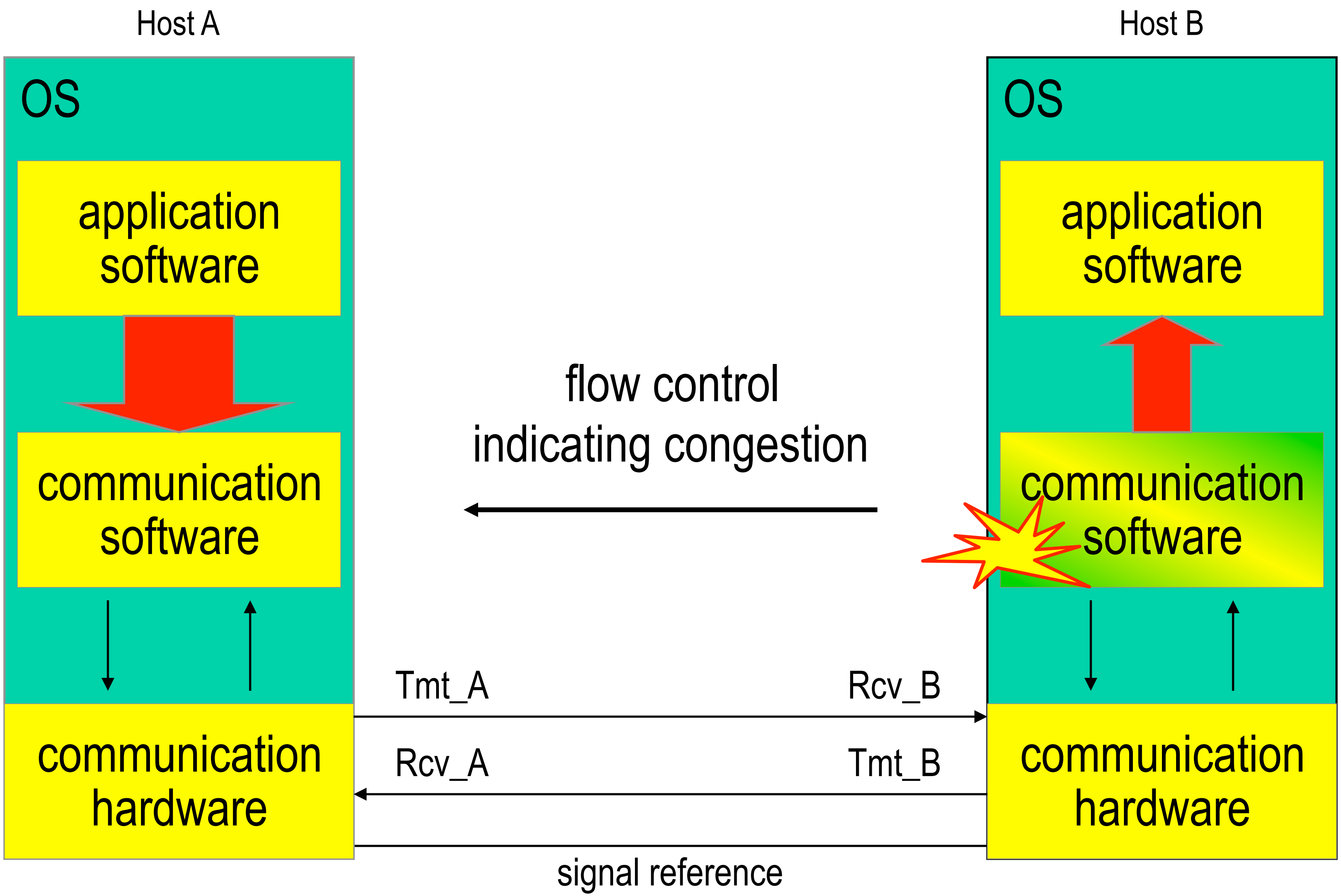
This situation corresponds with a true jumping window

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

Jumping Window



Flow Control



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 of free buffer memory)
    - Advertised window size = 0 -> STOP
    - Advertised window size > 0 -> GO
  - Adaptive windowing (e.g used by TCP)

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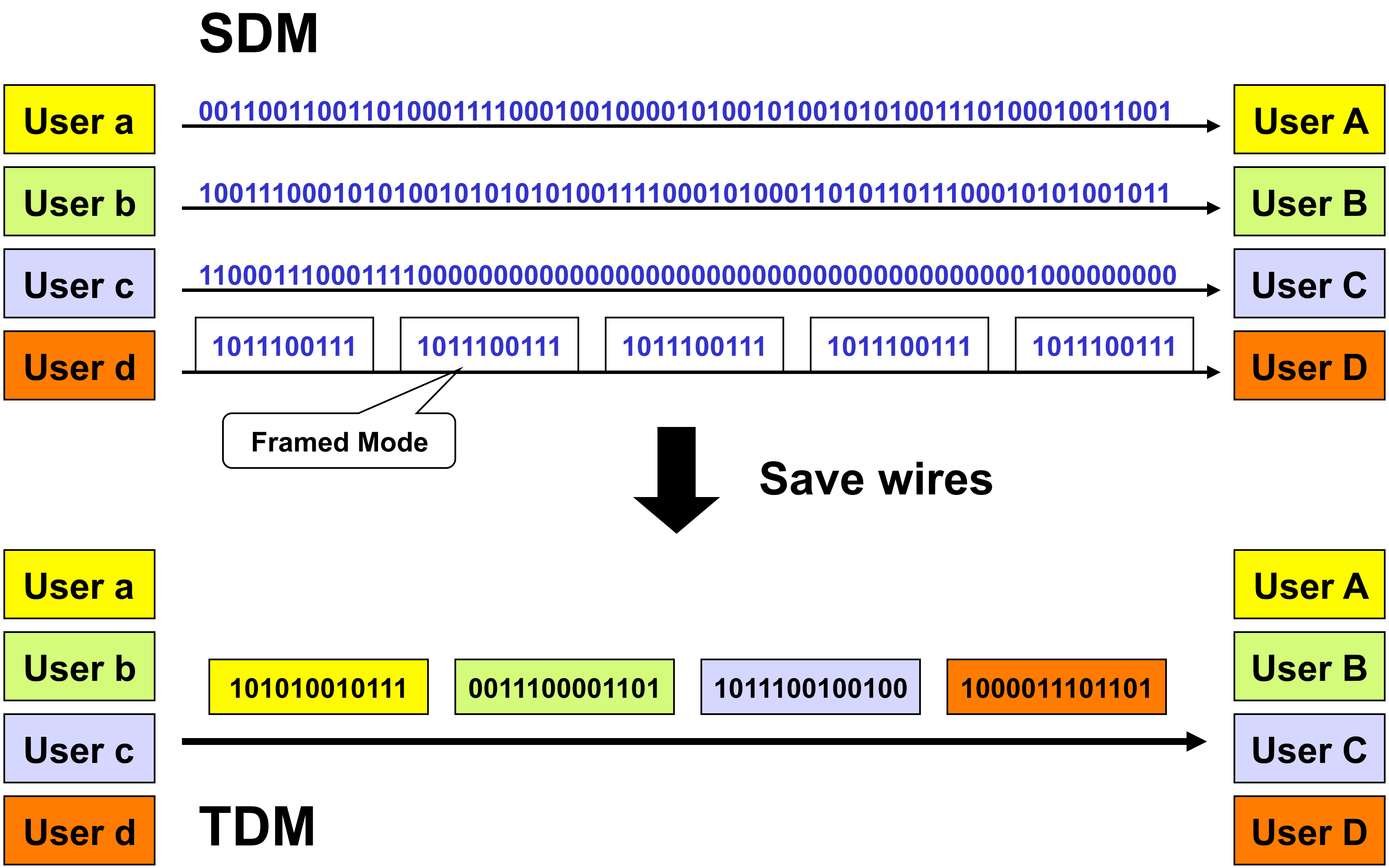
Introduction

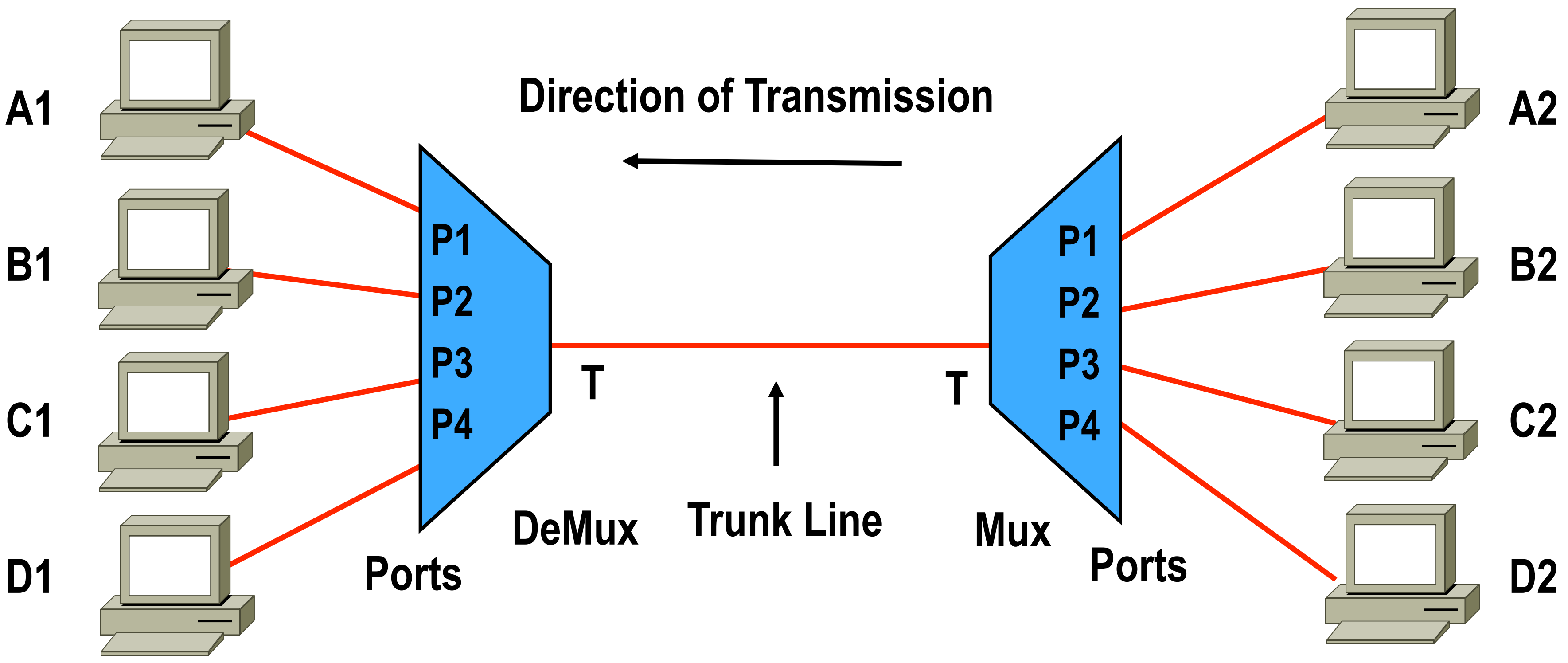
- **Line protocol techniques**
  - Were developed for communication between two devices over one physical point-to-point link
  - Bandwidth of physical link is exclusively used by the two stations
- **In case multiple communication channels are necessary between two locations**
  - Multiple physical point-to-point links are needed
  - Every point-to-point link is operated by line protocol techniques
  - SDM (Space Division Multiplexing)
  - Expensive solution
- **One method to use one physical link for multiple channels is**
  - TDM (Time Division Multiplexing)
  - Note: FDM, DWDM, CDM are other methods

TDM versus SDM



TDM Multiplexing / Demultiplexing

- **TDM multiplexer**
  – Take a number of input channels and - by interleaving them - output them as one data stream on one physical **trunk** line
  – Demultiplexer does the opposite



Types of TDM

- **Depending on timing behavior two basic TDM methods**
  - Synchronous (deterministic) TDM
    - Timeslots have constant length (capacity) and can be used in a synchronous, periodical manner
    - Examples: PDH (E1, T1), SDH (STM-1, STM-4)
  - Asynchronous (statistical) TDM
    - Timeslots have variable length and are used on demand (depending on the statistics of the individual channel communication)
    - Examples: Ethernet, WLAN

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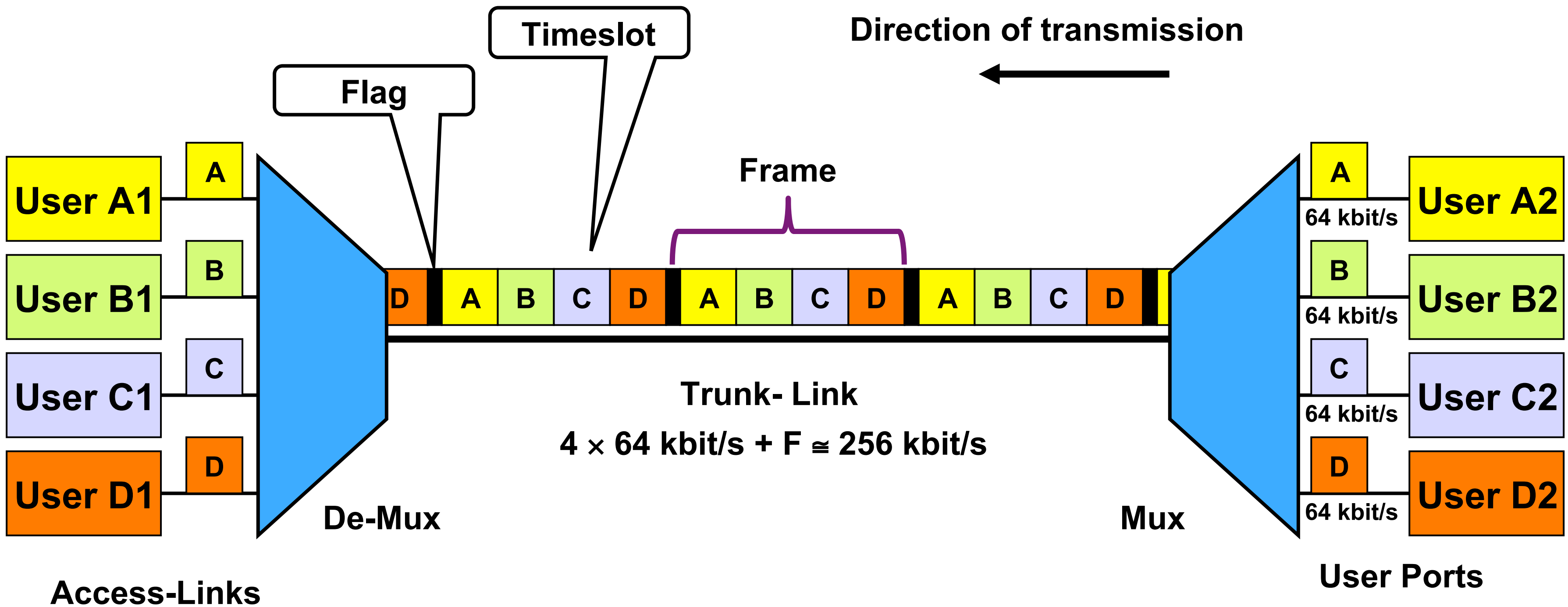
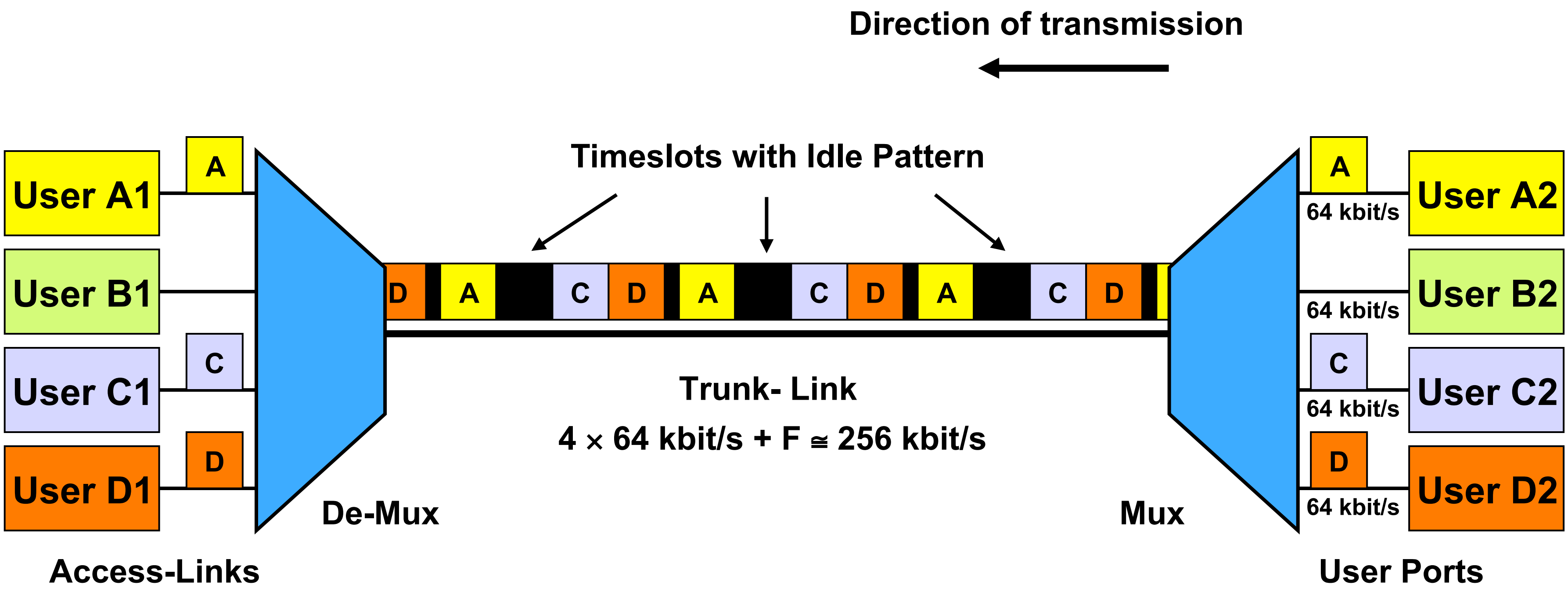
Synchronous TDM (1)



Periodic frames consisting of a constant number of timeslots
Every channel occupies a dedicated timeslot
Implicit addressing given by the position of a timeslot in the frame
Trunk rate = number of timeslots x access-link rate

Each channel experiences constant delay and no delay variation (jitter)

Synchronous TDM (2)



Timeslot can be used for any kind of communication
-> protocol transparency
But empty timeslots are not useable by other communication channels
-> waste of bandwidth during times of inactivity

<u>Lead to development of asynchronous/statistical multiplexing</u>

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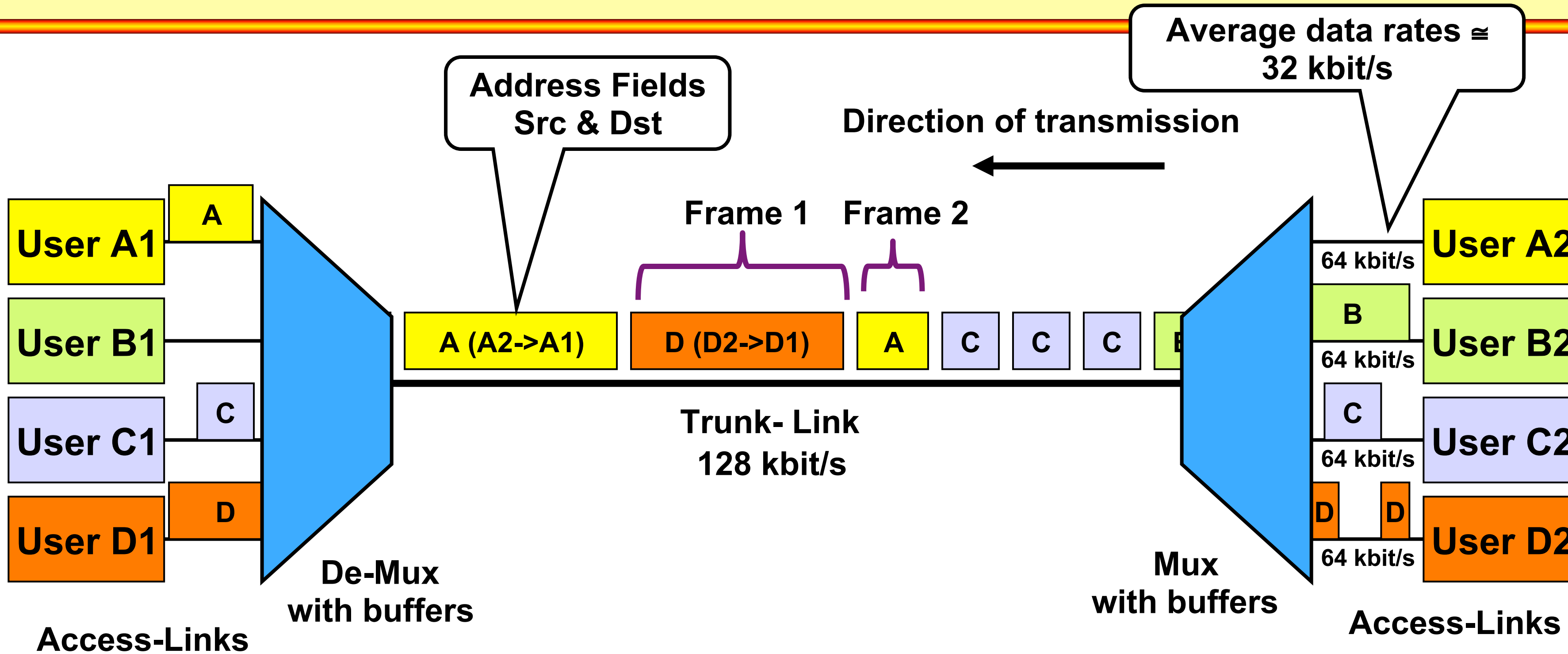
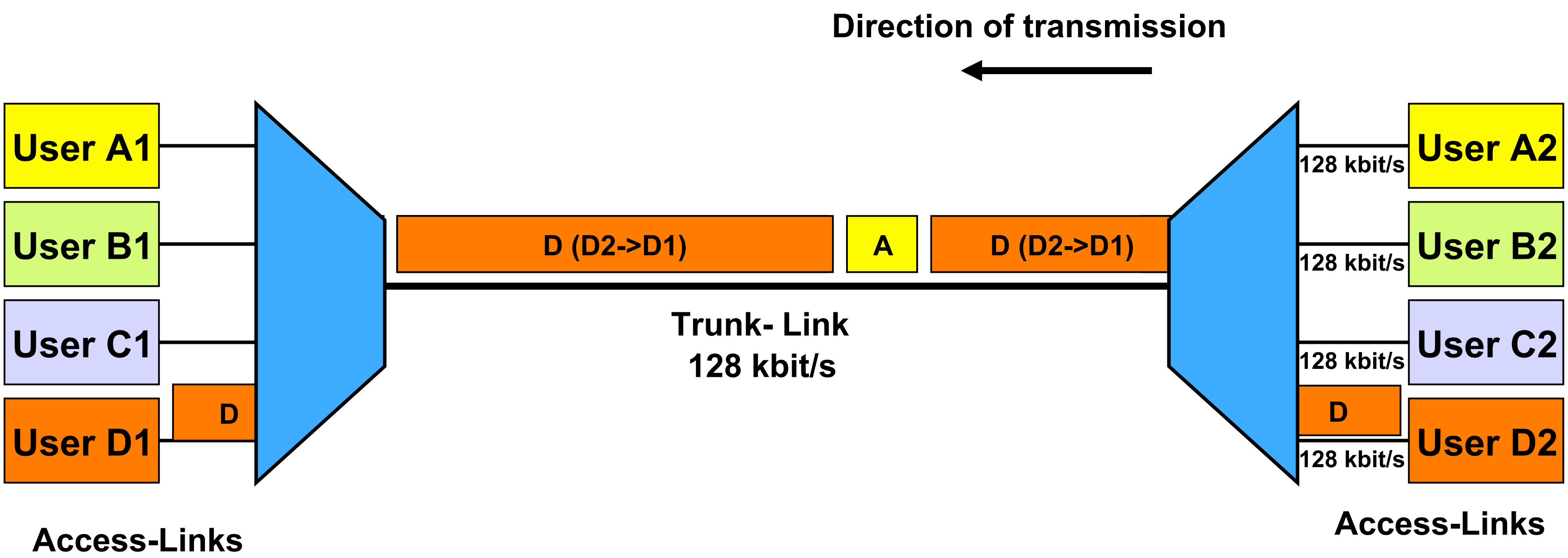
Asynchronous TDM (1)



- Trunk rate is dimensioned for average usage in statistical manner
- Each user channels can send packets whenever he/she wants
- Frames have different lengths
- Buffering is necessary if trunk is already occupied by another channel
- Explicit addressing by usage of address fields in the frame
- Not protocol-transparent any more

Asynchronous TDM (2)



If other channels are silent, one channel can fully utilize his/her access rate -> better usage of network bandwidth

<u>Variable delay and variable delay variation (jitter)</u>
<u>Buffer overflow leads to loss of packets</u>

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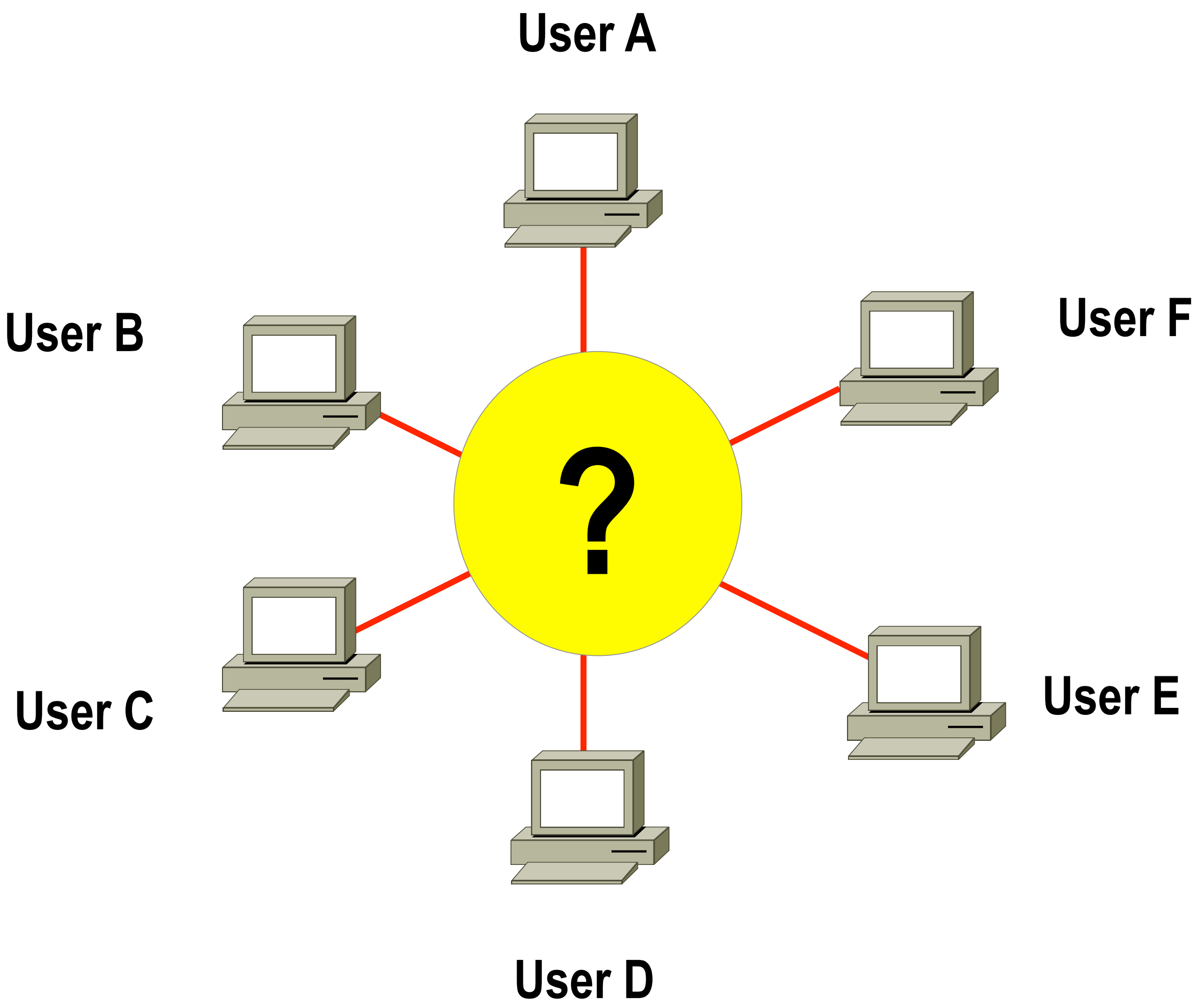
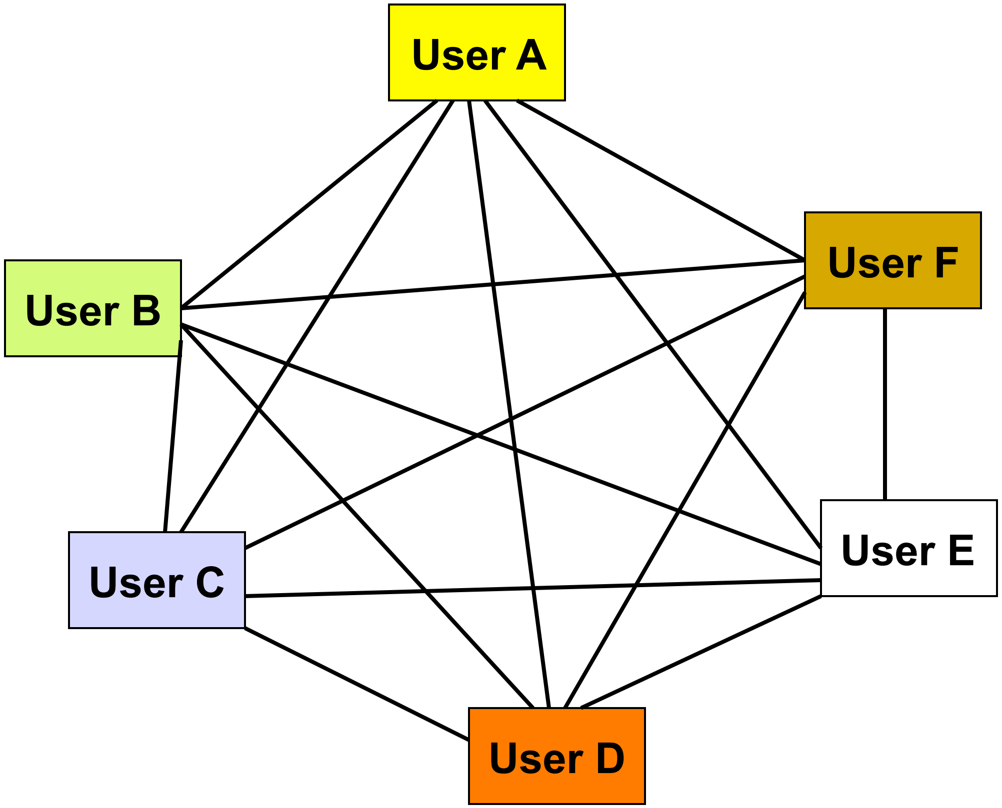
How To Connect All Locations?

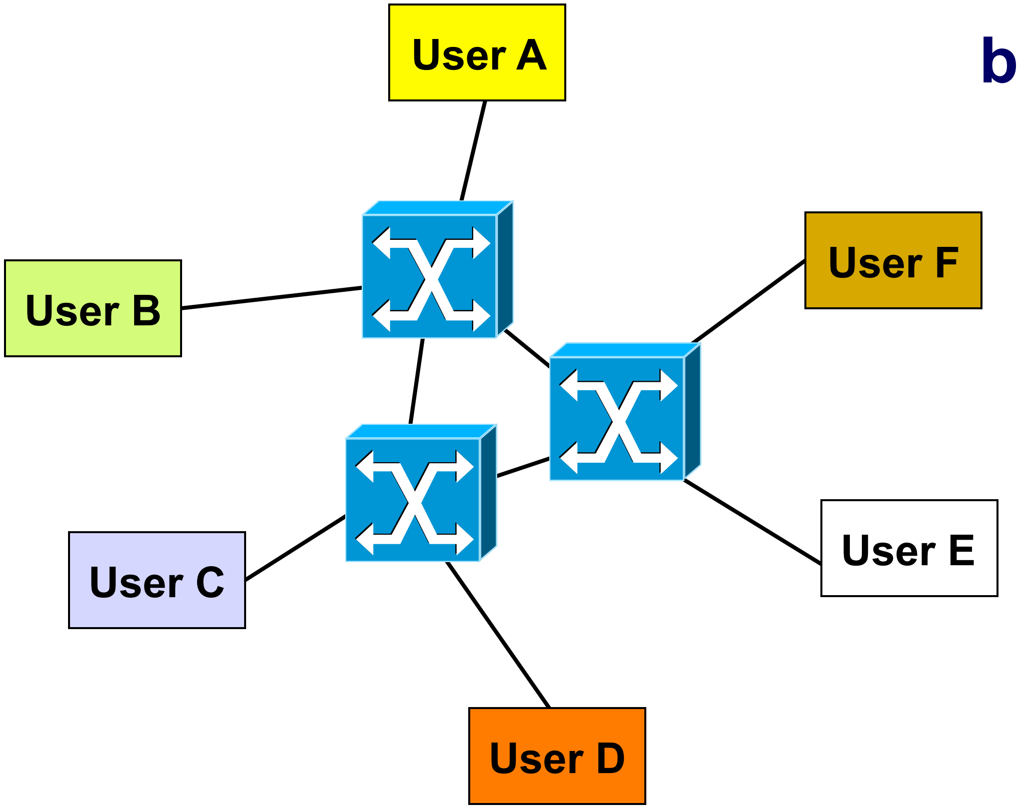


Networking: Fully Meshed



- Metcalfe's Law: n(n-1)/2 links
- Good fault tolerance
- Expensive

Networking: Switching



Network switches could be based on:

Synchronous TDM
- **Circuit Switching**

or

Asynchronous TDM
- **Packet Switching**

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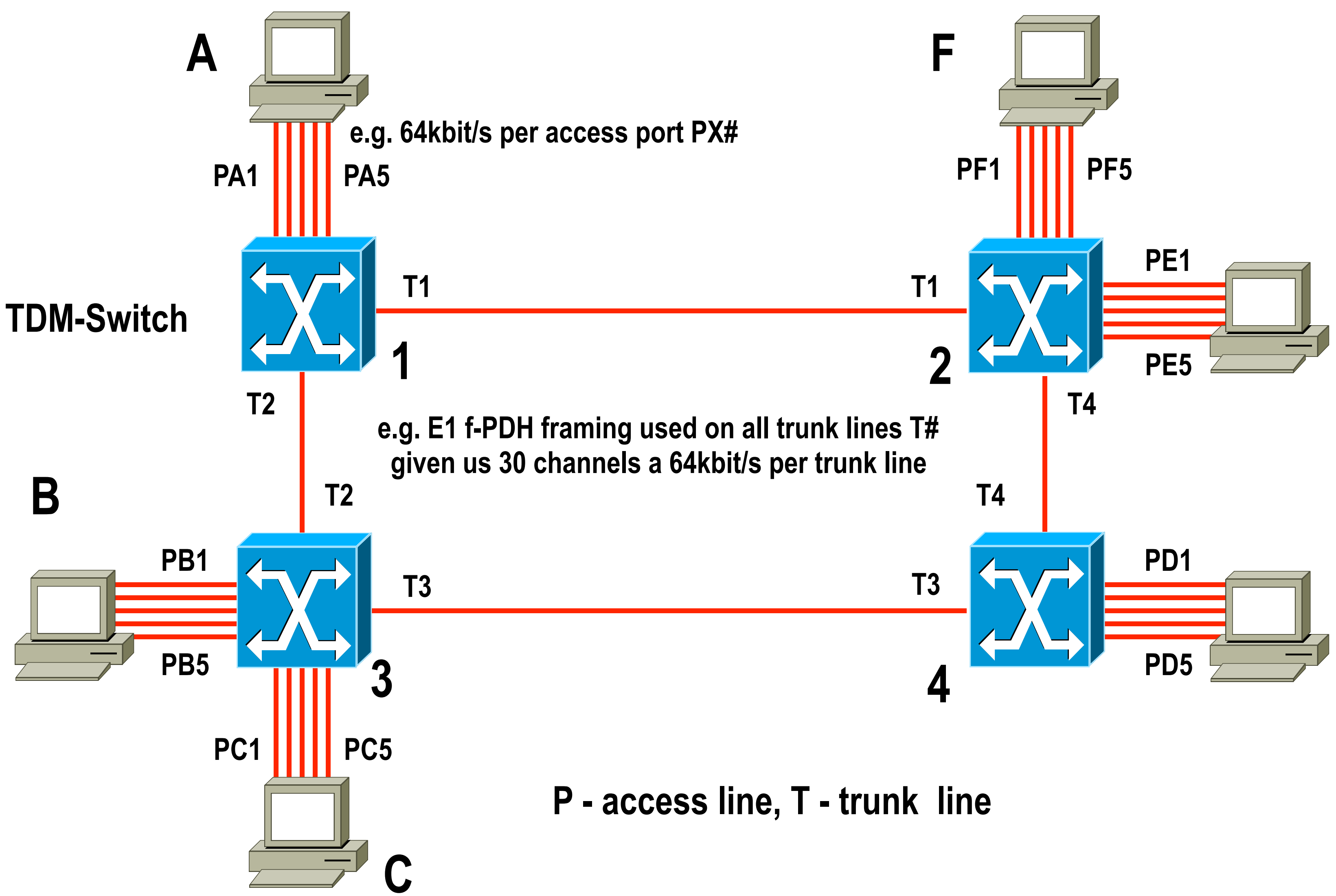
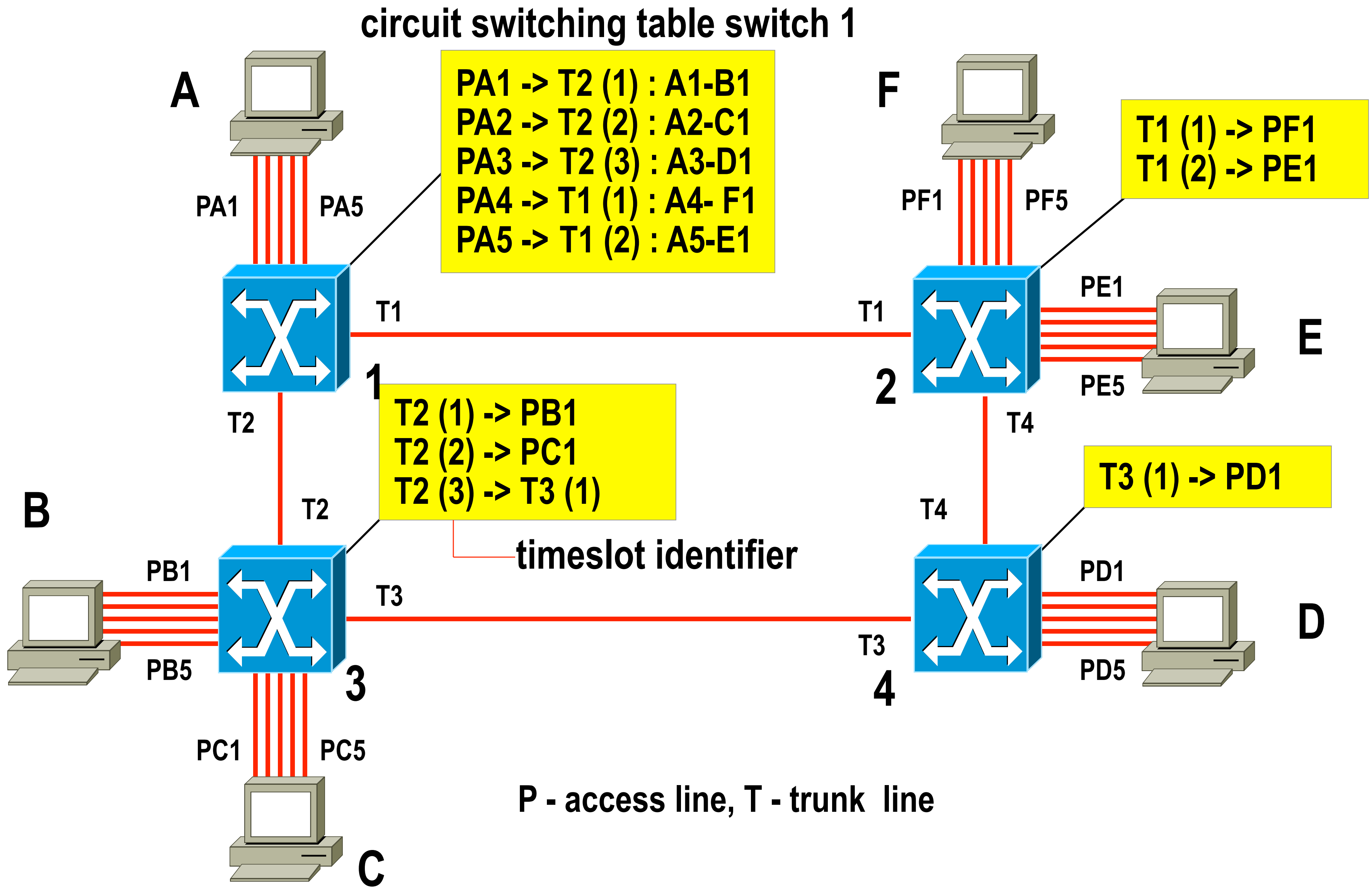
Circuit Switching

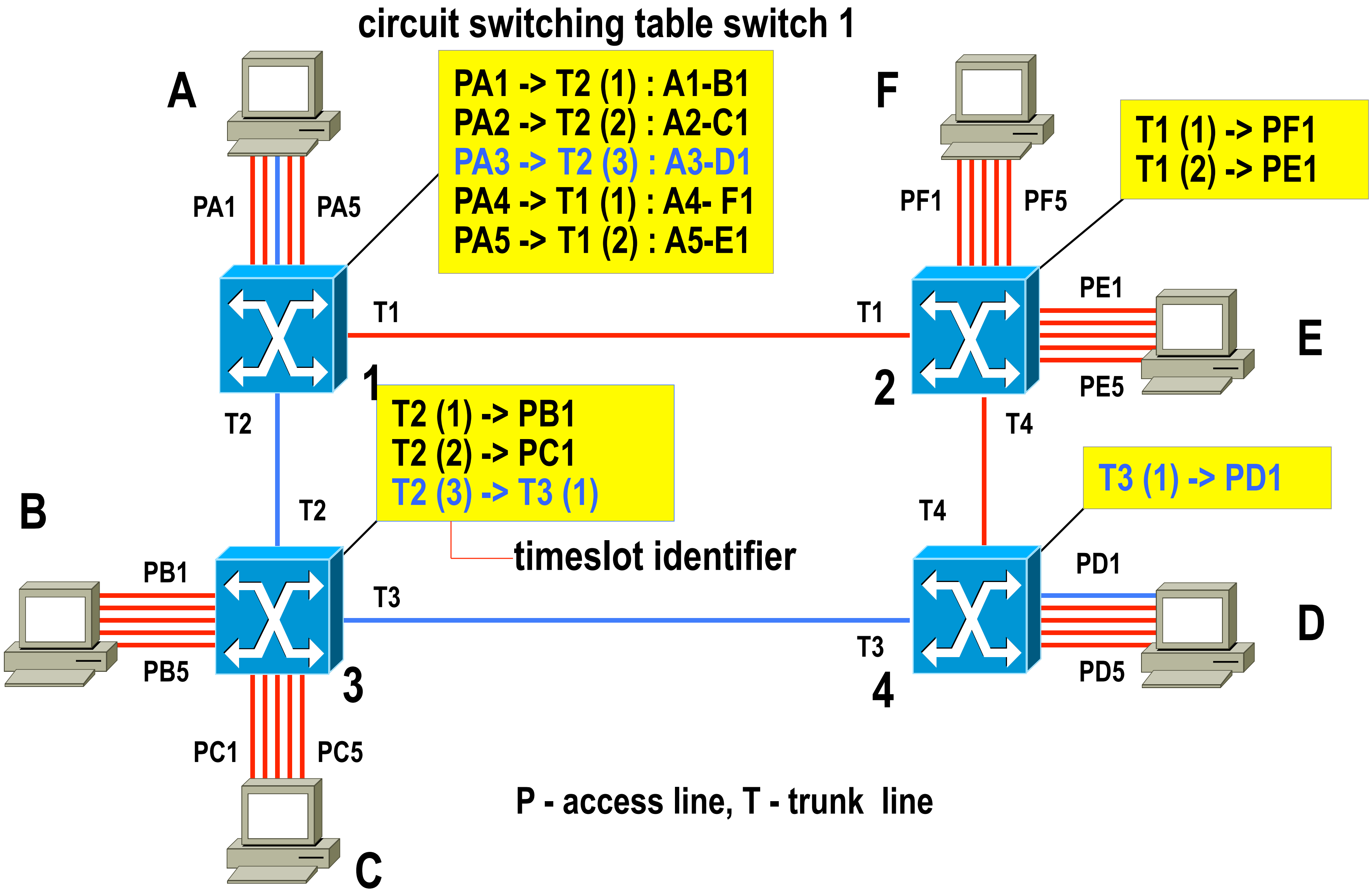


Connections of Device A



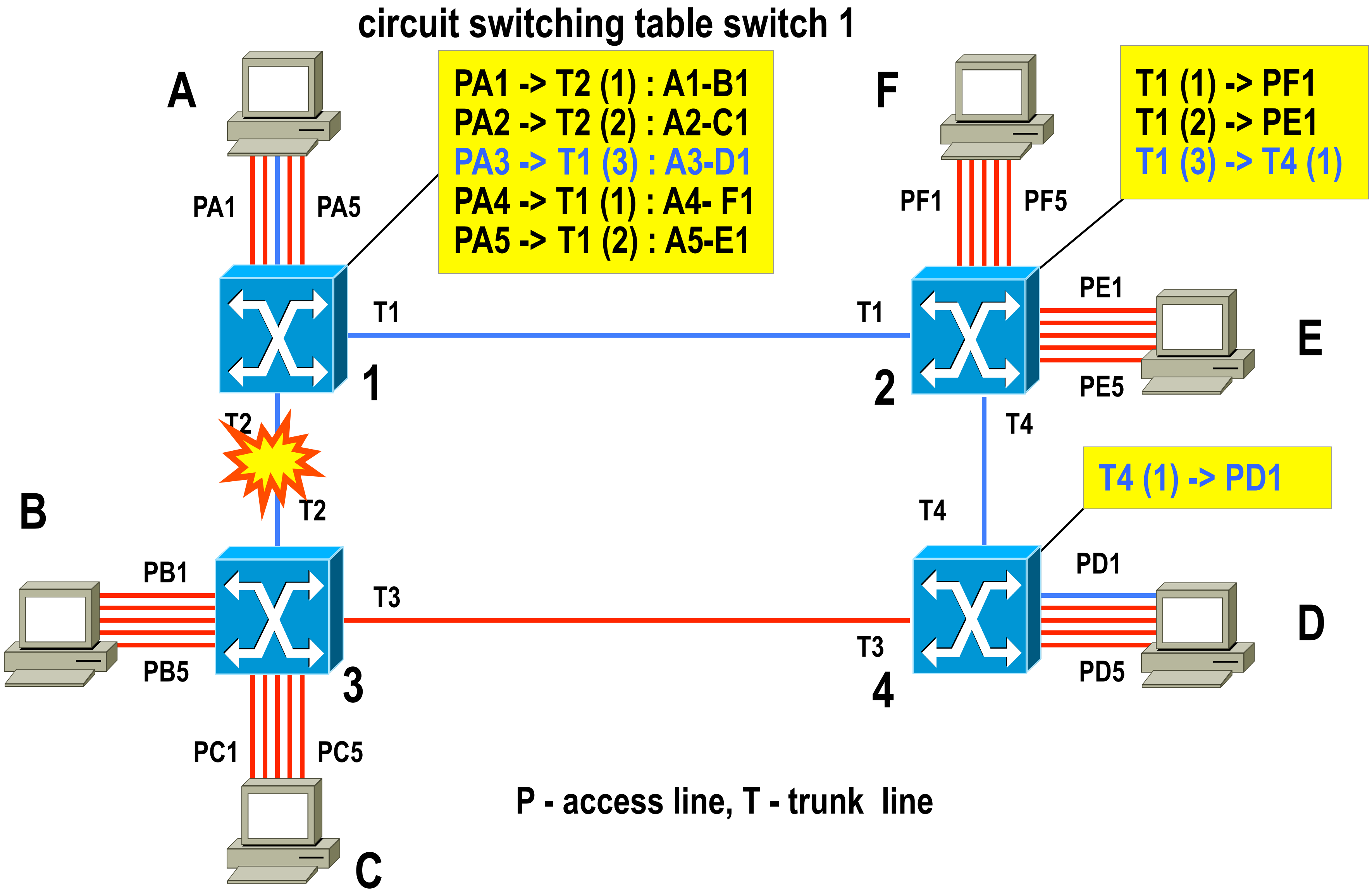
Connections of Device A

Circuit Path PA3 (A) - PD1 (D)



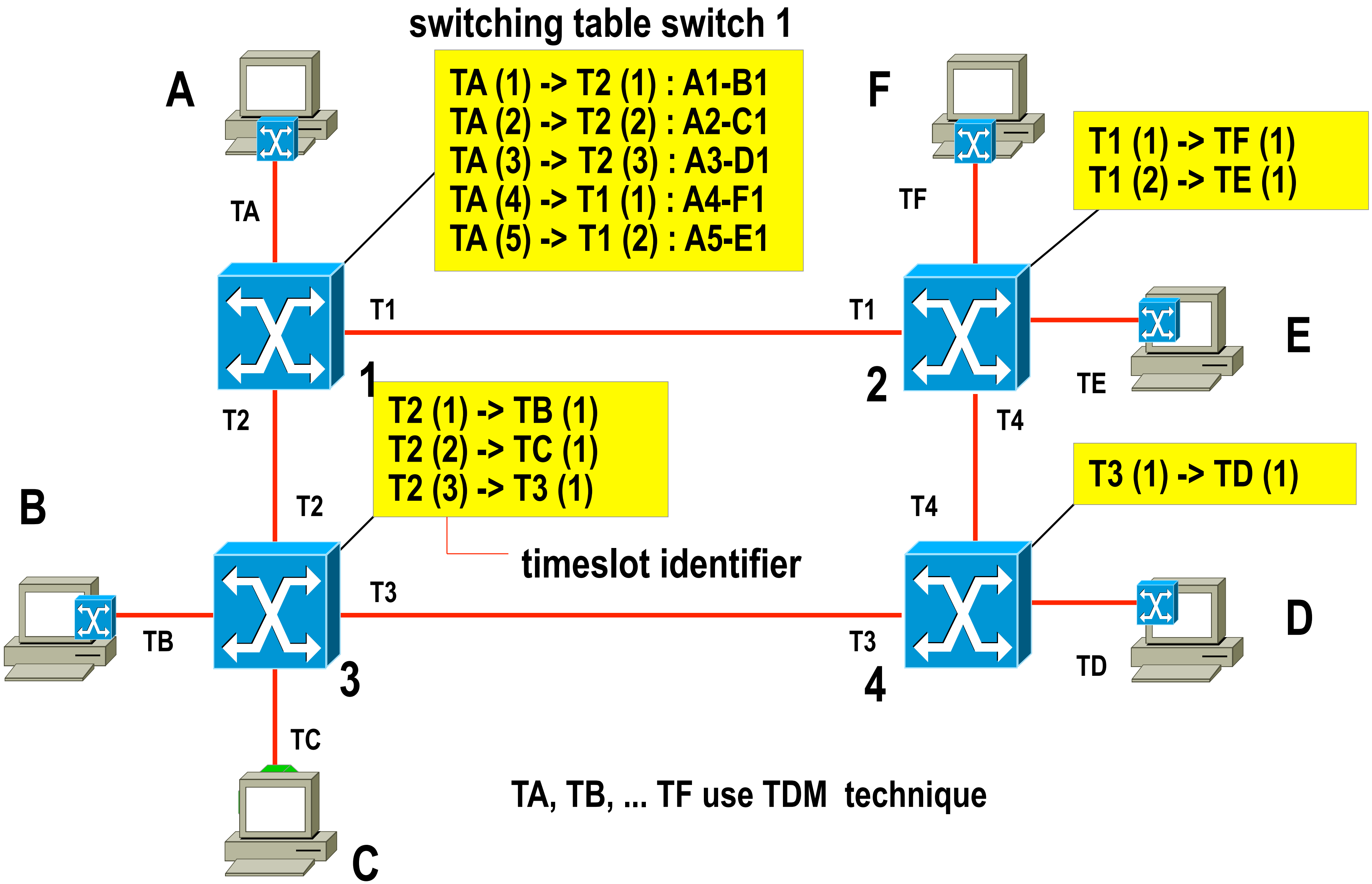
P - access line, T - trunk line

Connections of Device A
Circuit Path PA3 (A) - PD1 (D) Restoration



P - access line, T - trunk line

TDM lines to Devices



Circuit Switching – Facts

- **Based on synchronous (deterministic) TDM**
  - Minimal and constant delay
  - Protocol transparent
  - High bit rate on trunk lines
    - Sum of access links traversing a given trunk
  - Possibly bad utilization
    - Idle pattern in timeslots if no data present
  - Good for isochronous traffic (voice)

- **Switching table entries**
  - Static (manually configured)
  - Dynamic (signaling protocol)
  - Scales with number of connections!

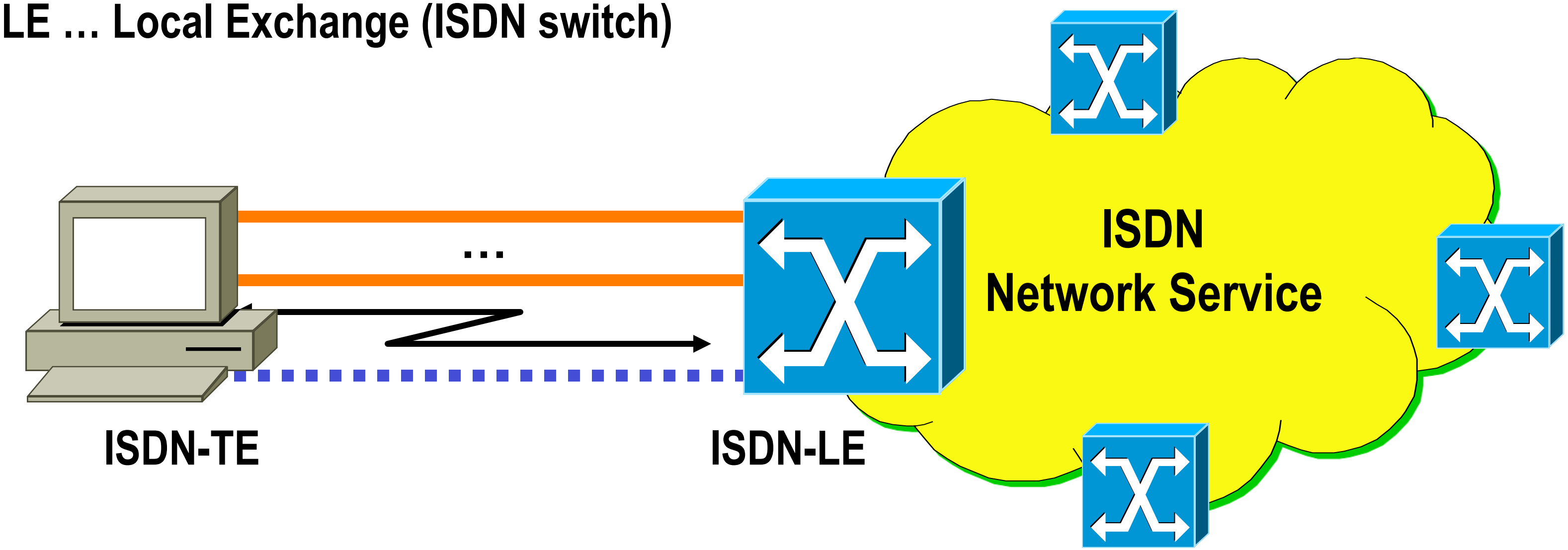
Circuit Switching Data Networks

- **Network providers offer permanent circuit services**
  - With permanent entries in circuit switching tables
  - Optional with fast automatic switchover (50ms) in case of trunk failure
  - **Leased line**

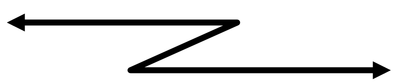
- **Network providers offer switched circuit services**
  - With dynamic entries in circuit switching tables generated on demand
  - Today implementations are based on **ISDN** only
  - **Integrated Services Digital Network**
  - Outband signaling (via D-channel) between ISDN end system (ISDN-TE) and ISDN-LE (Local Exchange) = that is the local TDM switch
  - Communication between ISDN-LEs is based on Signaling System 7 (SS7)
- **Base is PDH or SDH transmission infrastructure**

ISDN User-to-Network Interface (UNI)

TE … Terminal Equipment (ISDN end system)
LE … Local Exchange (ISDN switch)



logical channels multiplexed on physical channel

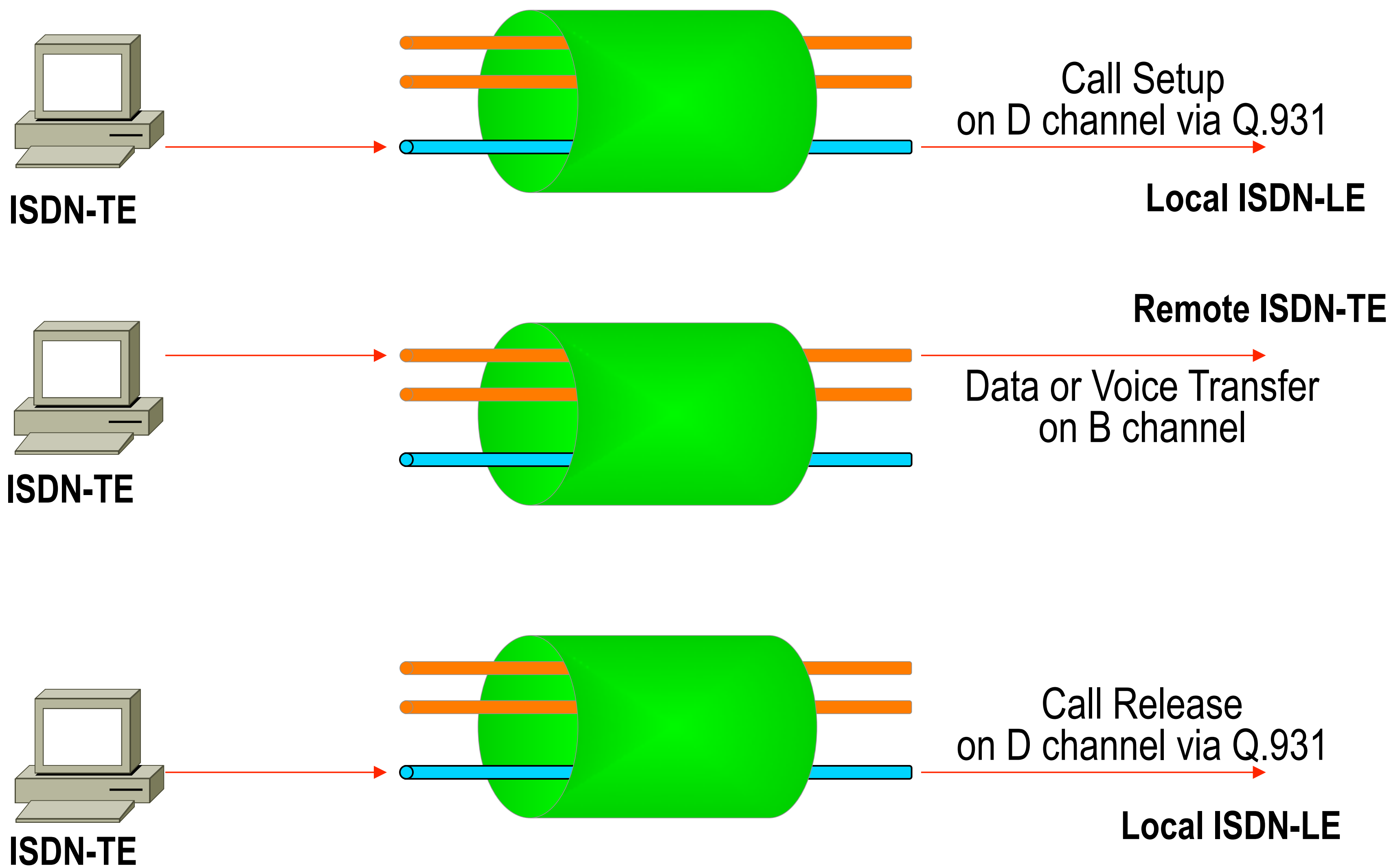


physical access link
(I.430, I.431)

channel
for user data
(B-channel)

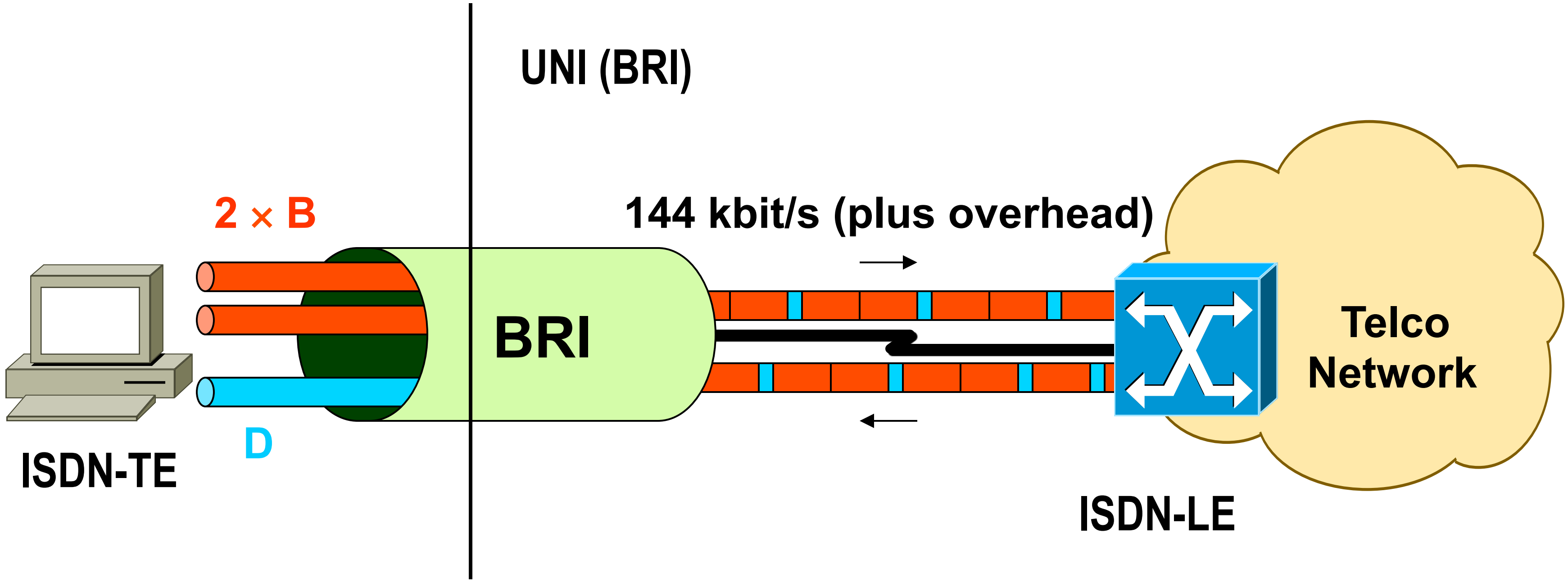
channel
for signaling
(D-channel)
(Q.921, Q.931)

Usage D-Channel vs. Bearer Channel



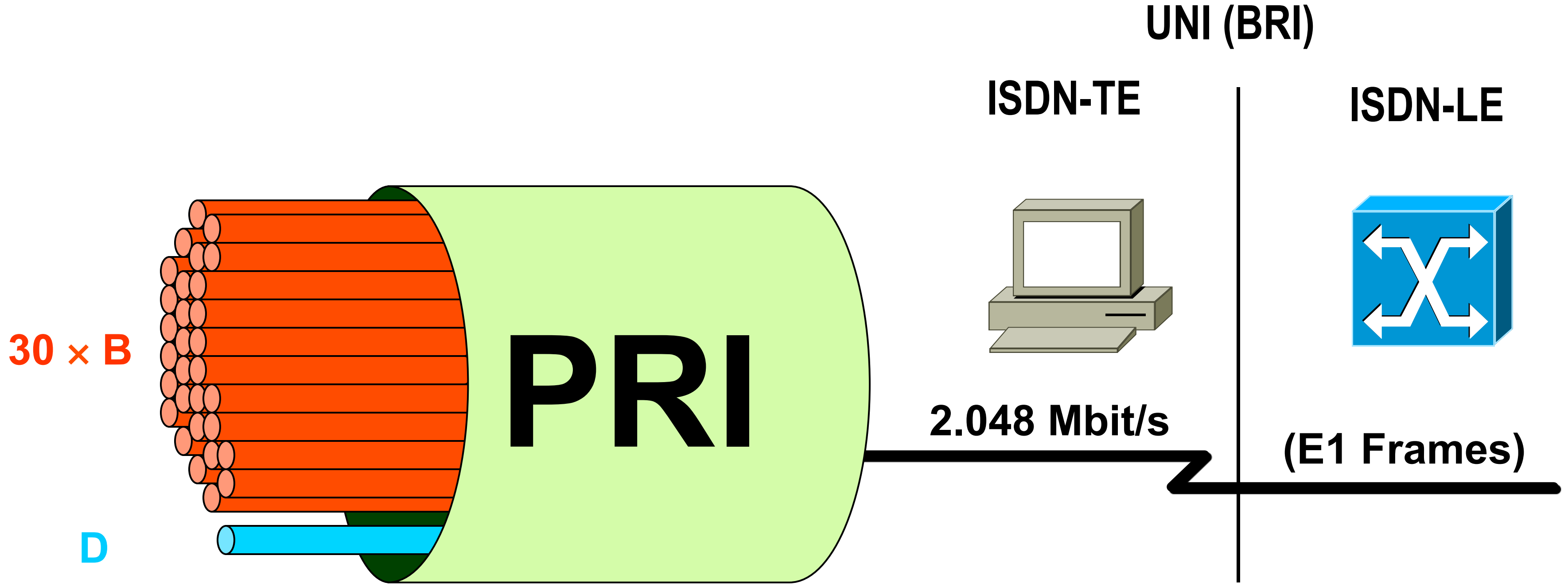
Basic Rate Interface (BRI)

– 2 B (bearer) channels with 64 kbit/s each
  - carrying digitized voice or data
– 1 D (data) channel with 16 kbit/s
  - for outband signaling purposes (e.g. Q.931 protocol)
– 2 B and D are synchronous TDM-multiplexed on physical access line

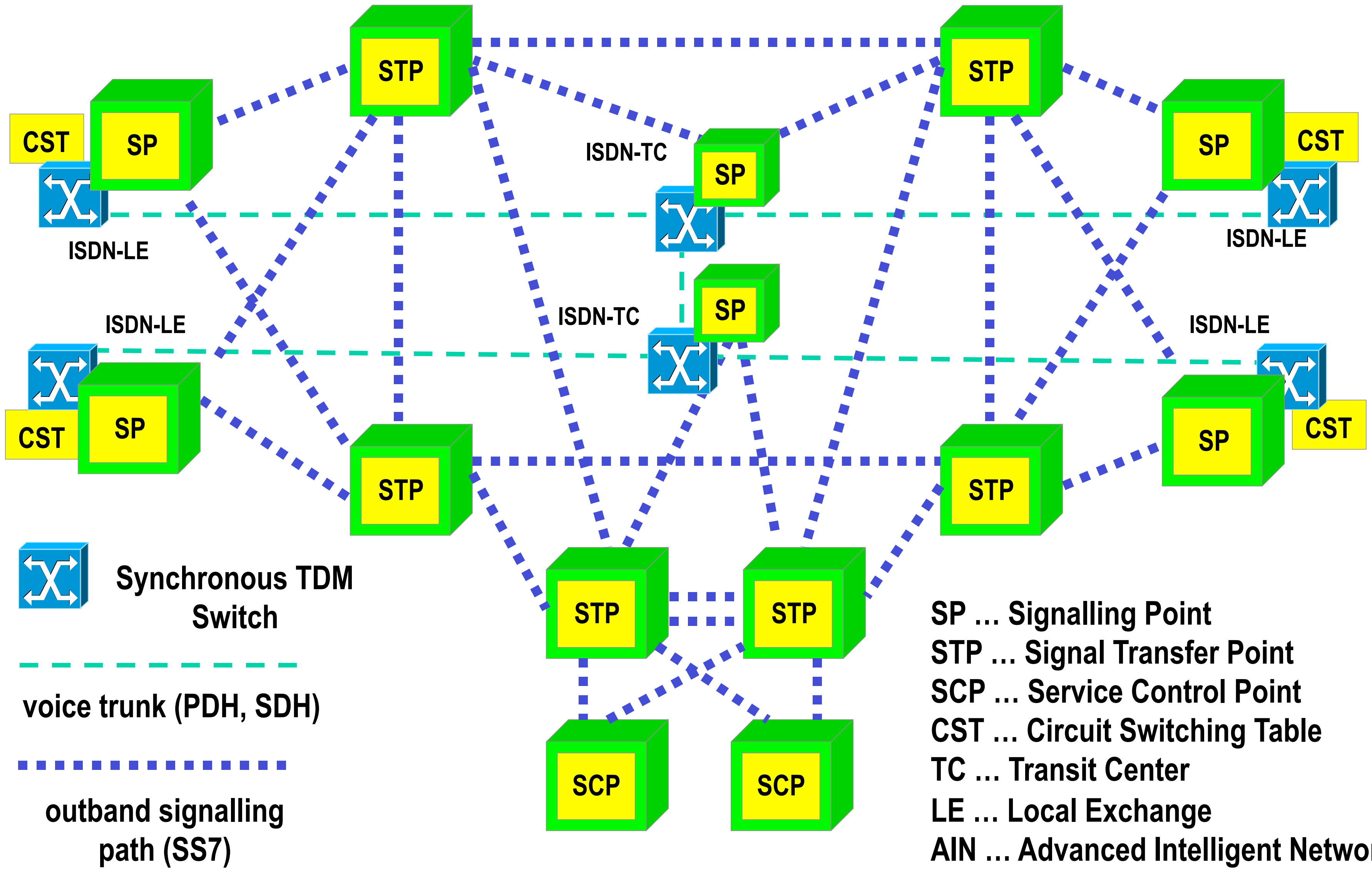


Primary Rate Interface (PRI)

- 30 B (Bearer) channels with 64 kbit/s each (USA 23 B)
- 1 D (Data) channel with 64 kbit/s
  - for signaling purposes (e.g. Q.931 protocol)
- 30 B and D are synchronous TDM-multiplexed on one physical access line



ISDN Big Picture (AIN, SS7)



SP … Signalling Point
STP … Signal Transfer Point
SCP … Service Control Point
CST … Circuit Switching Table
TC … Transit Center
LE … Local Exchange
AIN … Advanced Intelligent Network

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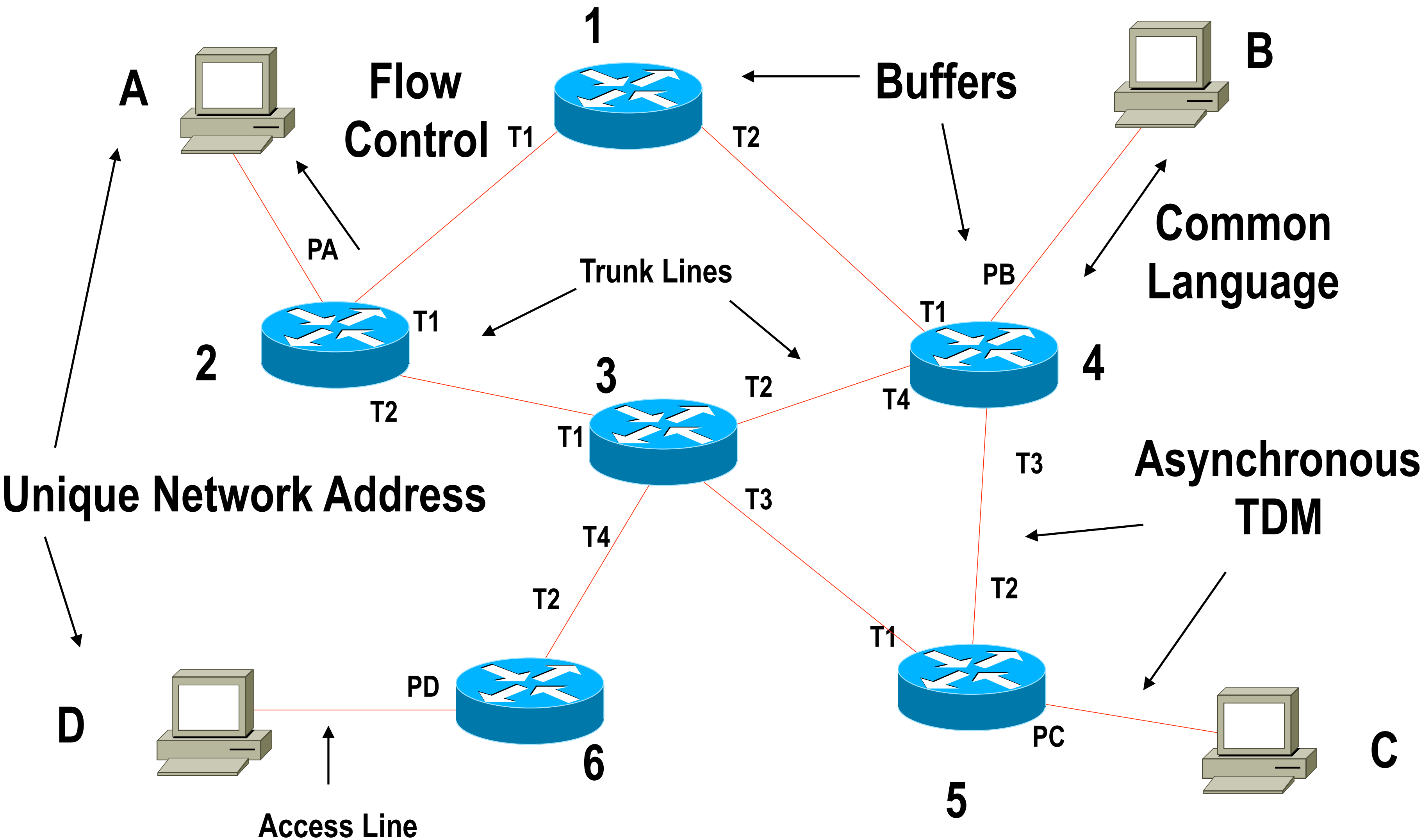
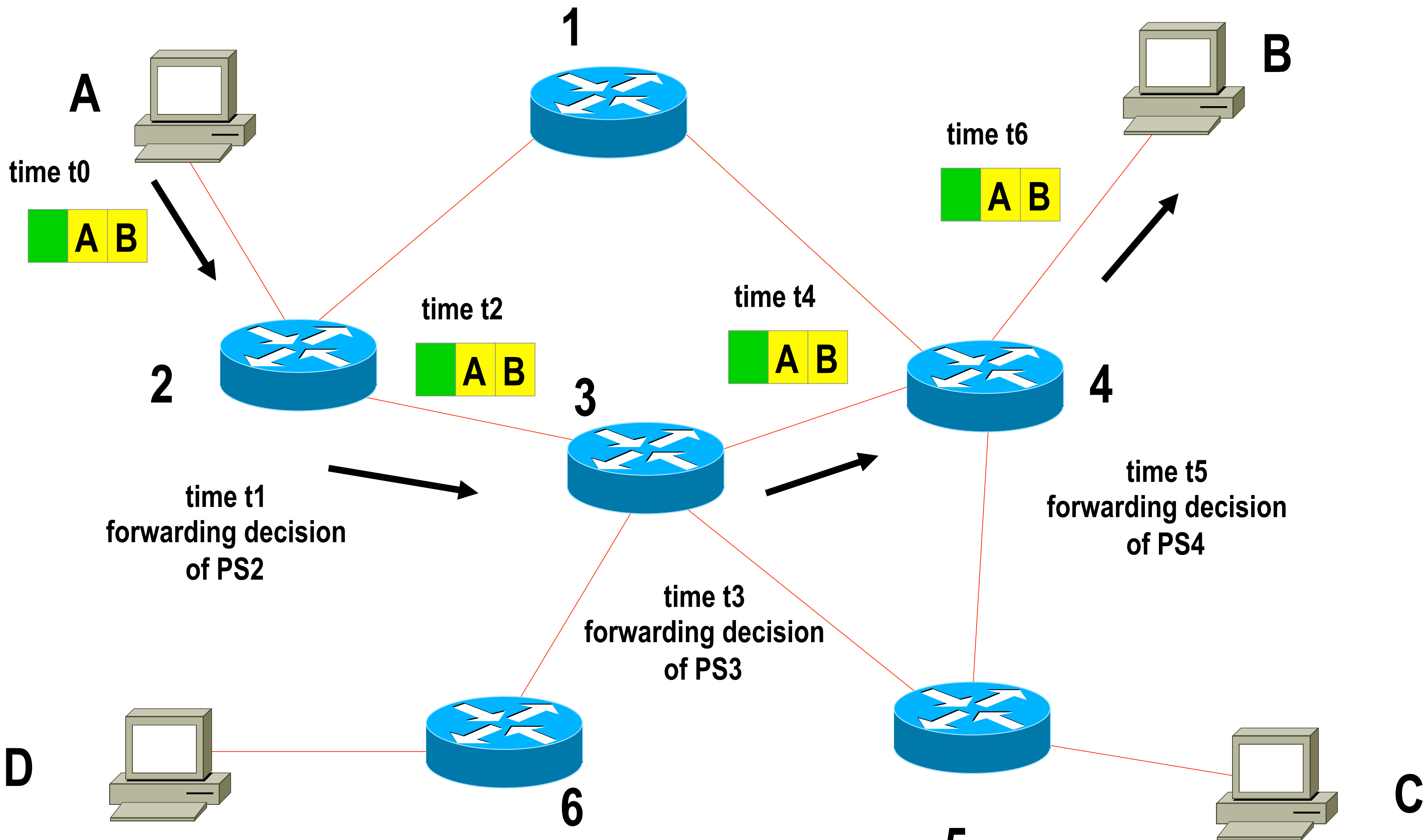
Packet Switching Topology



Packet Forwarding Principle (Store and Forward)



... Packet payload

A B ... Source Address / Destination Address

Packet Forwarding is based on Tables

- Tables contains
  - Information how to reach destinations
  - Mapping between destination address or local connection identifier and outgoing trunk or access port
  - "**Signposts**"

- Two types of tables
  - Depending on the actual implementation of packet switching technology
  - **Routing tables**
  - **Switching tables**

Routing - Addressing

- **Routing in packet switched networks**
  - Process of path selection in order to forward a packet to a given destination
  - Selection based on (destination) address
- **Address specifies the location of end system**
  - Contains topology information
  - Address must be unique within the network in order to enable routing based on signposts
- **Protocol using unique <u>and</u> structured addresses**
  - Is called <u>**routed**</u> or <u>**routable protocol**</u>

Routing Types

- **Static routing**
  - Routing table entries are static
  - Based on preconfigured routing tables
  - Configuration done by the network administrator
  - Non-responsive to network topology changes
- **Dynamic routing**
  - Routing table entries are variable (dynamic)
  - Changes done by **routing protocols**
    - Communication protocol used between packet switches to find out the network topology and to calculate the best path to any given destination
  - Responsive to any network topology changes

Routing Table Usage / Type of Service

- **Routing tables are differently used**
  - Depending on the type of service of the packet switching network
- **Packet switched networks based on**
  - Connectionless Service (CL) - Datagram service
    - Routing tables are used to forward all kind of packets
  - Connection-oriented Service (CO) – Virtual Call service
    - Routing tables are used to forward control packets for connection establishment
    - These control packets generate entries in switching tables
    - After connection establishment, only the switching tables are used to forward data packets

Technology Differences - Summary

- **Datagram Principle**
  - Global and routable addresses
  - Connectionless
  - Routing table for forwarding of packets

- **Virtual Call Principle**
  - Local addresses
  - Connection-oriented
  - Routing table for setup of connections
  - Switching table for forwarding of packets

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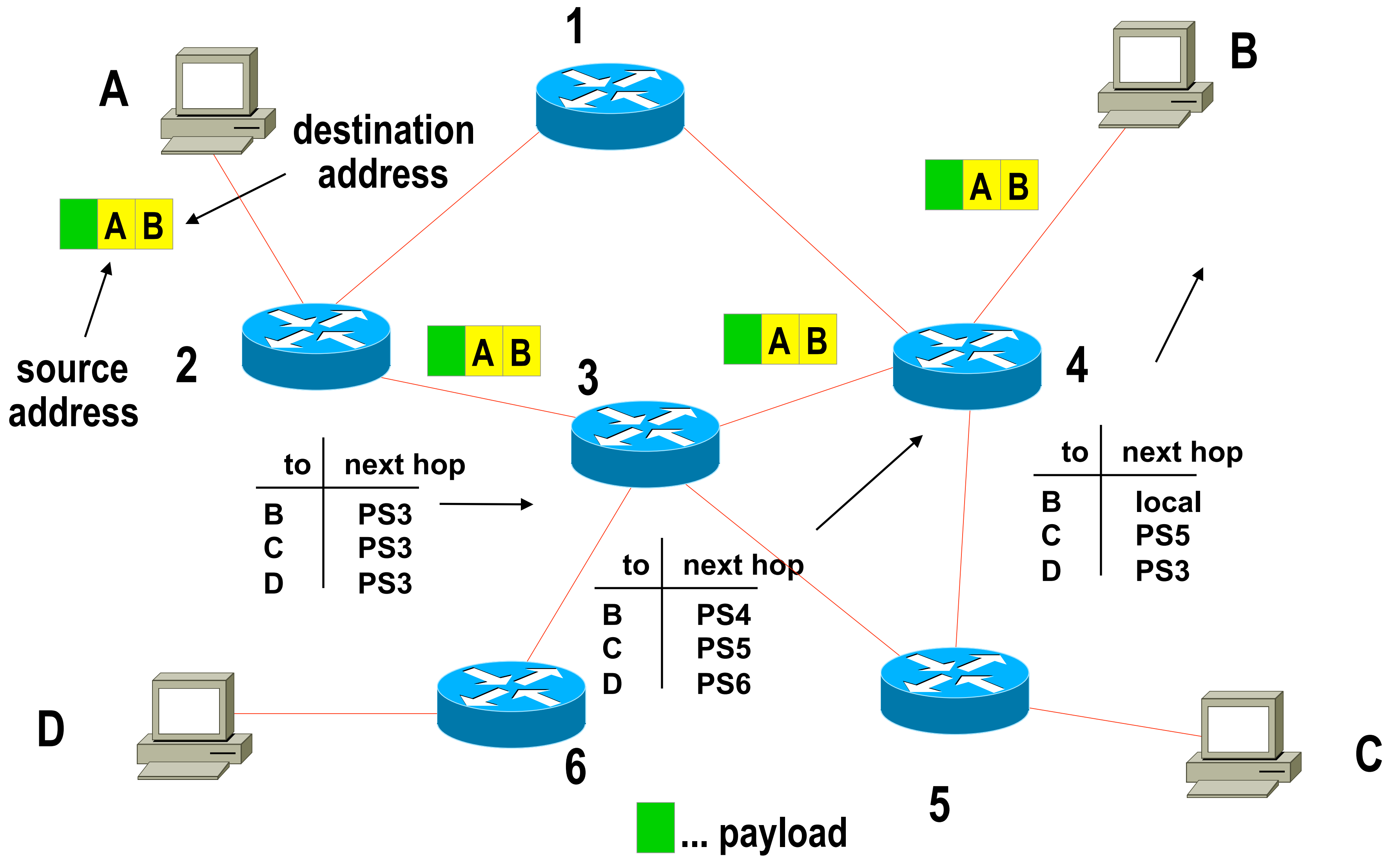
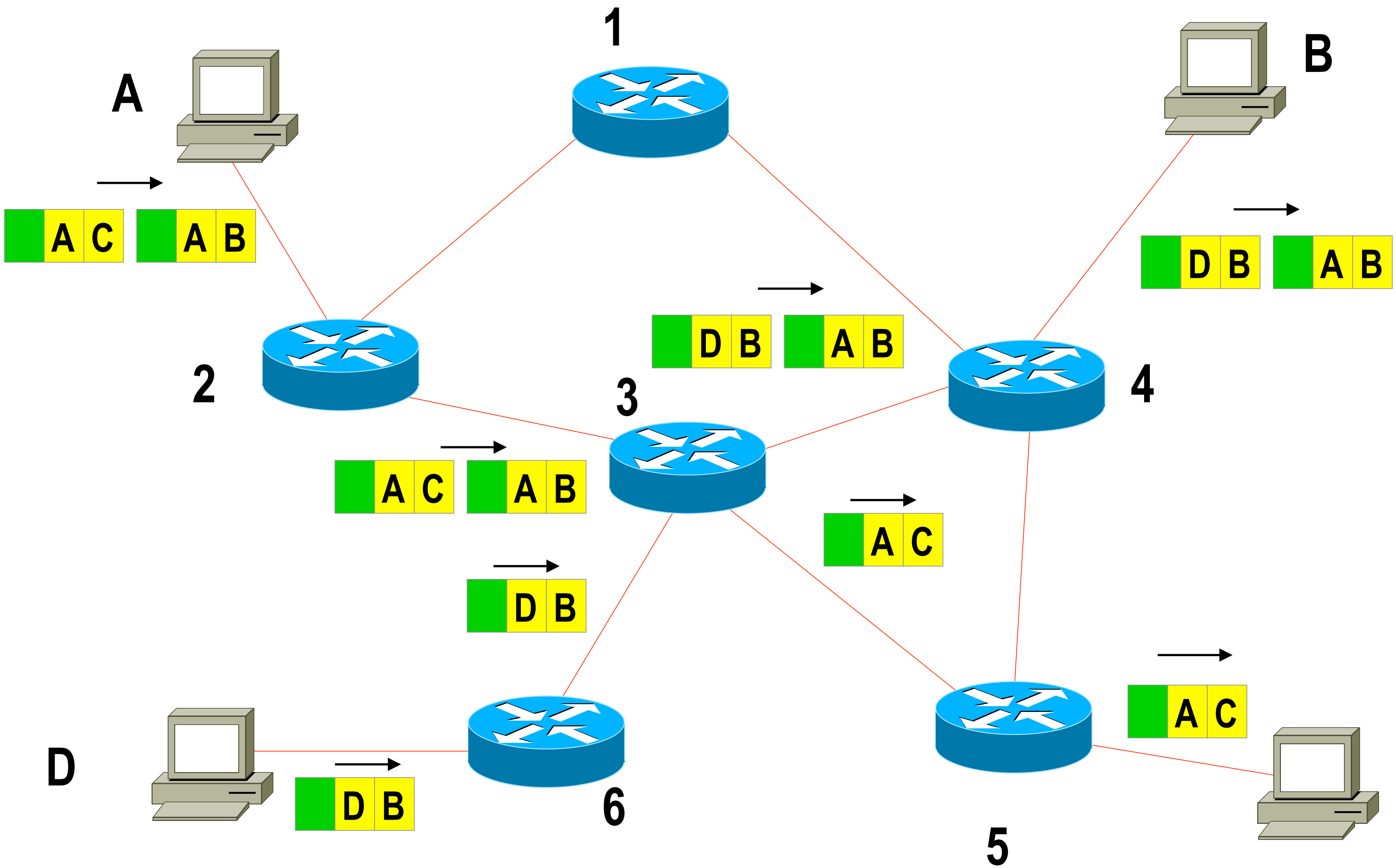
Datagram Service Principles

- **Connectionless service**
  - Packets can be sent without establishing a logical connection between end systems in advance
  - Packets have no sequence numbers
  - They are called **"Datagrams"**
- **Every incoming datagram**
  - Is processed independently regarding to all other datagrams by the packet switches
- **The forwarding decision for incoming packets**
  - Depends on the current state of the routing table
- **Each packet contains**
  - Complete address information (source and destination)

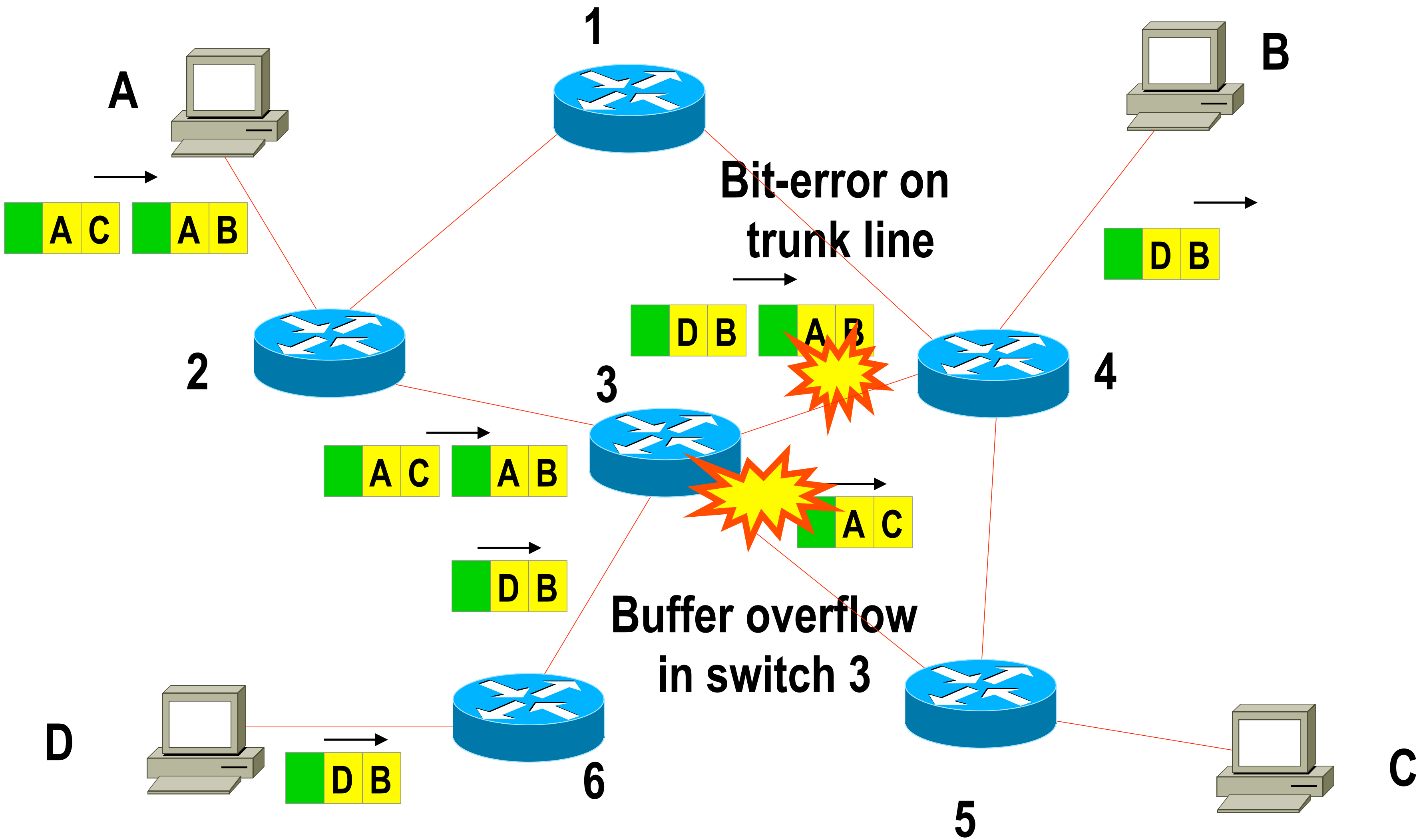
Packet forwarding (CL) is based on routing tables only
(Datagram Service, Best-Effort Service)



Datagrams are forwarded completely independent from each other based on current state of routing tables



Best-Effort Service



Datagram Service Facts (1)

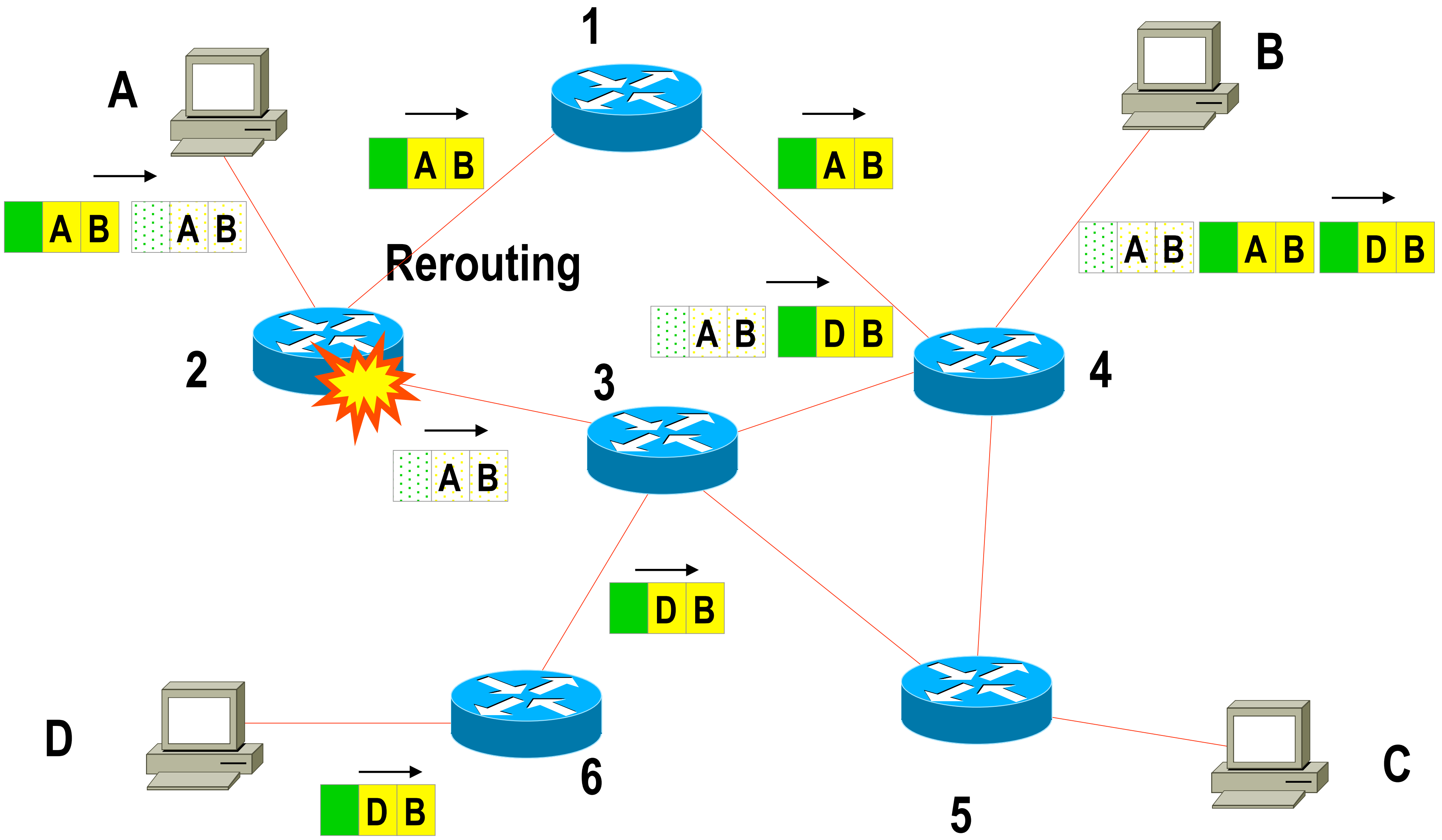
- **Packets may be discarded / dropped by packet switches**
  – In case of network congestion
  – In case of transmission errors

- **Best effort service**
  – Transport of packets depends on available resources

- **The end systems may take responsibility**
  – For error recovery (retransmission of dropped or corrupted packets)
  – For sequencing and handling of duplicates

- **Reliable data transport requires good transport layer**
  – "Dumb network, smart hosts"

Rerouting – Sequencing Not Guaranteed !

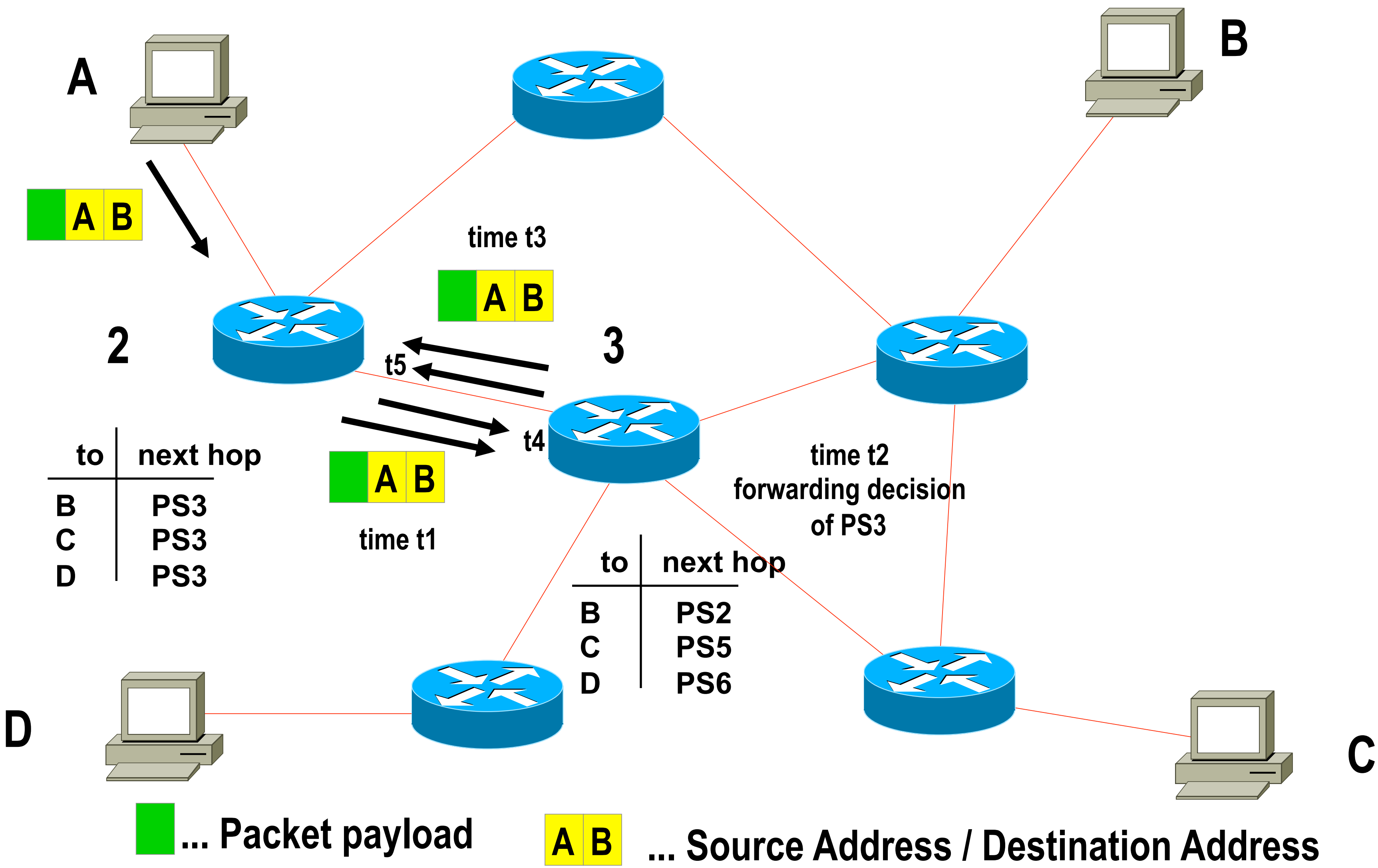


Datagram Service Facts (2)

- **Rerouting in case of topology changes or load balancing means**
  - Packets with the same address information can take different paths to destination
  - Packets may arrive out of sequence

- **Sequence not guaranteed**
  - Rerouting on topology change
  - Load sharing on redundant paths
  - End stations must care

Datagram forwarding needs a kill-mechanism to overcome inconsistent routing tables



Datagram Service Facts (3)

- **Connectionless behavior**
  - Faster delivery of first data
  - No resource reservation is possible
    - e.g. bandwidth on trunk line for a certain communication between end systems
    - e.g. buffer memory on packet switches
  - Bad "**Quality of Service**" (QoS)
  - Flow control between packet-switch and end-system
    - Would help in case of congestion if proactively performed
    - But lack of trust makes it impossible to implement it

Datagram Service Facts (4)

- **Advantages**
  - Small protocol overhead (easy to implement in end systems and packet switches)
  - Fastest delivery of data between end systems because no connection must be established in advance
- **Disadvantage**
  - Delivery of packets is not guaranteed by the network, must be handled by end systems using higher layer protocol
  - Proactive flow control between end-system and packet switch is not possible

Network Technologies based on Datagram Method

- **IP**
  - Packet is called IP datagram
  - End system is called IP host
  - Packet switch is called IP router
- **IPX (Novell)**
- **XNS**
- **Appletalk**
- **Decnet Phase IV**
- **OSI CNLP**

Agenda

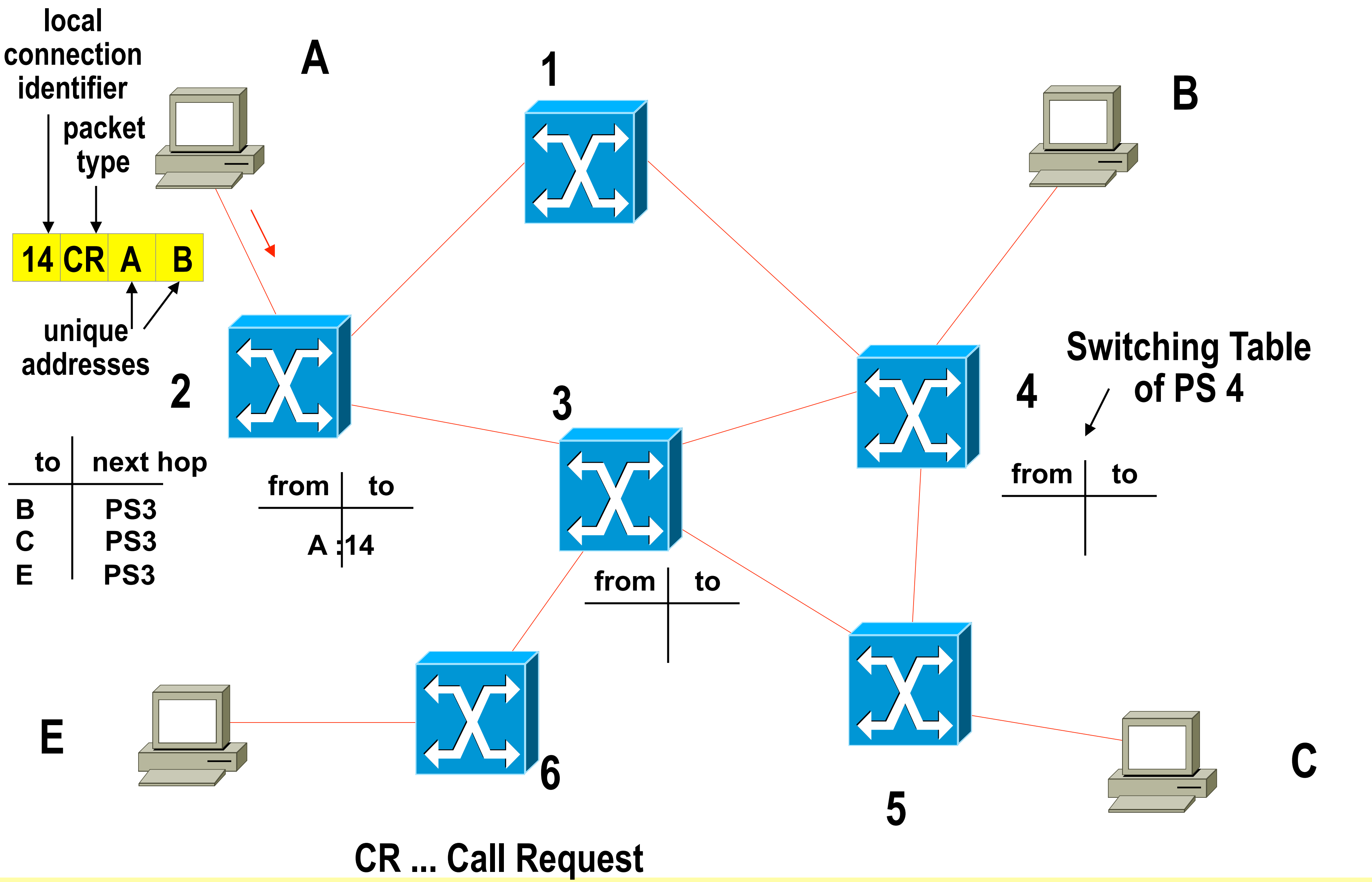
- **Physical Aspects**
  - Serial Transmission, Coding
  - Framing, Delay Types
- **Protocol Basics**
  - Layering / CL versus CO
  - Error Recovery / Automatic Repeat Request (ARQ)
  - Windowing, Delay Bandwidth Product, Flow Control
- **TDM Basics**
  - Synchronous TDM
  - Asynchronous TDM
- **Network Basics**
  - Circuit Switching
  - Packet Switching
    - Datagram Service / Connectionless Service
    - Virtual Call Service / Connection-Oriented Service
  - Summary
- **OSI Model – DoD Model**

Virtual Call Principles

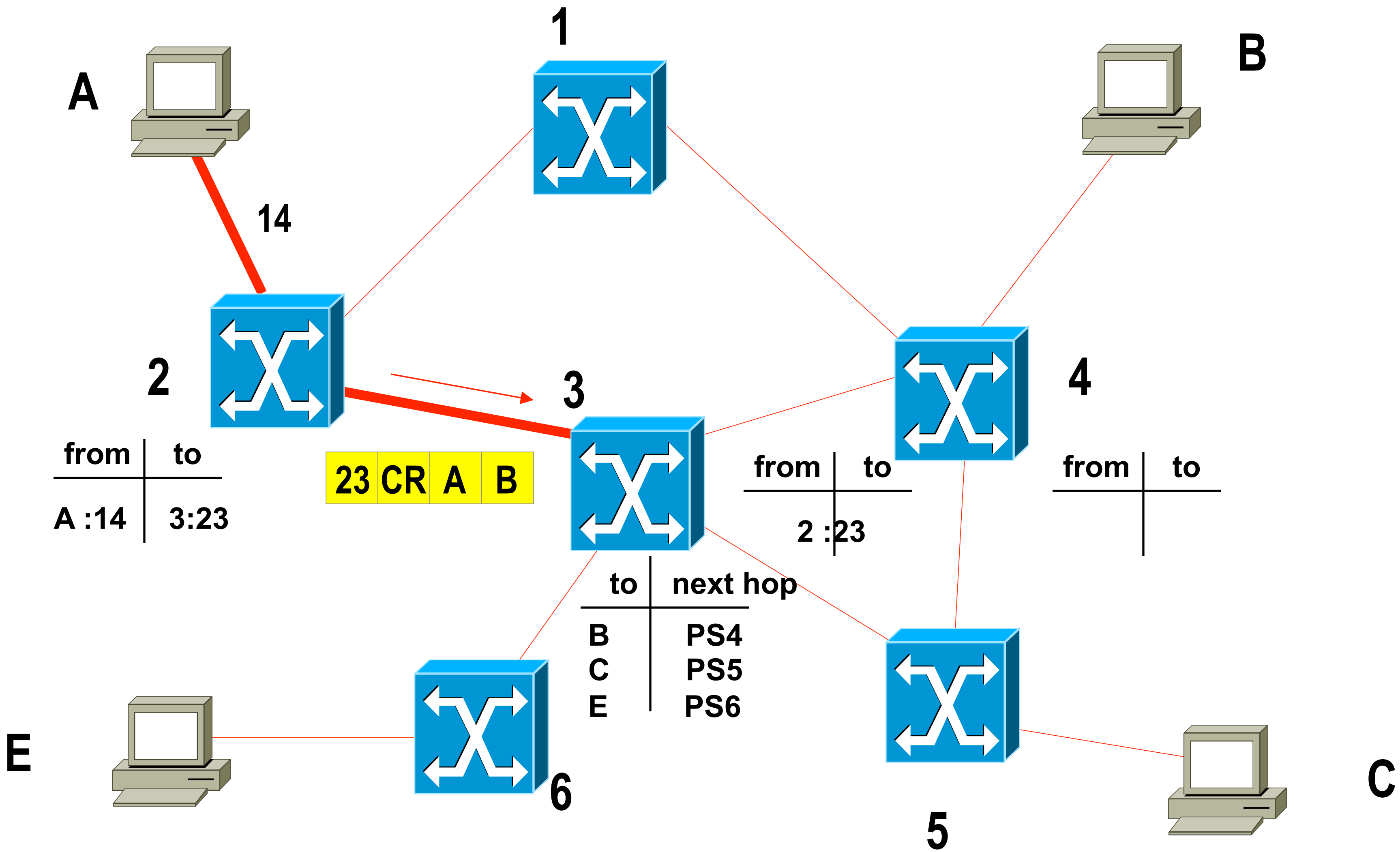
- **Connection-oriented service**
  - Special control packets (call setup packets) establish a logical (virtual) point-to-point connection between end systems first
  - We call that connection a **Virtual Circuit**
  - After connection is established
    - Data packets can be transmitted across that virtual circuit
    - Typically virtual circuit will be closed after data transfer is finished

- **Different methods are possible**
  - To establish a virtual call service

Packet forwarding (CO) is based on special switching tables but call-setup still uses conventional routing tables (Virtual Call Setup 1)

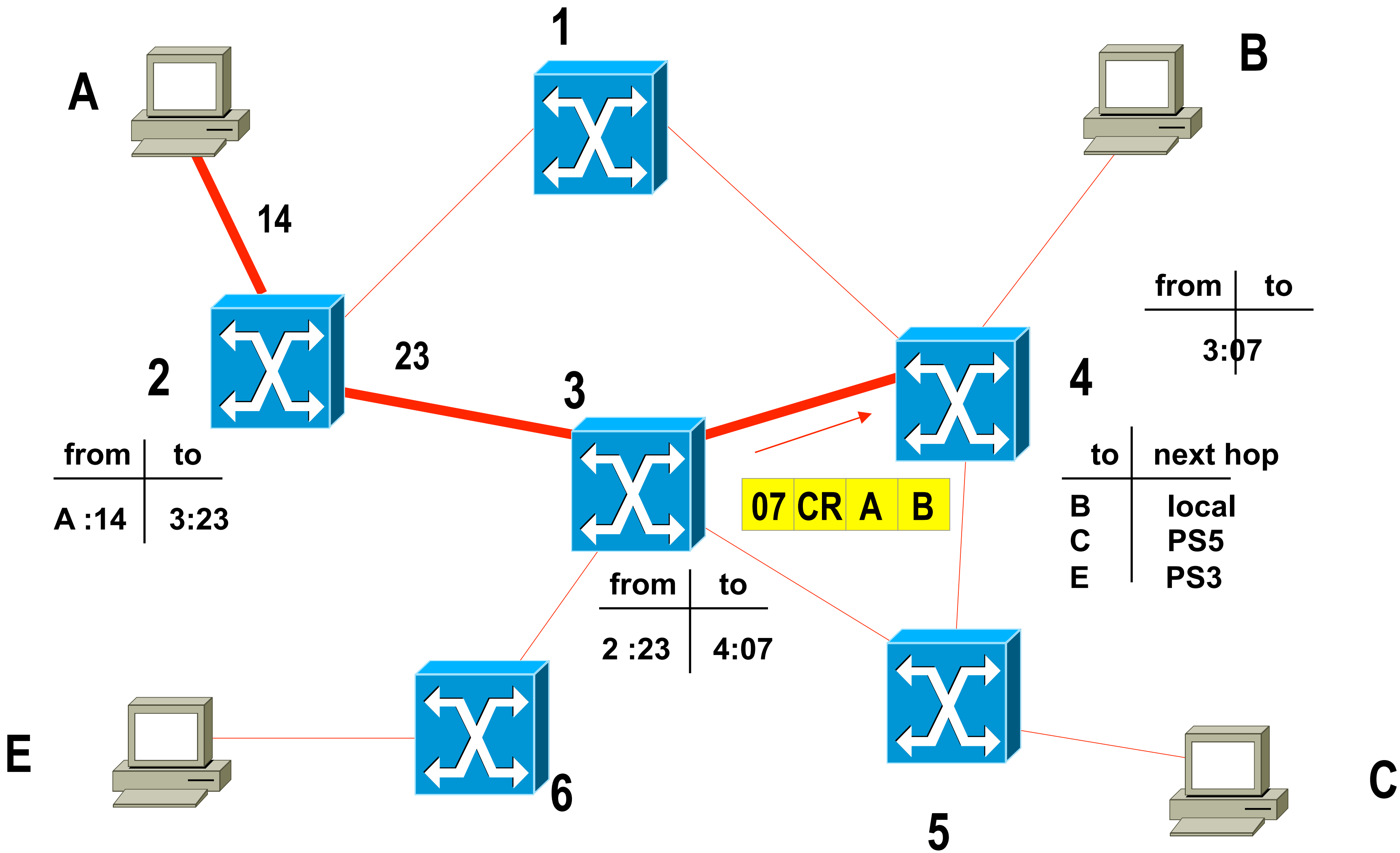


Virtual Call Setup 2



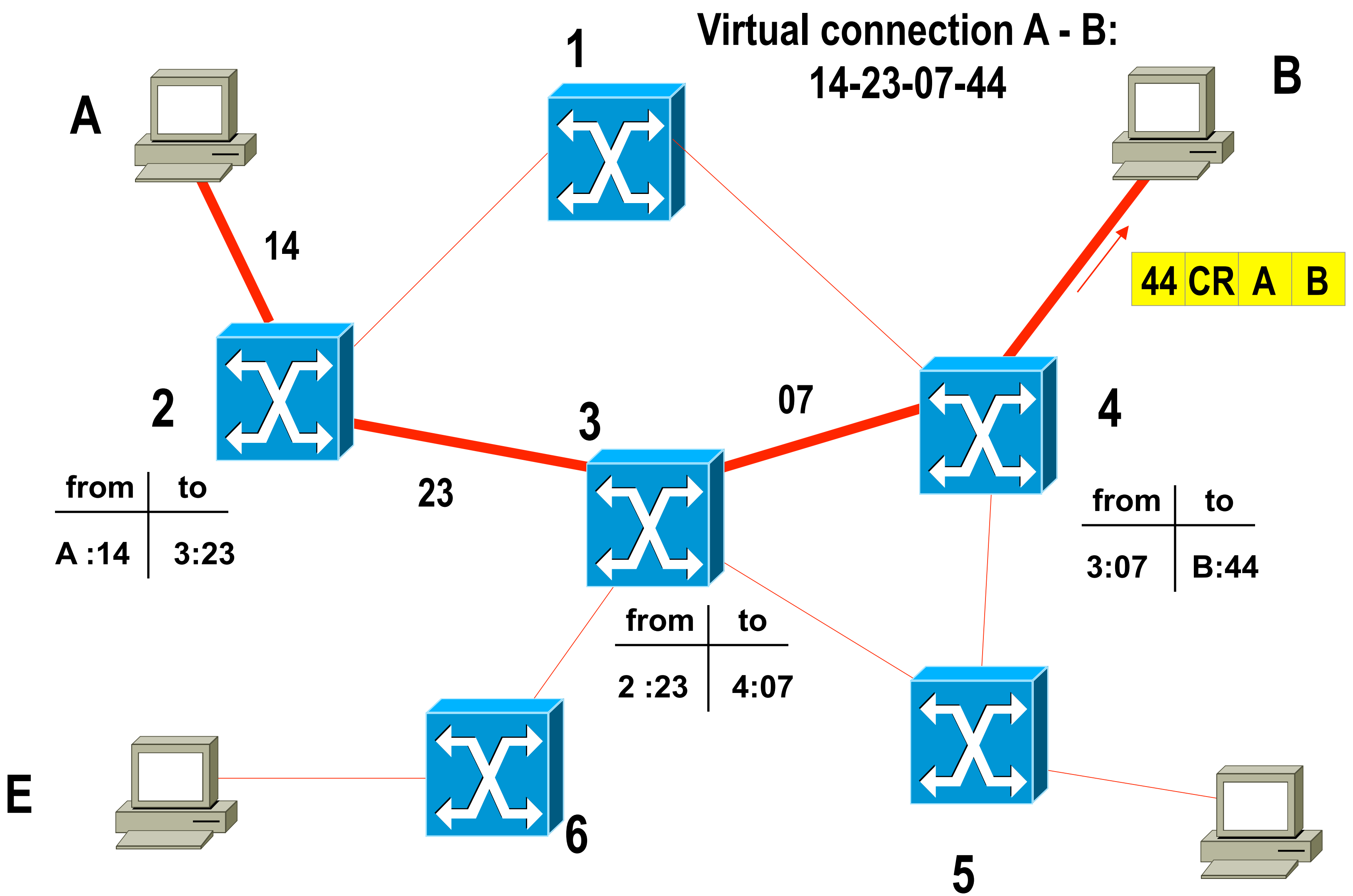
CR ... Call Request

Virtual Call Setup 3



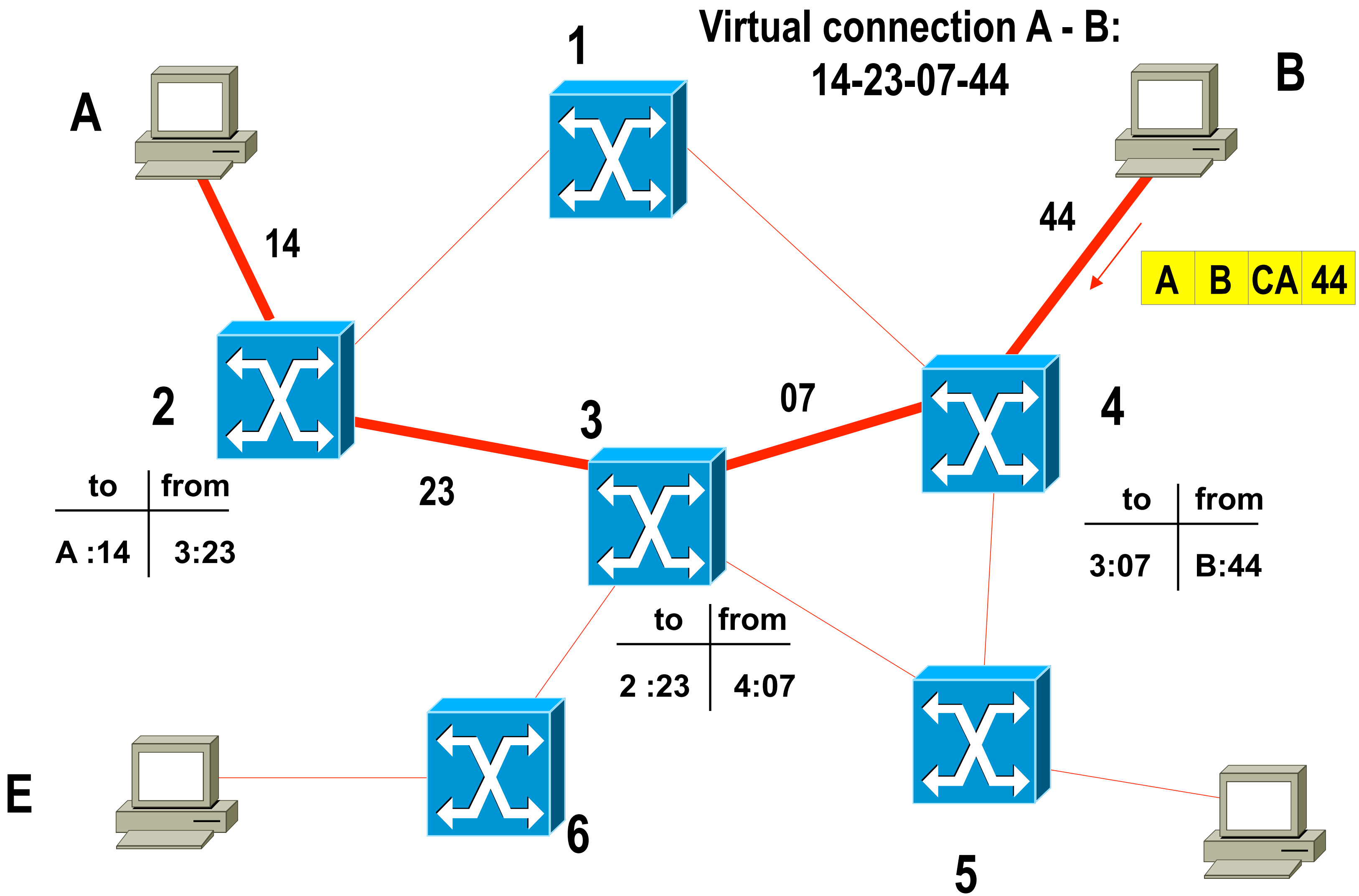
CR ... Call Request

Virtual Call Setup 4



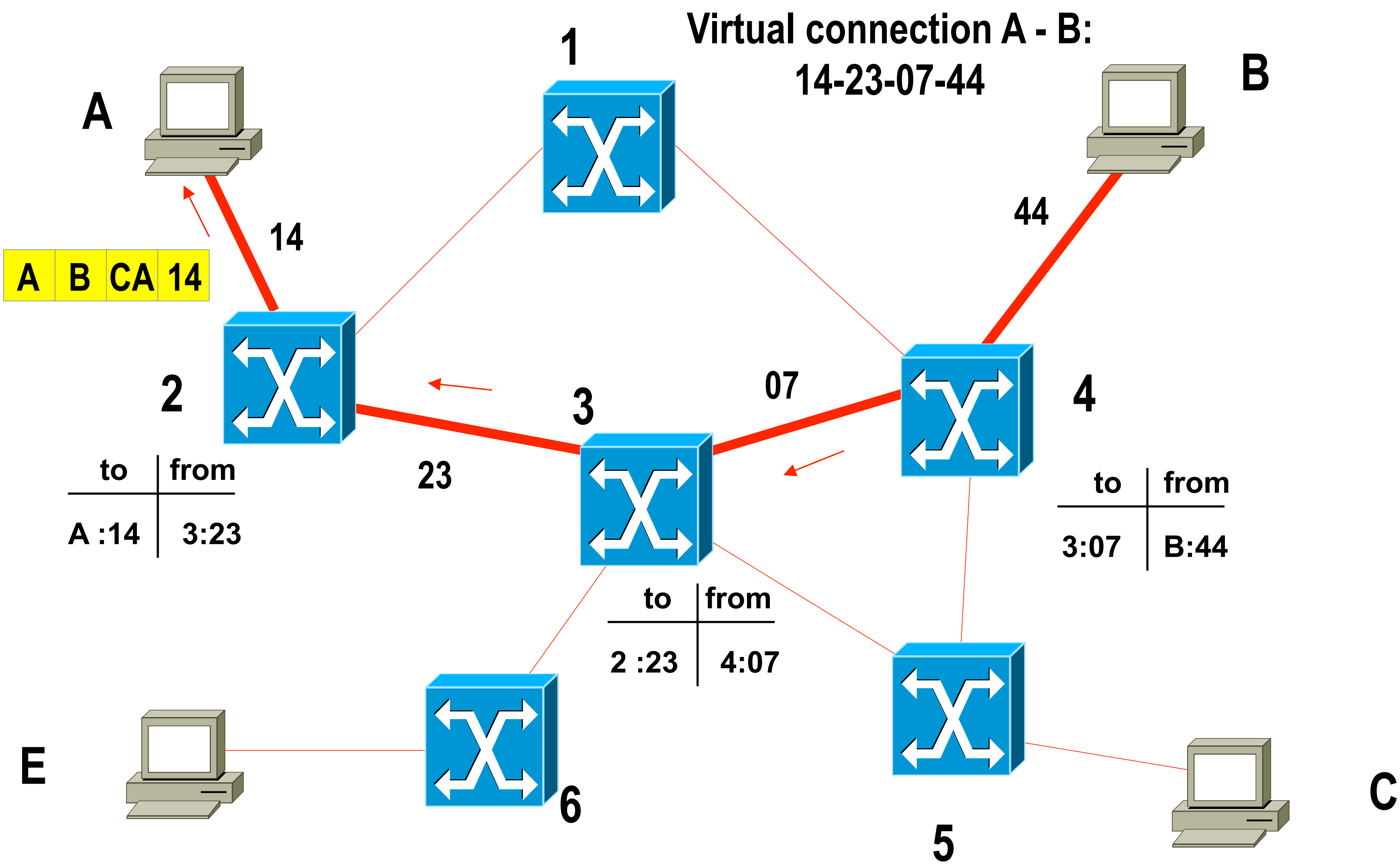
CR ... Call Request

Virtual Call Setup 5



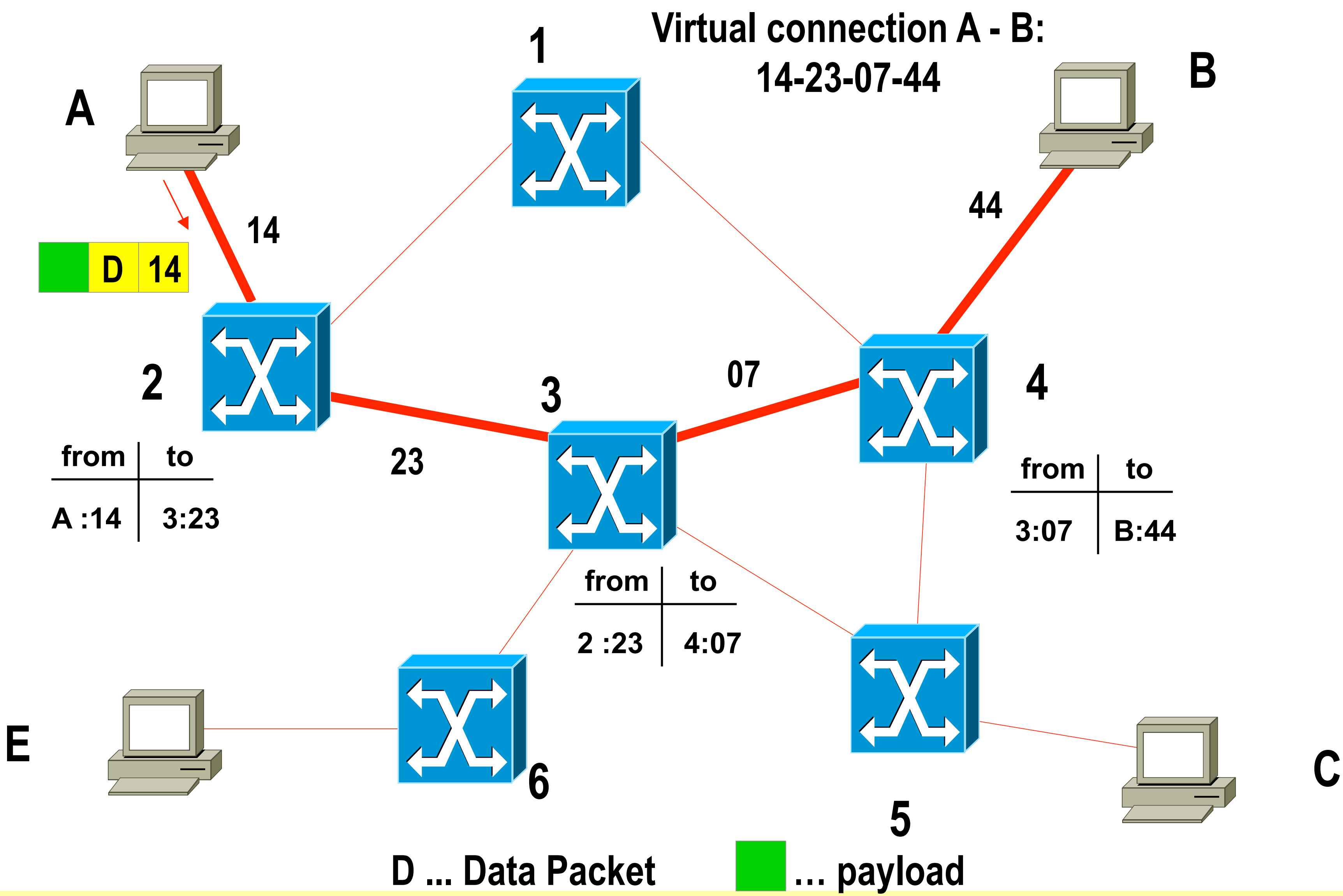
CA ... Call Accepted

Virtual Call Setup 6

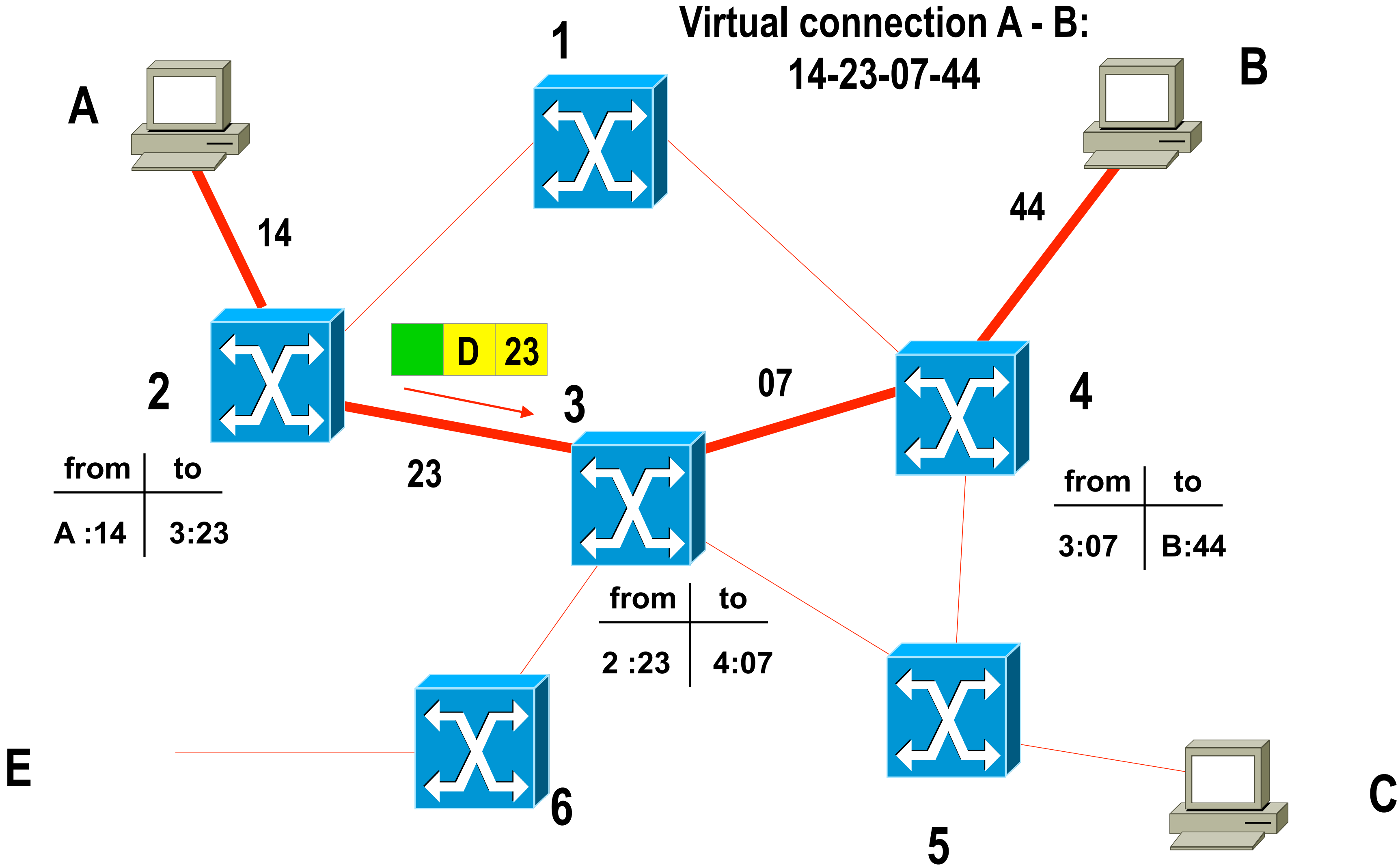


CA ... Call Accepted

Data Forwarding 1

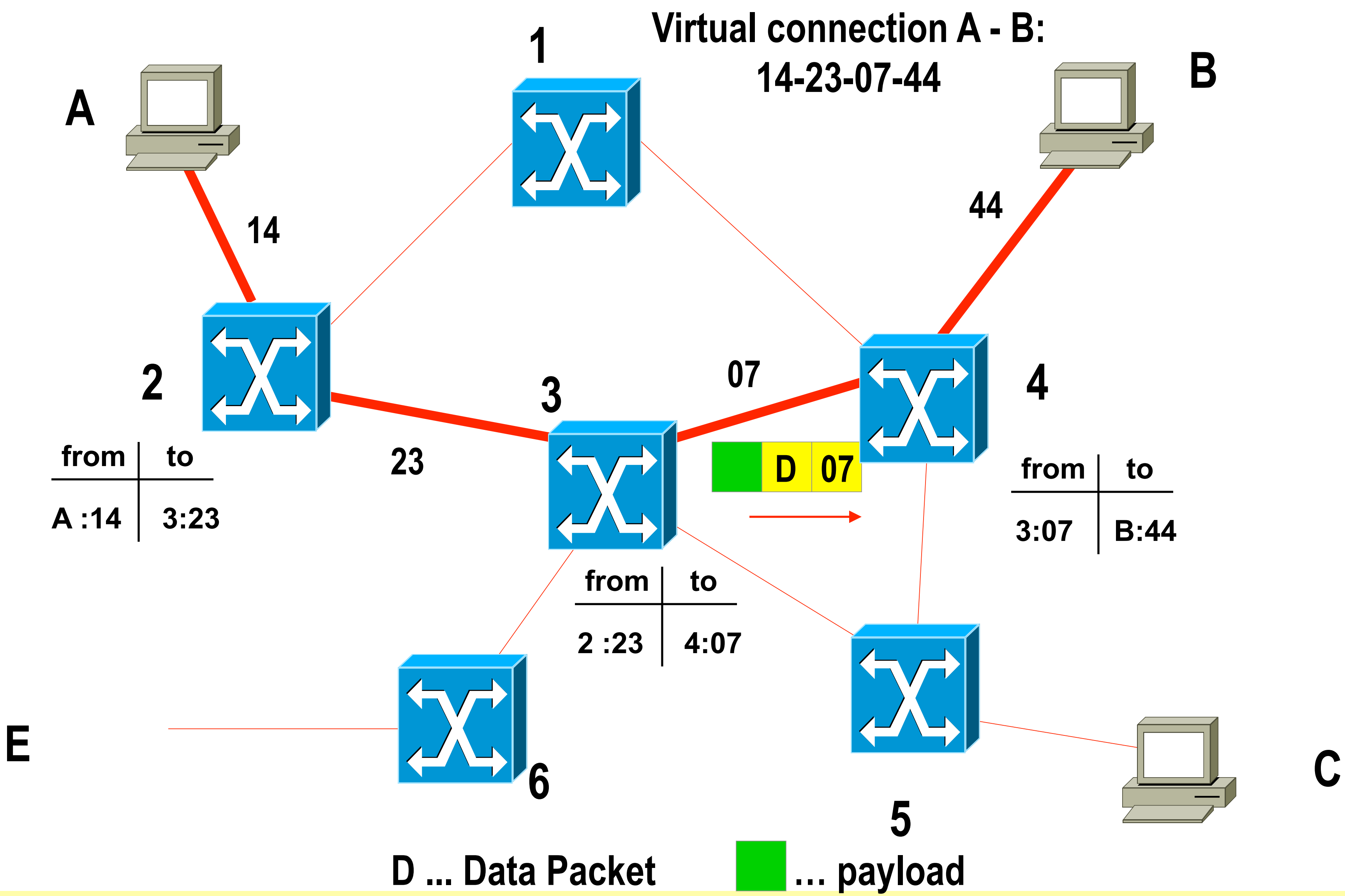


Data Forwarding 2

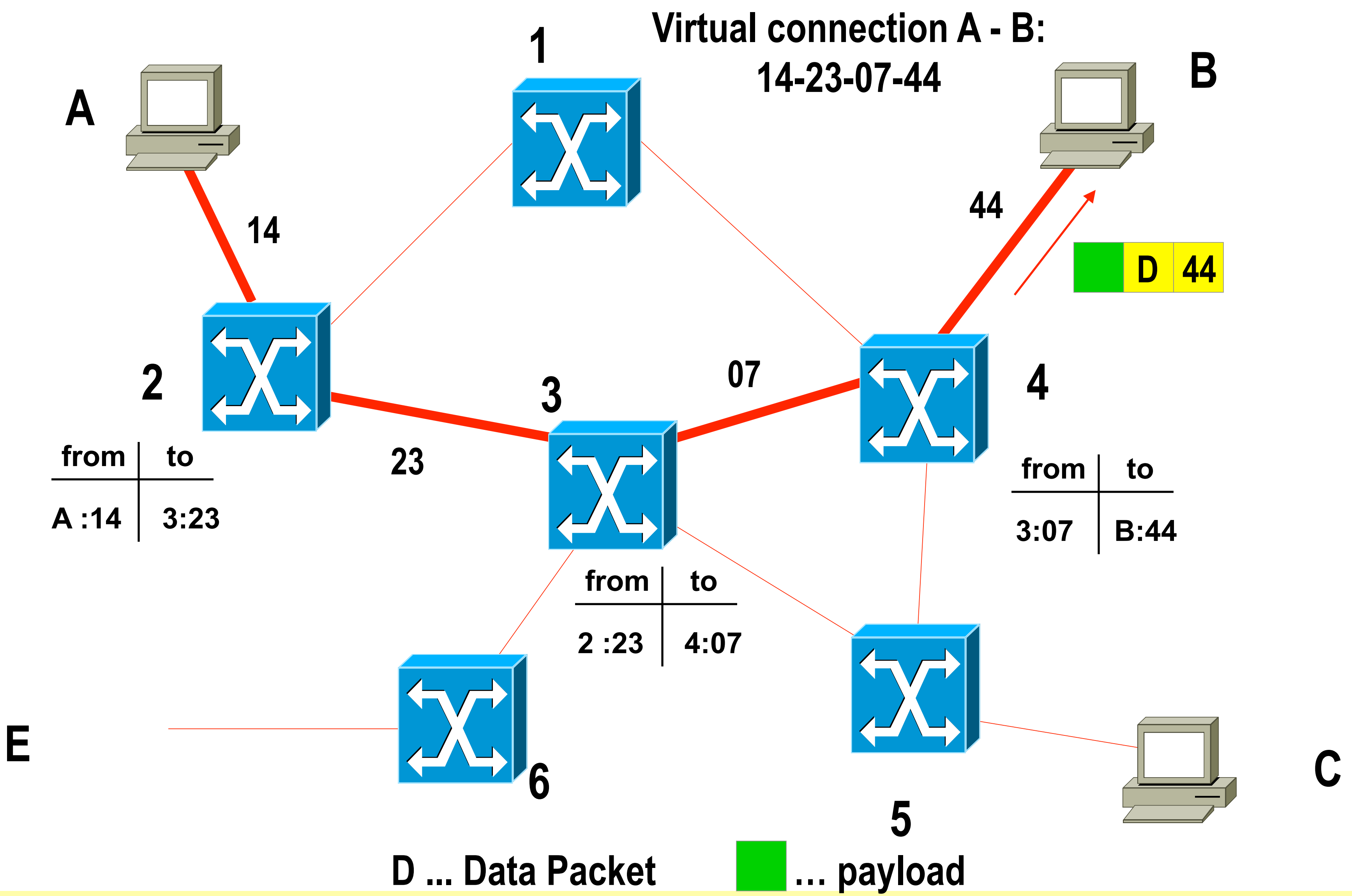


D ... Data Packet ... payload

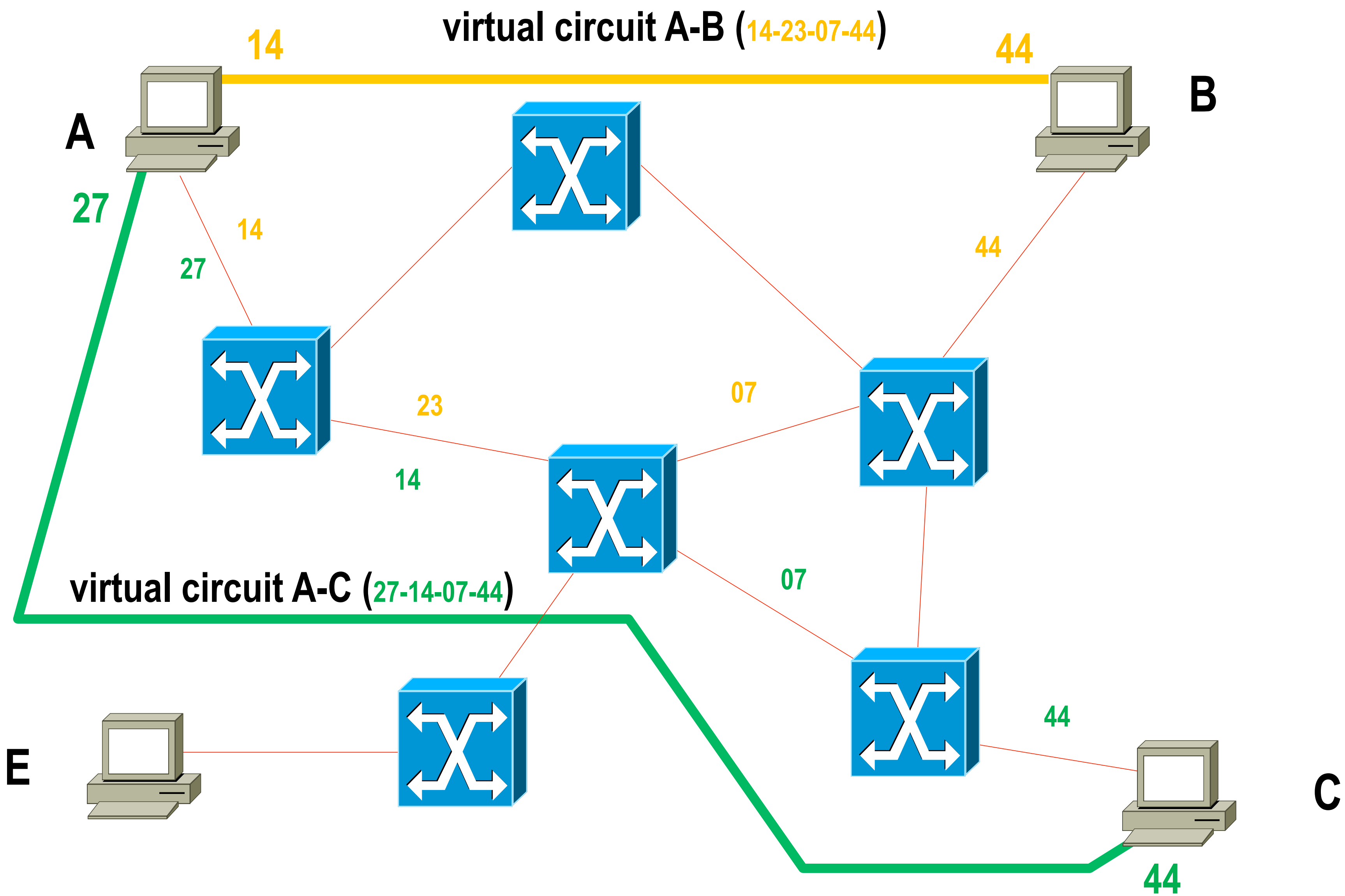
Data Forwarding 3



Data Forwarding 4



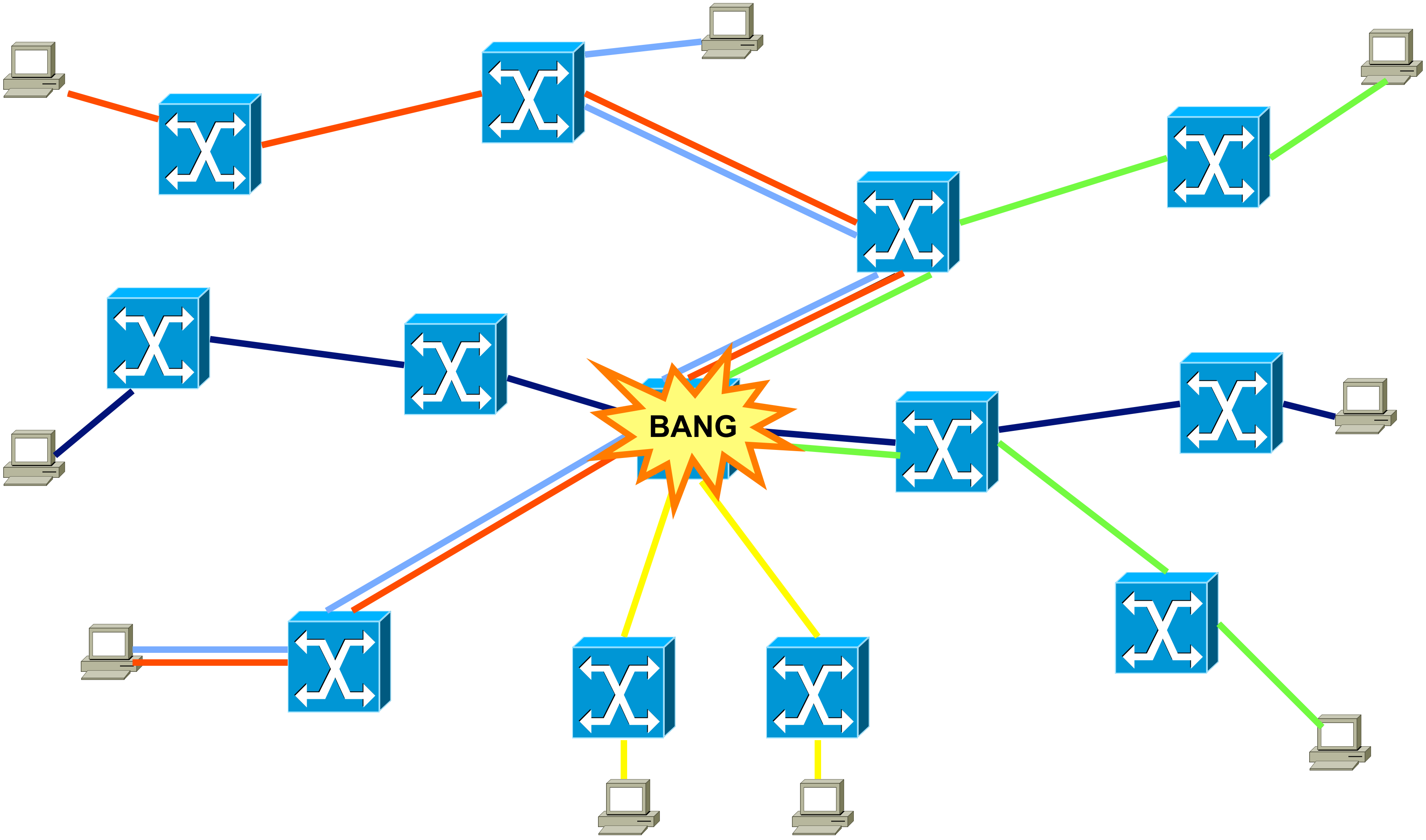
Multiplexing of Virtual Circuits



Virtual Call Service Facts (1)

- **The sequence of data packets is guaranteed by the network**
  - Packets can use the established path only
- **Path selection is done during connection setup**
  - Afterwards, entries of routing table are not used
- **In case of trunk line or packet switch failure**
  - Virtual circuits will be closed and must be reestablished again by end systems using call setup packets
  - If there is at least one redundant path, packet switches can establish a new virtual circuit taking the redundant path

Example



Virtual Call Service Facts (2)

- **Connection-oriented packet switching**
  - Allows flow control procedures between end system and packet switch because of connection-oriented approach
    - In connectionless packet switching networks flow control is not possible or only poorly implemented
  - Flow control procedures can avoid buffer overflow and hence network congestion
  - Allows reservation of resources
    - Capacity, buffers, cpu time, etc.
  - Can offer Quality of Service (QoS)
  - Call setup can be denied by network if QoS can not be guaranteed

Virtual Call Service Facts (3)

- **Advantages**
  - Required resources of packet switches can be reserved during call setup and hence QoS could be provided
  - End system view of the network
    - Reliable point-to-point transport pipe based on network internal error recovery, flow control and sequencing procedures (X.25)
    - Higher protocol layers can rely on network services (X.25)
  - Readiness for receipt is tested in advance
    - Call setup of SVC service
- **Disadvantages**
  - Call setup takes time
  - More complex protocols for end systems and packet switches than datagram service

Virtual Call – Summary (1)

- **Connection establishment**
  - Through routing process (!)
  - Globally unique topology-related addresses necessary
  - Creates entries in switching tables
  - Can reserve switching resources (QoS)
- **Packet forwarding relies on local identifiers**
  - Not topology related
  - Only unique per port
  - Swapping of local identifiers (labels) according to the switching table

Virtual Call – Summary (2)

- **Connection can be regarded as virtual pipe**
  - Sequence is guaranteed
  - Resources can be guaranteed
- **Virtual call multiplex**
  - Multiple virtual pipes per switch and interface possible
  - Pipes are locally distinguished through connection identifier
- **Network failures disrupt pipe**
  - Connection re-establishment necessary
  - Datagram networks are more robust

Network Technologies based on Virtual Call Method

- **X.25**
  - Reliable transport pipe because of protocol inherent error recovery and flow control
  - Local identifier = LCN
  - In-band signaling
- **Frame Relay**
  - Virtual circuit technique but no error recovery
  - Congestion indication instead of flow control
  - Local identifier = DLCI
  - Out-band signaling
- **ATM (Asynchronous Transfer Mode)**
  - Same as Frame Relay but packets with fixed length
  - Hence called cell switching
  - Local identifier = VPI/VCI
  - Out-band signaling

Agenda

- **Physical Aspects**
  - Serial Transmission, Coding
  - Framing, Delay Types
- **Protocol Basics**
  - Layering / CL versus CO
  - Error Recovery / Automatic Repeat Request (ARQ)
  - Windowing, Delay Bandwidth Product, Flow Control
- **TDM Basics**
  - Synchronous TDM
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  - Packet Switching
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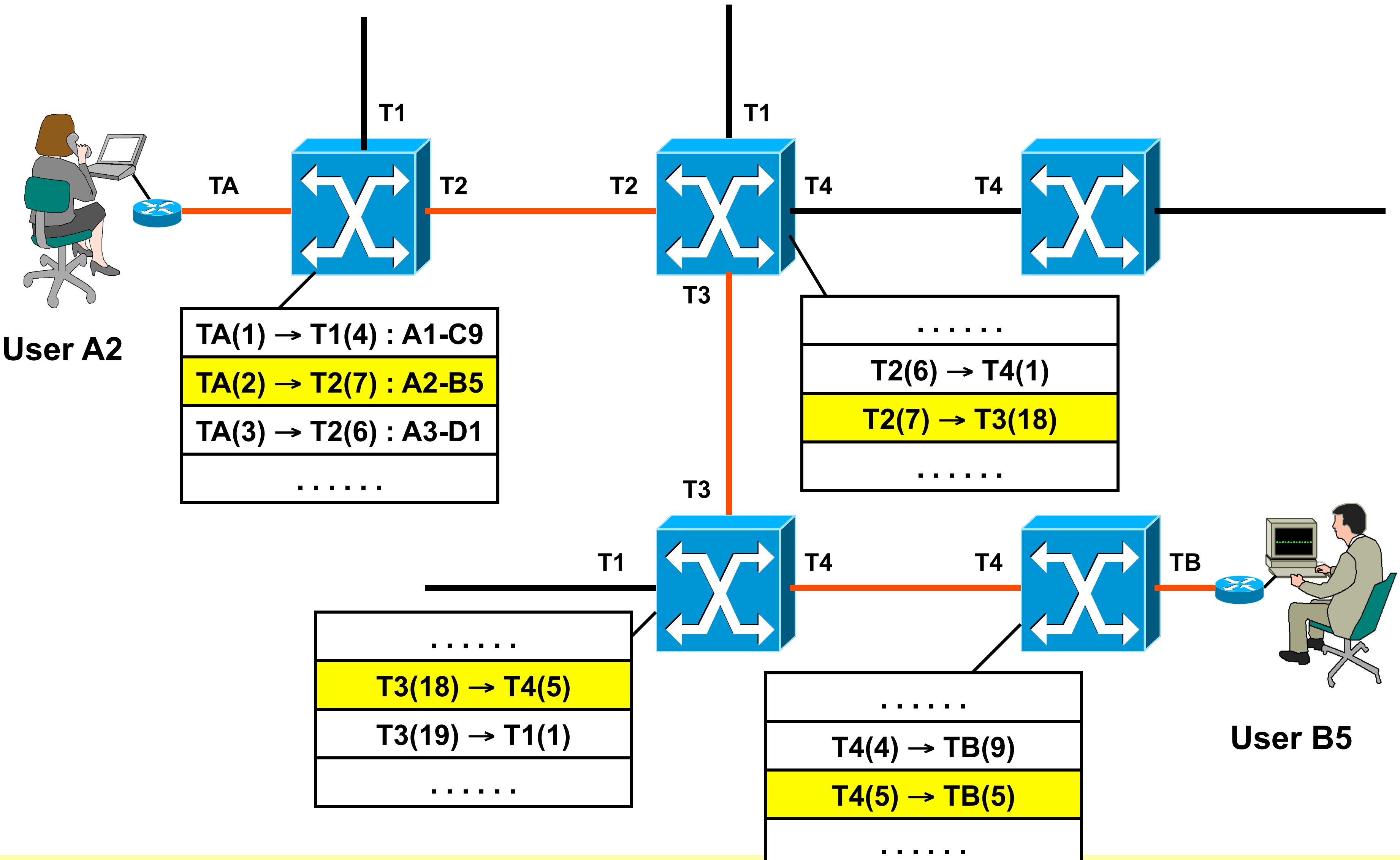
  - Summary
- **OSI Model – DoD Model**

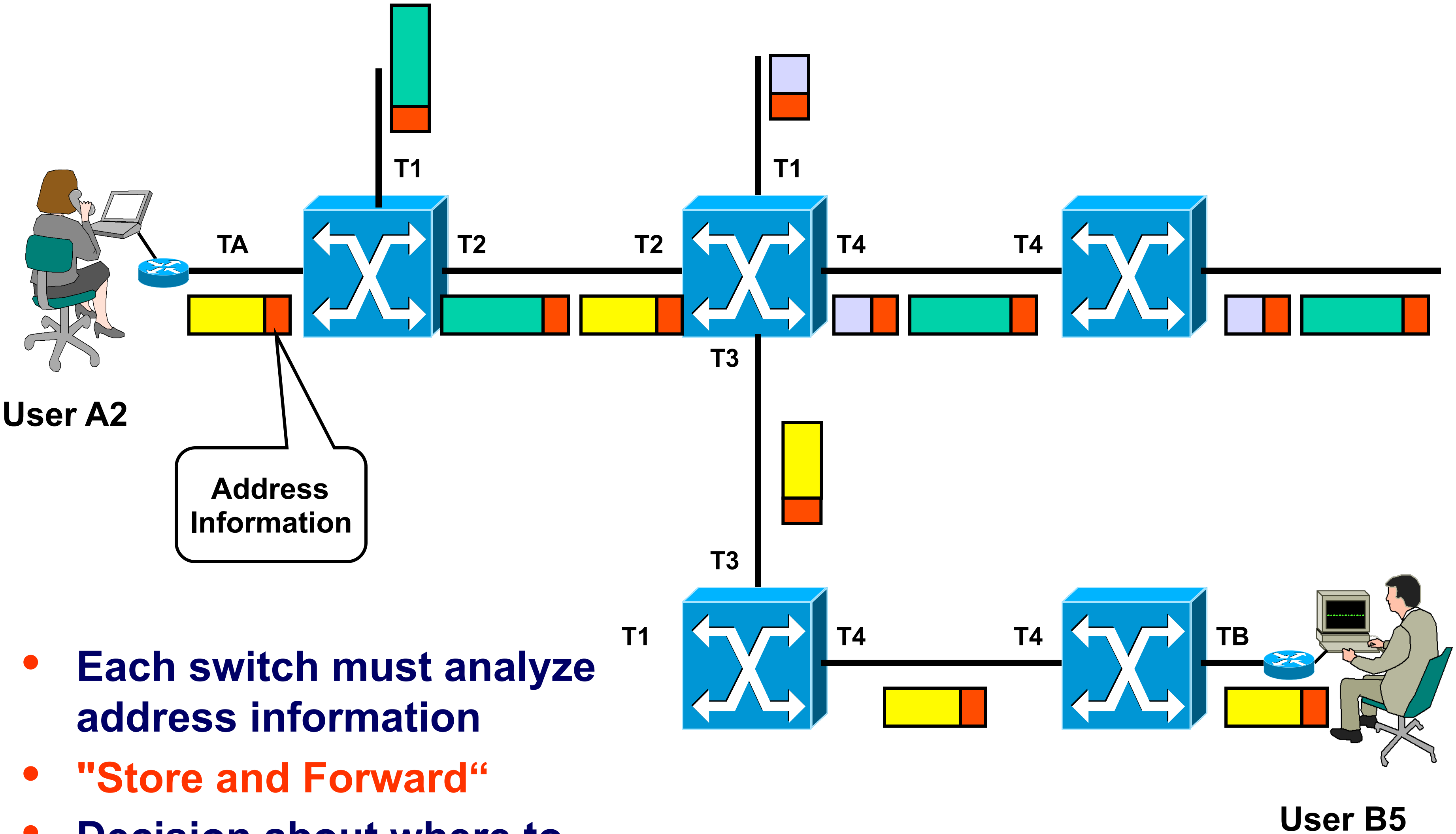
Summary

- **Only two fundamental network principles**
  - Circuit switching
  - Packet switching
  - The first is good for real-time voice (traffic) the latter is good for data traffic
  - But everybody wants to have the best of both worlds
- **Packet switching allows two basic types:**
  - Datagram (CL) versus Virtual Call (CO)
  - Different address types (!) for forwarding decision of data packet
    - Unique routable address (CL)
    - Local connection identifier (CO)

Circuit Switching

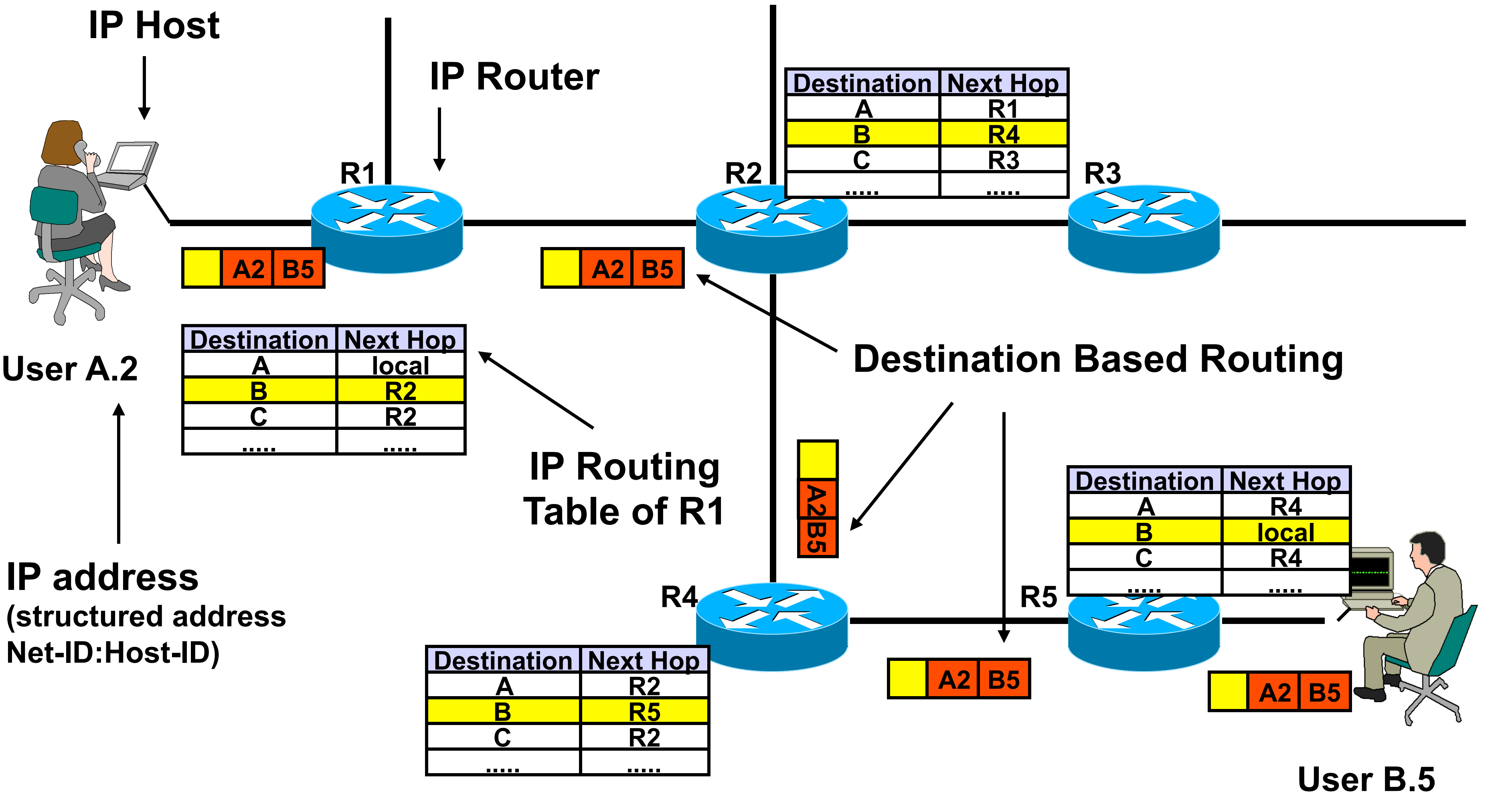


Packet Switching



- **Each switch must analyze address information**
- **"Store and Forward"**
- **Decision about where to forward is based on tables**

IP Datagram Service



IP Routing Table of R1:

Destination	Next Hop
A	local
B	R2
C	R2
.....	.....

Table at R2:

Destination	Next Hop
A	R1
B	R4
C	R3
.....	.....

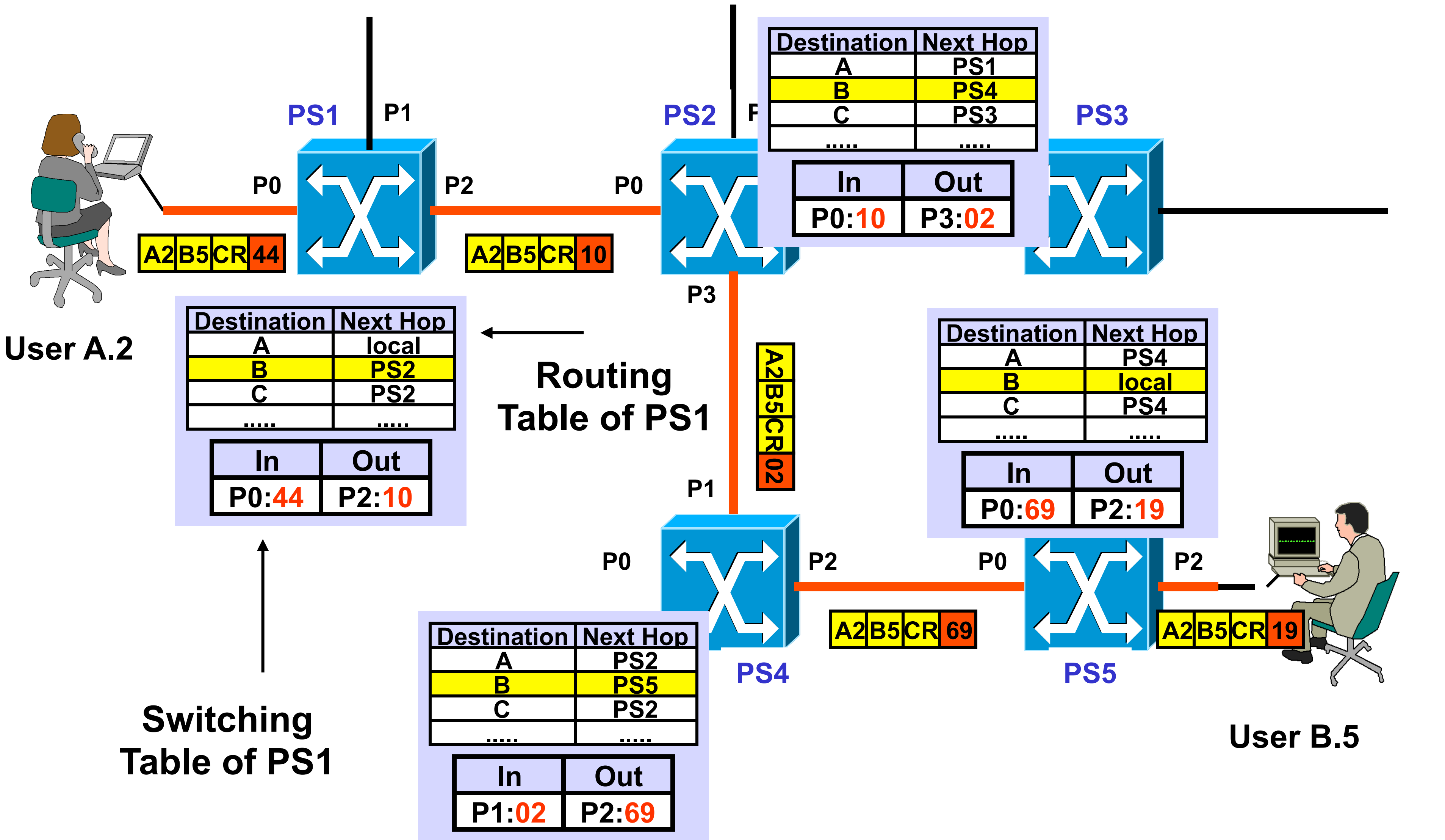
Table at R4:

Destination	Next Hop
A	R2
B	R5
C	R2
.....	.....

Table at R5:

Destination	Next Hop
A	R4
B	local
C	R4
.....	.....

Virtual Call – Call Request (CR)



PS1

Destination	Next Hop
A	local
B	PS2
C	PS2
.....	.....

In	Out
P0:44	P2:10

PS2

Destination	Next Hop
A	PS1
B	PS4
C	PS3
.....	.....

In	Out
P0:10	P3:02

PS4

Destination	Next Hop
A	PS2
B	PS5
C	PS2
.....	.....

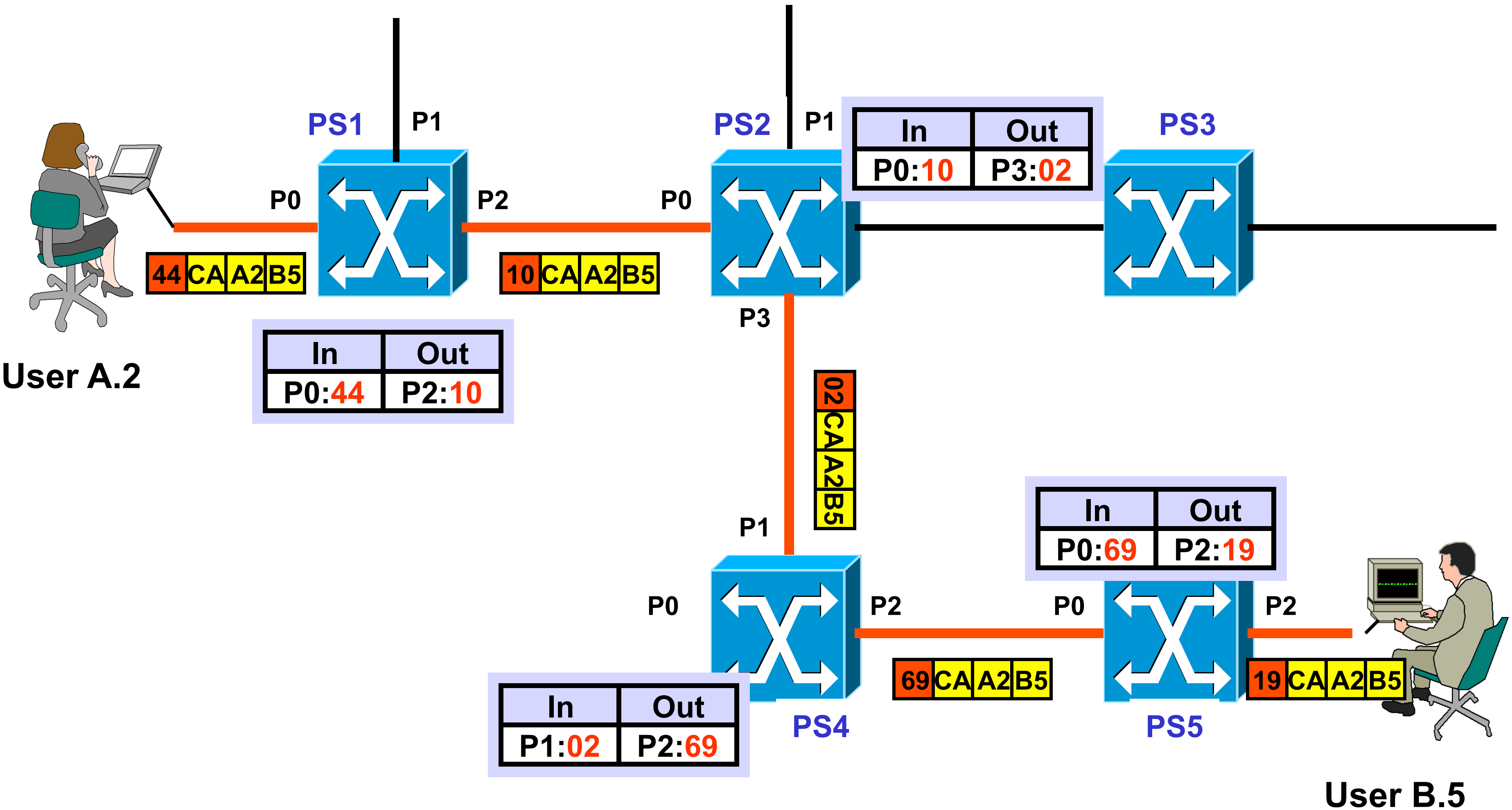
In	Out
P1:02	P2:69

PS5

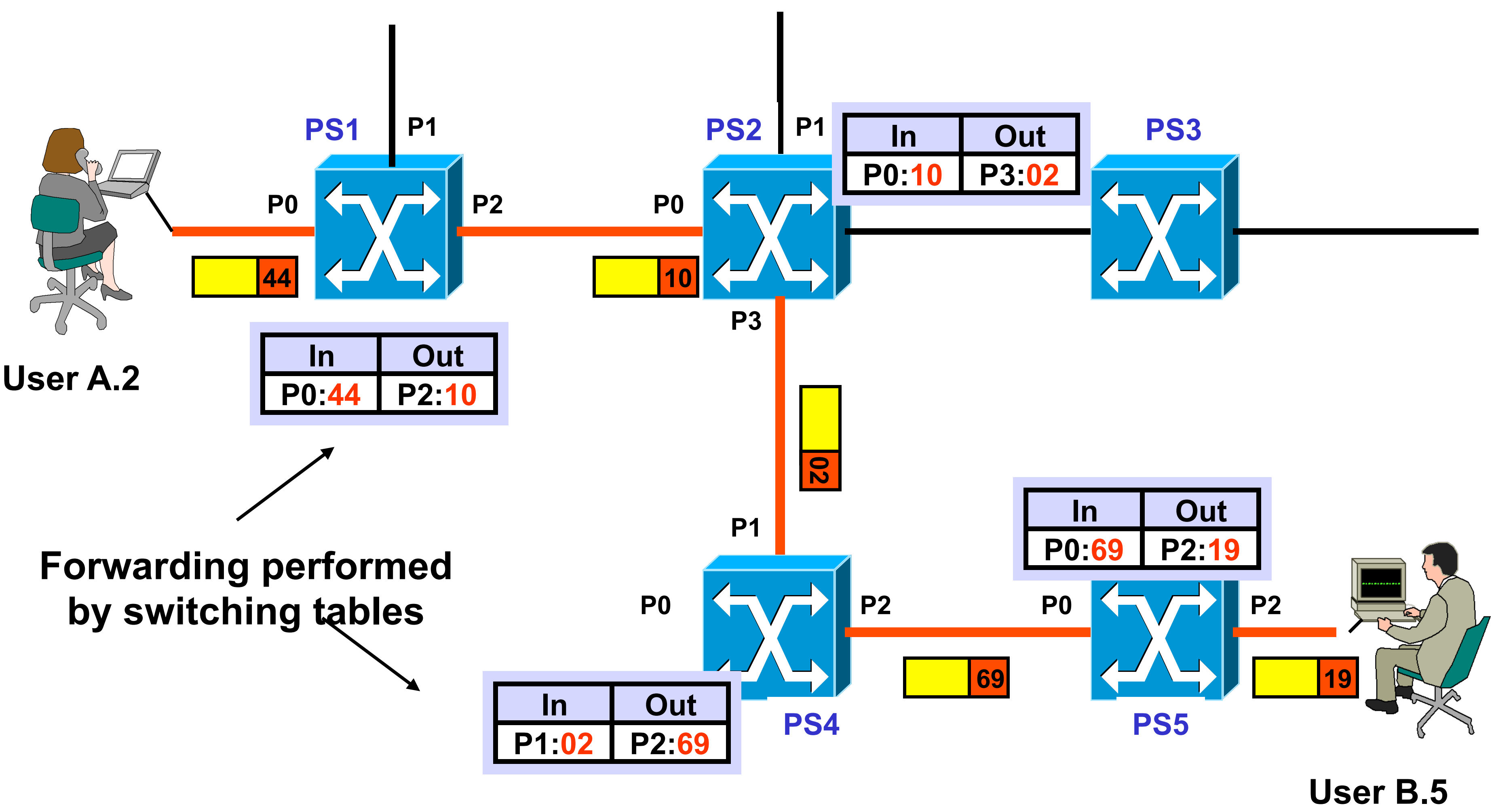
Destination	Next Hop
A	PS4
B	local
C	PS4
.....	.....

In	Out
P0:69	P2:19

Virtual Call – Call Accepted (CA)



Virtual Call – Data Transfer



Taxonomy of Network Technologies

Circuit Switching

- Synchronous (Deterministic) Multiplexing
- Low latency (constant delay)
- Designed for isochronous traffic

Dynamic Signalling

Q.931, SS7, ...

ISDN

Static Configuration

Manual configuration

PDH
SONET/SDH

Packet Switching

- Asynchronous (Statistical) Multiplexing
- Store and forward (variable delay)
- Addressing necessary
- Designed for data traffic

Datagram

Connectionless

IP
IPX
AppleTalk

Virtual Call

Connection-oriented

X.25
Frame Relay
ATM

Agenda

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  - Framing, Delay Types
- **Protocol Basics**
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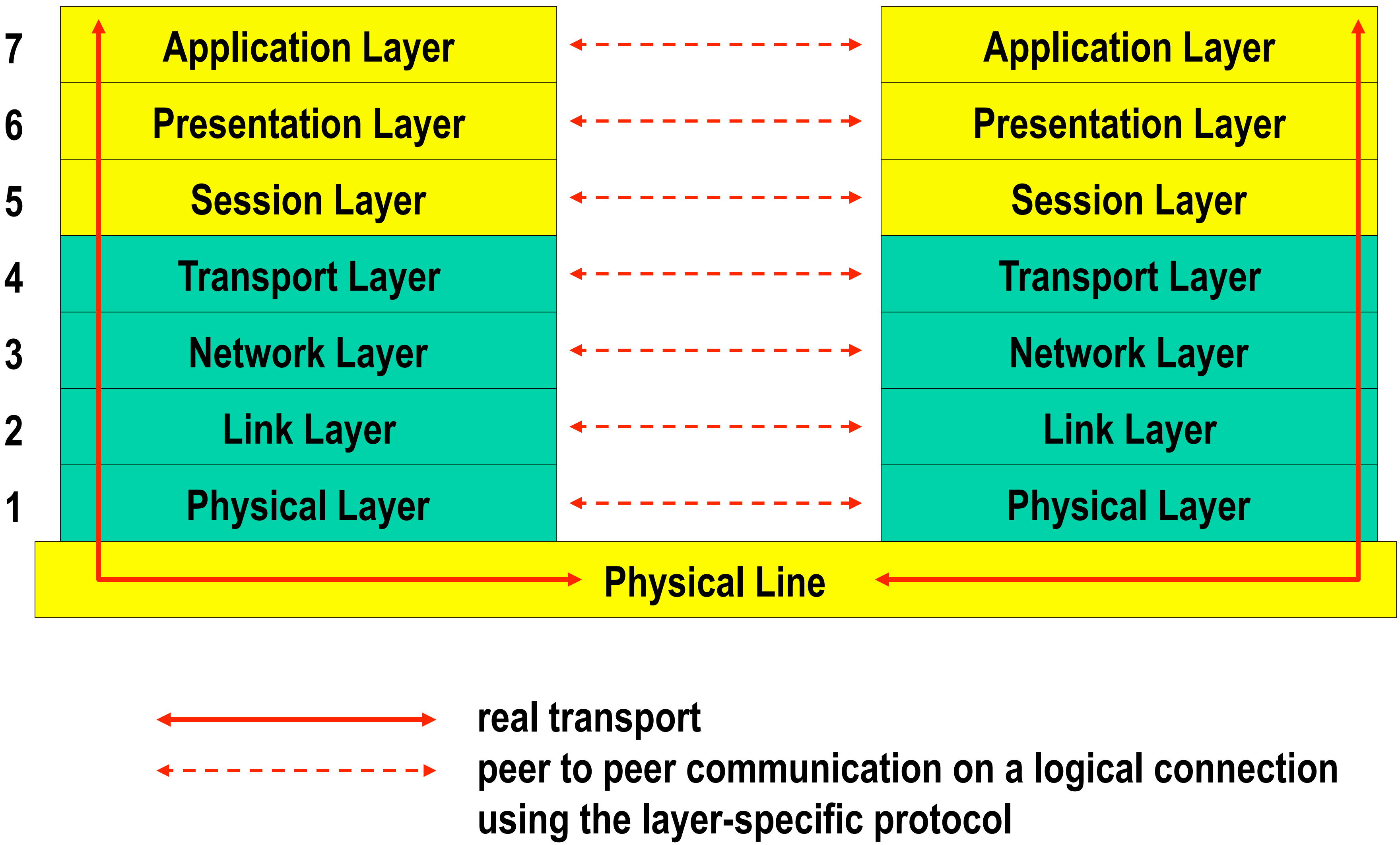
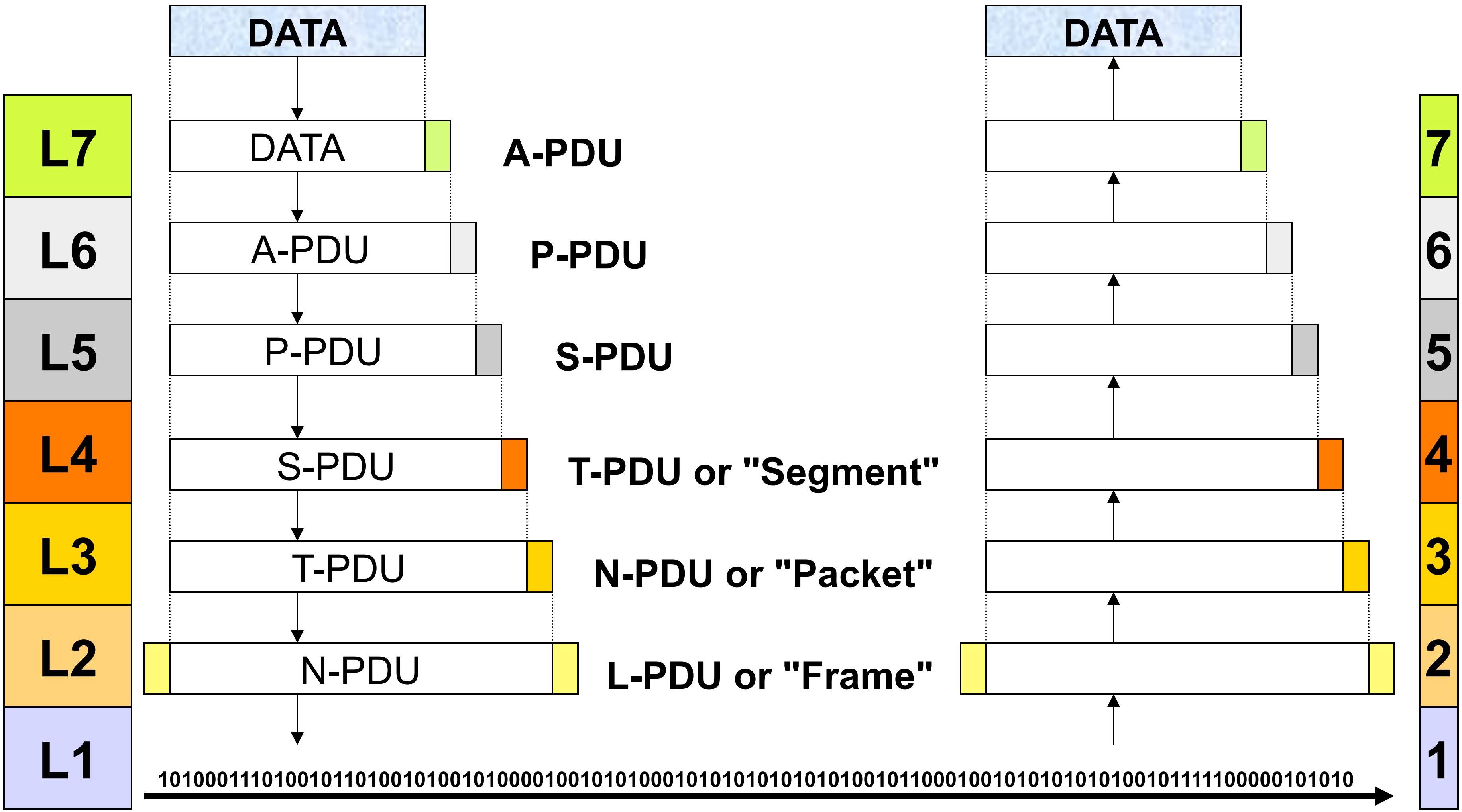
- **OSI Model – DoD Model**

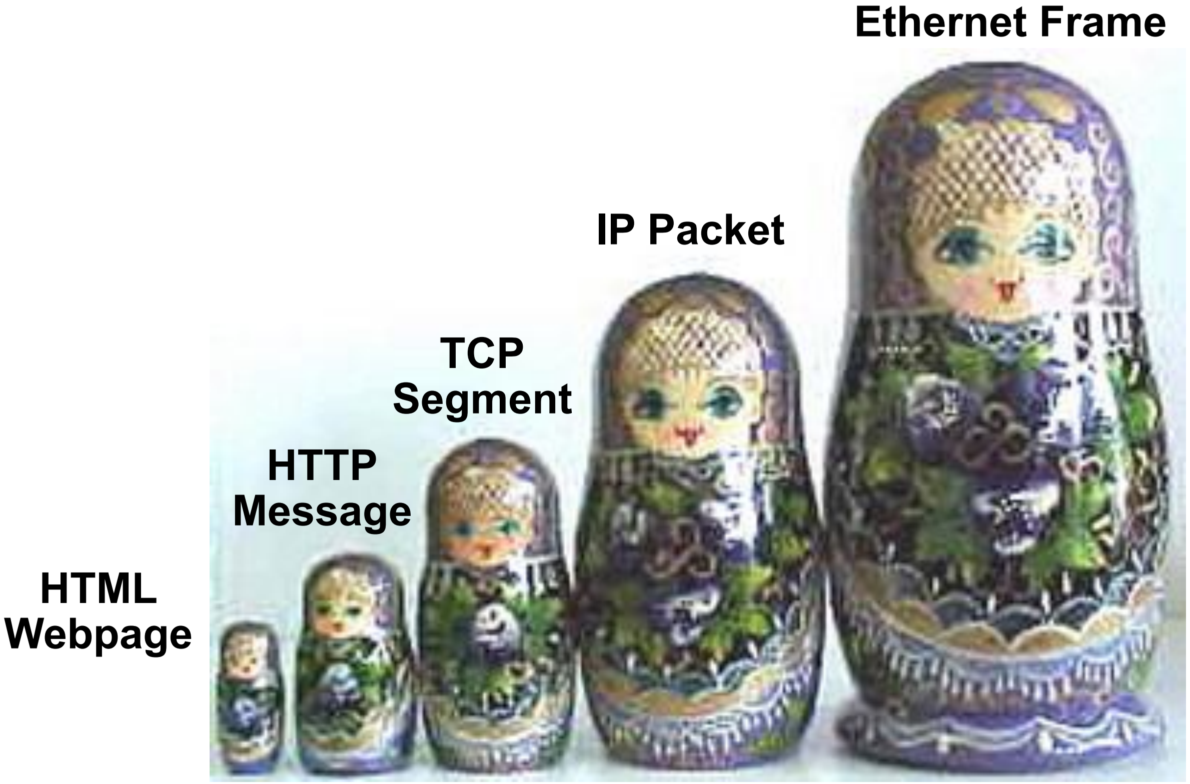
The 7 OSI Layers



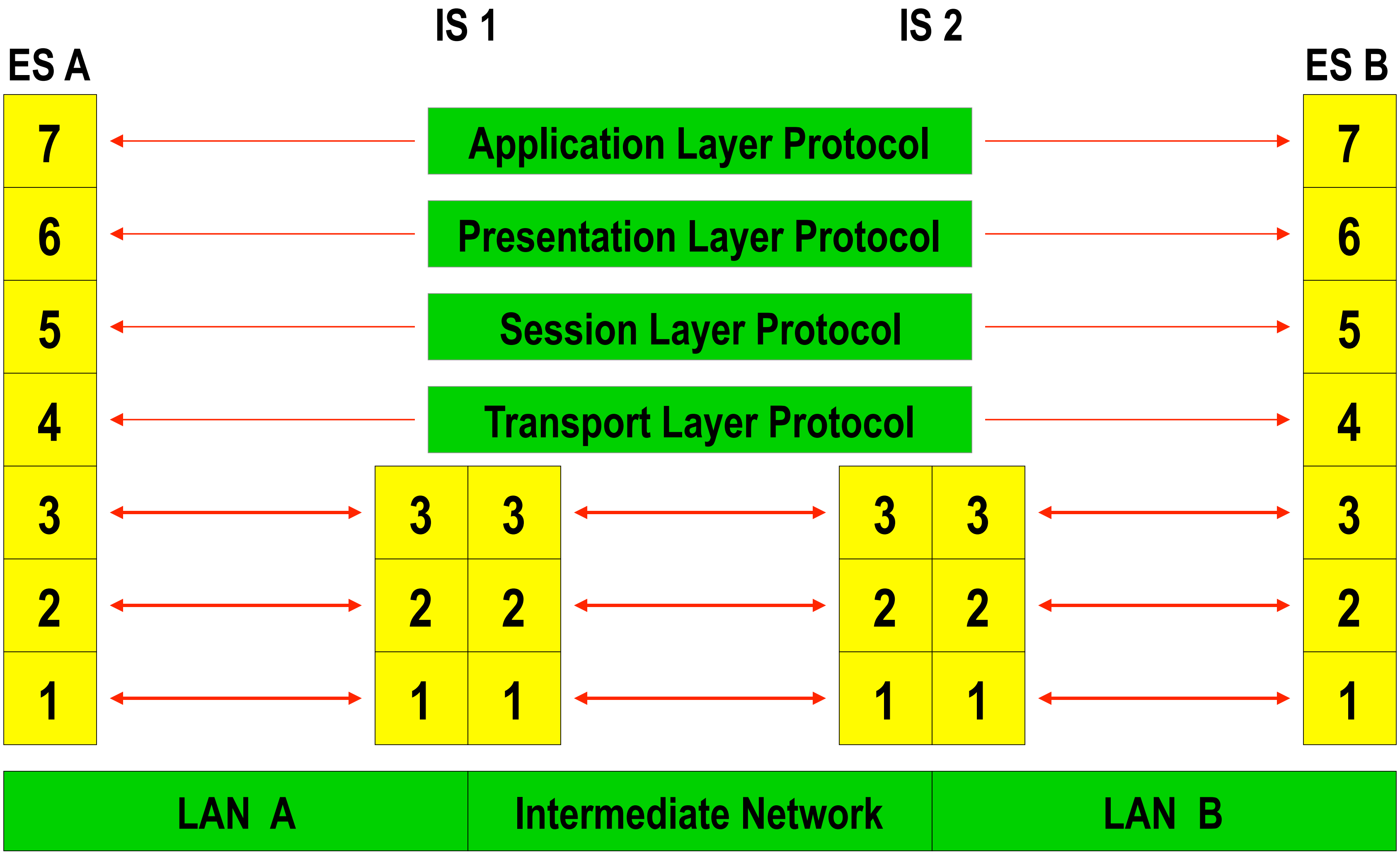
Encapsulation and Decapsulation Principle



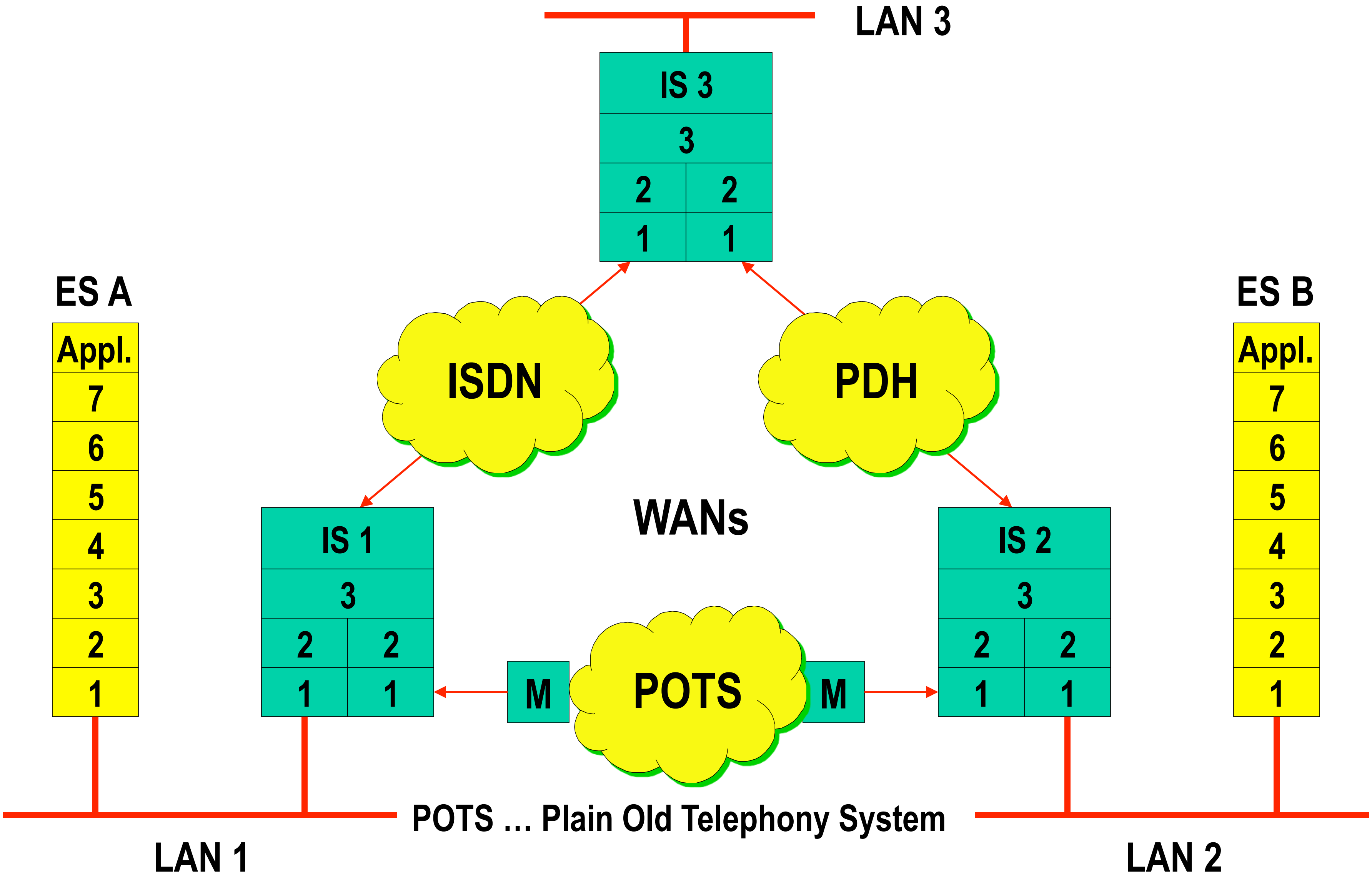
Practical Encapsulation



OSI Model with Intermediate Systems



Example Topology with ES and IS



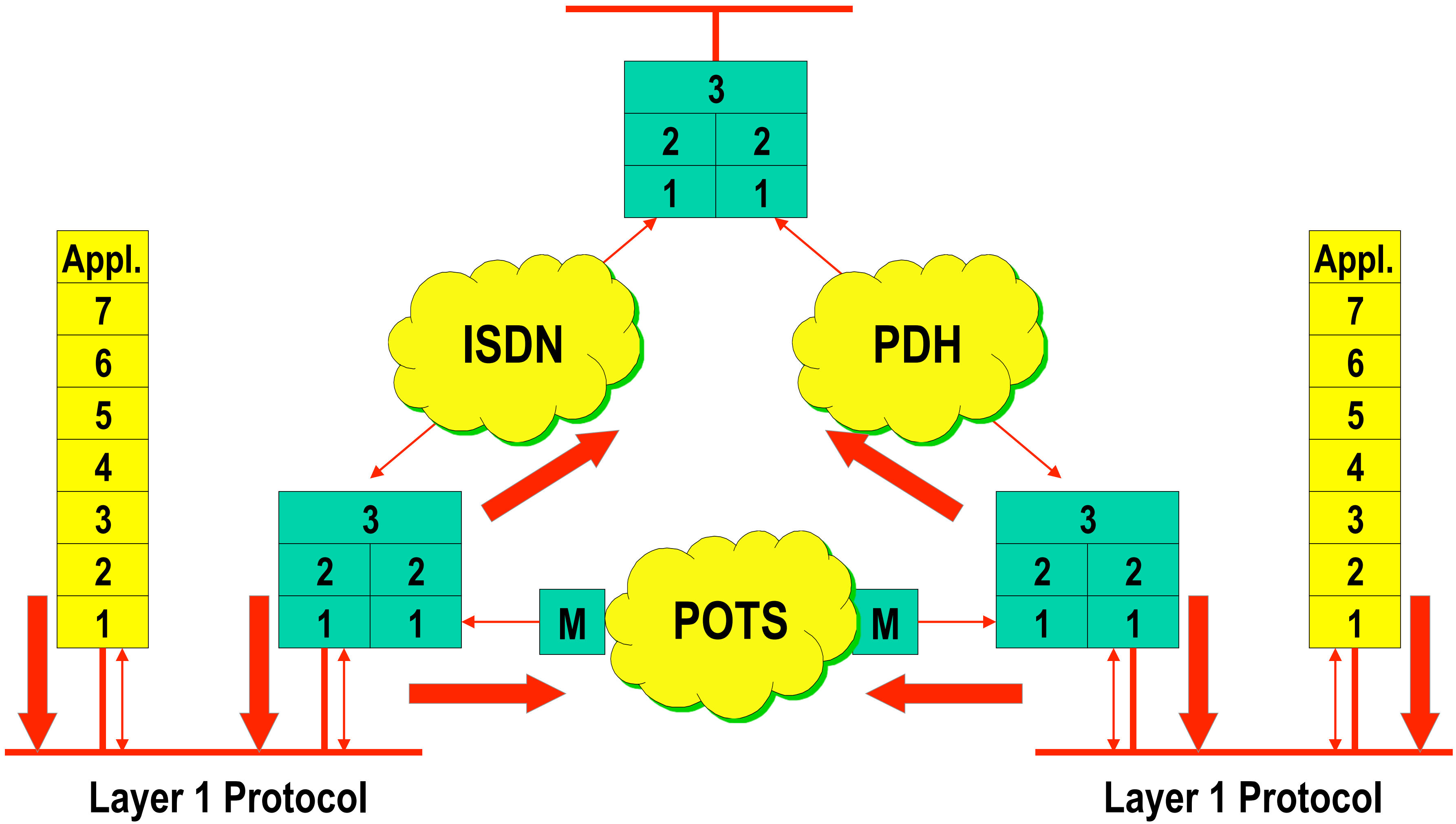
POTS … Plain Old Telephony System

Physical Layer (1)

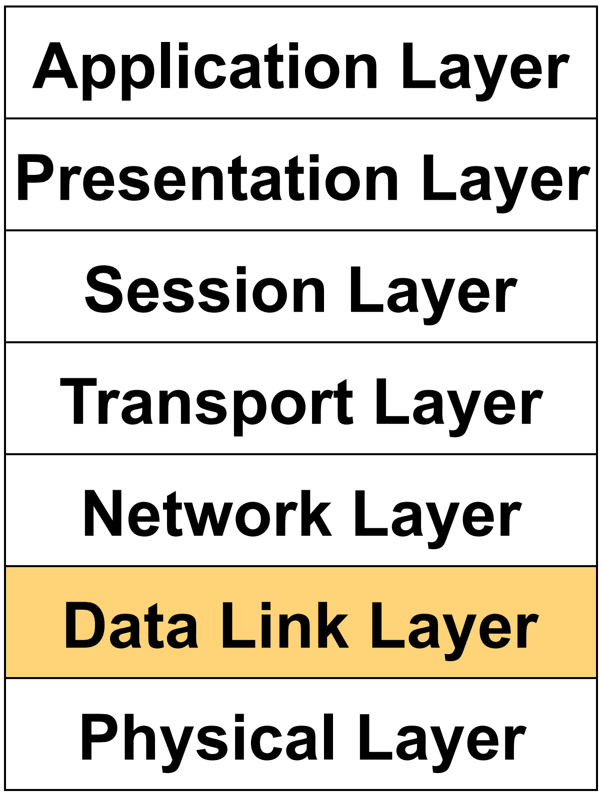
Application Layer
Presentation Layer
Session Layer
Transport Layer
Network Layer
Data Link Layer
Physical Layer

- **Mechanical and electrical specifications**
- **Access to physical medium**
- **Generates bit stream**
- **Line coding and clocking**
- **Bit synchronization**
- **Link management**
- **Examples**
  - LAN: Ethernet-PHY, 802.3-PHY
  - WAN: X.21, I.400 (ISDN), RS-232

Physical Layer (1)

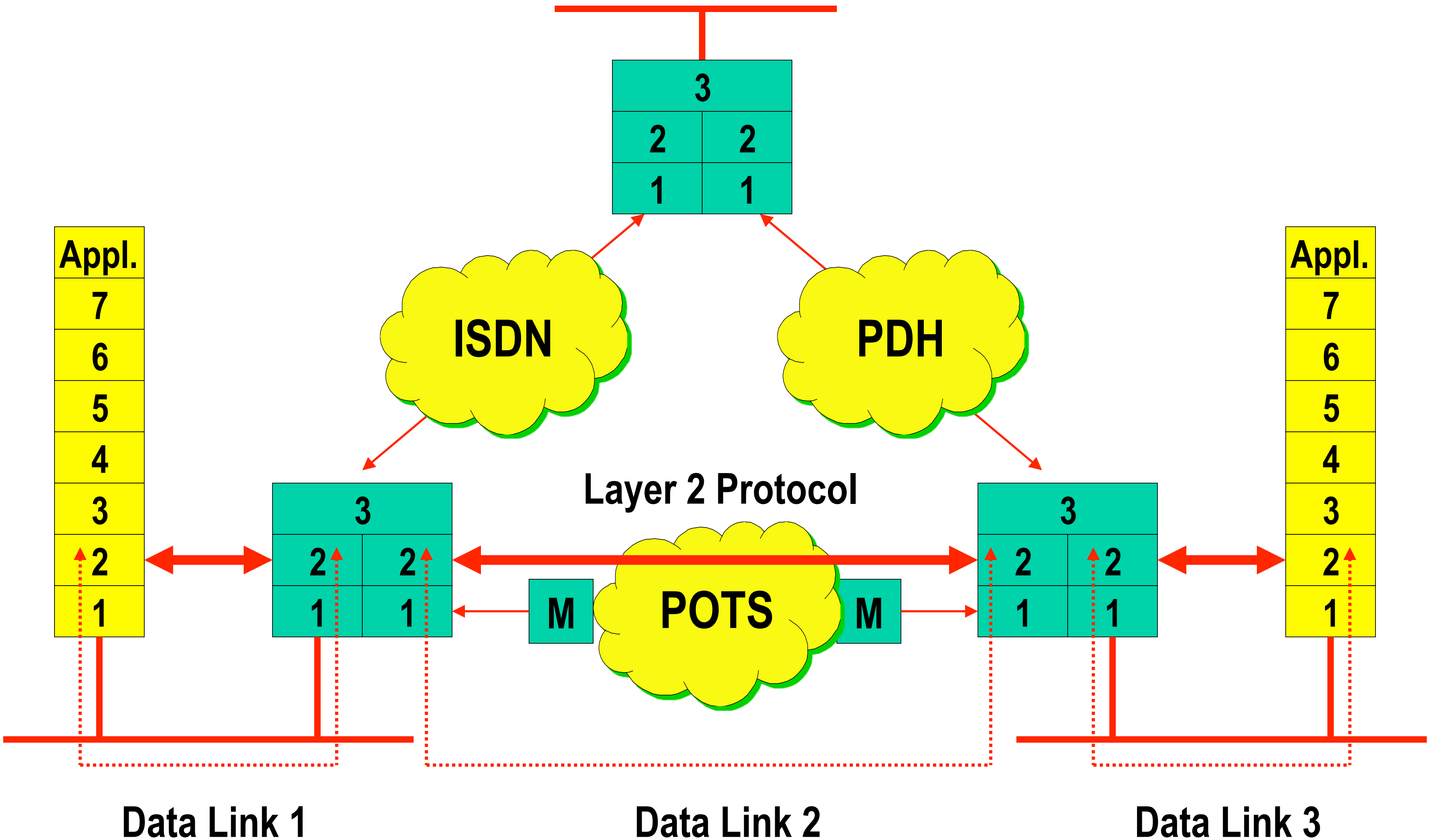


Data Link Layer (2)



- **Reliable transmission of *frames* between two NICs**
- **Framing**
- **Frame Synchronization**
- **FCS**
- **Physical Addressing of NICs**
- **Optional error recovery**
- **Optional flow control**
- **Examples:**
  - LAN: 802.2
  - PPP, LAPD, LAPB, HDLC

Data Link Layer (2)

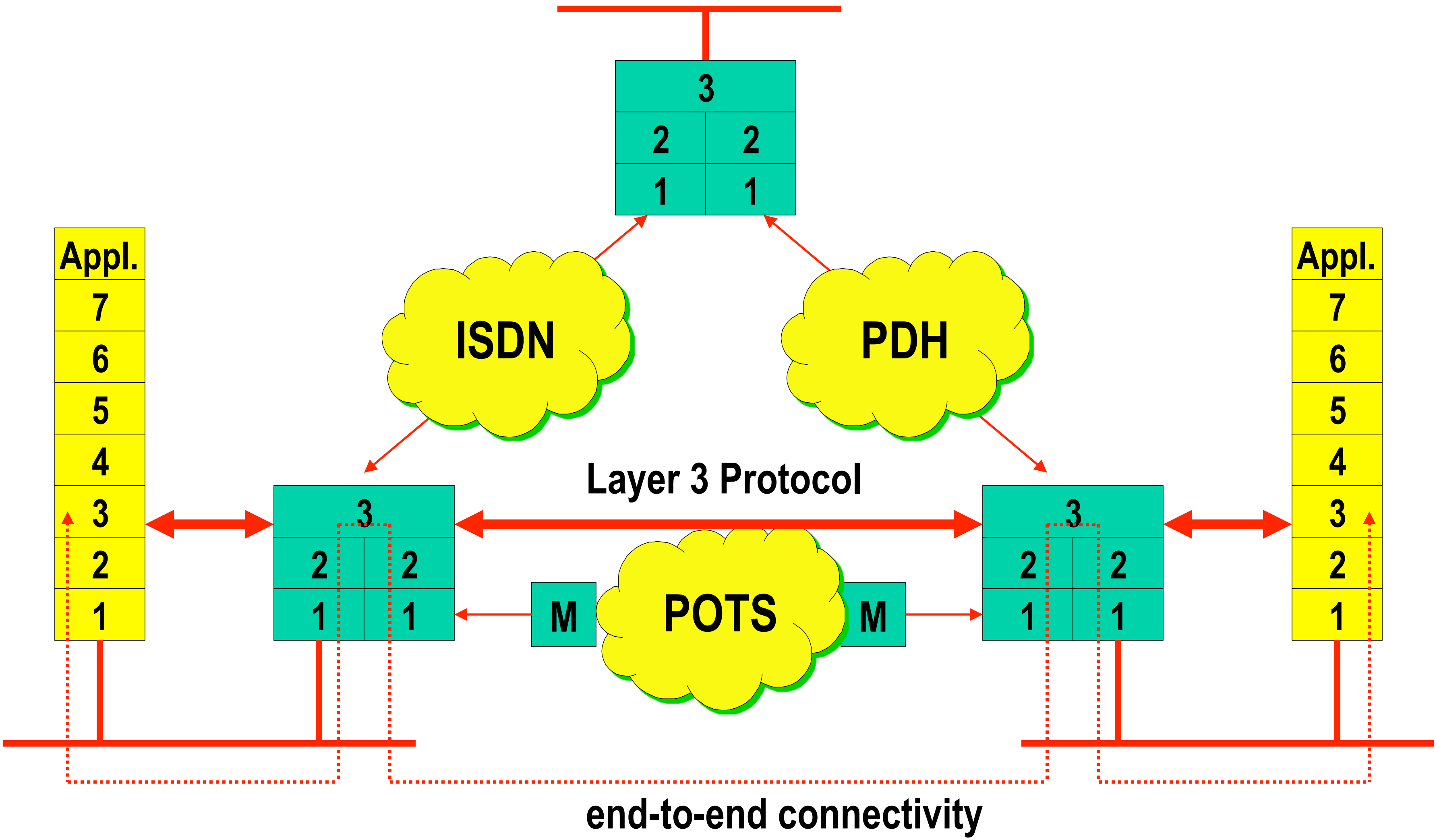


Network Layer (3)

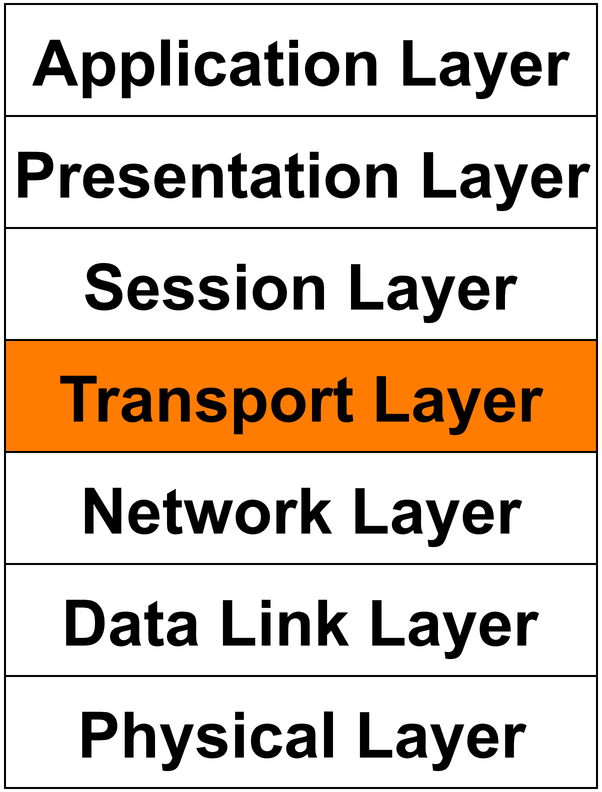
Application Layer
Presentation Layer
Session Layer
Transport Layer
Network Layer
Data Link Layer
Physical Layer

- **Transports *packets* over packet switching networks**
  - Routing / Switching
- **Provides structured addresses to name networks**
  - N-SAP address
- **Fragmentation and reassembling**
- **Examples:**
  - CLNP
  - IP, IPX
  - Q.931, X.25

Network Layer (3)

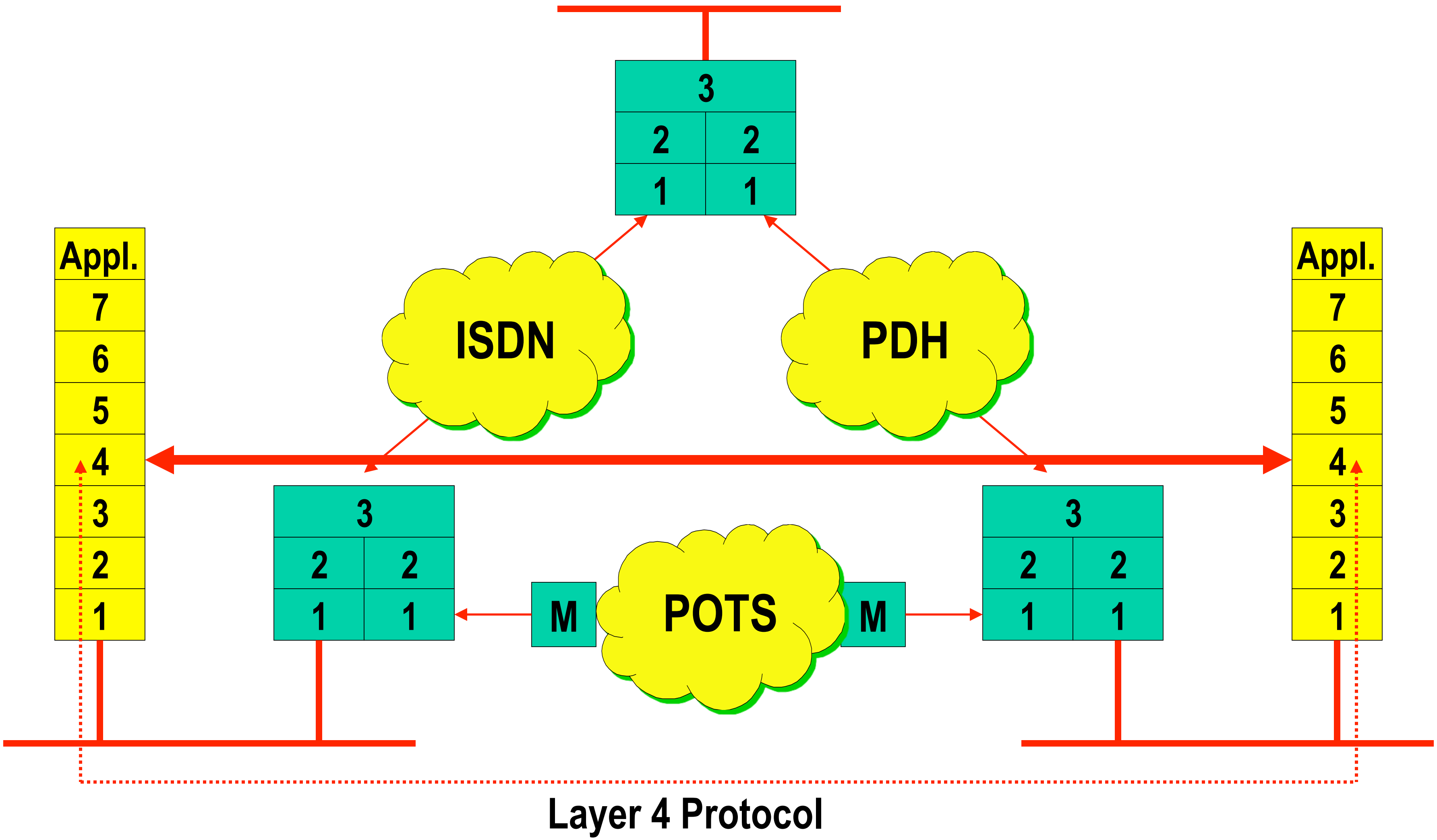


Transport Layer (4)

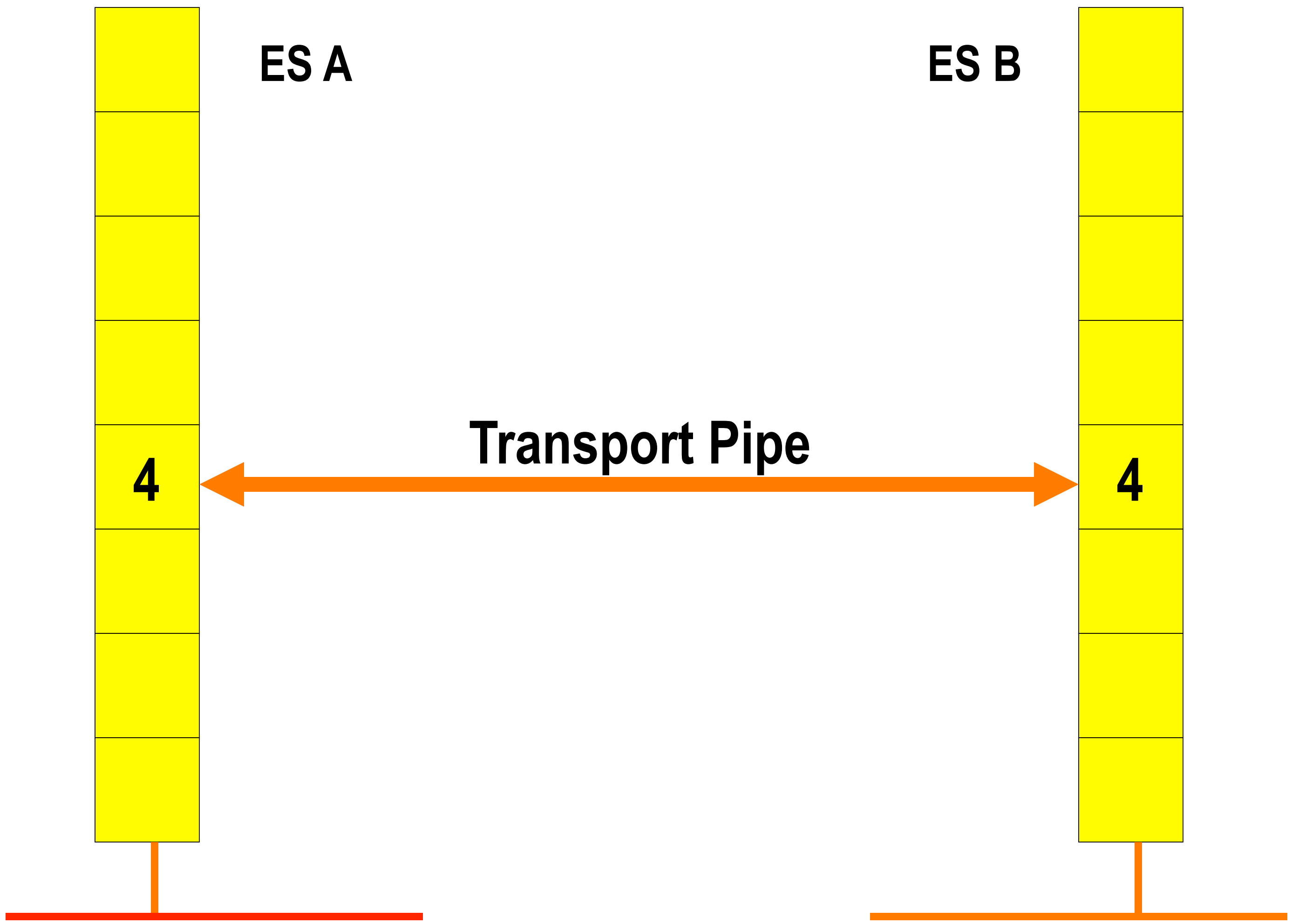


- **Transport of *segments* between applications (end systems)**
  - Reliable if error recovery by ARQ
- **Application multiplexing through T-SAPs**
  - Transport Addresses
- **Sequence numbers and Flow control**
- **Optional QoS Capabilities**
- **Examples:**
  - TCP (UDP)
  - ISO 8073 Transport Protocol

Transport Layer (4)



How Layer 5 sees the Network



Functions of Higher Layers

- **Layer 5 (session layer)**
  - Coordinates and controls dialogue between different end systems
- **Layer 6 (presentation layer)**
  - Responsible for common language between end systems (conversion, adaptation of data)
- **Layer 7 (application layer)**
  - Supports user with common network applications (e.g. file transfer, virtual terminal) or basic network procedures in order to implement distributed applications (e.g. transaction systems)

Session Layer (5)

Application Layer
Presentation Layer
Session Layer
Transport Layer
Network Layer
Data Link Layer
Physical Layer

- **Provides a user-oriented connection service**
  - *Synchronization Points*
- **Little capabilities, usually not implemented or part of application layer**
  - Telnet: GA and SYNCH
  - FTP: re-get allows to continue an interrupted download
  - ISO 8327 Session Protocol

Presentation Layer (6)

Application Layer
Presentation Layer
Session Layer
Transport Layer
Network Layer
Data Link Layer
Physical Layer

- **Specifies the data representation format for the application**
- **Examples:**
  - MIME (part of L7) and UUENCODING (part of L7)
  - ISO: ASN.1 and BER

Application Layer (7)

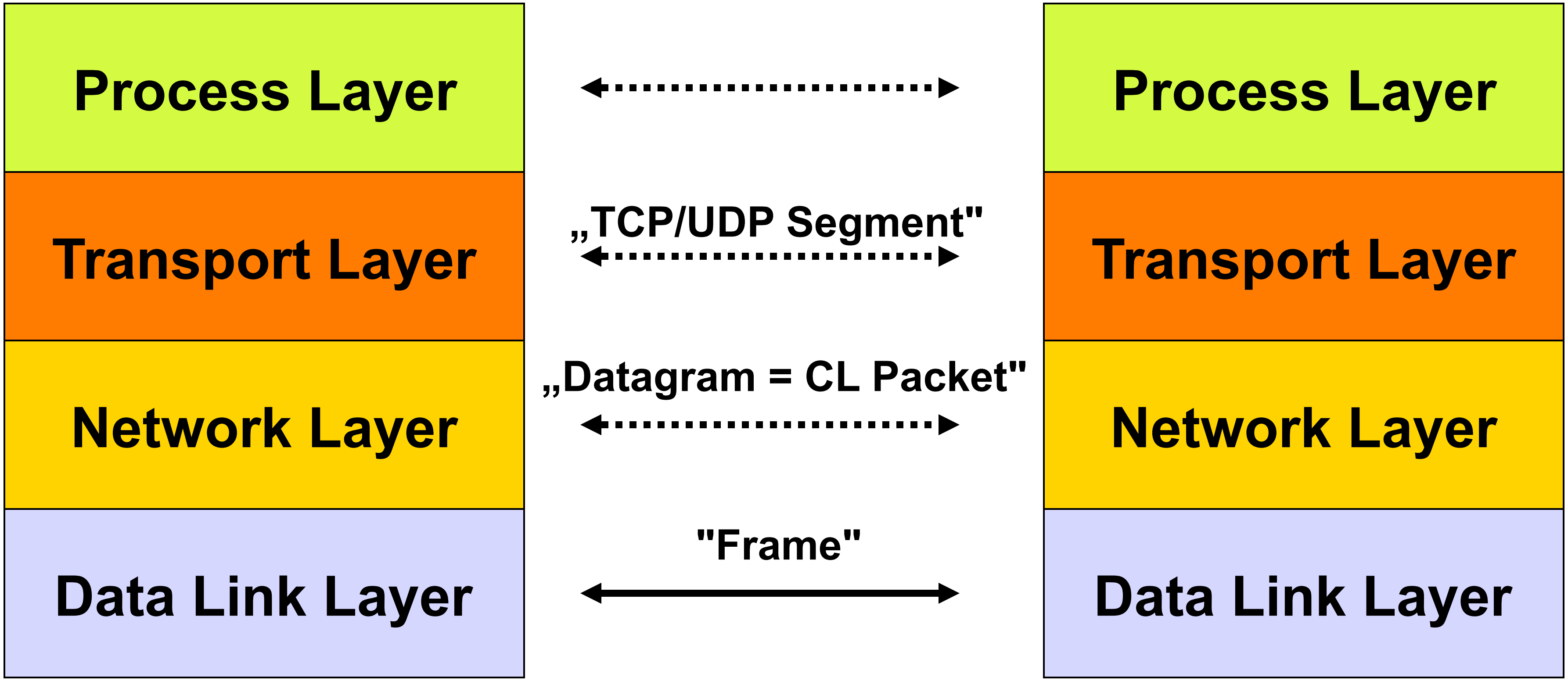
Application Layer
Presentation Layer
Session Layer
Transport Layer
Network Layer
Data Link Layer
Physical Layer

- **Provides network-access for applications**
- **Examples:**
  - ISO 8571 FTAM File Transfer Access + Management,
    X.400 Electronic Mail, CMIP
  - SMTP, FTP, SNMP, HTTP, Telnet, DNS, …

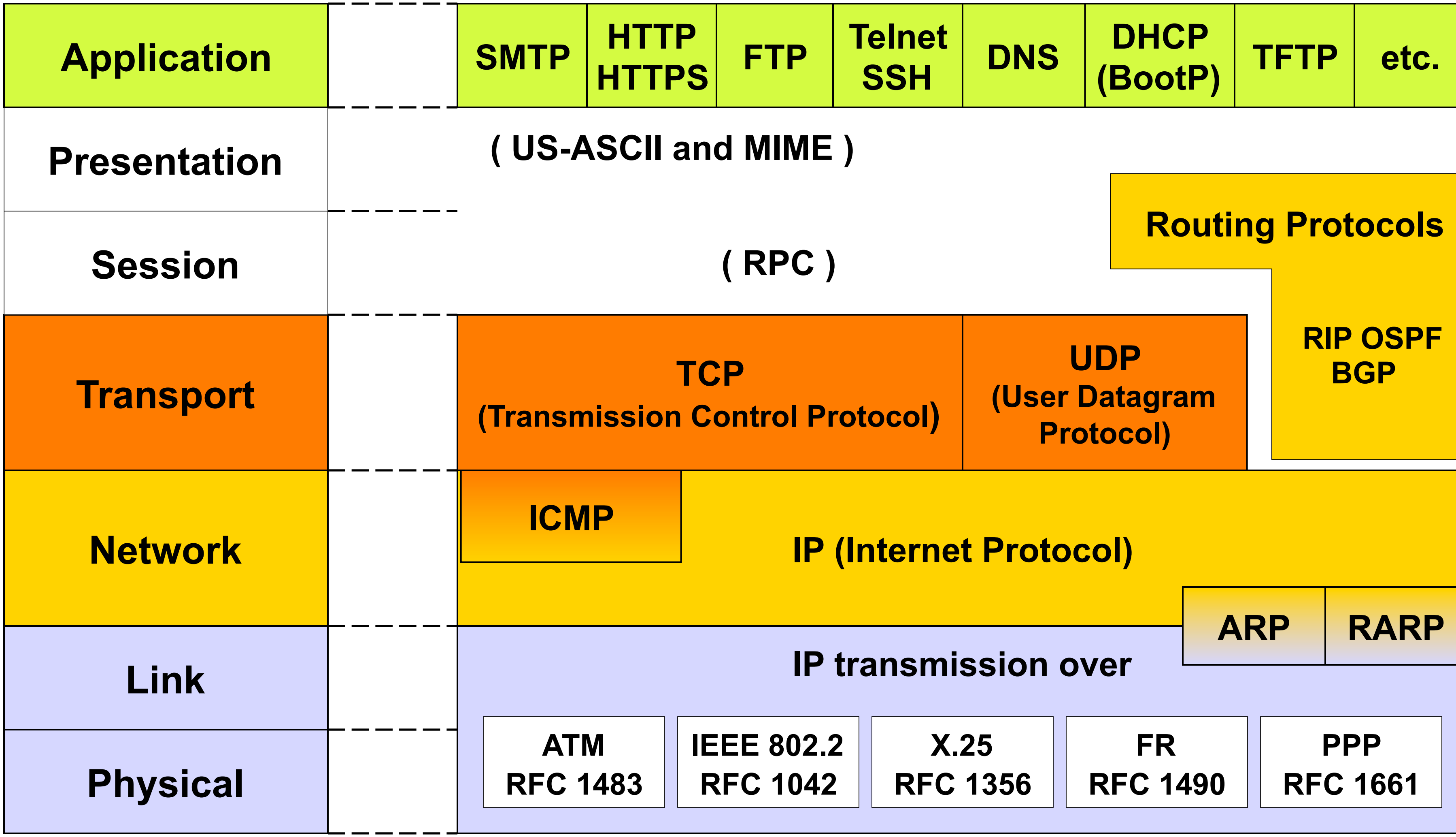
Padlipsky's Rule

If you know what you're doing, three layers is enough. If you don't, even seventeen won't help.

DoD 4-Layer Model (Internet)



TCP/IP Protocol Suite



The Internet perspective is implement it, make it work well, then write it down.

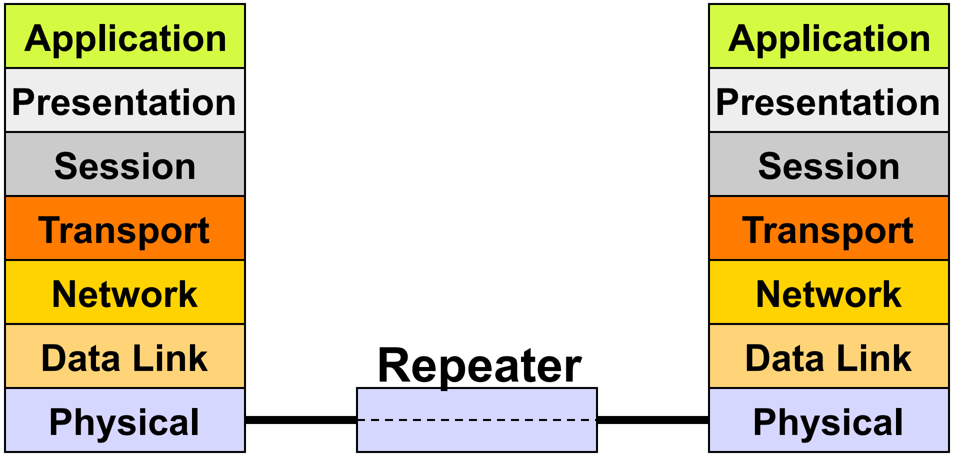
The OSI perspective is to agree on it, write it down, circulate it a lot and now we'll see if anyone can implement it after it's an international standard and every vendor in the world is committed to it.

One of those processes is backwards, and I don't think it takes a Lucasian professor of physics at Oxford to figure out which.

Marshall Rose, "The Pied Piper of OSI"

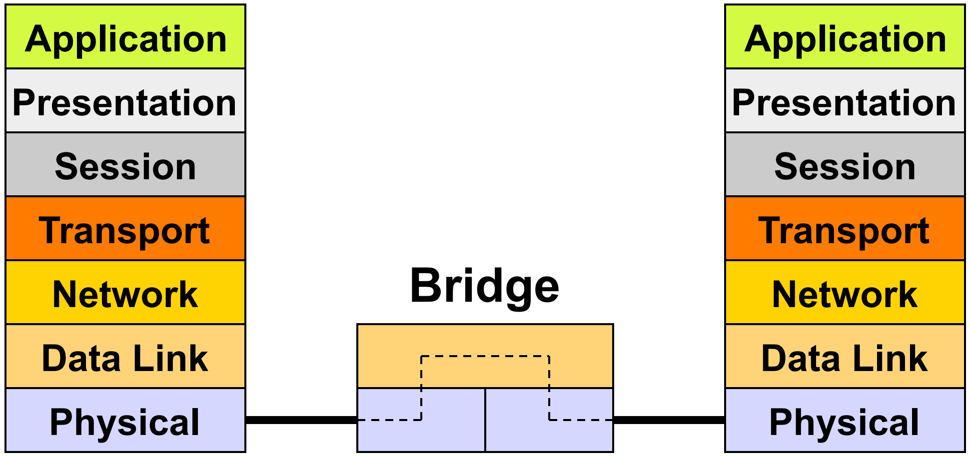
Layer 1 Devices

- Adapts to different physical interfaces
- Amplifies and/or refreshes the physical signal
- No intelligence
- Examples: Repeater, Hub, ISDN NT1



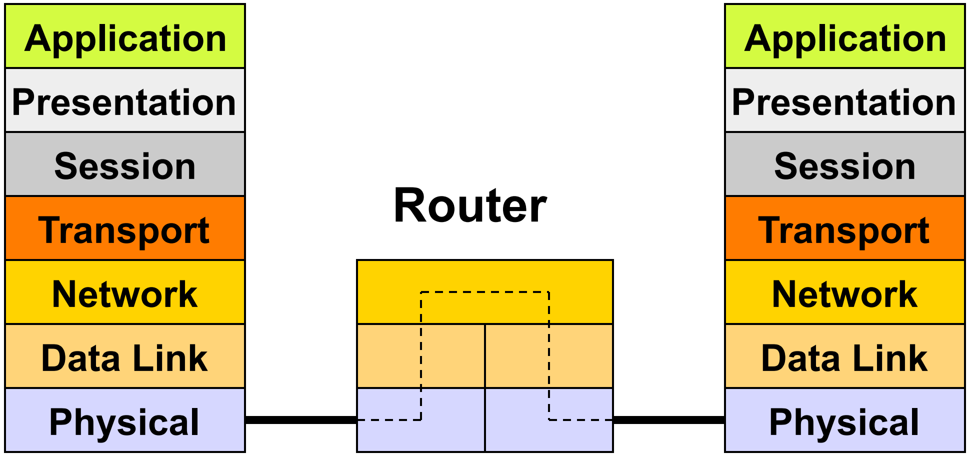
Layer 2 Devices

- Filter/Forwards frames according Link Layer Address
- Incorporates Layer 1-2
- LAN-Bridge (“Ethernet Switch")



Layer 3 Devices

- "Packet Switch" or "Intermediate System"
- Forwards packets to other ***networks*** according ***structured*** address
- Terminates Links
- IP Router, WAN-Switch
  - X.25
  - Frame-Relay
  - ATM



A Practical Example