Legacy Network Technologies

Introduction to ISDN, X.25, Frame Relay
and ATM (Asynchronous Transfer Mode)

Agenda

- ISDN
- X.25
- Frame Relay
- ATM

Why ISDN (Integrated Services Digital Network)?

- **During the century, Telco's**
  - Created telephony networks
    - Originally analog end-to-end using SDM
    - Later digital backbone technology (PDH, SDH, SS7)
      - Still analogue between telephone and local exchange
  - Created separate digital data networks
    - Based on circuit switching -> leased line
    - Based on packet switching -> X.25
- **Today: Demand for various different services**
  - Voice, fast signaling, data applications, real-time applications, video streaming and videoconferences, music, Fax, ...
  - All digital world

What is ISDN?

- **ISDN is the digital unification of the telecommunication networks for different services**
  - Offers transport of voice, video and data
    - Offers digital telephony to the end system too
  - All-digital interface at subscriber outlet

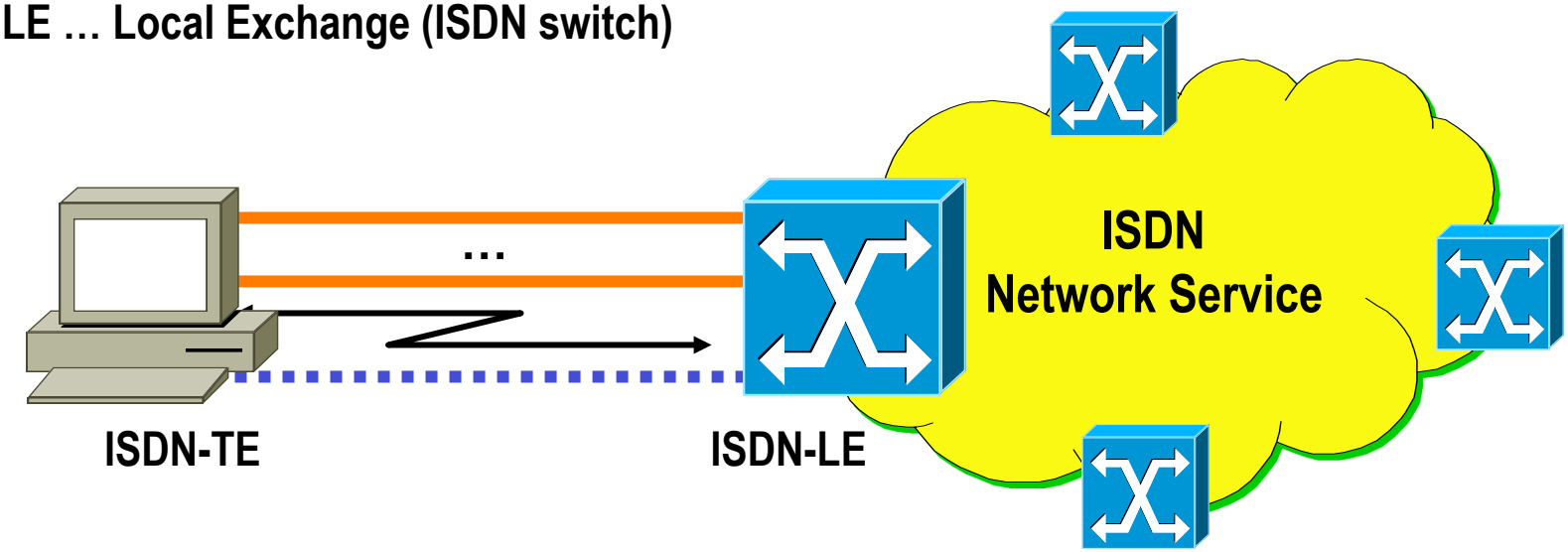
- **N-ISDN ensures world wide interoperability**
  - Standardized user-to-network interface (UNI)
    - BRI (Basic Rate Interface)
    - PRI (Primary Rate Interface)

Technical Overview

- **Implementation of a circuit switching**
  - Synchronous TDM
  - Constant delay
  - Constant bandwidth
  - Protocol-transparent
- **Dynamic connection establishment**
  - User initiated
  - Temporarily
  - Signaling Protocol
    - Q.931 between end-system and local exchange
    - SS7 between local exchanges

ISDN User-to-Network Interface (UNI)

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



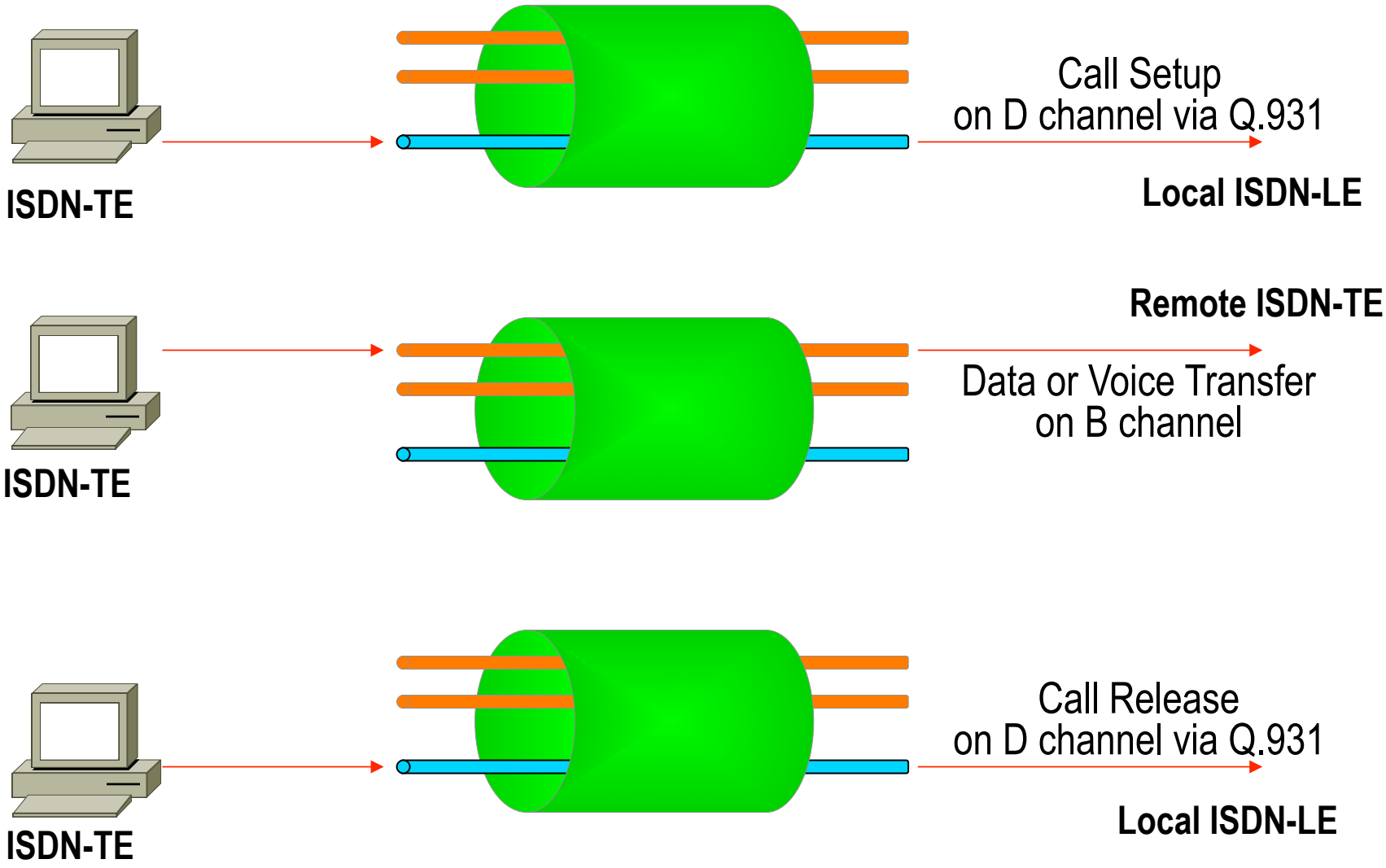
logical channels multiplexed on physical channel

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

channel
for user data
(B-channel)

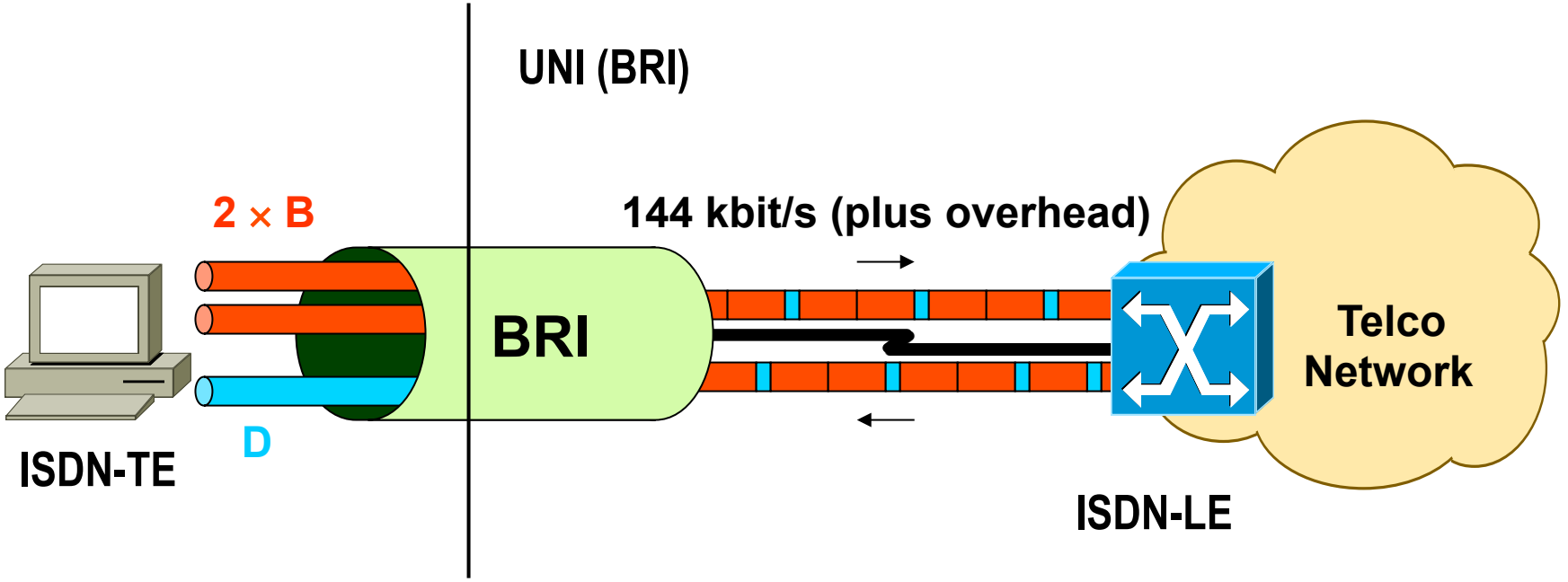
channel
for signaling
(D-channel)
(Q.921, Q.931)

Usage D-Channel vs. Bearer Channel



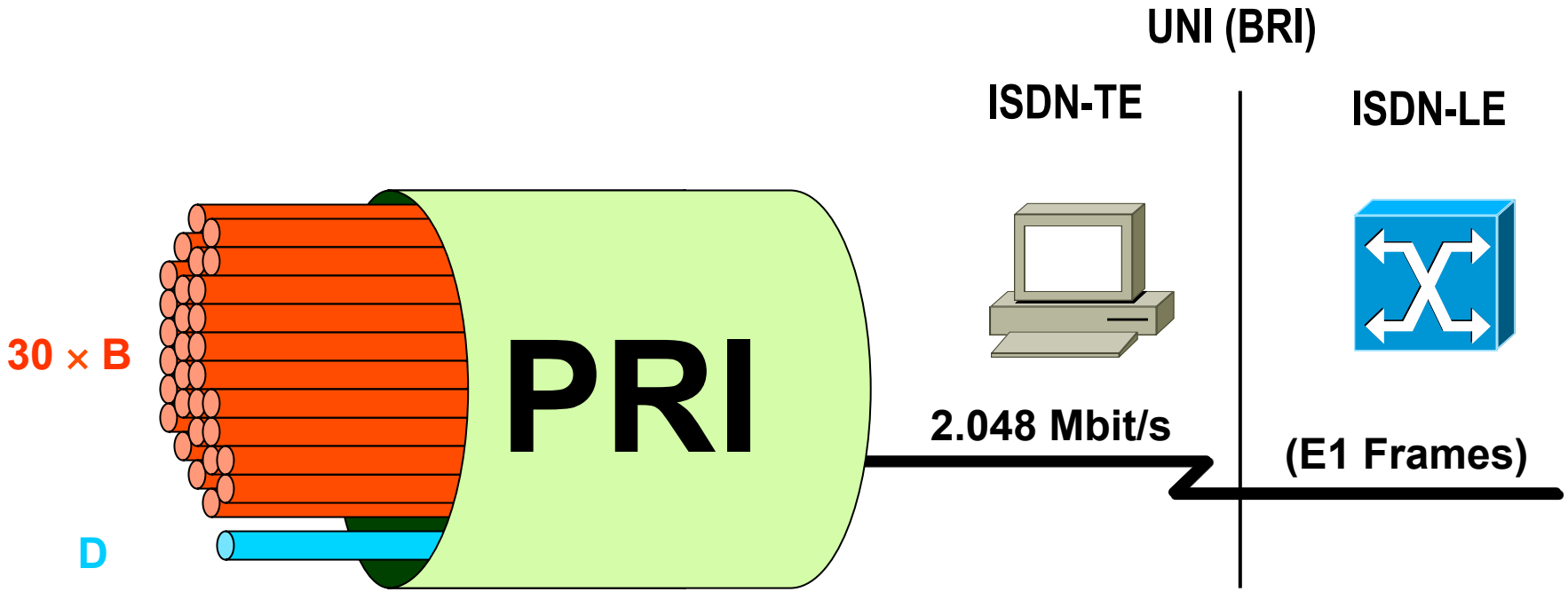
Basic Rate Interface (BRI)

- 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 Services

- **CCITT defined three services**
  - Bearer services (Circuit or Packet)
  - Teleservices (Telephony, Telefax, ...)
  - Supplementary services
    - Reverse charging
    - Hunt groups
    - etc...

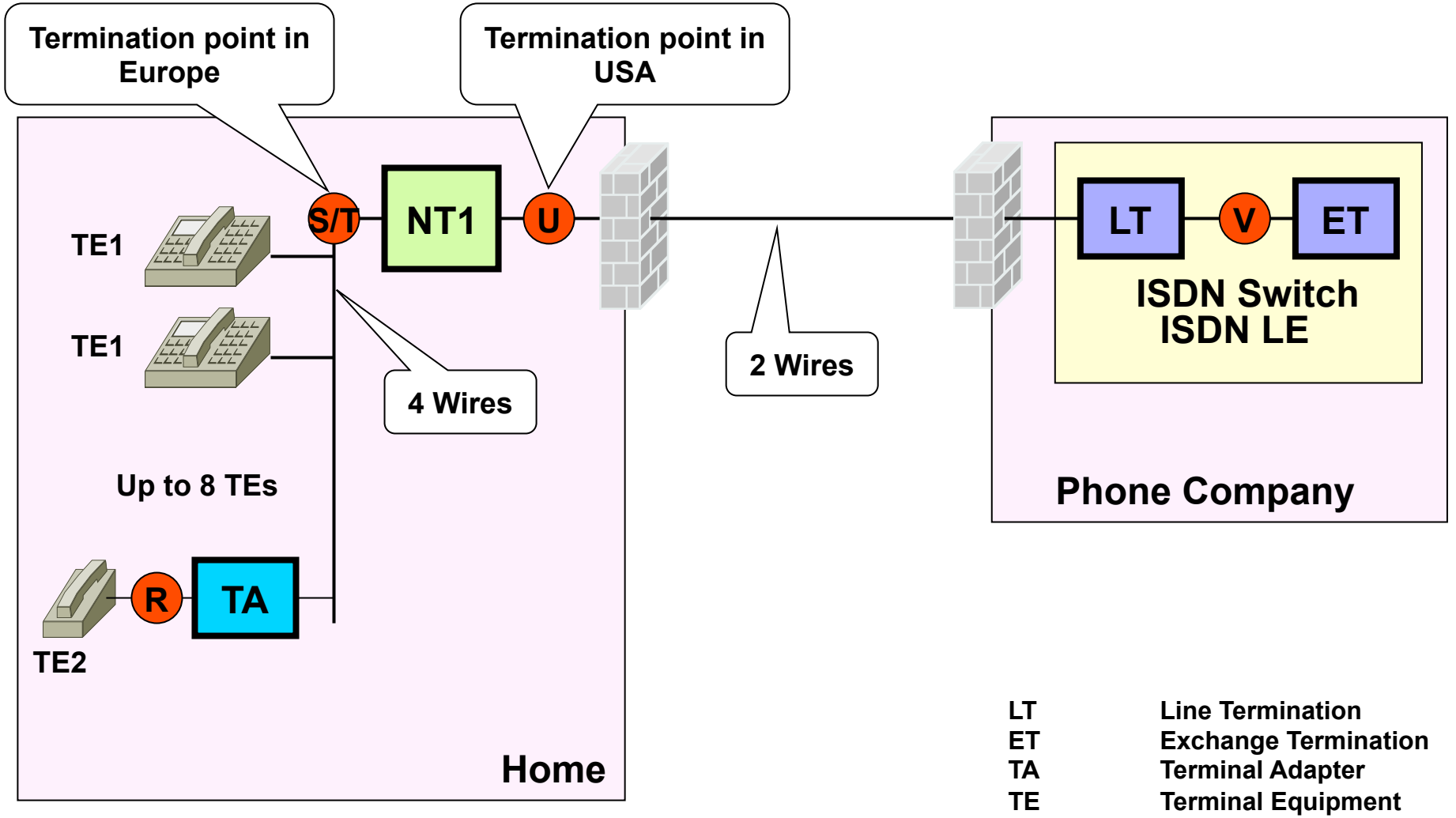
Functional Groups

- **Terminal Equipment (TE)**
  - TE1 is the native ISDN user device (phone, PC-card, ...)
  - TE2 is a non-ISDN user device (Analog telephone, modem, ...)
- **Network Termination (NT)**
  - NT1 connects TEs with ISDN
  - NT2 provides concentration and supplemental services (PBX)
- **Terminal Adapter (TA)**
  - TA connects TE2 with NT1 or NT2

Reference Points

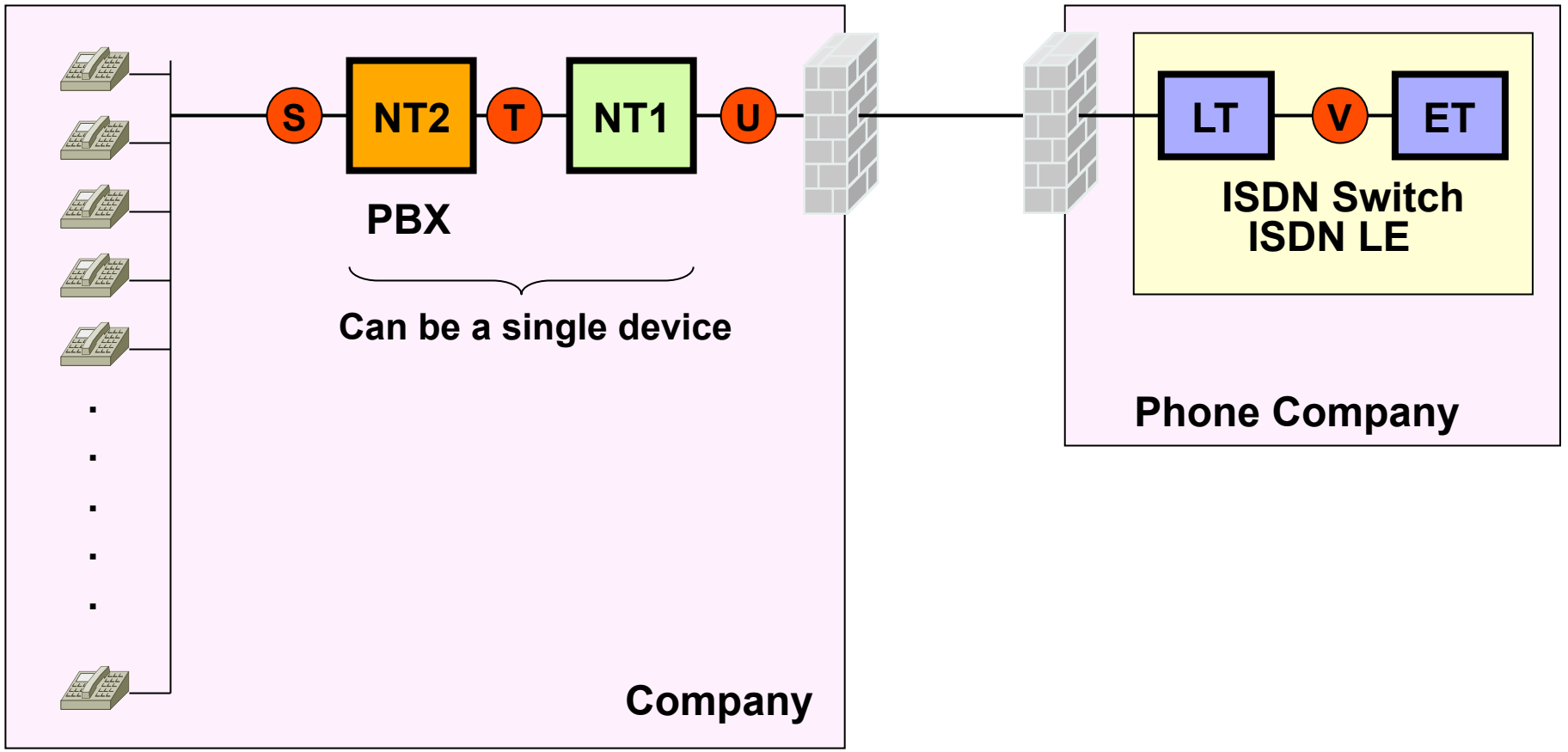
- **Logical interfaces between functional groups**
  - R connects PSTN equipment with TA
  - S connects TEs with NT2
  - T connects NT2 with NT1
  - U connects NT1 with Exchange Termination (ET)

Reference Diagram (BRI)



LT	Line Termination
ET	Exchange Termination
TA	Terminal Adapter
TE	Terminal Equipment
NT	Network Termination

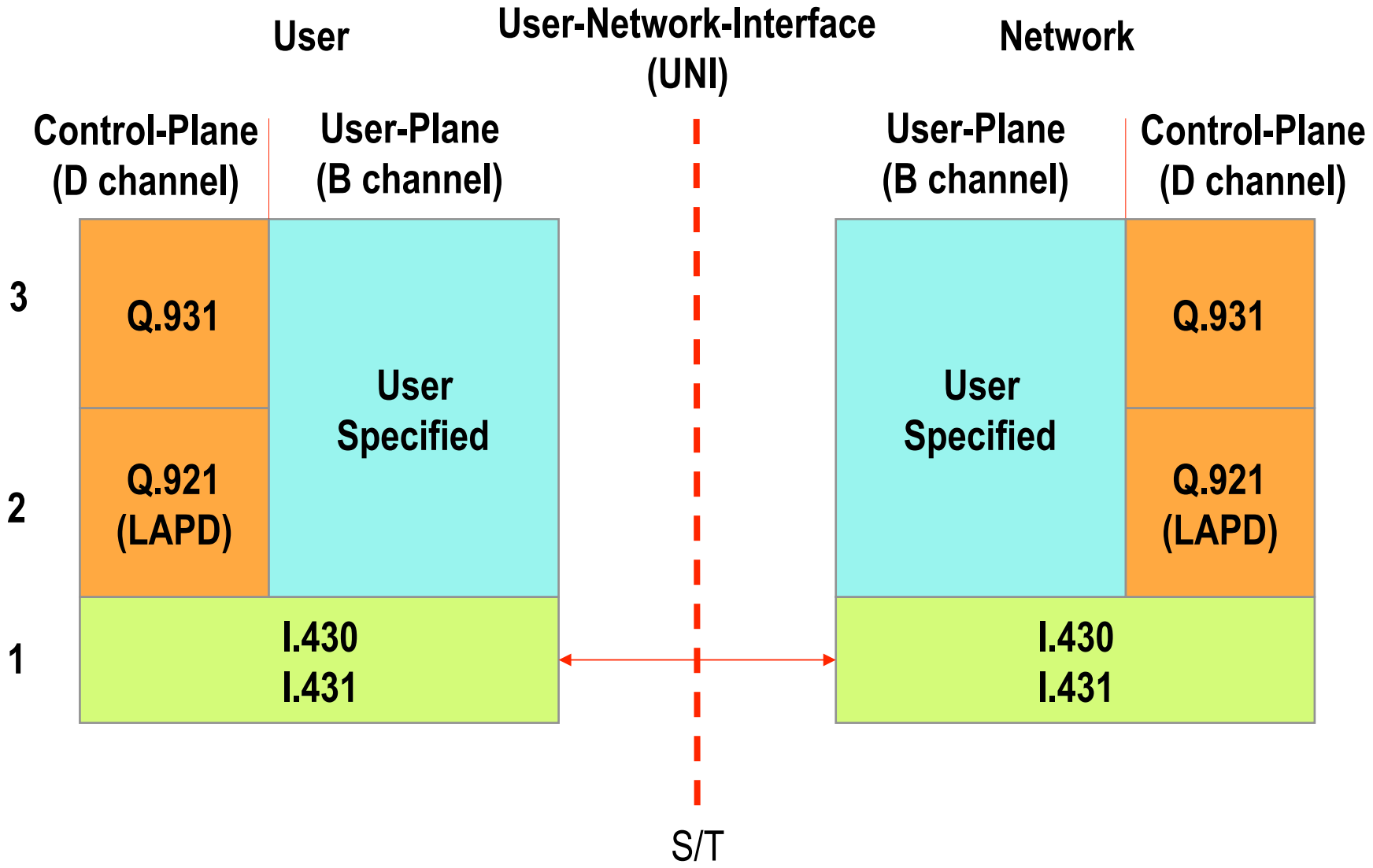
Reference Diagram (PRI)



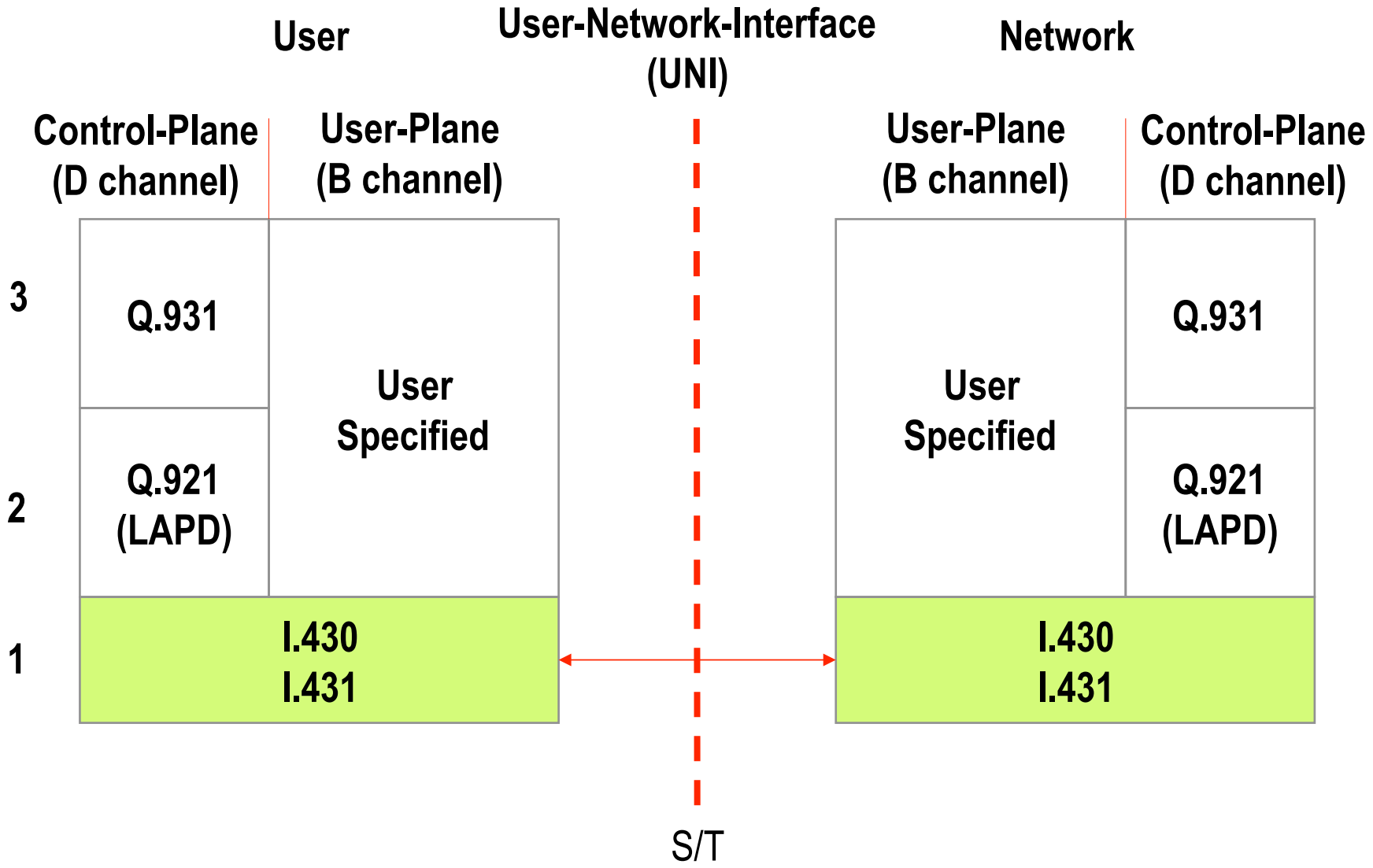
U-Interface

- **Recommendation G.961**
  - 160 kbit/s (remaining capacity used for framing and synchronization)
- **Either echo cancellation or time compression (ping-pong)**
- **2B1Q (ANSI T1.601)**
  - -2.5 V, -0.833 V, +0.833 V, +2.5 V
  - Requires half the BW of NRZ
  - Plus scrambling for synchronization and uniform PSD distribution

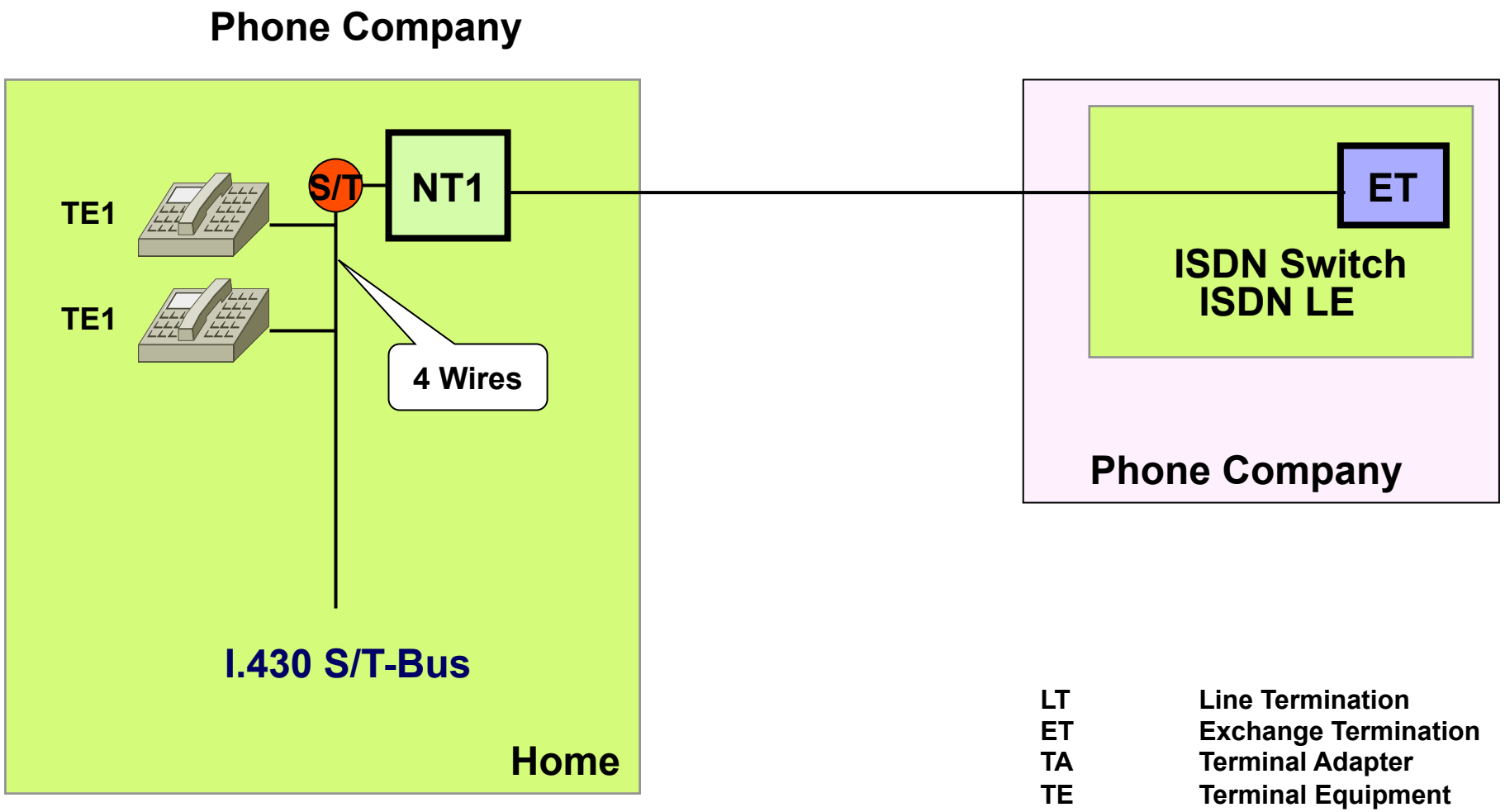
ITU-T ISDN Layers ("Protocol Stack")



ITU-T ISDN Physical Layer



I.430 S/T-Bus



LT	Line Termination
ET	Exchange Termination
TA	Terminal Adapter
TE	Terminal Equipment
NT	Network Termination

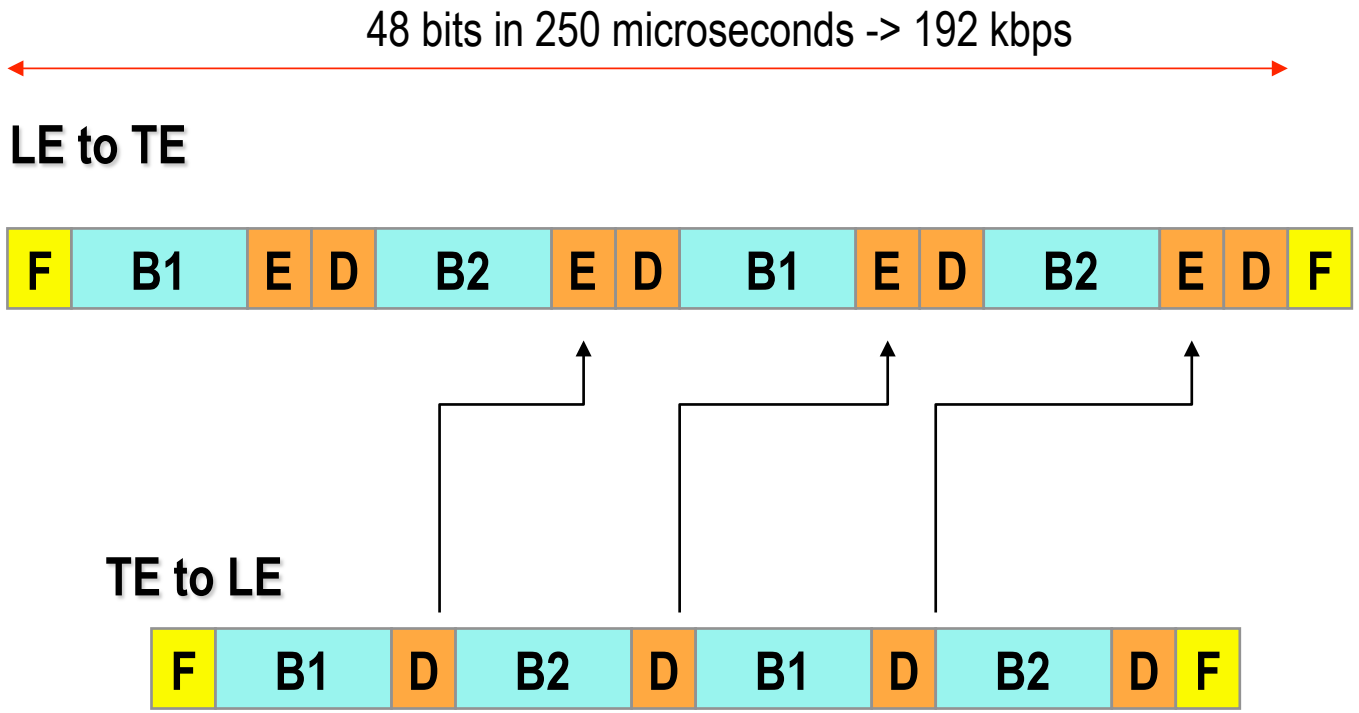
I.430 S/T-Bus

- **S/T interface is implemented as bus**
  - Point-to-point
    - Maximum distance between TE and NT is 1km (!)
    - Requires a PBX
  - Multipoint
    - Up to 8 TEs can share the passive bus
    - Maximum distance between TE and NT is 200 meters (short bus) or 500 meters (extended bus)
    - D channel is shared by all TEs in order to request usage of B channels
    - **Contention mode** on D channel
    - B channels are dynamically assigned to TEs
      - But exclusive usage only (!)

I.430 S/T Bus Details

- **192 kbit/s=**
  144 kbit/s (2B+D) ***+ 48 kbit/s***
  for Framing, D-echoing, and DC balancing
- **48 bit frames every 250 μs**
  - Modified AMI code (zero-modulation)
  - Bit-stuffing in D channel
  - Synchronization through code violation

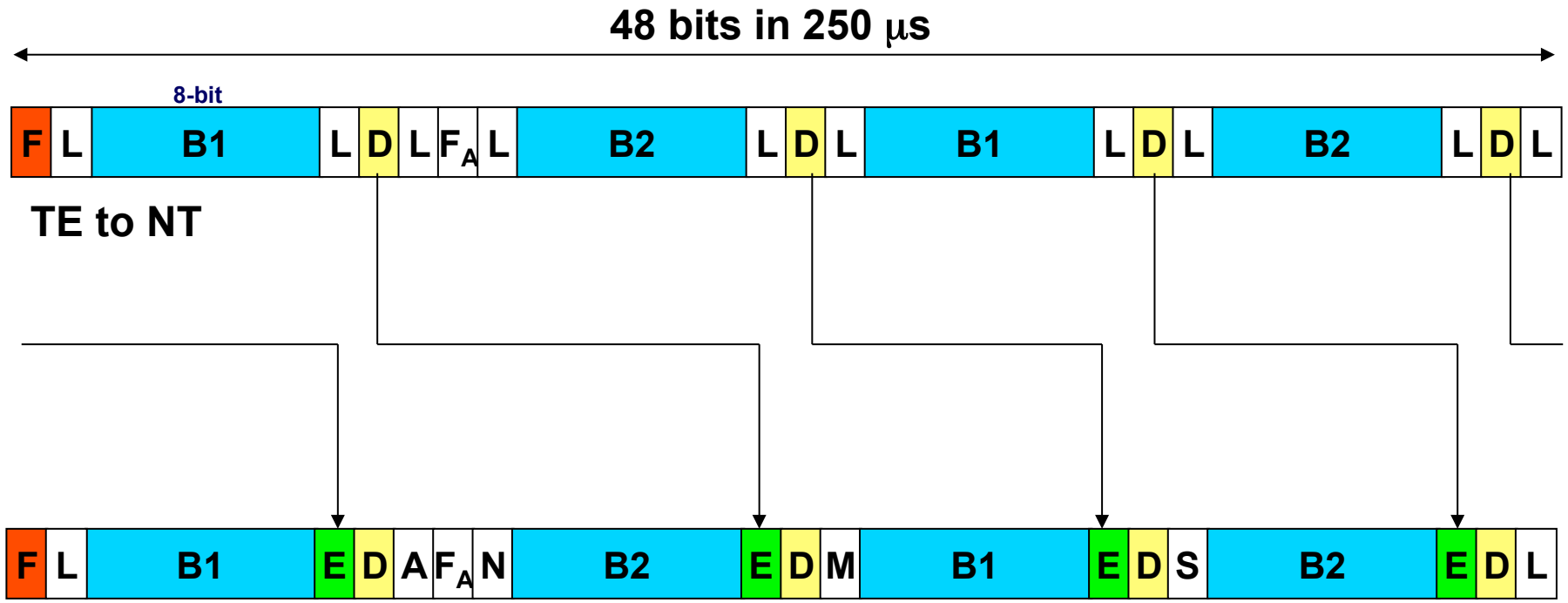
Simplified Frame Structure I.430 S/T-Bus



F … Starting Delimiter SD for frame synchronization
D … D-channel bit
E … Echo-channel bit

B1 … 8 B1-channel bits
B2 … 8 B2-channel bits

Frame Structure I.430 S/T-Bus



F... Framing bit
L... DC balancing bit
E... D-echo channel bit
A... Activation bit
F_A.. Auxiliary framing bit
N... Set to opposite of F_A
M... Multiframing bit
S.... Spare bits

D – Channel Access Control (1)

- **Before TE may use D channel: Carrier Sense**
  - At least eight ones (no signal activity) in sequence must be received
- **Then TE may transmit on D channel: Collision Detection**
  - If E bits unequal D bits TE will stop transmission and wait for next eight ones in sequences

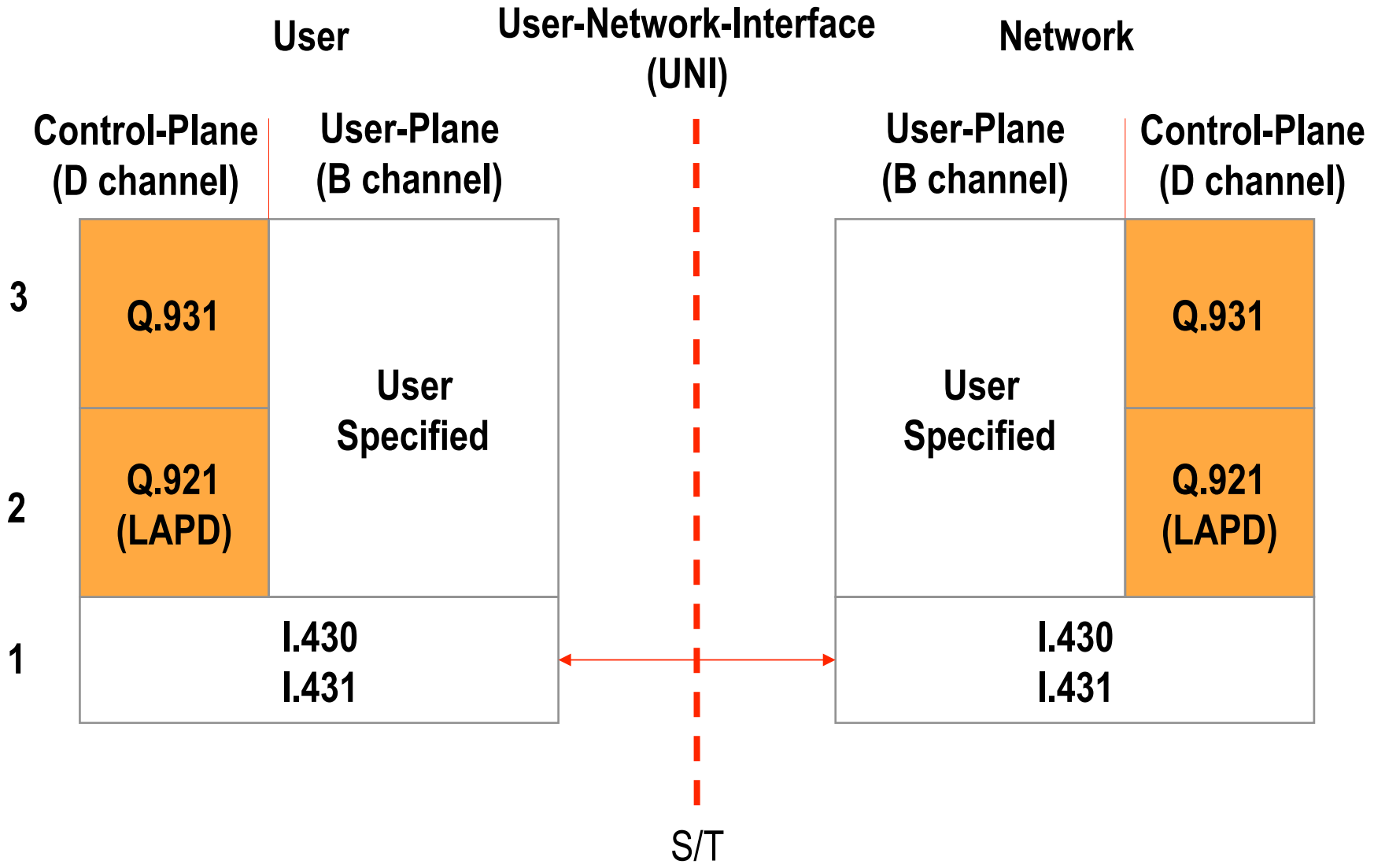
D – Channel Access Control (2)

- **When using D channel**
  - Bit-stuffing prevents sequence of eight ones for the rest of the message carried on the D channel
- **Fairness**
  - TE must release D channel after message was sent
  - Next time, this TE must wait for a sequence of nine ones

PRI (I.431)

- **Primary rate interface**
  - Allows point-to-point configuration only
  - Based on E1 or T1 specifications
- **Europe: E1**
  - 30 B channels
  - 1 D channel (also 64 kbit/s)
  - 1 Framing Channel
    - HDB3 encoding
    - 2.048 Mbps total speed
    - timeslot 0 used for synchronization
    - timeslot 16 used for D channel information
    - timeslots 1-15 and 17-31 for 30 B-channels
- **USA: T1**
  - 23 B channels
  - 1 D channel

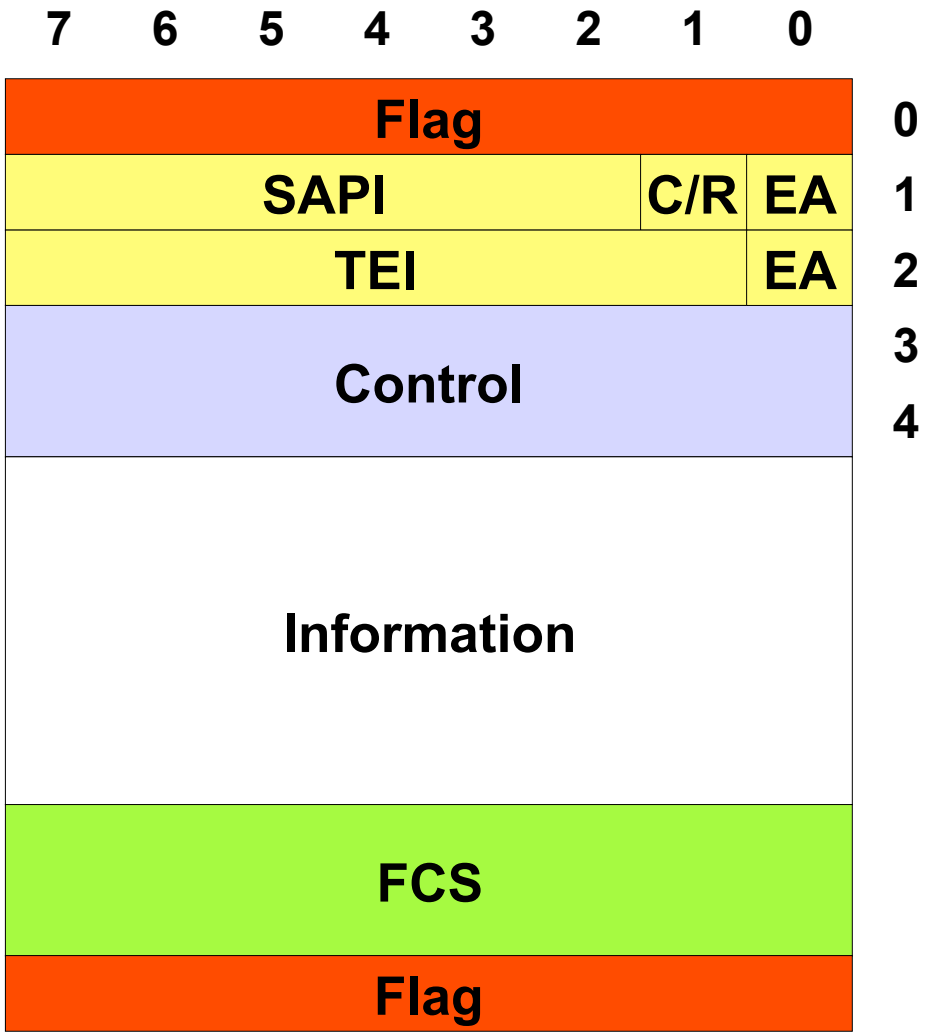
ITU-T ISDN Signaling Layers



LAPD (Q.921)

- **Link Access Procedure D-Channel**
  - Based on HDLC ABM mode
  - 2 byte address field (SAPI + TEI)
  - Optionally extended sequence numbering (0-127)
- **Carries Q.931 packets**
  - Travels in the information field of the LAPD I-frame
- **May also be used to carry user traffic**
  - For example X.25 packets

LAPD Frame Format



EA = 0 -> address octet follows
EA = 1 -> last address octet

C/R = 1 Command (Network -> User)
C/R = 0 Response (Network -> User)
User -> Network ... vice versa

SAPI … Service Access Point Identifier
TEI ….. Terminal Endpoint Identifier
EA ….. Address Field Extension Bit
C/R …. Command/Response Bit

SAPI

- **Service Access Point Identifier (SAPI)**
  - OSI interface to layer 3
  - “Identifies payload”
    - 0 signaling information (s-type)
    - 16 packet data (p-type)
    - 63 management information

TEI

- **When TE occupies D channel, the ET (switch) assigns a Terminal Endpoint Identifier (TEI) to it**
- **LAPD frames carry TEI**
  - To identify source (TE ➔ ET)
  - To identify destination (ET ➔ TE)
- **Possible values: 0-127**

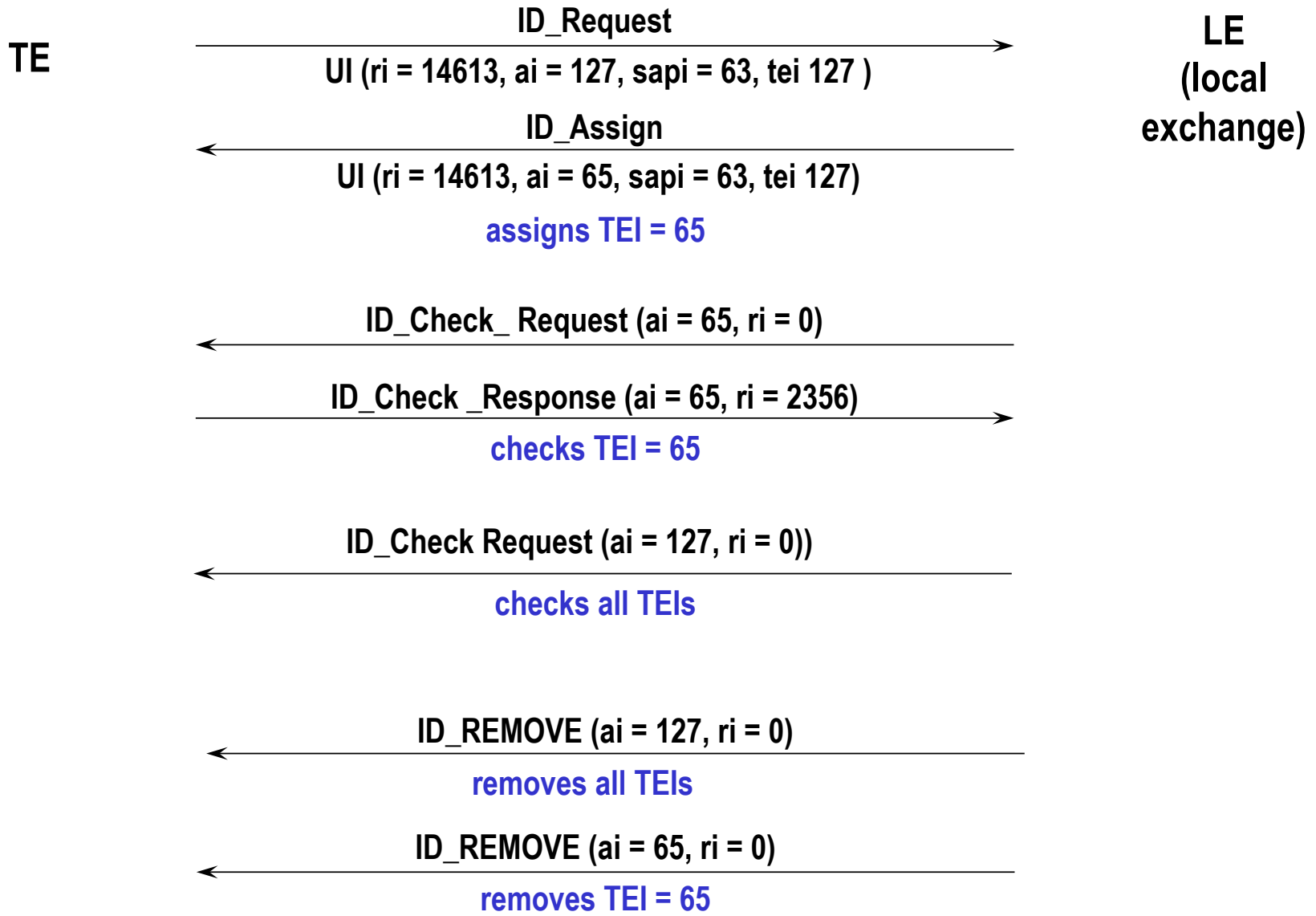
TEI Management

- **TEIs are either assigned automatically**
  - By switch (ET)
  - TEI value range 64-126
- **Or preconfigured**
  - Checking for duplicates necessary
  - TEI value range 0-63
- **TEI = 127 reserved for broadcasting**

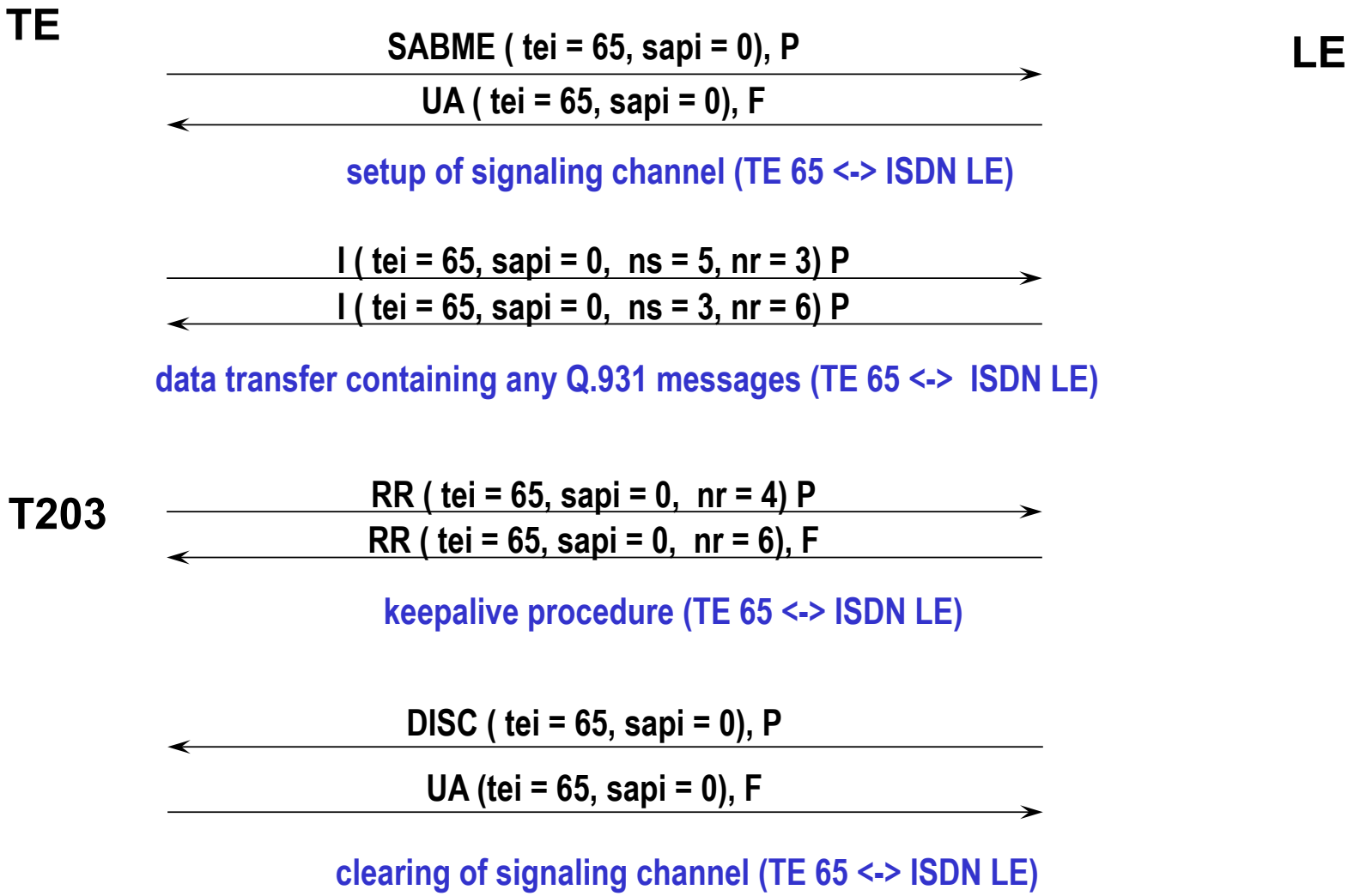
TEI Management Messages

- **LAPD UI frames with SAPI = 63 and TEI 127**
- **Information field contains**
  - Reference indicator (RI) to correlate request and responses
  - Action indicator (AI) to specify TEI in question
  - Message type

TEI Assignment, Checking, Removal



Example Signaling Channel Active



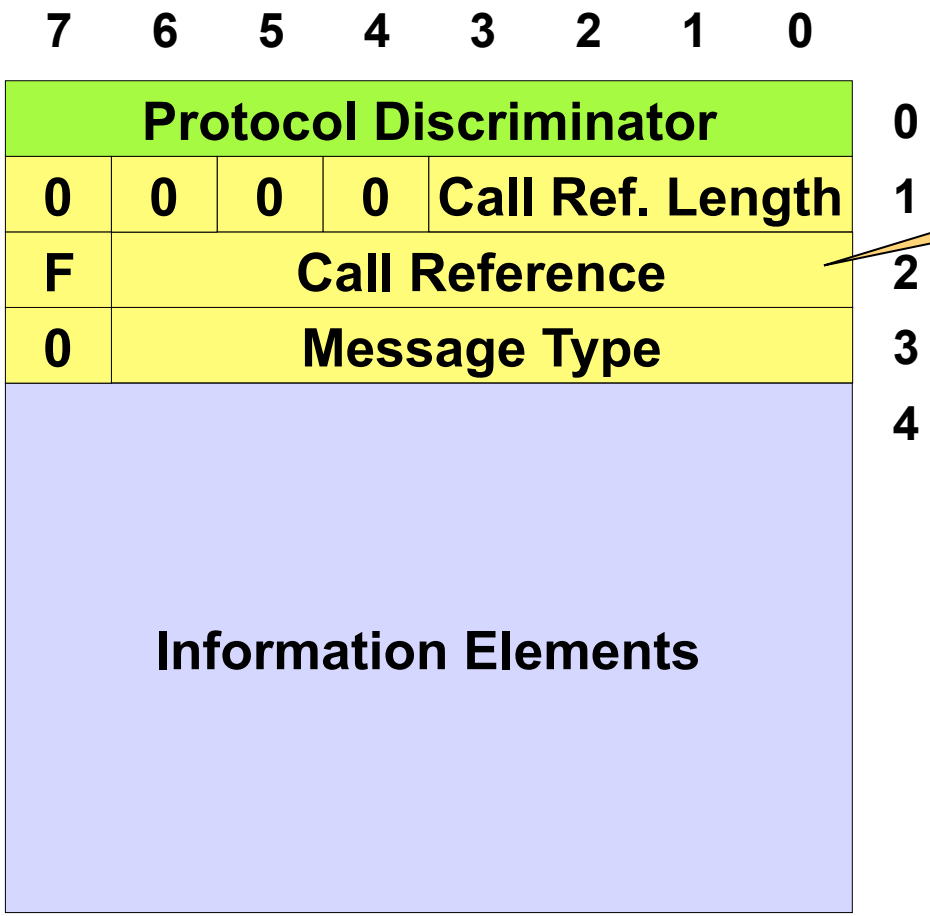
Q.931

- **Carries signaling information**
  - Call control
  - E. g. dial number and ring information
  - Terminated by ET (ISDN-LE)
    - Not used end-to-end (local ISDN-TE to remote ISDN-TE)
- **ET is real 7-layer gateway**
  - Translates Q.931 into Signaling System 7 (SS#7)
  - Used between ISDN-LEs
- **Country-dependent versions (!)**

ISDN Switch Types

- **BRI**
  - Basic-net3 (Euro ISDN)
  - 5ESS, DMS-100, NT1 (USA)
  - NTT (Japan)
  - Basic 1TR6 (Germany, old)
  - VN2, VN3 (France)
  - TS013 (Australia)
- **PRI**
  - primary-net5 (Euro ISDN)
  - 4ESS, 5ESS, DMS-100 (USA)
  - NTT (Japan)
  - TS014

Q.931 Packet Format



Message Types

Call Clearing
DETatch
DETach ACKnowledge
DISConnect
RELease
RELease COMplete
REStart
REStart ACK

Call Information Phase
RESume
RESume ACKnowlegde
RESume REJect
SUSPend
SUSPend ACKnowledge
SUSPend REJect
USER INFO

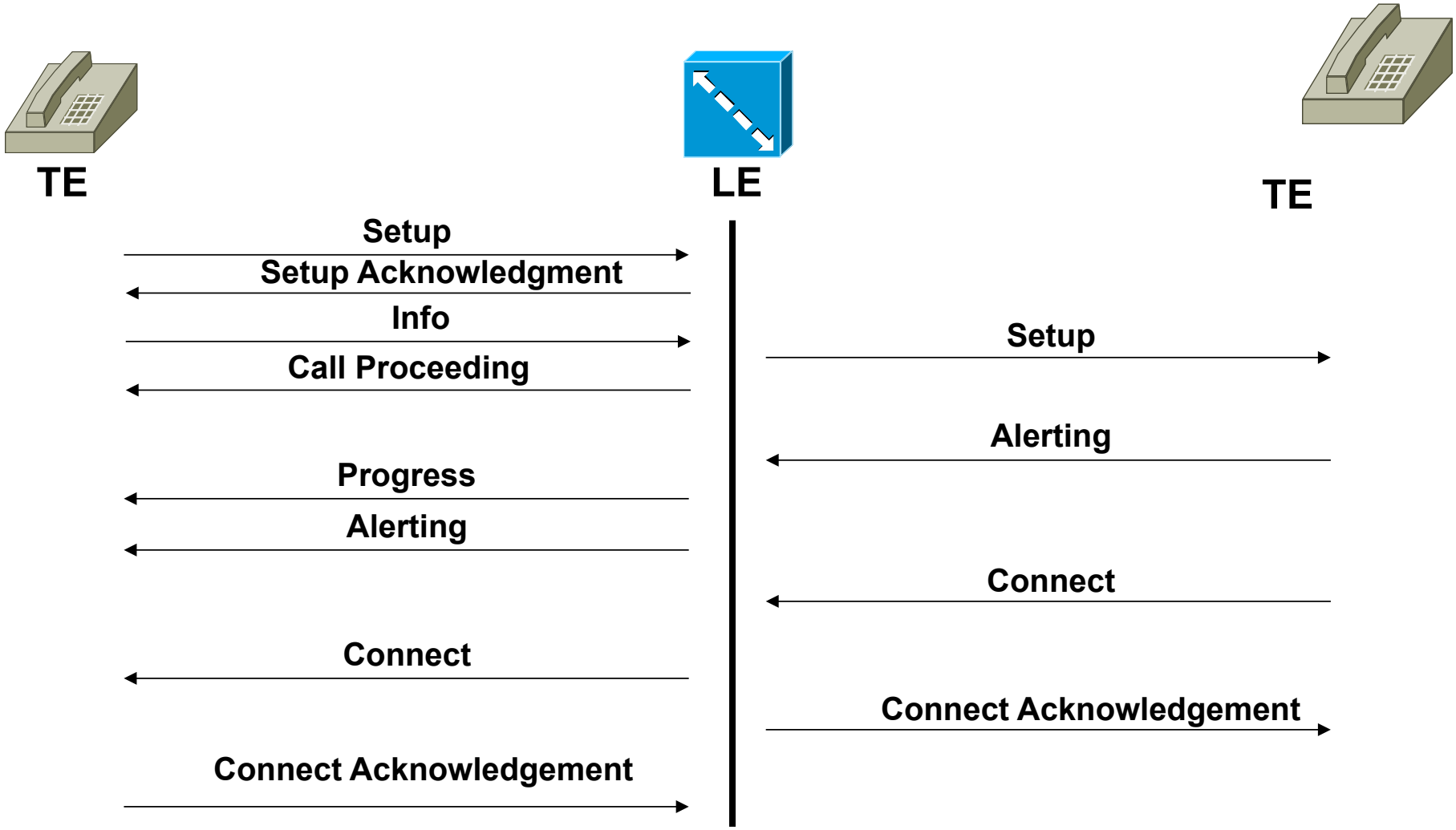
Call Establishment
ALERTing
CALL PROCeeding
CONNect
CONNect ACKnowledge
SETUP
SETUP ACK

Miscellaneous
CANCel
CONgestion CONtrol
FACility (Ack, Rej)
INFOrmation
REGister (Ack, Rej)
STATUS

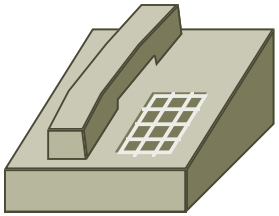
Information Elements Examples

0x04	Bearer Capability (eg. 0x8890 .. dig. 64kb/s Circuit)
0x08	Cause (reason codes for call disconnect)
0x18	Channel Identification
0x1E	Progress Indicator (check for 56kb/s connection)
0x2C	Keypad
0x6C	Calling Party Number
0x6D	Calling Party Sub address
0x70	Called Party Number
0x71	Called Party Subaddress
0x7C	Low-Layer Compatibility
0x7D	High-Layer Compatibility

Call Establishment



Call Release

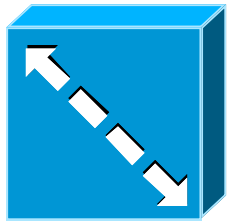


TE

Disconnect (cause)

Release

Release Complete



LE

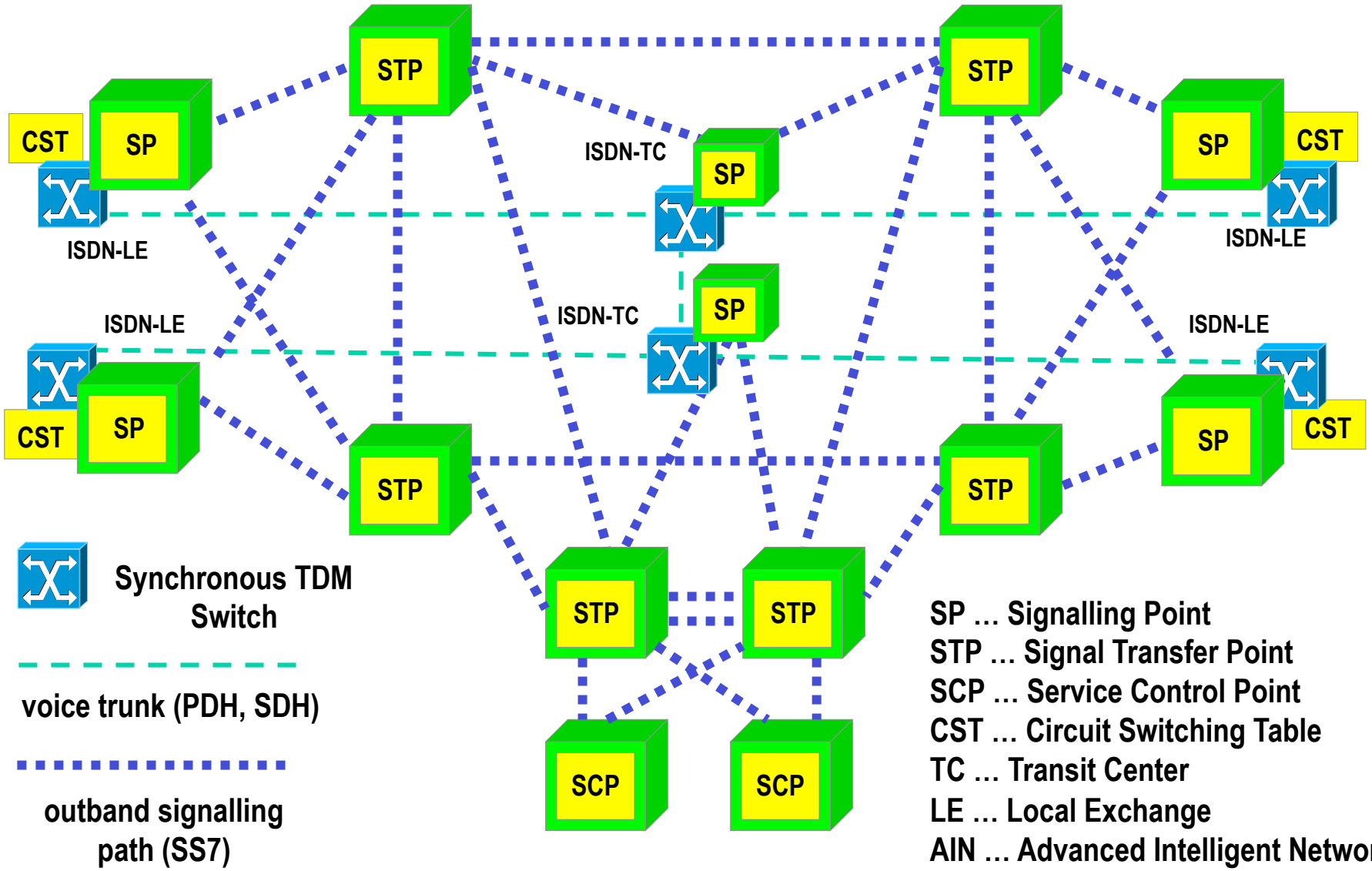
OR

Disconnect (cause)

Release

Release Complete

ISDN Big Picture (AIN, SS7)



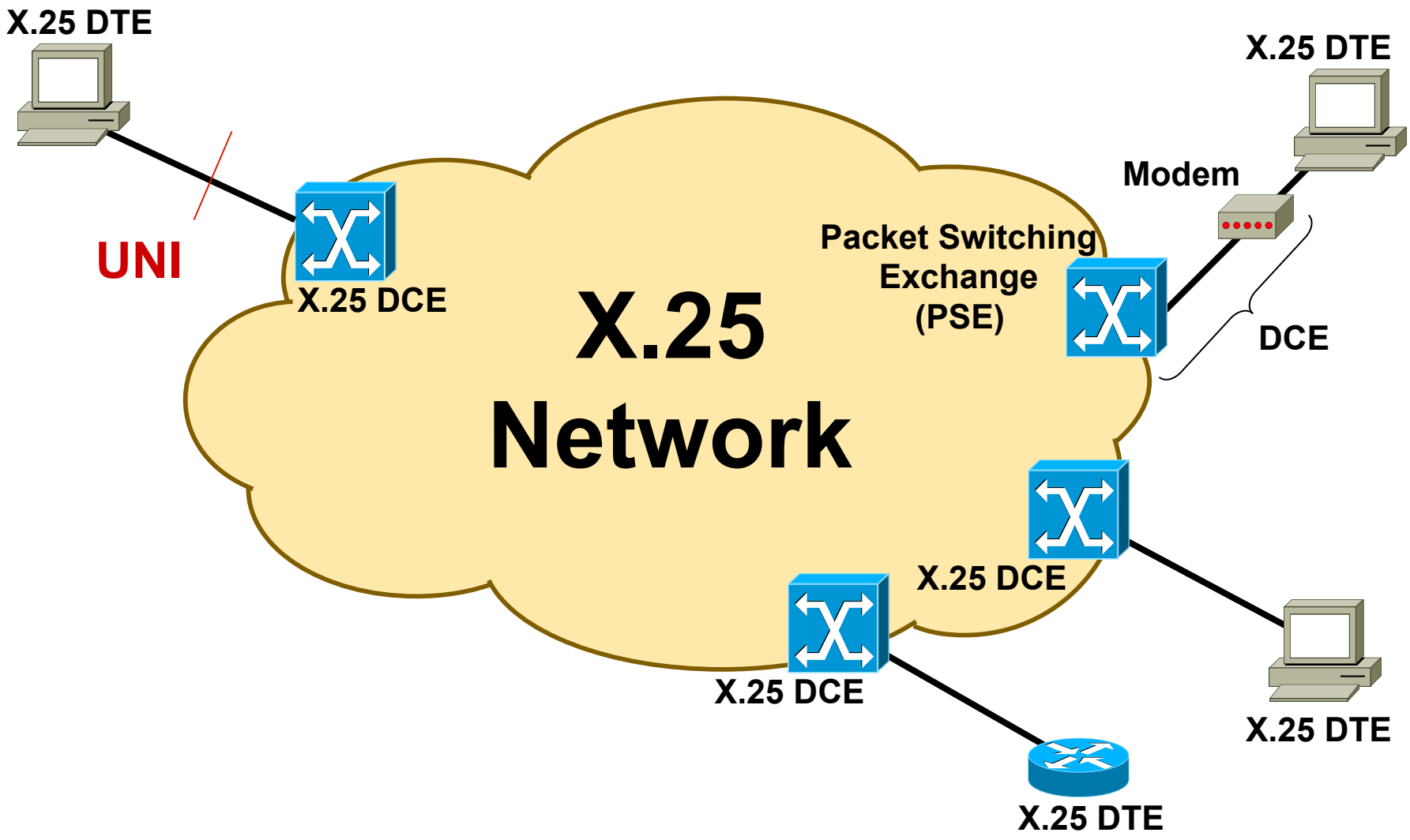
Agenda

- ISDN
- X.25
- Frame Relay
- ATM

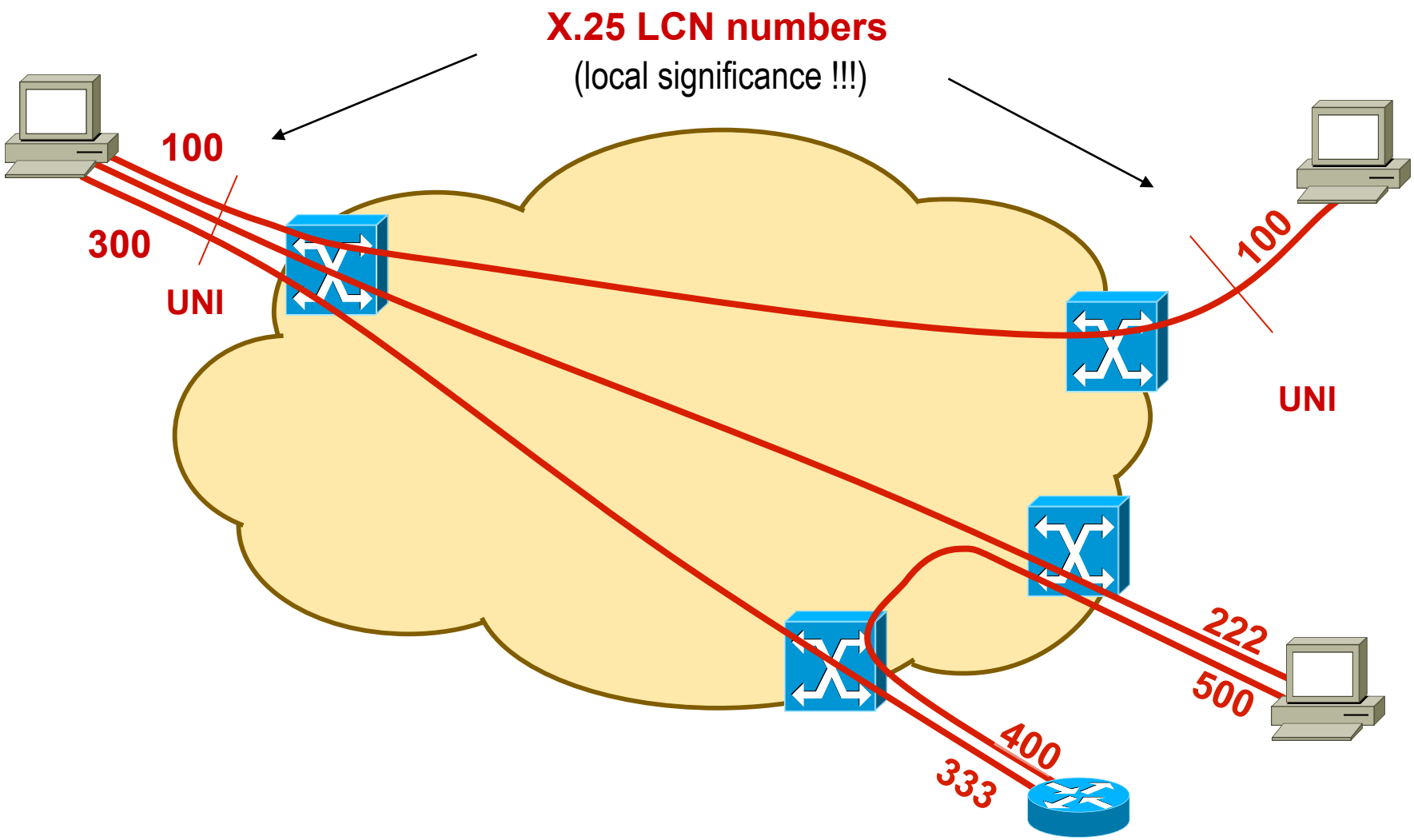
What is X.25?

- **Packet switching technology**
  - Based on store-and-forward of packets
  - Connection oriented
  - Variable delays (!)
- **Interface definition between user and network equipment (UNI)**
  - X.25 - DTE (e.g. router) <-> X.25 - DCE (packet switch)
- **Wide area network service**
  - Based on virtual circuit technique can be implemented
  - PVC or SVC service
- **Does not specify network itself (!)**
- **Created by CCITT for Telco data networks in 1976**
  - Example: Datex-P
- **Adopted and extended by ISO**
  - Defined as OSI-layer 3 protocol

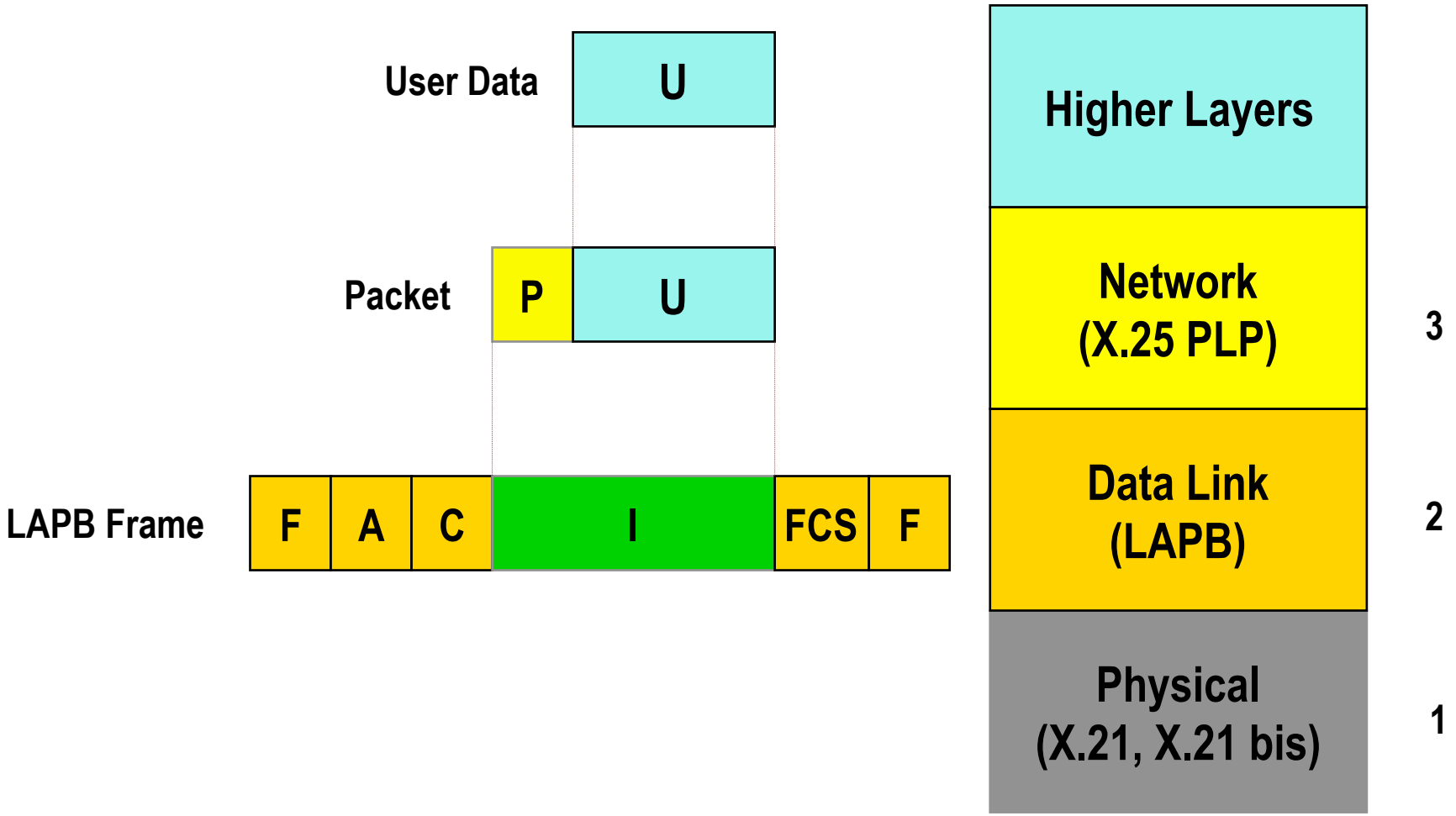
X.25 Network: Physical Topology



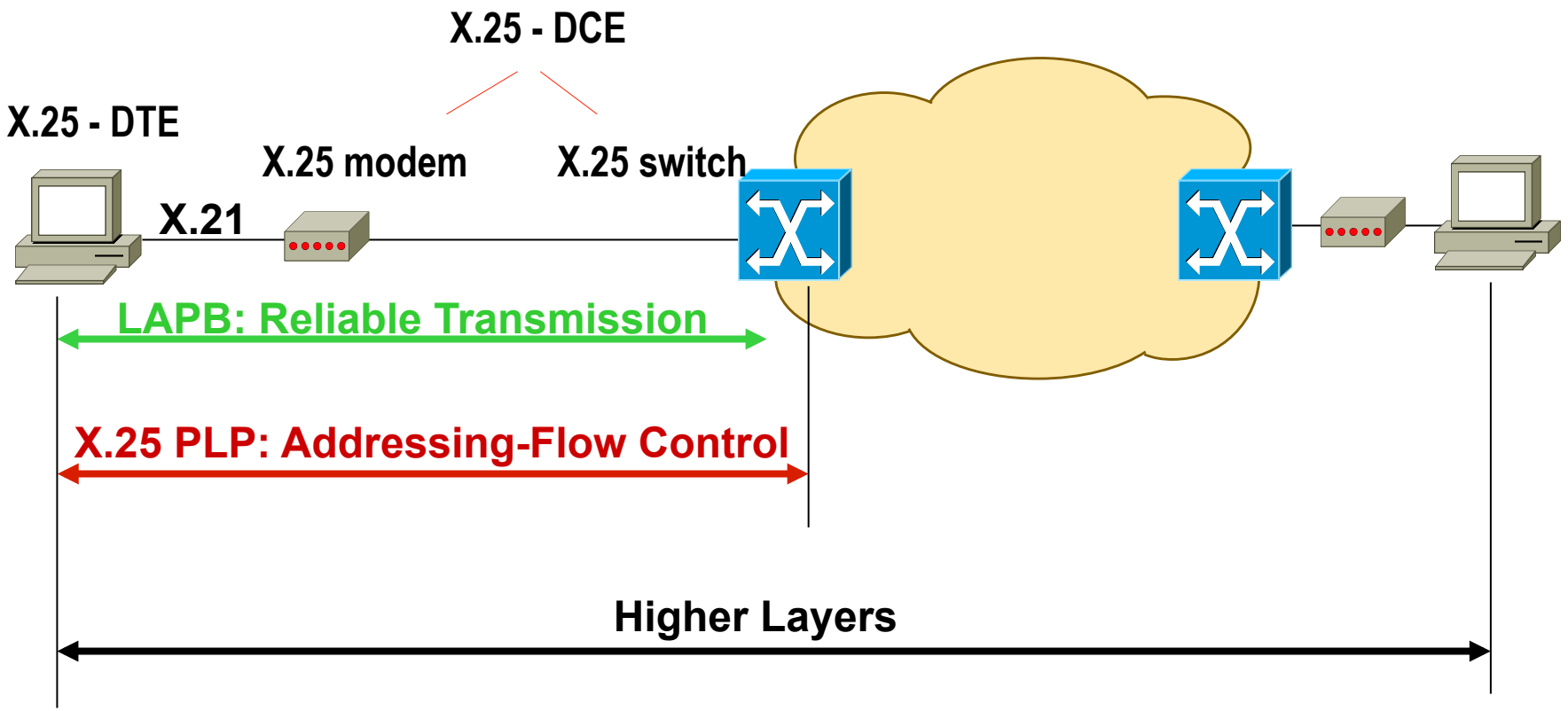
X.25 Network: Virtual Circuits
Local Connection Identifiers and Logical Channels



X.25 Layers (CCITT)



Scope of Each Layer

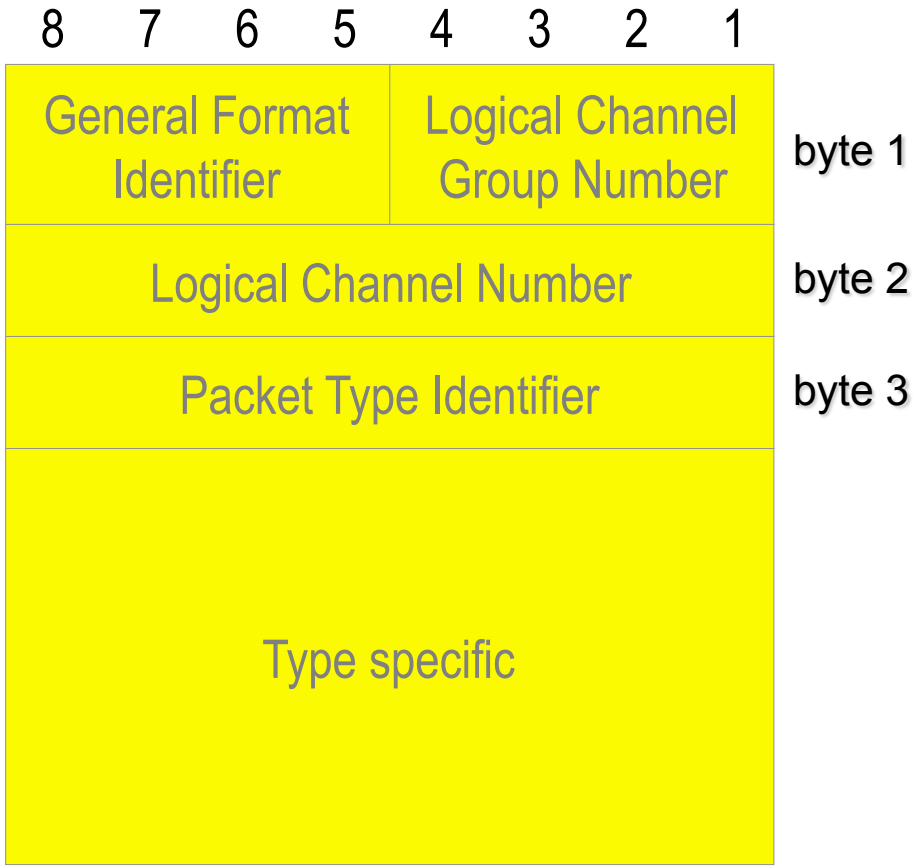


X.25 Features

- **Reliable**
  - Error recovery on layer two
  - Optional on layer three
  - Can be used on bad links
- **Flow Control**
  - On layer 2 between X.25 DTE and local X.25 switch using LAPB RR and RNR frames
  - Additionally on layer 3 between X.25 DTE and local X.25 switch between local and remote X.25 switch using PLP windowing
  - That is because layer 2 can not differentiate the virtual circuits
    - Hence if on the UNI one virtual circuit should be stopped while the other is still allowed to go on -> you have to do it in layer 3
- **High accountability**
  - Vendor specific technology includes ability to measure packet counts for creating bills

PLP Header: General Format

- **Every packet contains at least three bytes**
- **Third byte is used either**
  - Packet type identifier for non data packets
  - Sequencing byte for data packets
    - First bit set to 0 to indicate data packet
- **Logical channel group number together**
  - With LCN number allows up to 4096 virtual channels

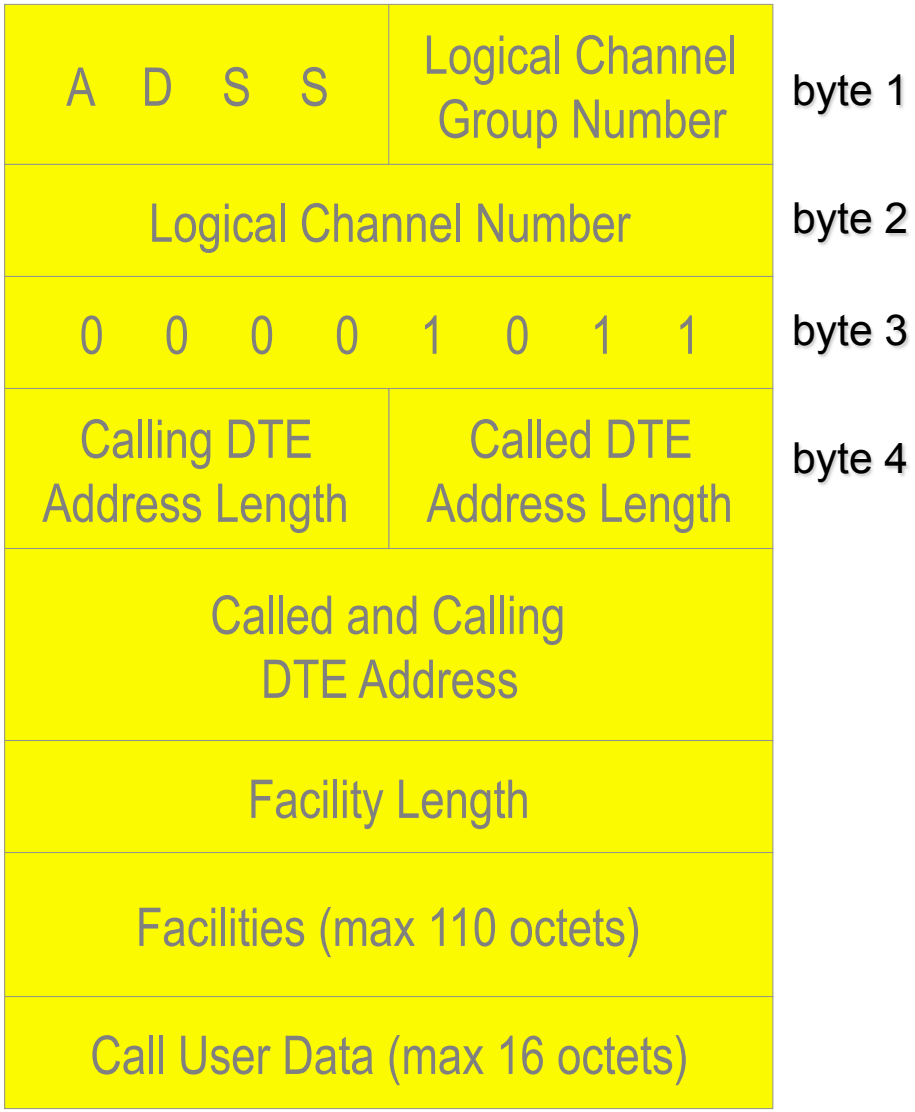


Important X.25 Packet Types

Packet Type		Service	
From DCE to DTE	**From DTE to DCE**	**SVC**	**PVC**
Call Setup and Clearing			
Incoming Call	**Call Request**	**X**	
Call Connected	**Call Accepted**	**X**	
Clear Indication	**Clear Request**	**X**	
DCE Clear Confirmation			
DTE Clear Confirmation		**X**	
Data			
DCE Data	**DTE Data**	**X**	**X**
Flow Control			
DCE RR	**DTE RR**	**X**	**X**
DCE RNR	**DTE RNR**	**X**	**X**

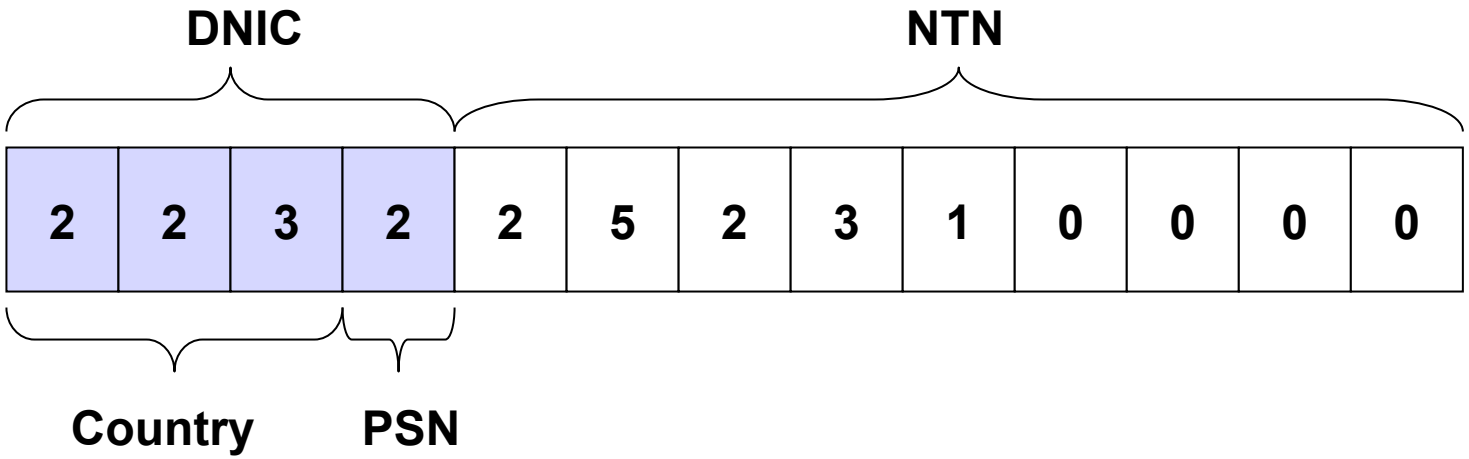
PLP Header Format: Call Setup

- **Call Request and Incoming Call**
  - Packet type (byte 3) = 0x 0B
  - SS = 01 (mod 8)
  - SS = 10 (mod 128)
  - D = 1 D-bit mechanism supported
  - D = 0 D-bit mechanism not supported
  - A = 1 escape from conventional X.25 addresses (1988)



X.121 Addresses

- Public data network numbering (ITU-T)
- Only used to establish SVCs
- Aka International Data Number (IDN)
- 4 + up to 10 digits

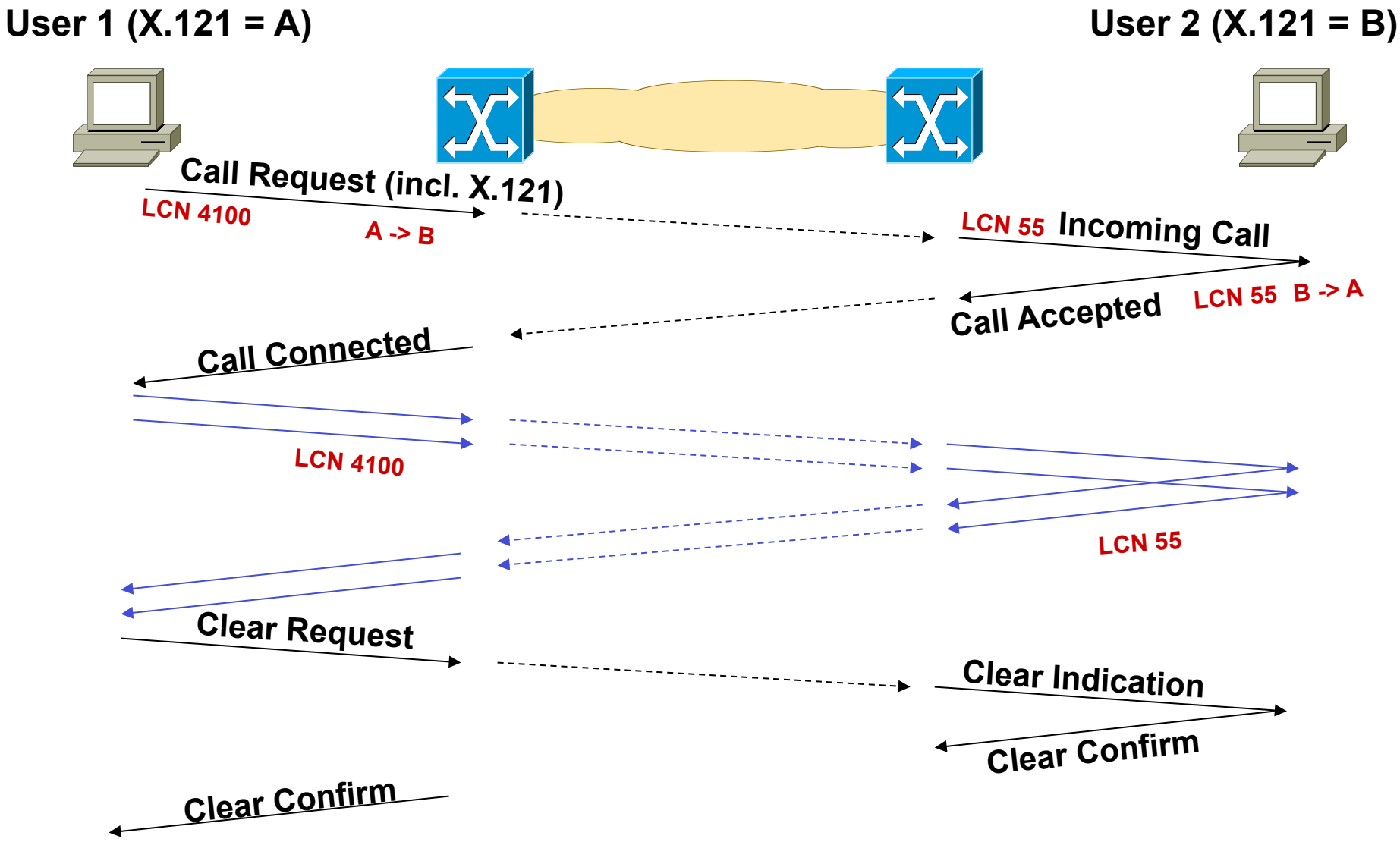


DNIC...Data Network Identification Code
NTN...National Terminal Number
PSN...Public Switched Network

X.25 Facilities

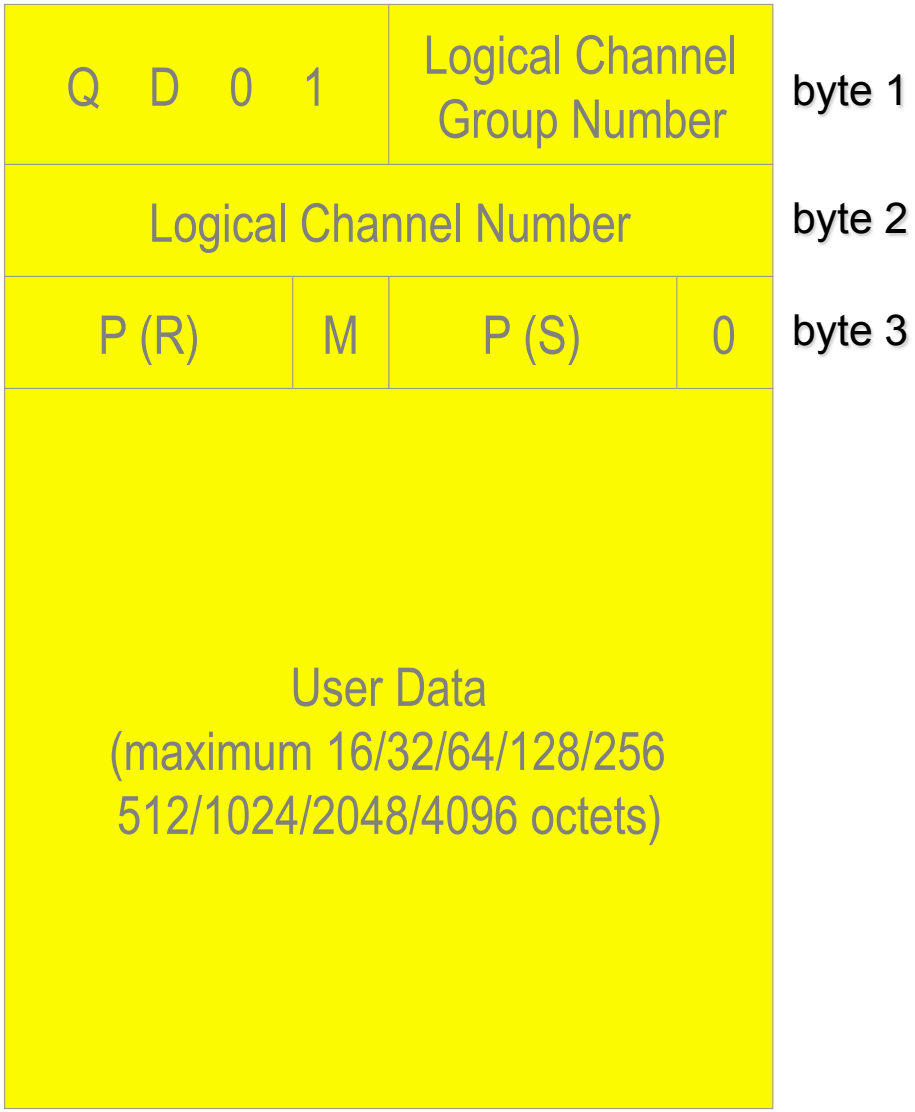
- **Essential Facilities**
  - Provided by all X.25 devices, have default values
    - Maximum packet size (Default: 128 Bytes)
    - Window size
    - Throughput class (75, ..., 48000 bit/s), “X.25 QoS”
    - Transit delay, “X.25 QoS”
- **Optional Facilities**
  - Don't need to be provided, default values and negotiation possible
    - Fast Select and Fast Select Acceptance
    - Closed user groups
    - Reverse charging
    - Hunt groups
    - Call redirection

X.25 Call Setup and Release

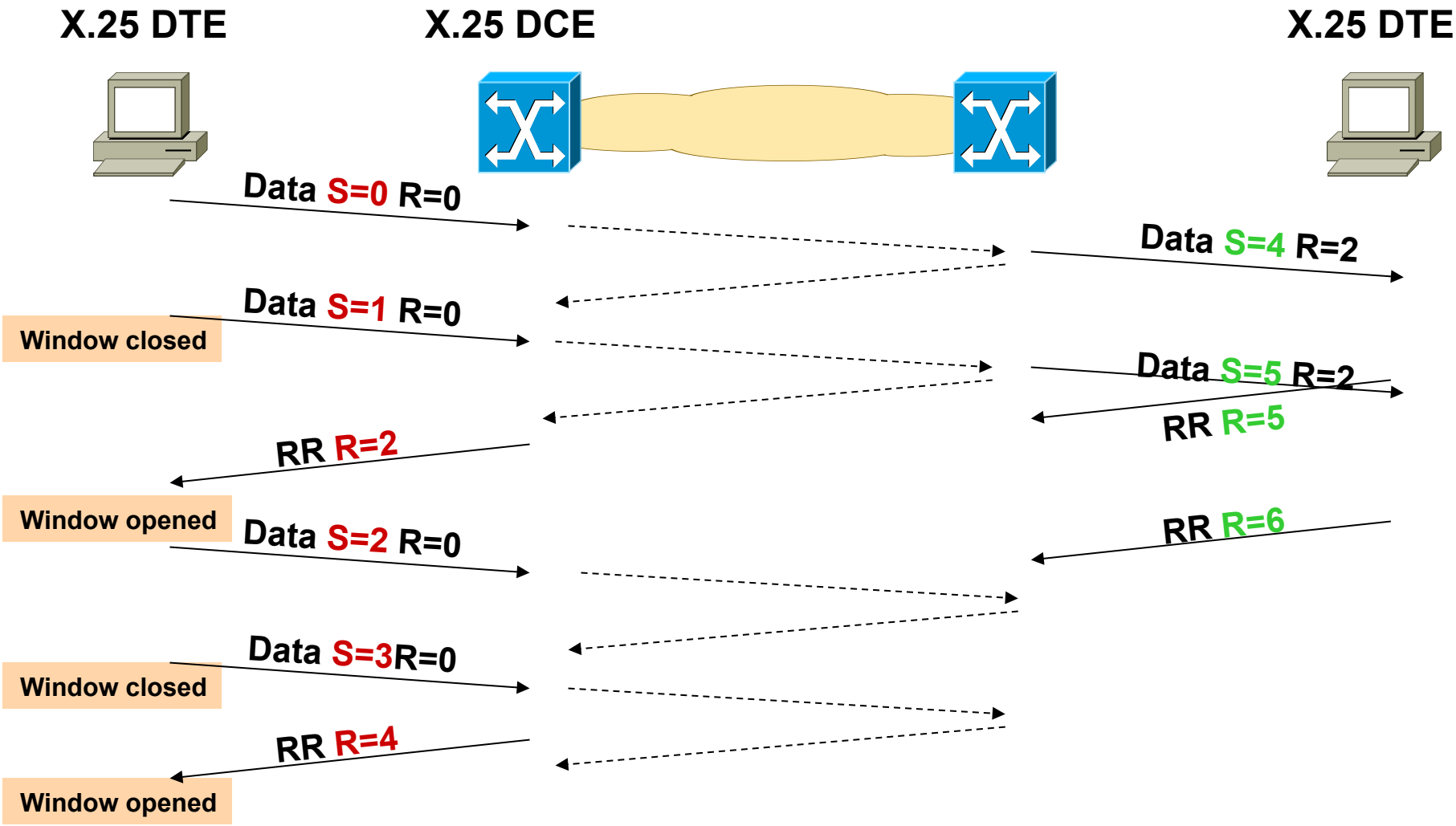


PLP Header Format: Data Transfer

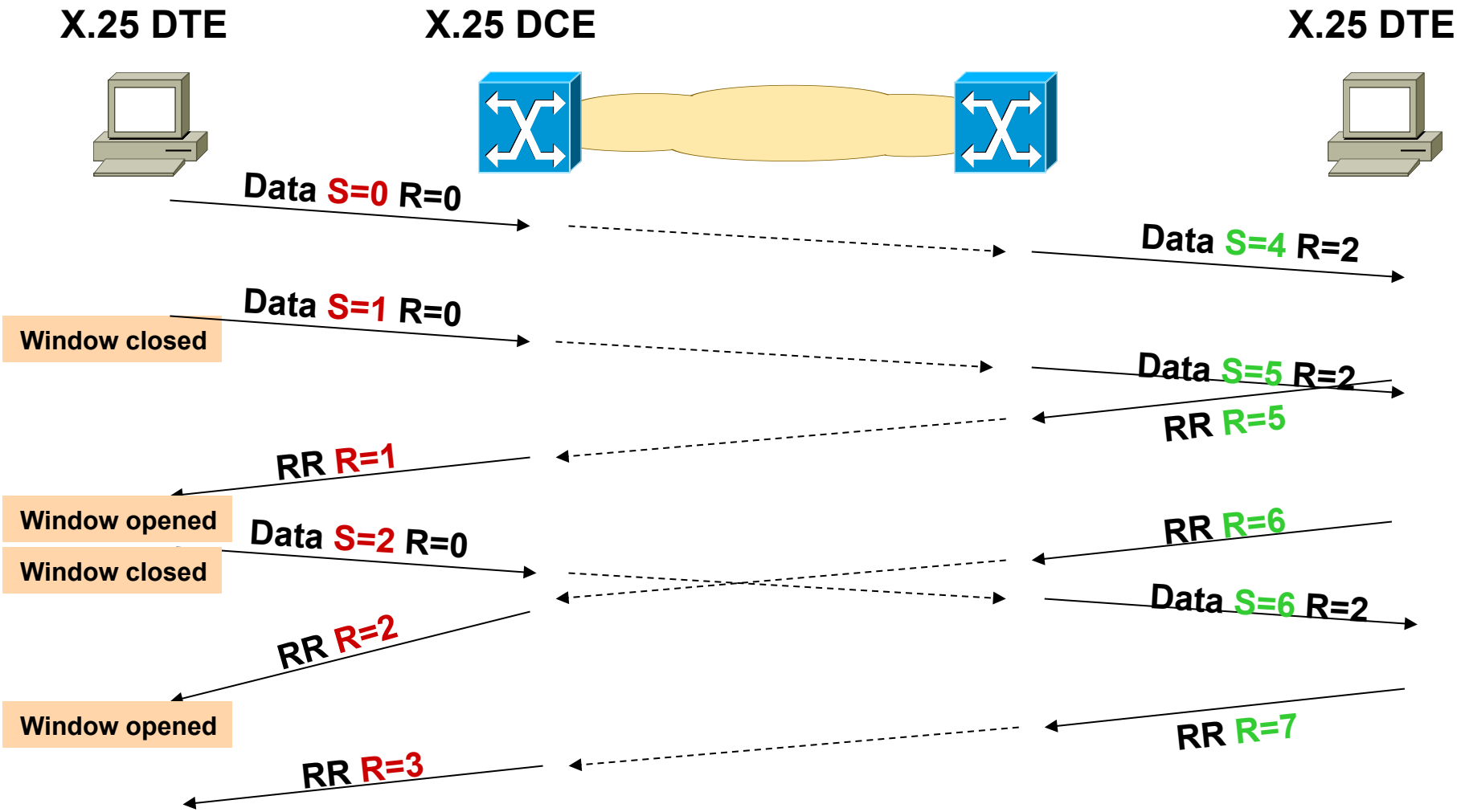
- **Data modulo 8**
  - Packet type -> last bit zero
  - D = 1 end-to-end ack. required
  - D = 0 only local ack. required
  - Q = 1 user data
  - Q = 0 control data
  - M bit used for fragmentation purpose
    - if one side use a lower maximum packet size



Local Flow Control (X.25 DTE and local X.25 DCE) Window=2 and D=0



End-to-End Flow Control (between X.25 DTEs) Window=2 and D=1

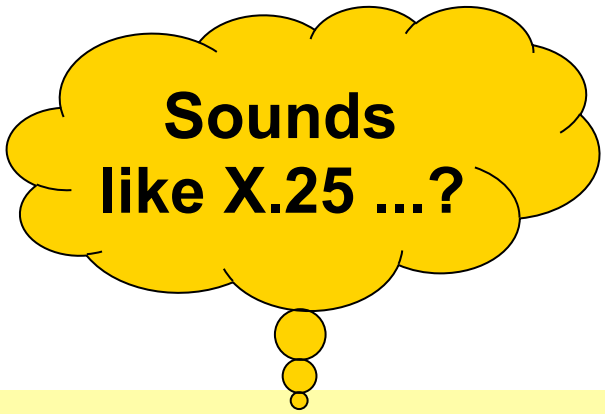


Agenda

- ISDN
- X.25
- Frame Relay
- ATM

What is Frame Relay?

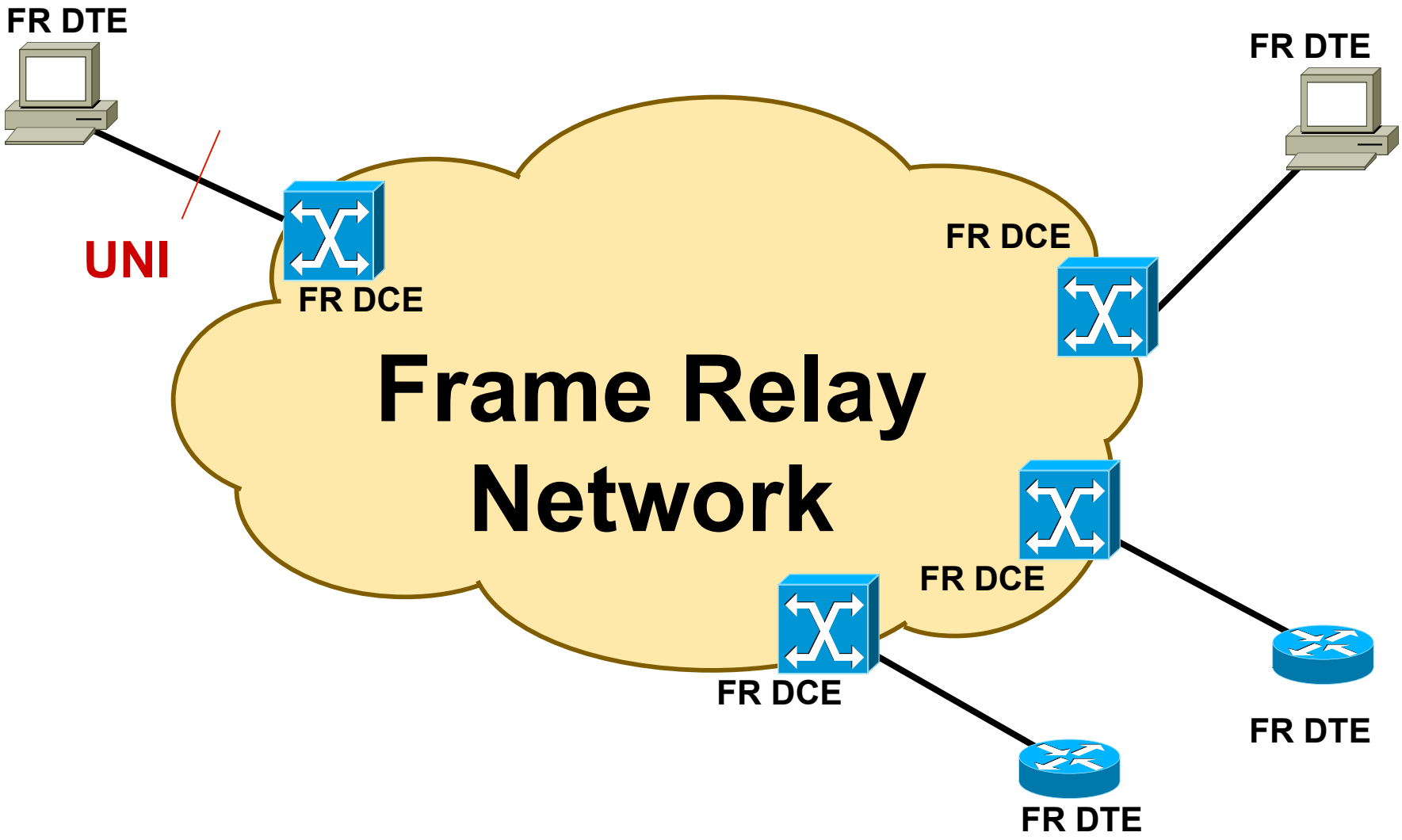
- **Packet switching technology**
  - Based on store-and-forward of packets
  - Connection oriented
  - Variable delays (!)
- **Interface definition between user and network equipment (UNI)**
  - FR - DTE (e.g. router) <-> FR - DCE (frame relay switch)
- **Wide area network service**
  - Based on virtual circuit technique can be implemented
  - PVC or (SVC) service
- **Does not specify network itself (!)**
- **Originally created**
  - by CCITT in 1984 as a replacement of X.25
  - but important and interoperable implementations driven by the Frame Relay Forum



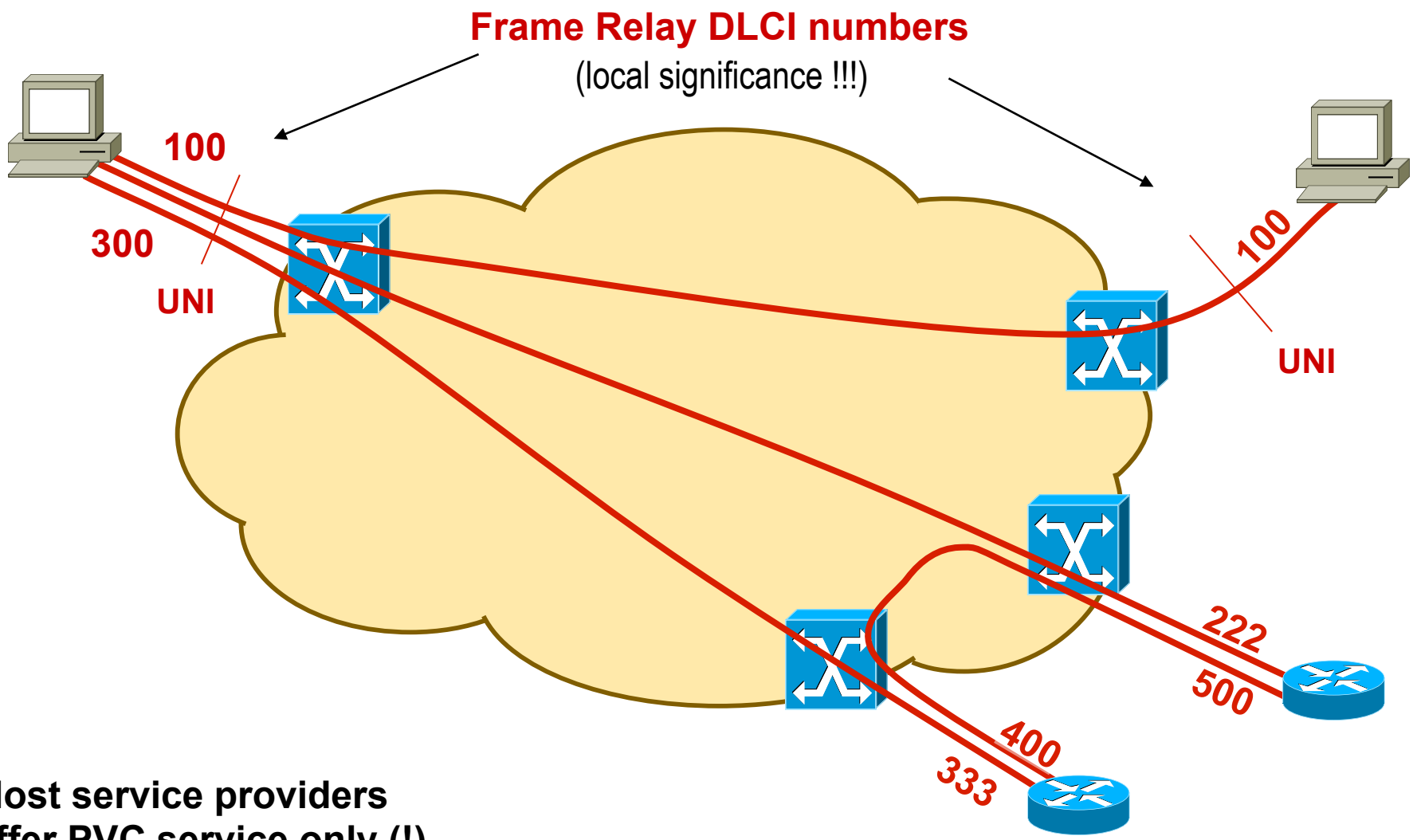
Basic Difference to X.25

- **Reduced overhead**
  - No error recovery (!)
  - No flow control (!)
    - instead flow congestion indication which may be used by congestion control techniques
  - Hence much faster
- **But this requires reliable links (!)**
- **Outband signaling**
- **Good for bursty and variable traffic**
  - Quality of Service *Ideas*
    - *CIR and EIR*

Frame Relay Network: Physical Topology

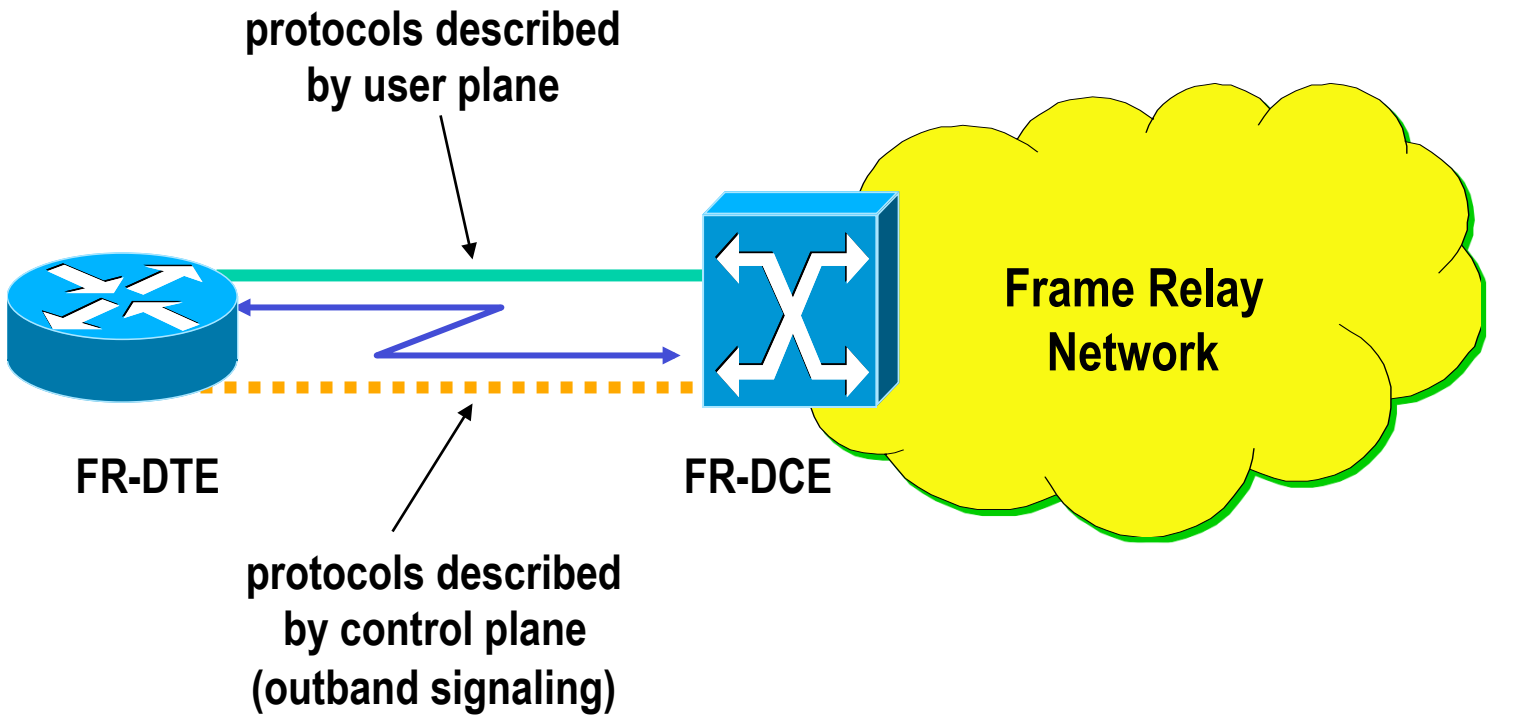


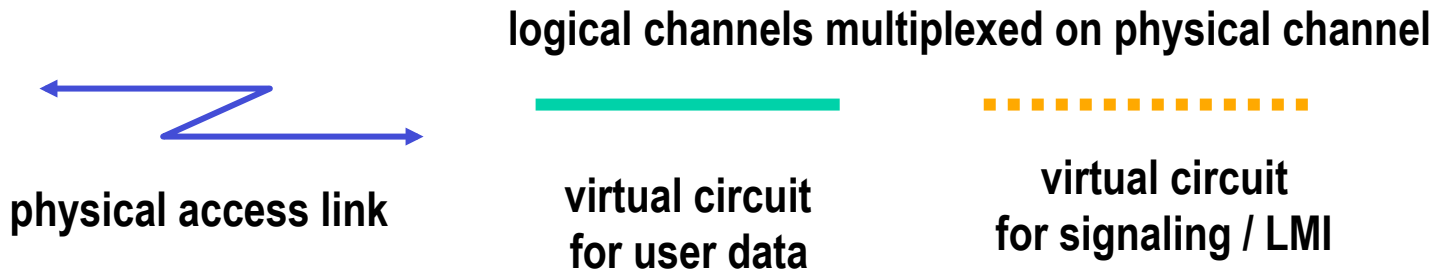
Frame Relay Network: Virtual Circuits
Local Connection Identifiers and Logical Channels



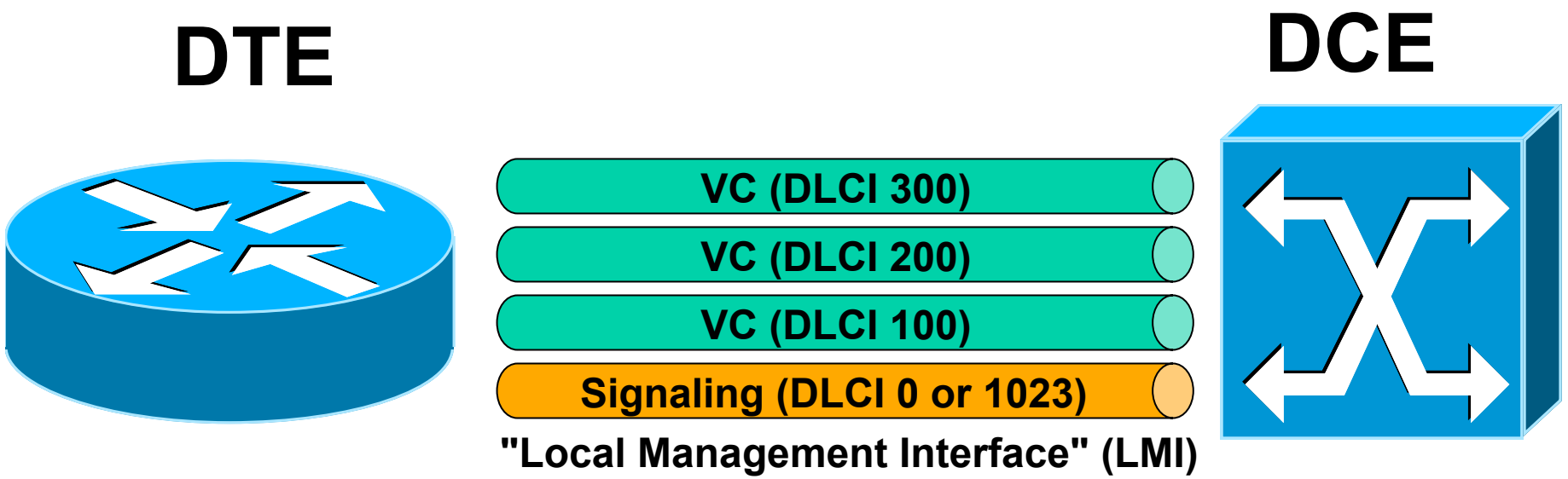
Most service providers offer PVC service only (!)

Control Plane <-> User Plane



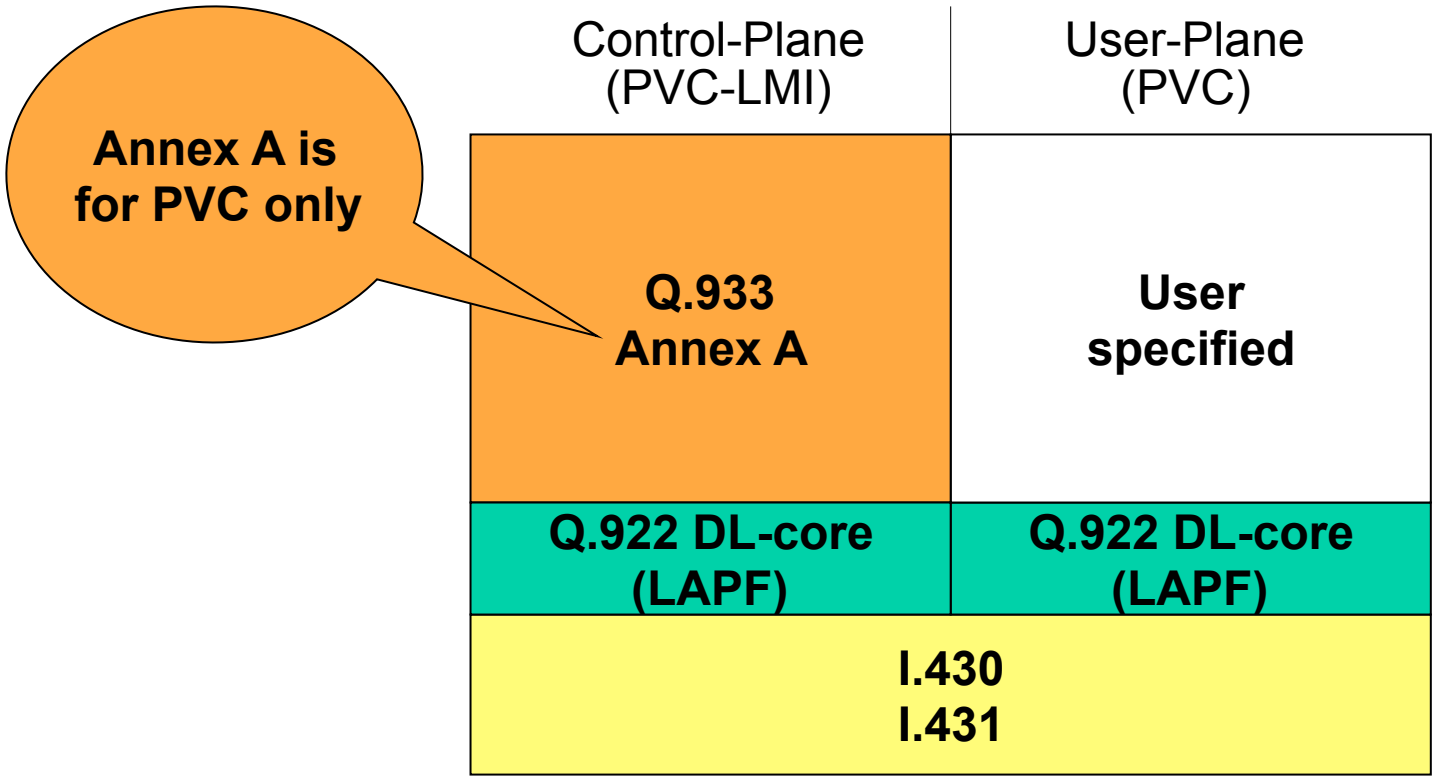


Outband Signaling

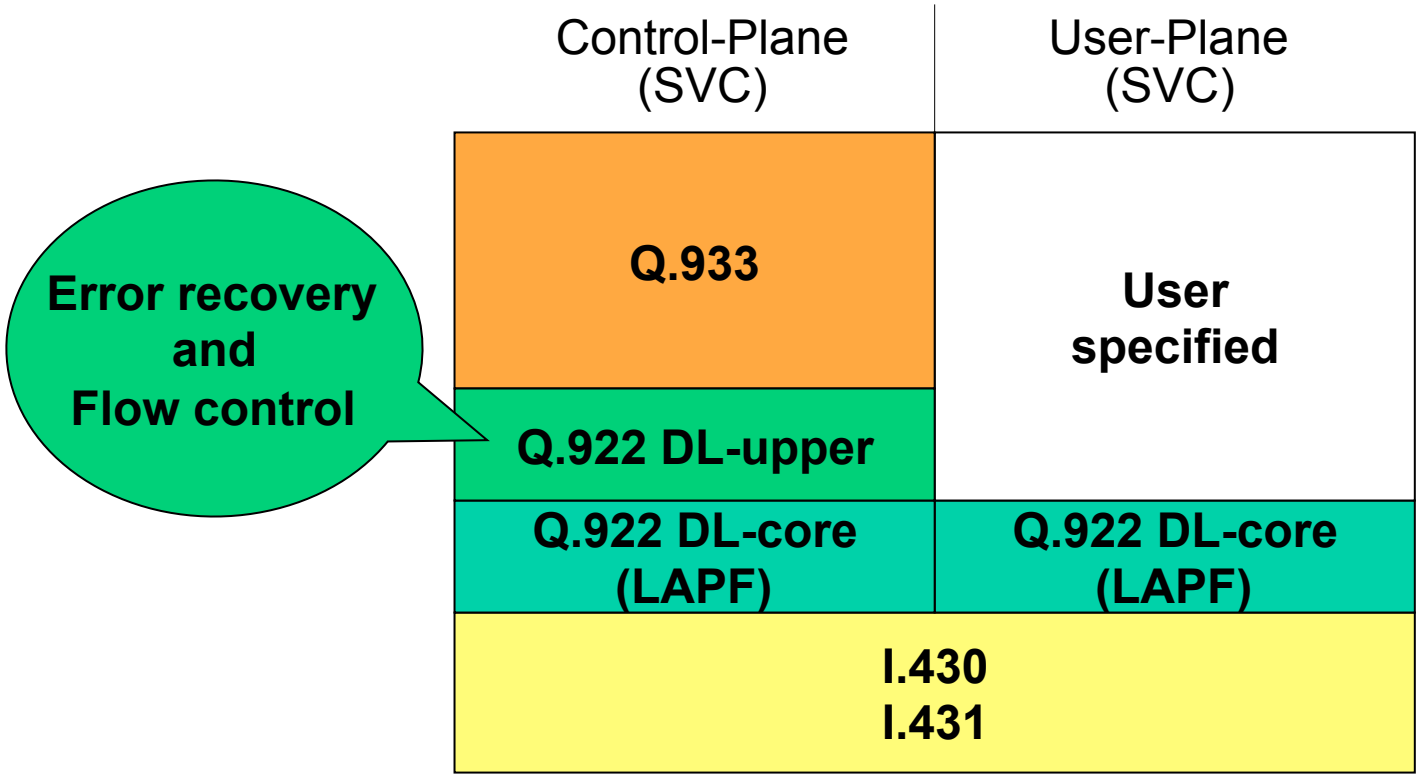


- Signaling through dedicated virtual circuit = "Outband Signaling"
- Signaling protocol is LMI

ITU-T PVC Service Model



ITU-T SVC Service Model



Layer Description

- **LAPF is a modified LAPD (ISDN)**
  - Specified in Q.922
- **Q.922 consists of**
  - Q.922 core (DLCIs, F/BECN, DE, CRC)
  - Q.922 upper (ARQ and Flow Control)
- **Q.933 is based on Q.931 (ISDN)**
  - Annex A for PVC management (LMI)

Frame Relay Forum (FRF)

FRF.1.1	User to Network Interface (UNI)
FRF.2.1	Network to Network Interface (NNI)
FRF.3.1	Multiprotocol Encapsulation
FRF.4	SVC
FRF.5	FR/ATM Network Interworking
FRF.6	Customer Network Management (MIB)
FRF.7	Multicasting Service Description
FRF.8	FR/ATM Service Interworking
FRF.9	Data Compression
FRF.10	Network to Network SVC
FRF.11	Voice over Frame Relay
FRF.12	Fragmentation
FRF.13	Service Level Agreements
FRF.14	Physical Layer Interface
FRF.15	End-to-End Multilink
FRF.16	Multilink UNI/NNI

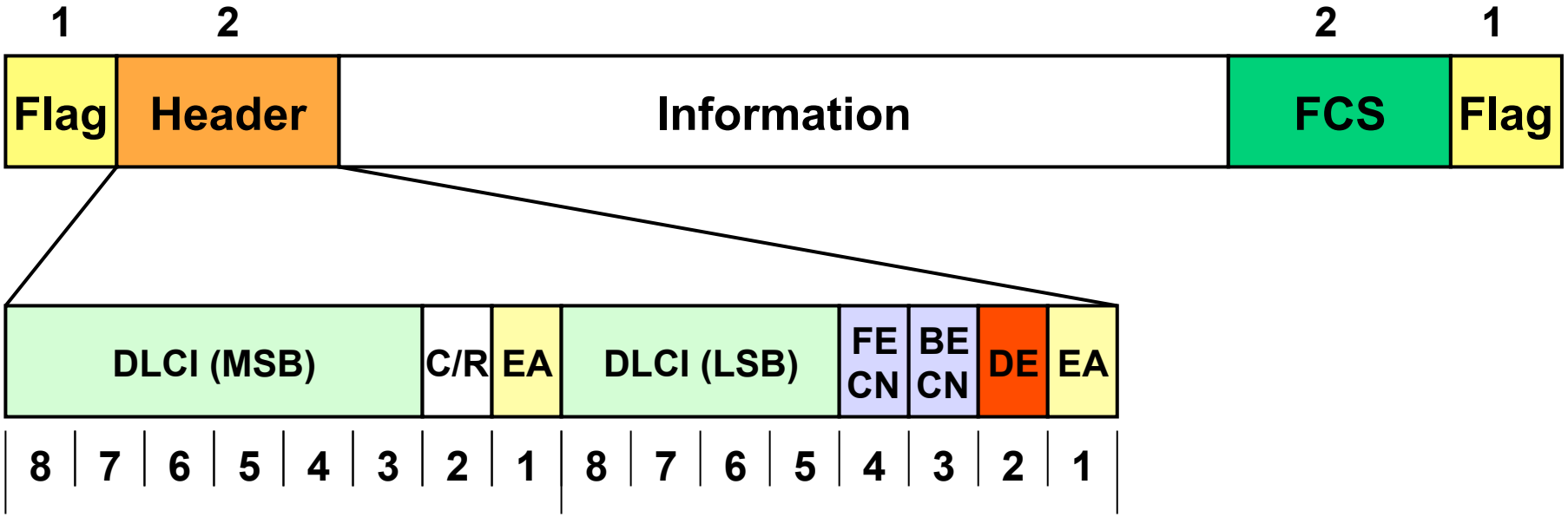
Physical Interfaces

- **Some UNI Specifications (FRF.1)**
  - ITU-T G.703 (2.048 Mbps)
  - ITU-T G.704 (E1, 2.048 Mbps)
  - ITU G.703 (E3, 34.368 Mbps)
  - ITU-T X.21
  - ANSI T1.403 (DS1, 1.544 Mbps)
  - ITU-T V.35
  - ANSI/EIA/TIA 613 A 1993 High Speed Serial Interface (HSSI, 53 Mbps)
  - ANSI T1.107a (DS3, 44.736 Mbps)
  - ITU V.36/V.37 congestion control

Layer 2 Tasks

- **Q.922 Annex A (LAPF) or T1.618 specifies**
  - Frame multiplexing according DLCI
  - Frame alignment (HDLC Flag)
  - Bit stuffing
  - 16-bit CRC error detection but no correction
  - Checks minimum size and maximum frame size
  - Congestion control

The Frame Relay Frame

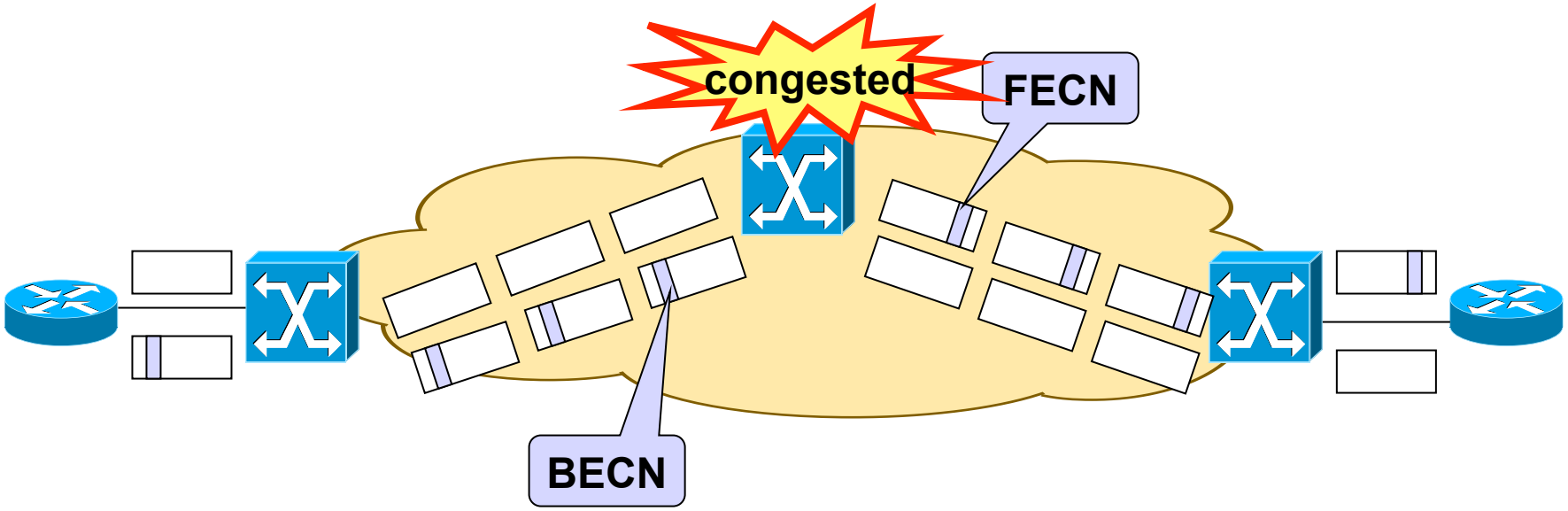


Legend:

DLCI	Data Link Connection Identifier
C/R	Command/Respond
EA	Extended Addressing
FECN	Forward Explicit Congestion Notification
BECN	Backward Explicit Congestion Notification
DE	Discard Eligibility

Congestion Control

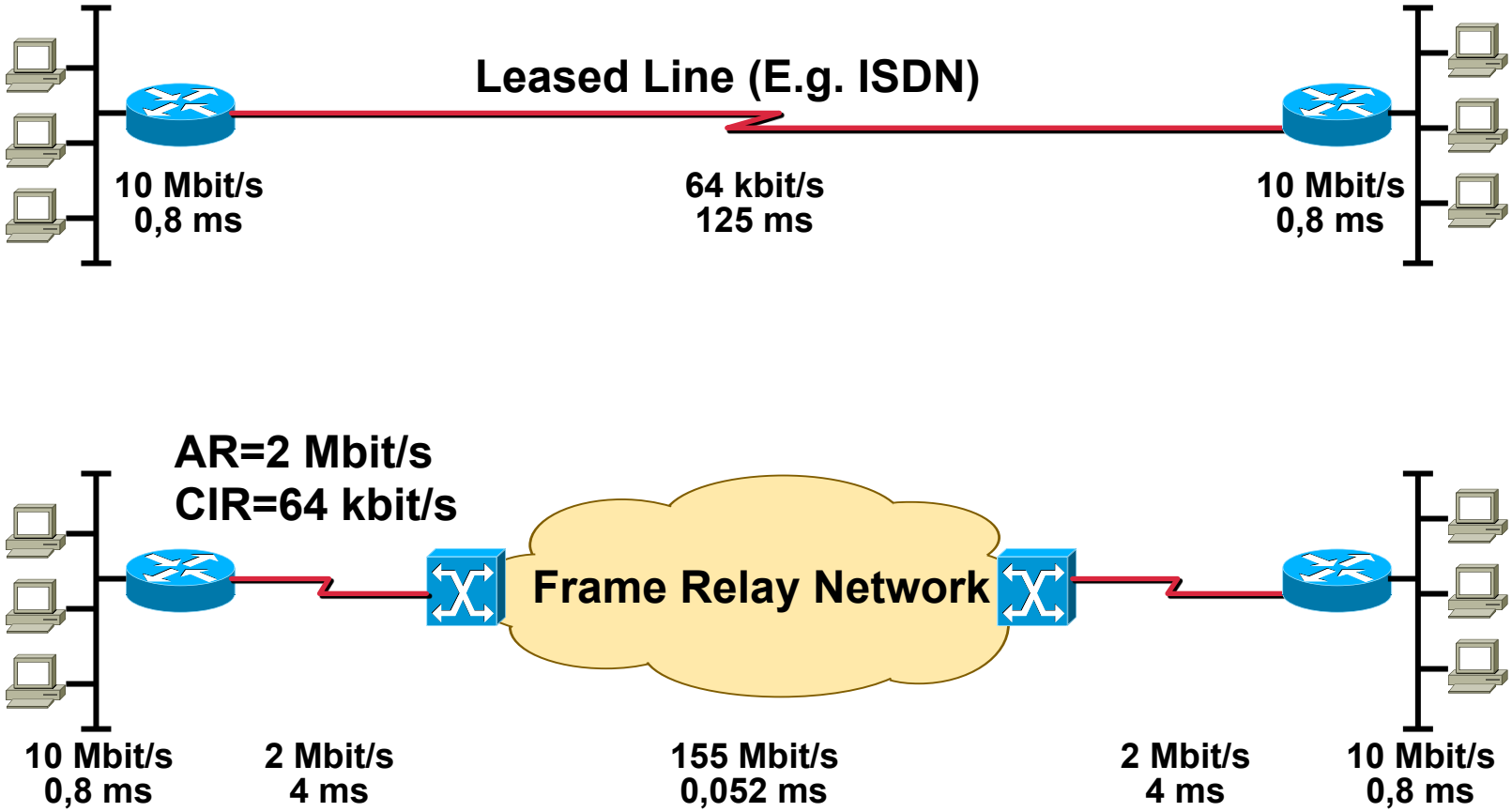
- FECN indicates congestion to the receiver
- BECN indicates congestion to the sender
- Problem: DTEs do not need to react (!)



Traffic Control

- **Statistical multiplexing is cheaper for service providers than deterministic-synchronous multiplexing**
- **Users are supposed to require less than the access rate on average**
- **Otherwise congestion will occur and frames are dropped**
  - Which causes the end-stations to retransmit...and further overload the network

Time to Transmit 1 kByte



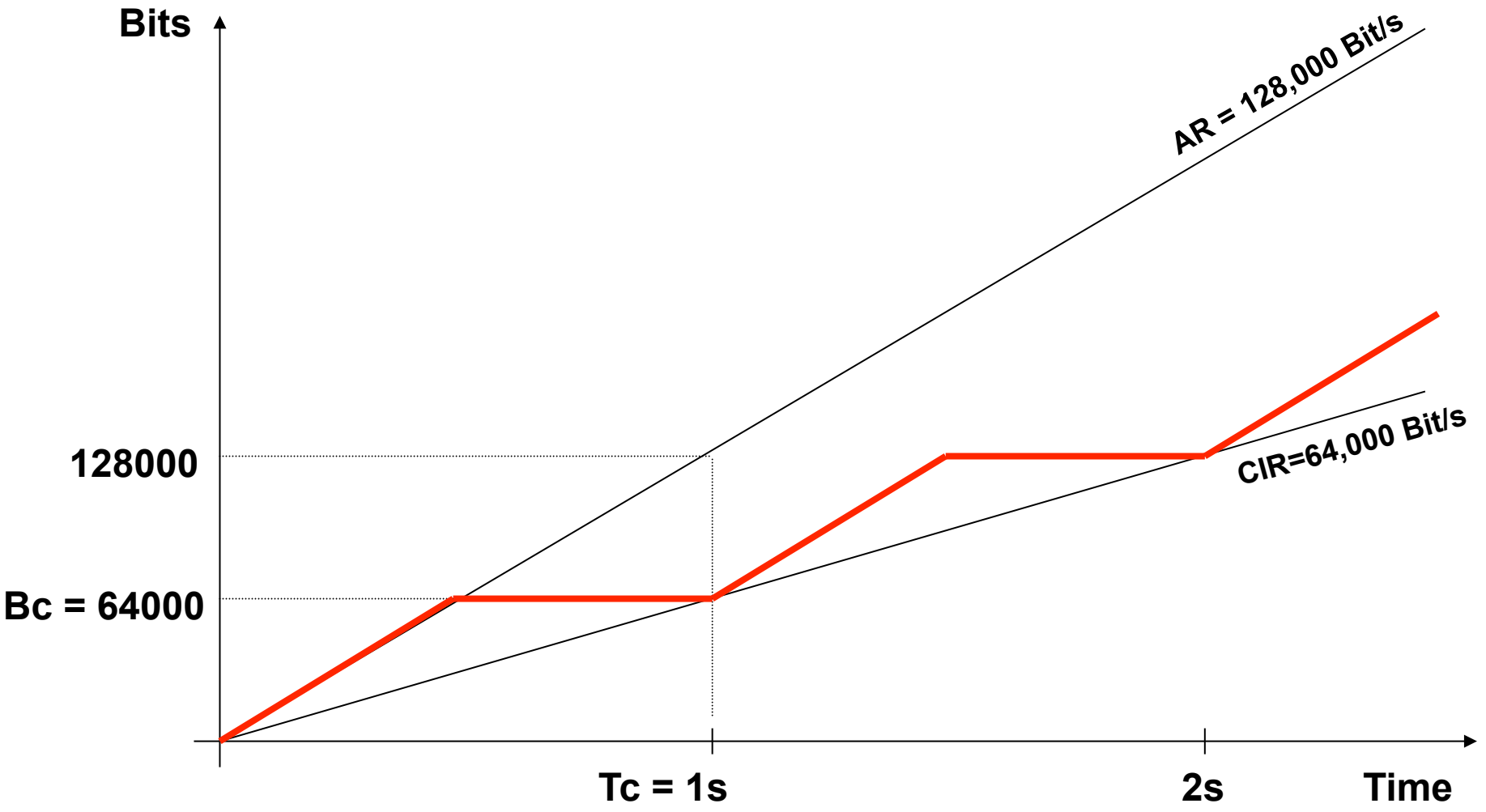
Bursty Traffic (1)

- **FR allows to differentiate between Access Rate (AR) and Committed Information Rate (CIR)**
  - CIR corresponds to average data rate
  - AR > CIR
- **Sporadic bursts can use line up to AR**
- **Optionally limited by Excess Information Rate (EIR)**

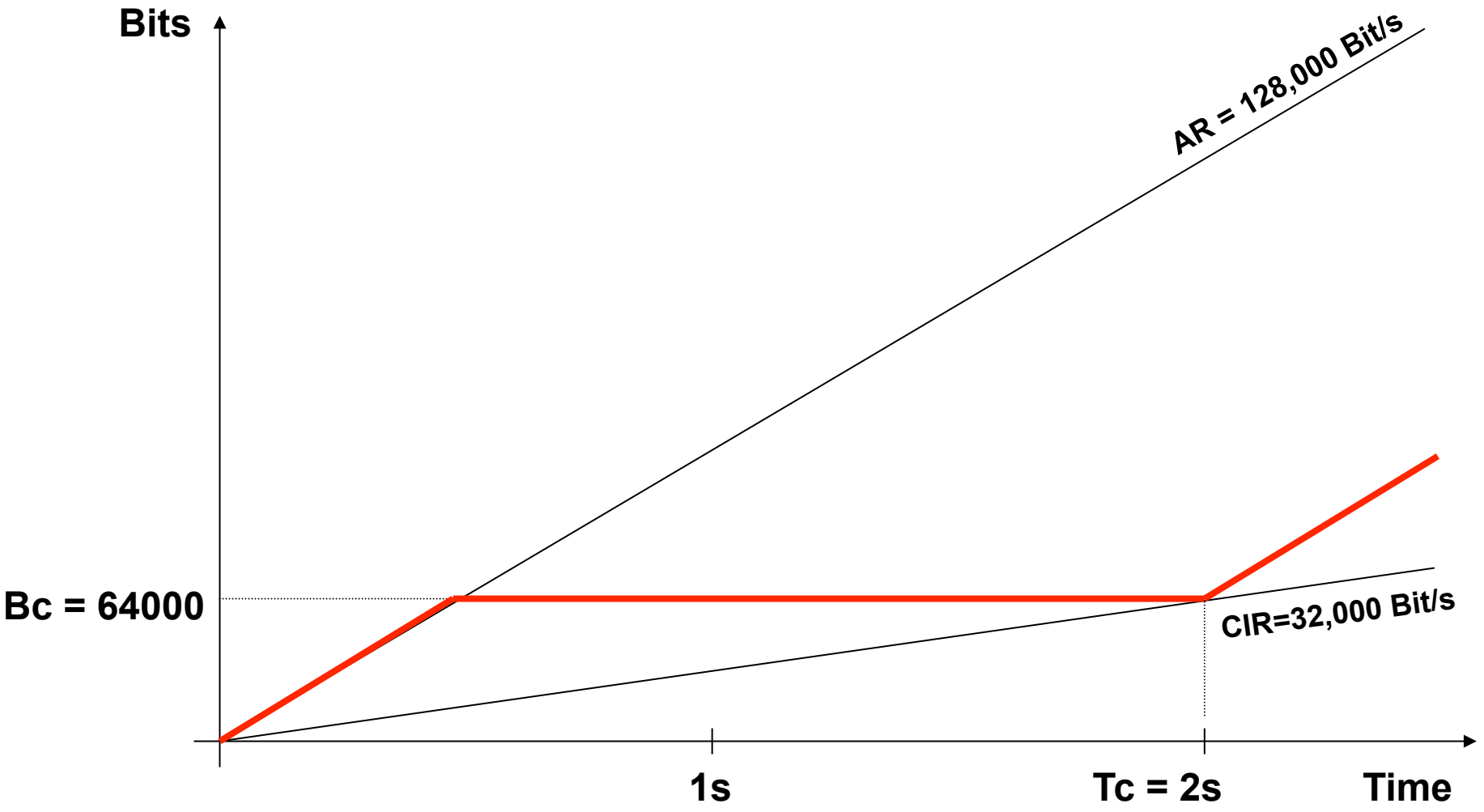
Bursty Traffic (2)

- **CIR and EIR are defined via a measurement interval Tc**
  - CIR = Bc / Tc (Bc...Committed Burst Size)
  - EIR = (Bc+Be) / Tc (Be...Excess Burst Size)
- **When traffic can be mapped on these parameters (provided by provider) then FR is ideal for bursty traffic**
  - Example: LAN to LAN connection
- **Parameters (Bc, Be, Tc, AR) are defined in a traffic contract**

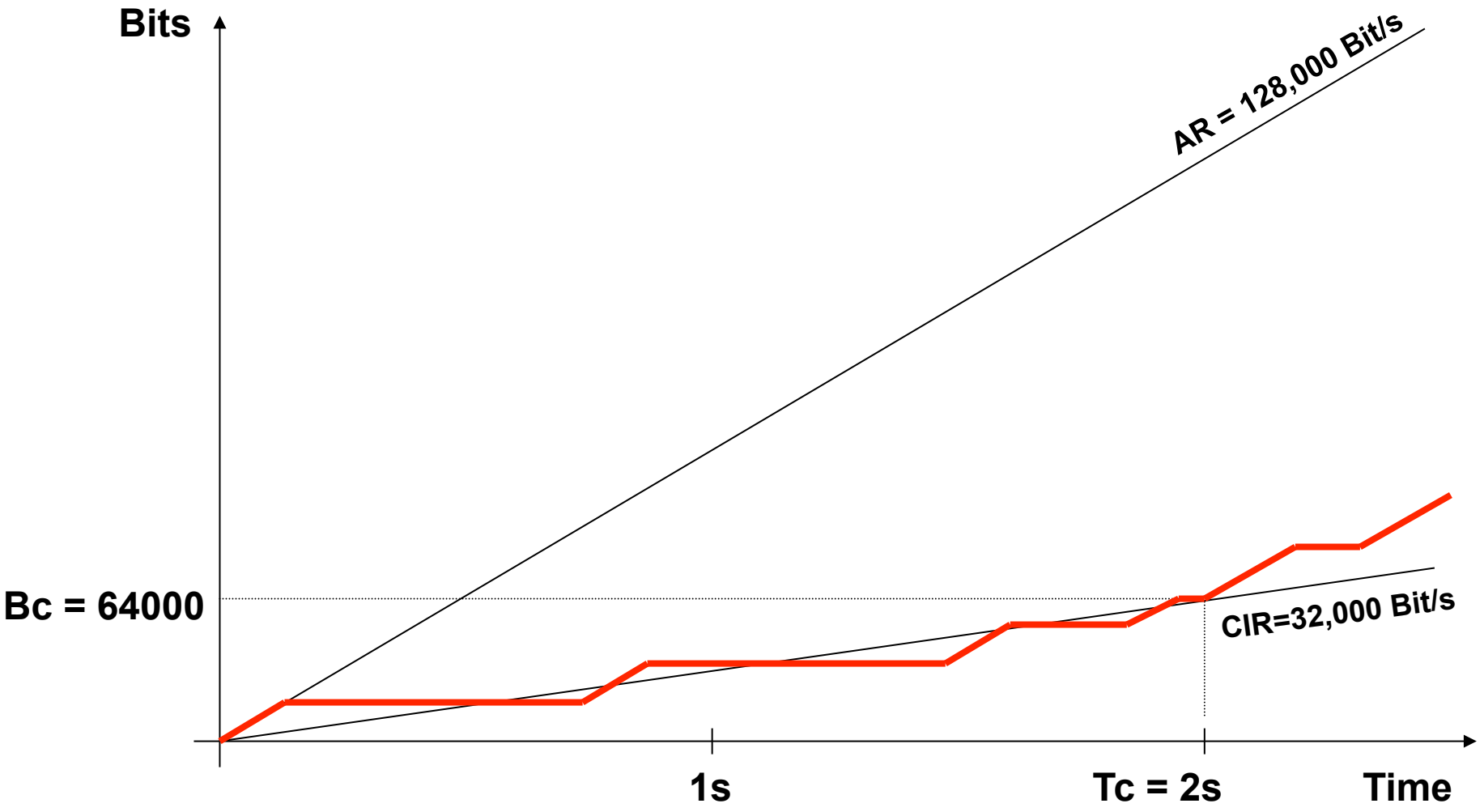
Parameter Example (1)



Parameter Example (2)



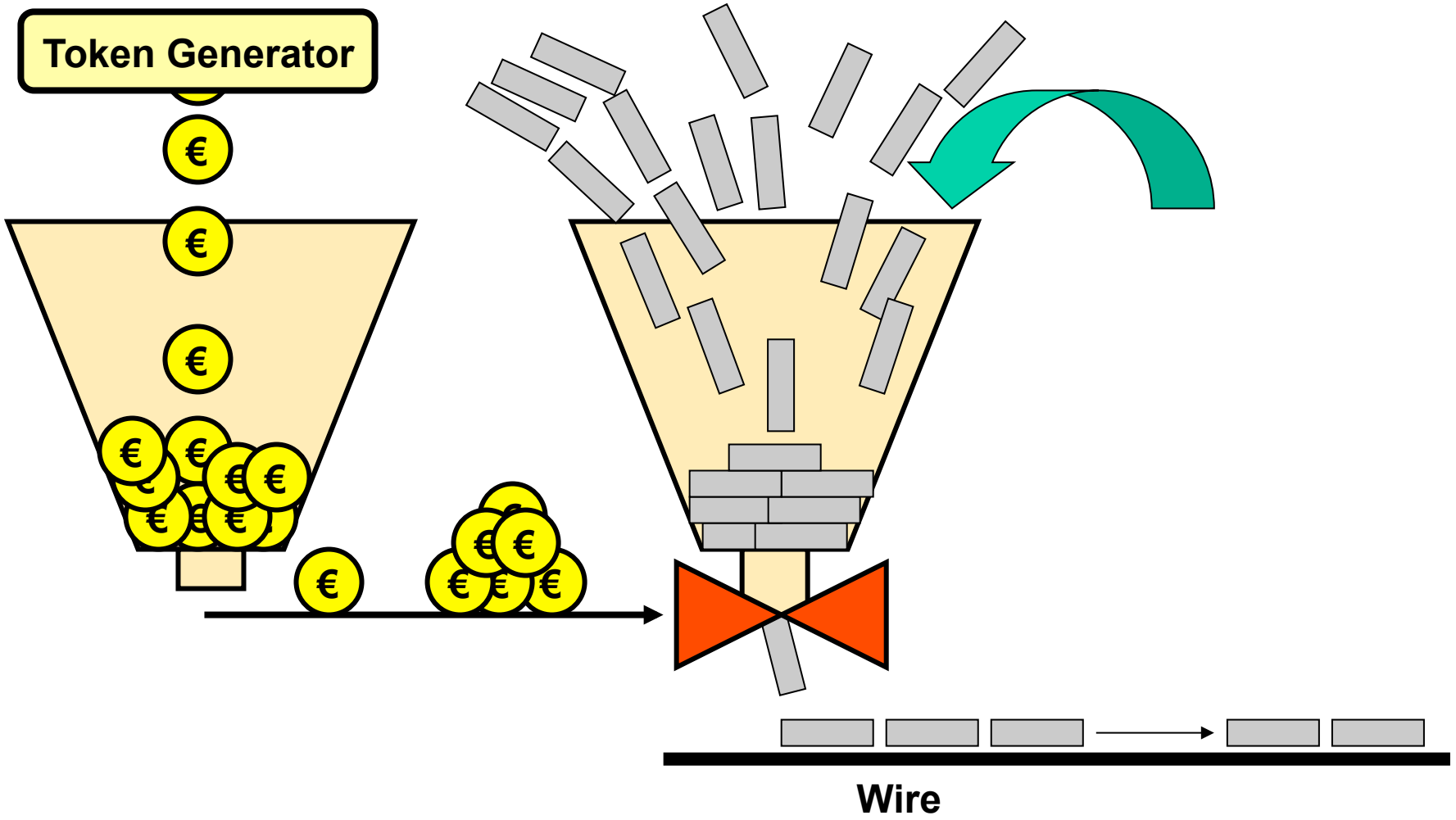
Parameter Example (3)



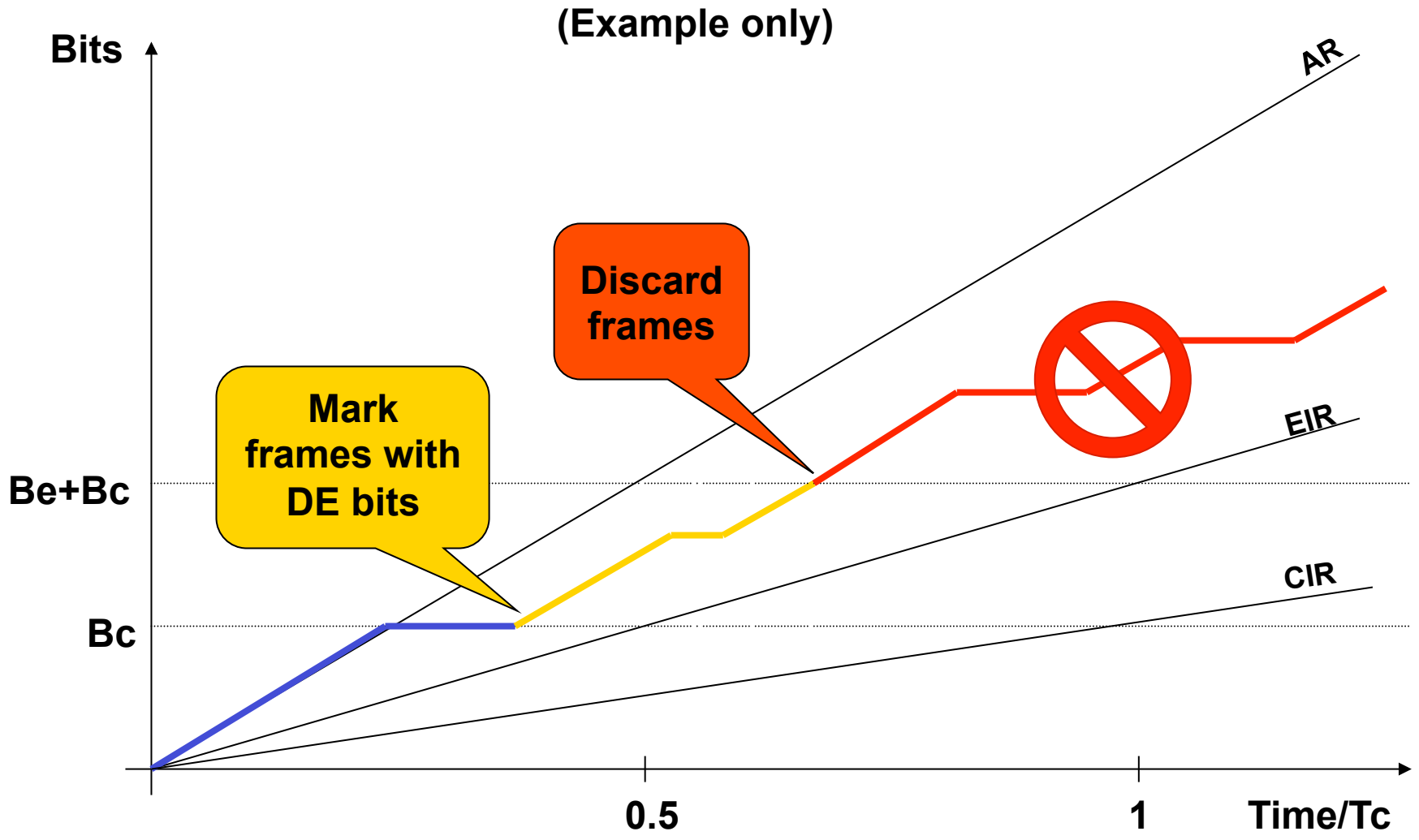
Traffic Management

- **Traffic Shaping**
  - Users task
  - Goal: smooth traffic profile, mitigate bursts
  - Token bucket methods
- **Traffic Policing**
  - Provider's task
  - Goal: Drop (excess) frames violating the traffic contract

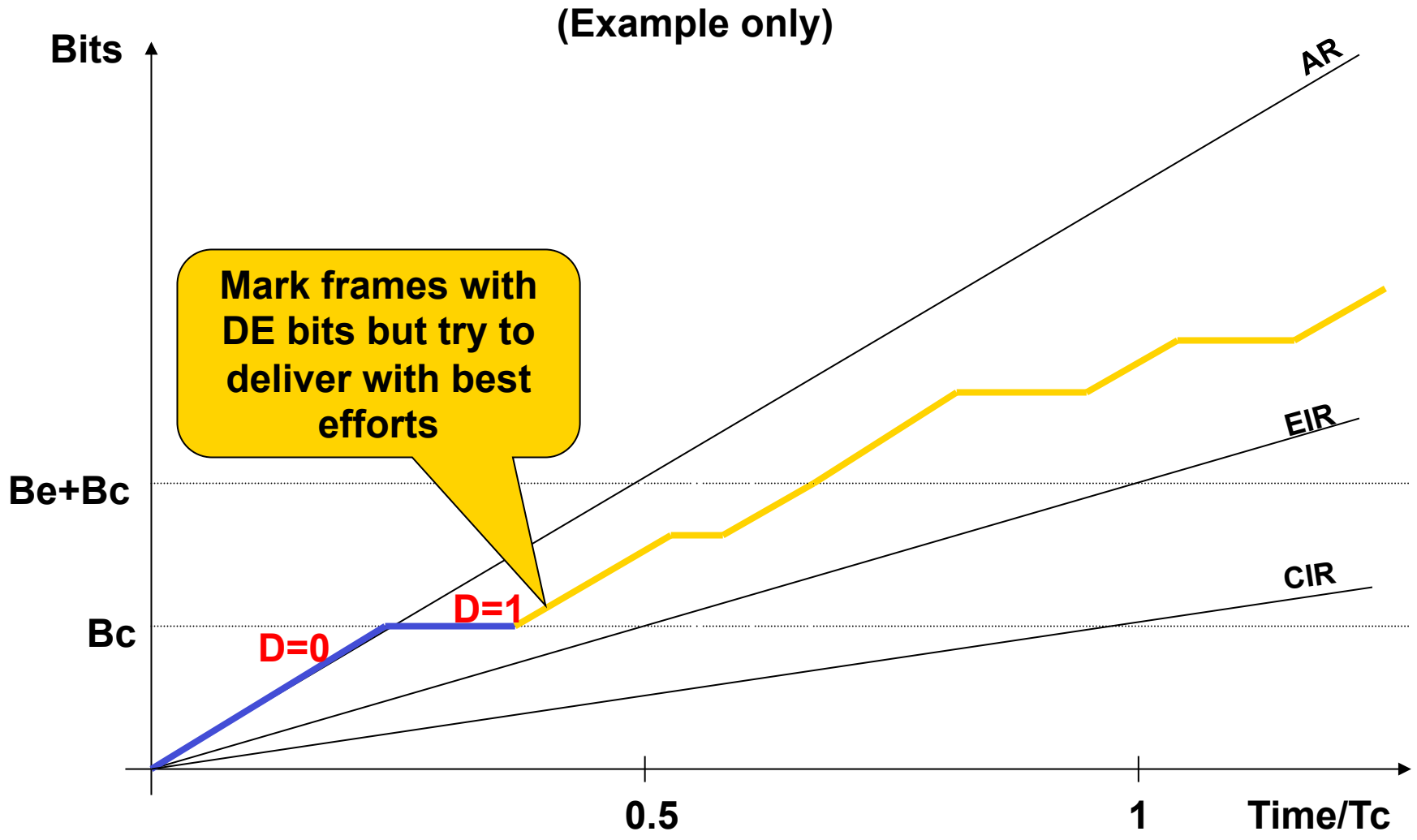
Token Bucket



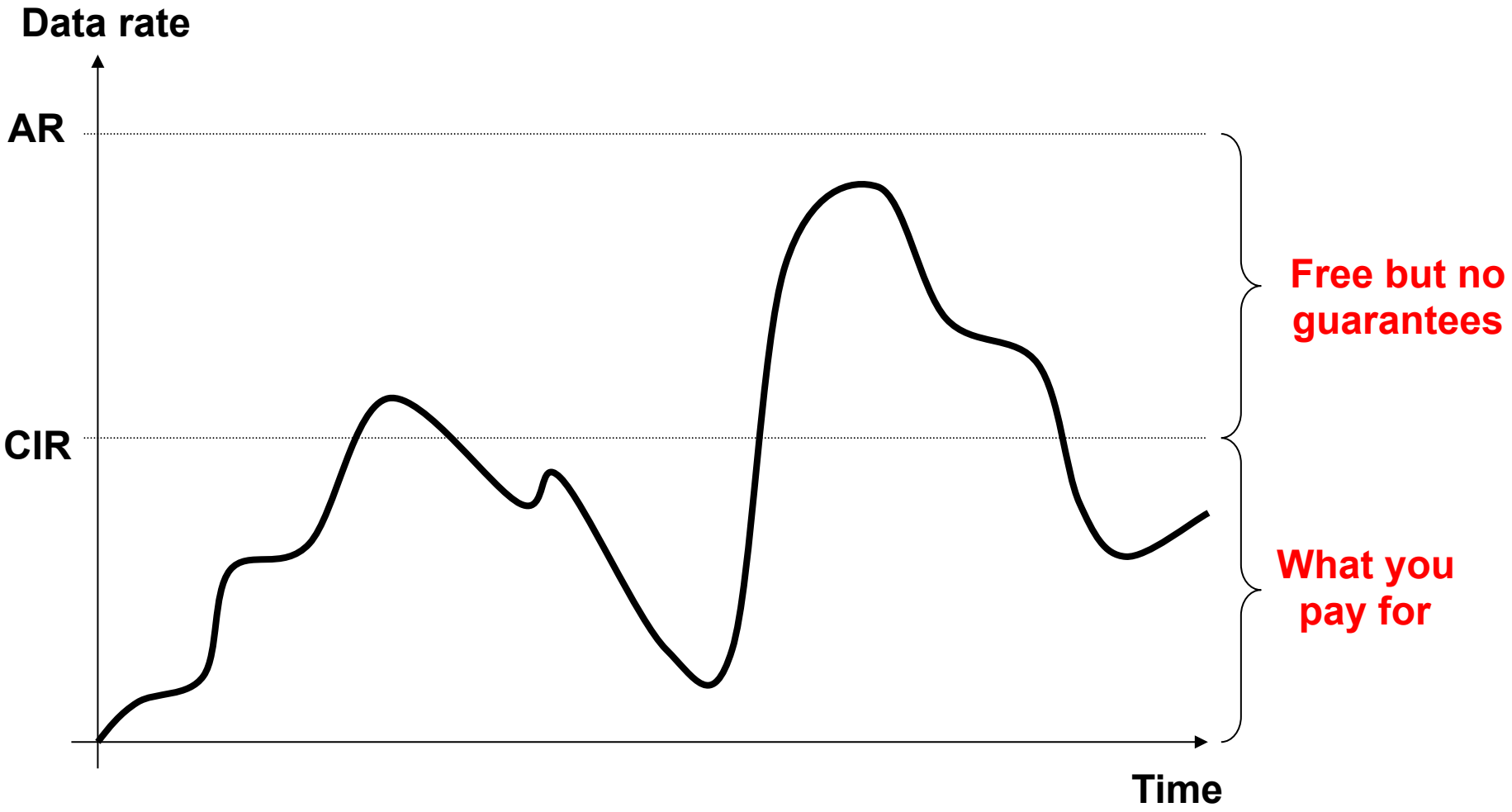
Traffic Management Possibility (1)



Traffic Management Possibility (2)



Typical Provider Offering



Agenda

- ISDN
- X.25
- Frame Relay
- ATM

What is ATM?

- **ATM**
  - Asynchronous Transfer Mode
  - Based on asynchronous TDM
    - Hence buffering and address information is necessary
    - Variable delay (!)
- **Cell switching technology**
  - Based on store-and-forward of cells
  - Connection-oriented type of service with PVC and SVC
  - But no error recovery (!)
- **ATM cell**
  - Small packet with constant length
  - 53 bytes long (5 bytes header + 48 bytes data)

What is Asynchronous Transfer Mode?

Synchronous TDM

(+) Constant delay
(good for voice)

(+) Protocol transparent

(–) Fixed channel assignment
(might be uneconomic)

(–) Trunk bandwidth = sum of
channel speeds (expensive)

Asynchronous TDM

(–) Variable delay
(variable frame sizes)

(+/~) Fairly protocol transparent

(+) Flexible channel assignment
(using addresses)

(+) Trunk bandwidth = average of
channel speeds

Asynchronous Transfer Mode (ATM)

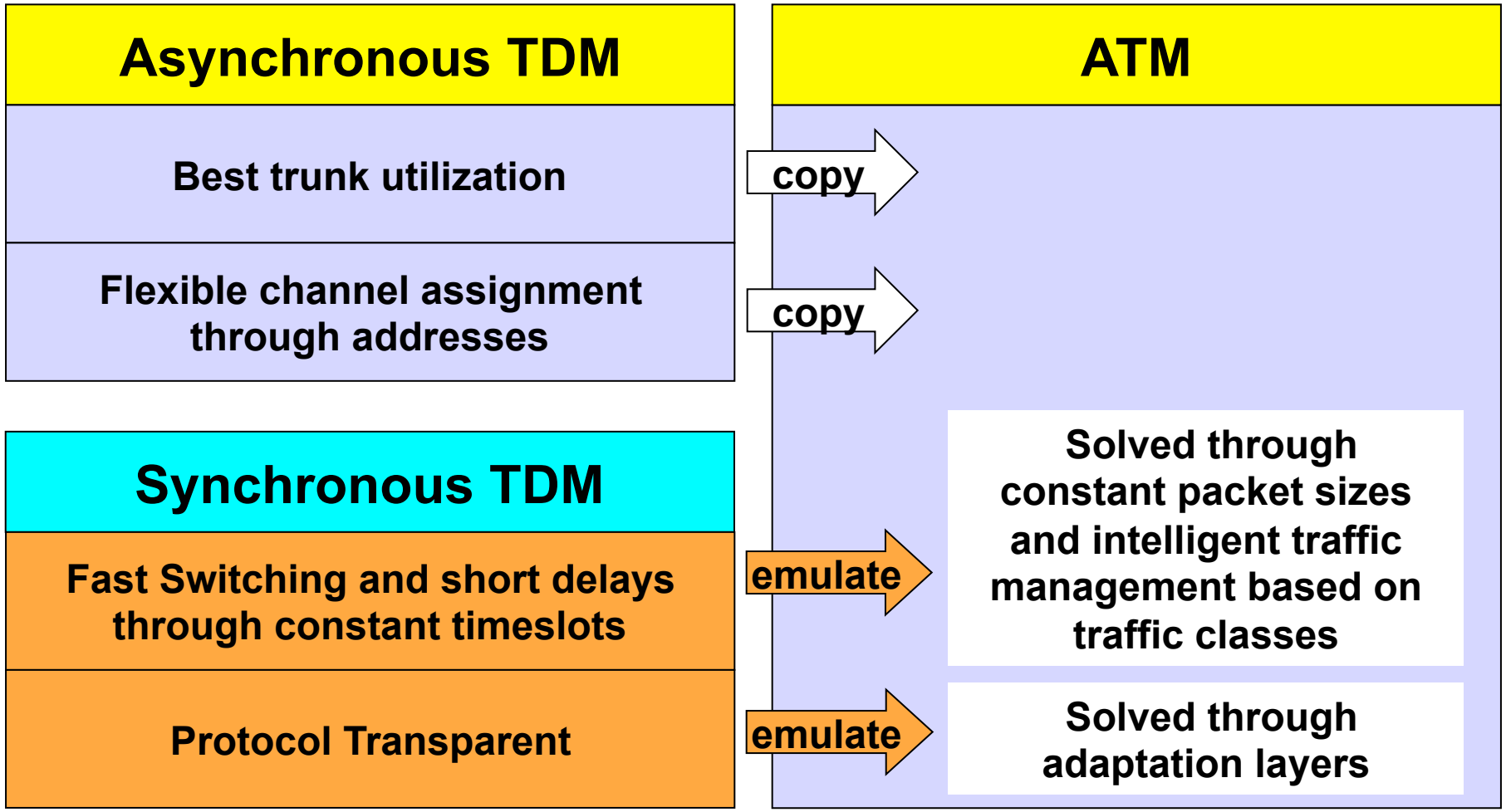
(+) Bounded delay through fixed cell sizes (53 bytes)

(+) Protocol transparent through higher layers (CPCS and SAR)

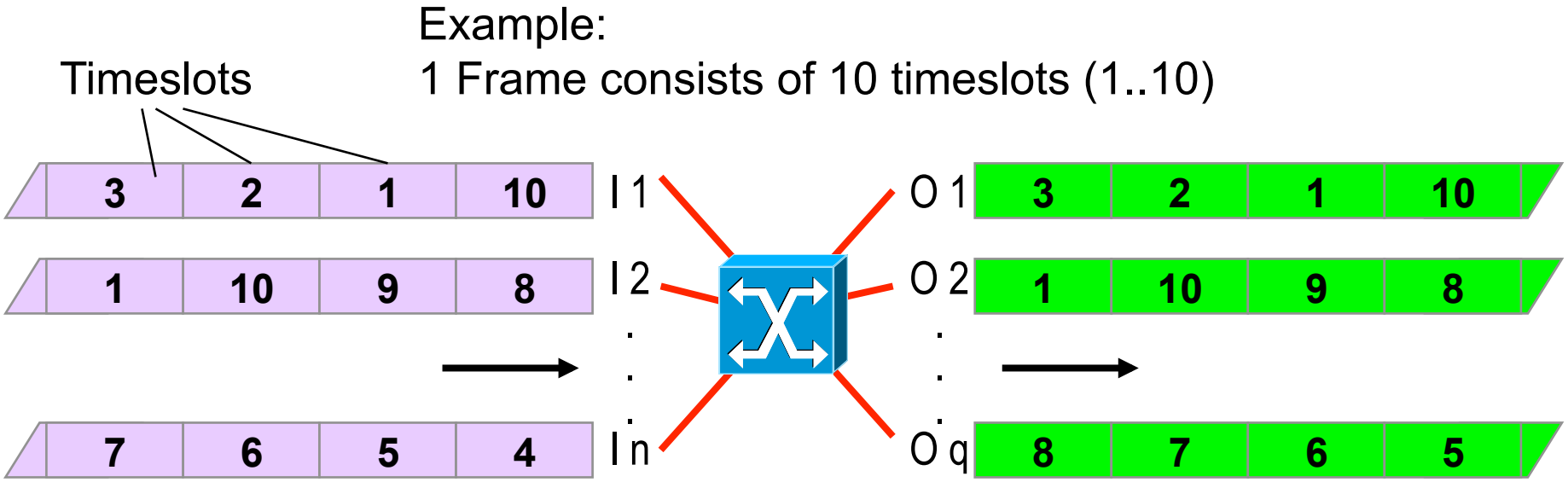
(+) Flexible channel assignment using addresses (VPI/VCI)

(+) Trunk bandwidth according average channel speeds
(different traffic classes)

Design Ideas



Synchronous Transfer Mode (STM)

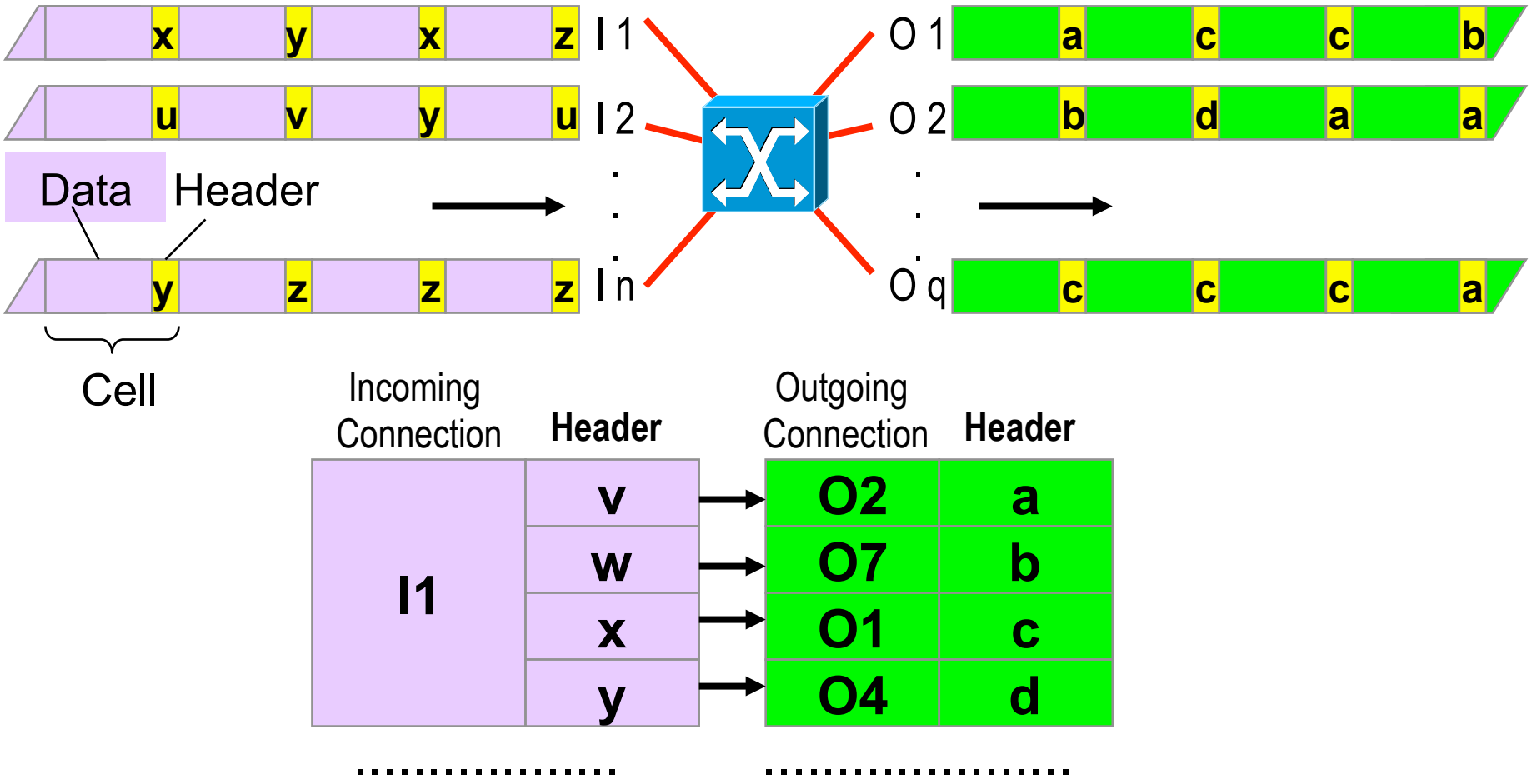


Incoming Connection	Timeslot	Outgoing Connection	Timeslot
I1	1	O2	8
	2	O7	3
	3	O1	3
	4	O4	5

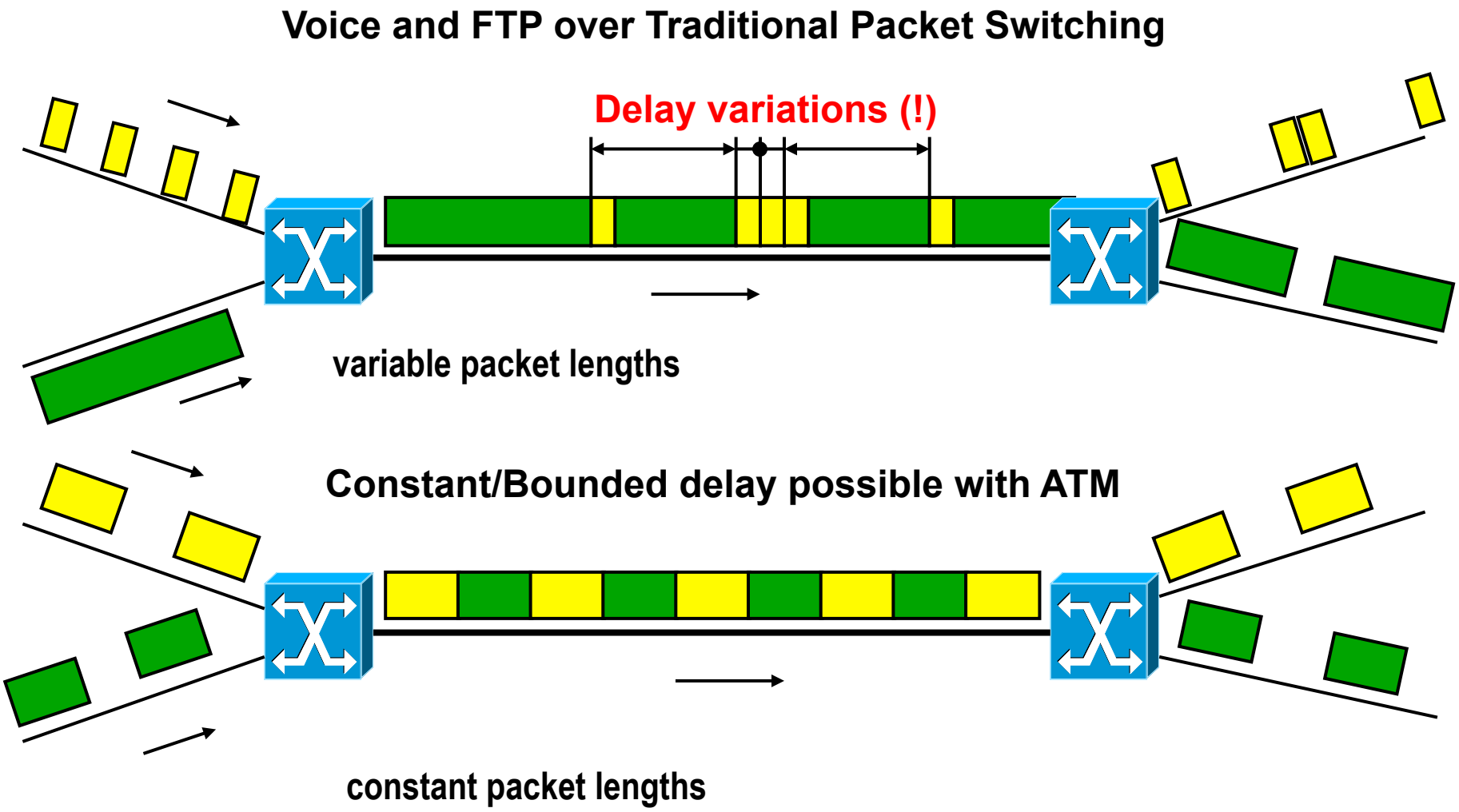
Fixed timeslot allocation !

Asynchronous Transfer Mode (ATM)

Cell header: addressing information for switching and dynamic bandwidth allocation



Cell Switching and Delay / Delay Jitter



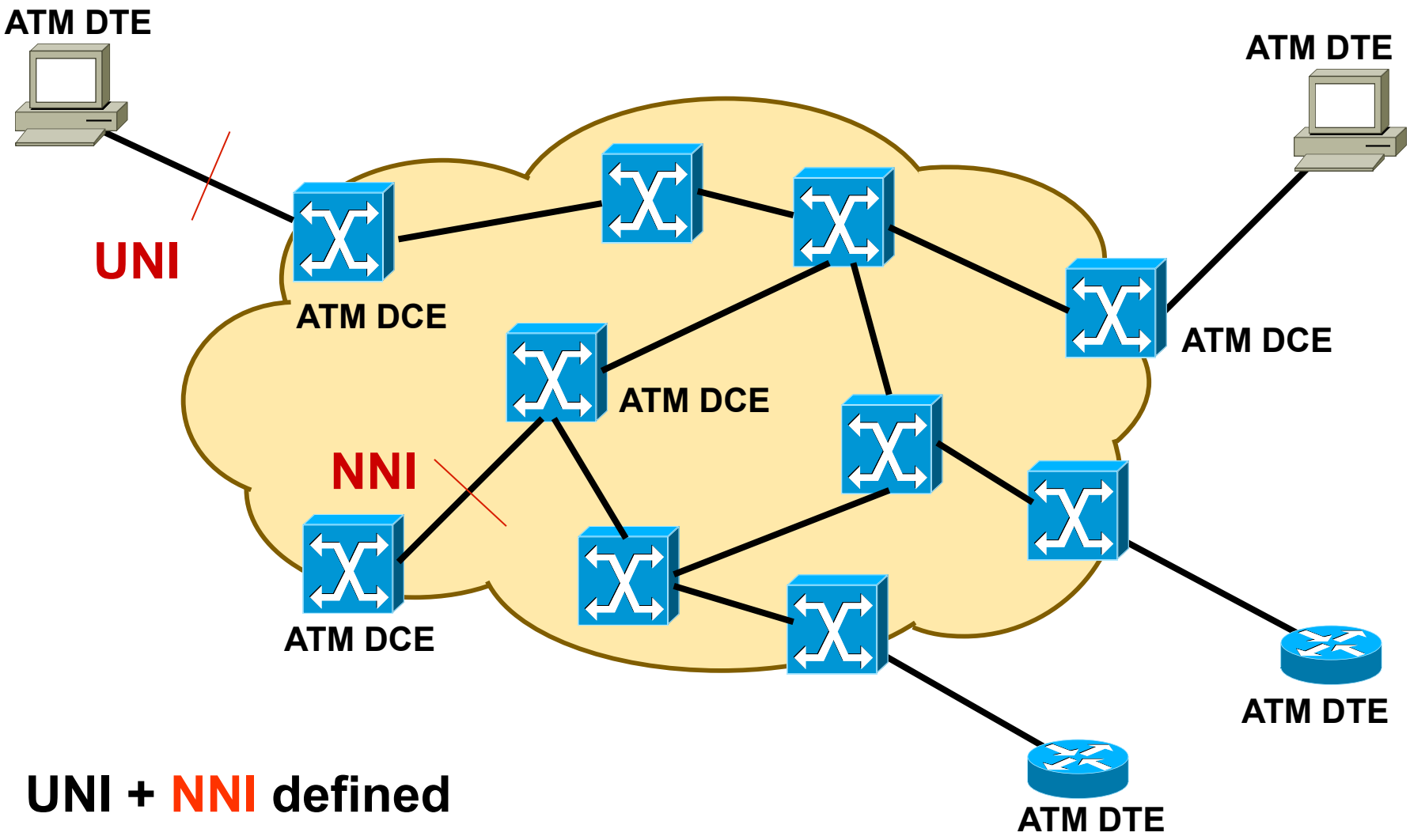
Why Cell Switching?

- **Forwarding of cells can be implemented in HW**
  - Very fast
  - More predictable and bounded delay and delay variation for a given cell
  - But it is still variable !
    - Because of asynchronous multiplexing
- **Because of constant cell size the queuing algorithms (part of QoS techniques) can guarantee**
  - Bounded delay
  - Maximum delay variations
- **Integration of voice, video and data**
  - Real-time traffic and non real-time traffic on the same network infrastructure

ATM Networks

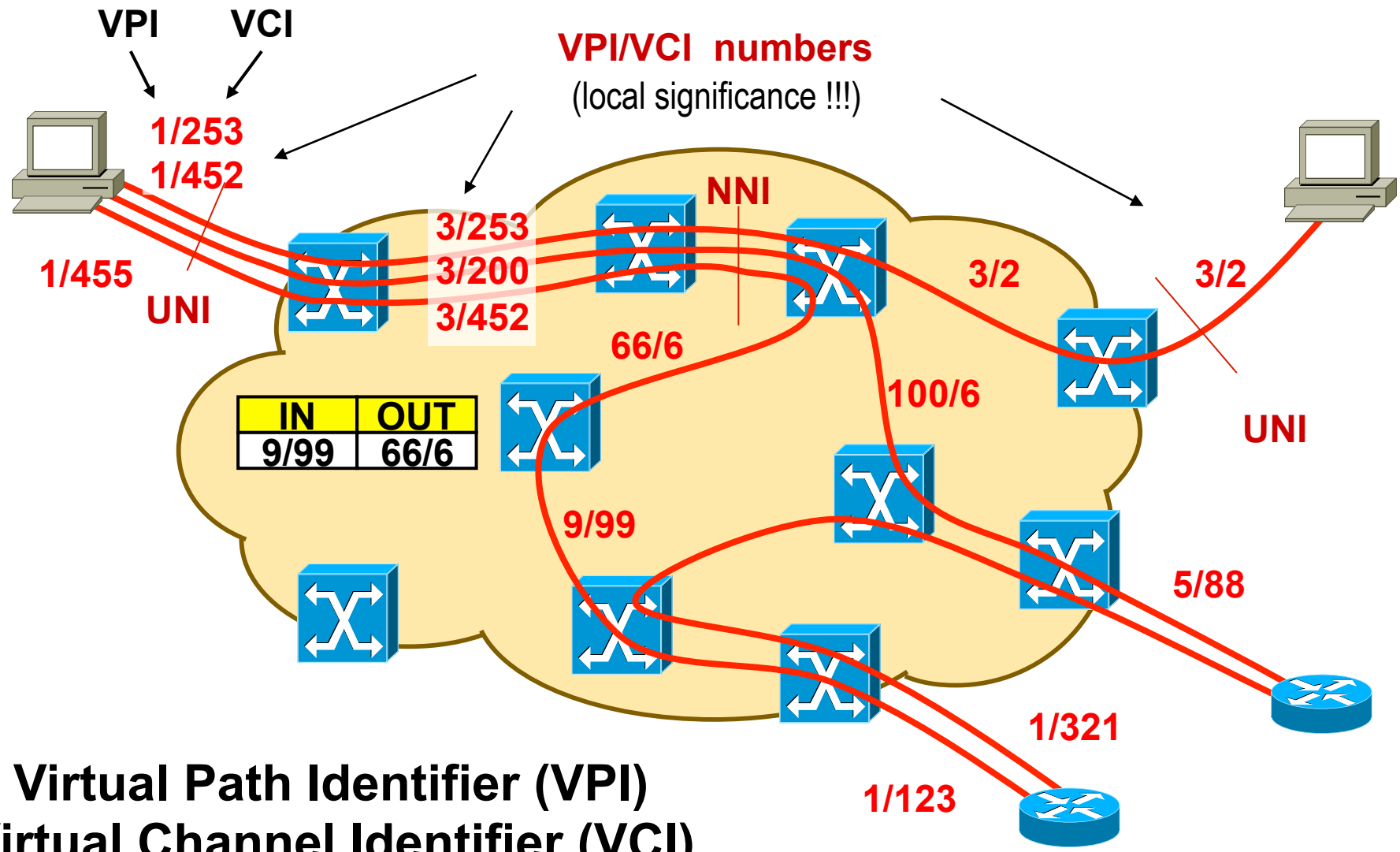
- **Originally WAN services but also MAN and LAN services possible**
  - Based on virtual circuit technique
  - Connection oriented, enables charging for carriers and providers
  - Sequencing of cell stream is guaranteed but no error recovery is done for damaged cells
  - One single technology to cover both WAN and LAN
  - B-ISDN (!)
- **Standardized interface definitions**
  - User Network Interface (UNI)
    - between ATM-DTE and ATM-DCE
  - Network Node Interface (NNI)
    - between ATM-DCE and ATM-DCE

ATM Network: Physical Topology



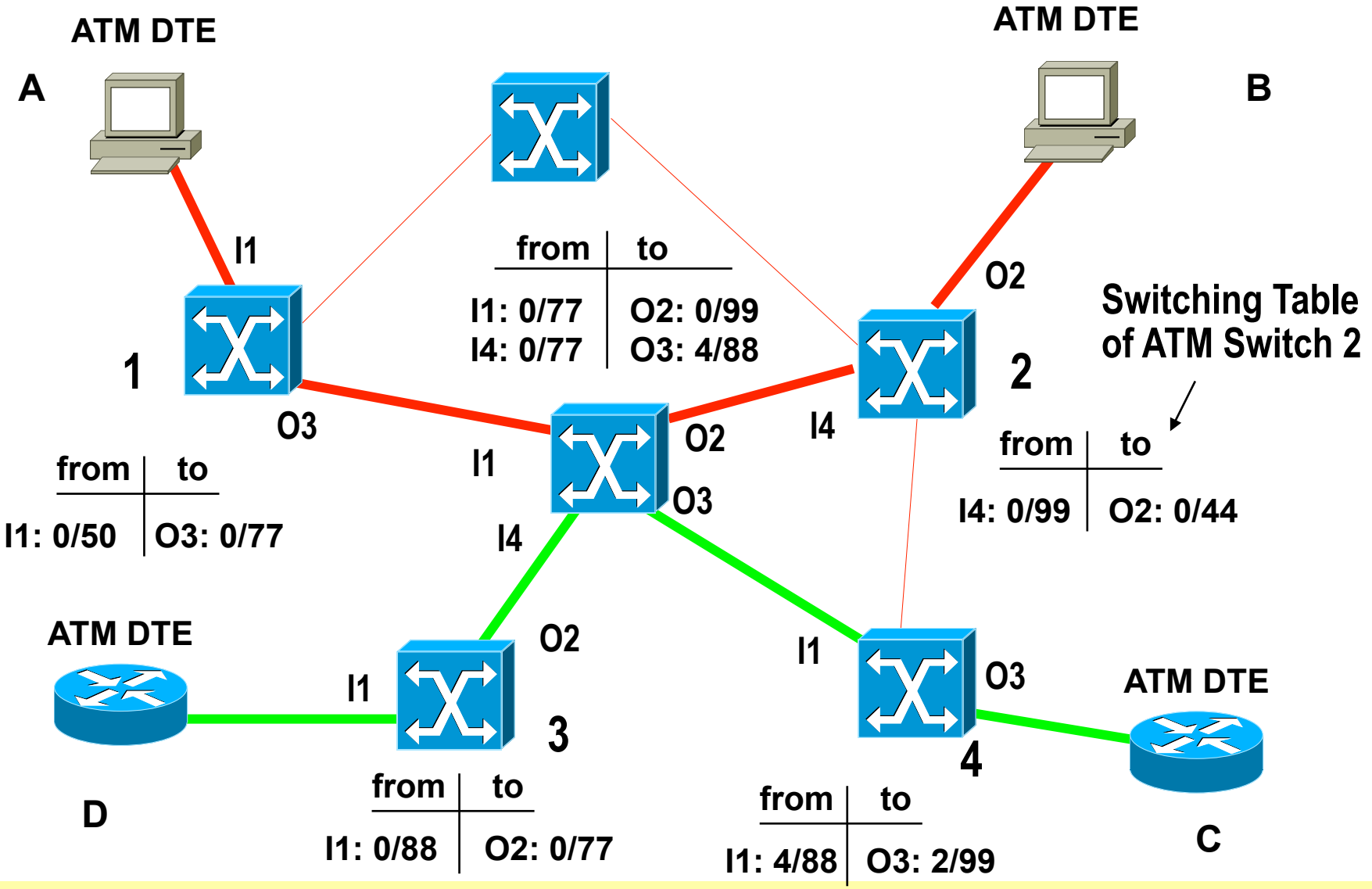
UNI + NNI defined

ATM Network: Virtual Circuits
Local Connection Identifiers and Logical Channels

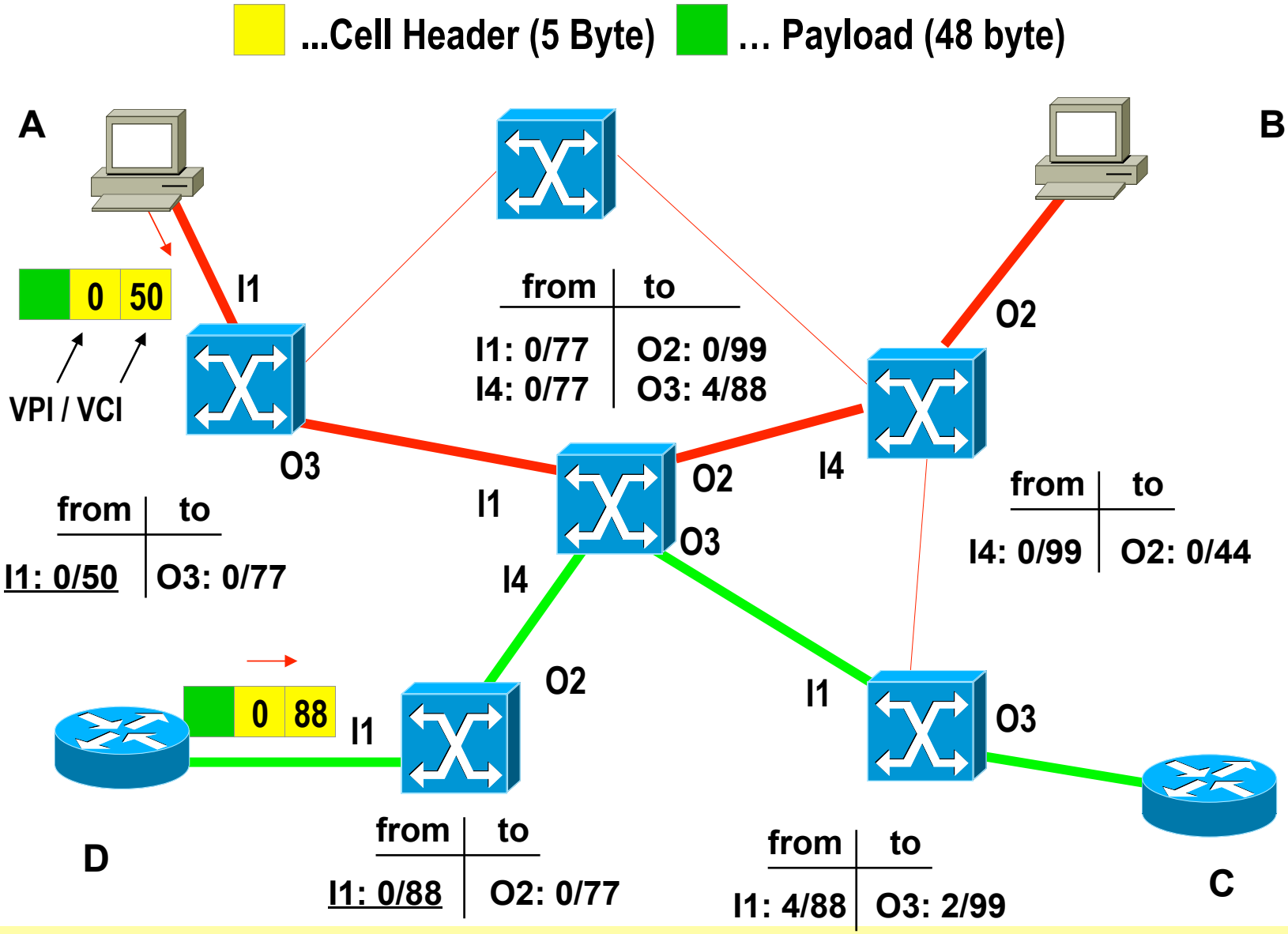


Virtual Path Identifier (VPI)
Virtual Channel Identifier (VCI)

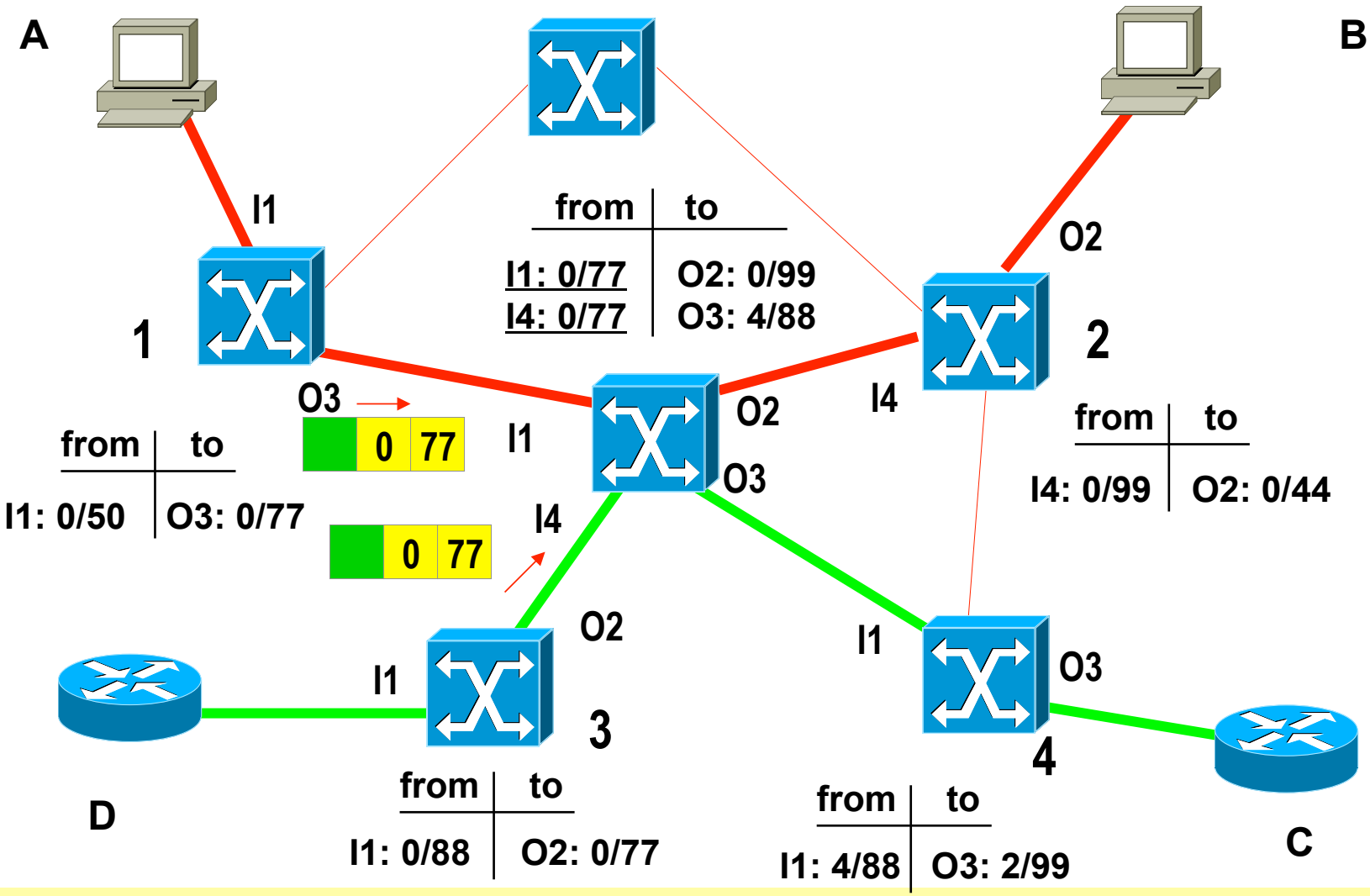
ATM Switching Tables



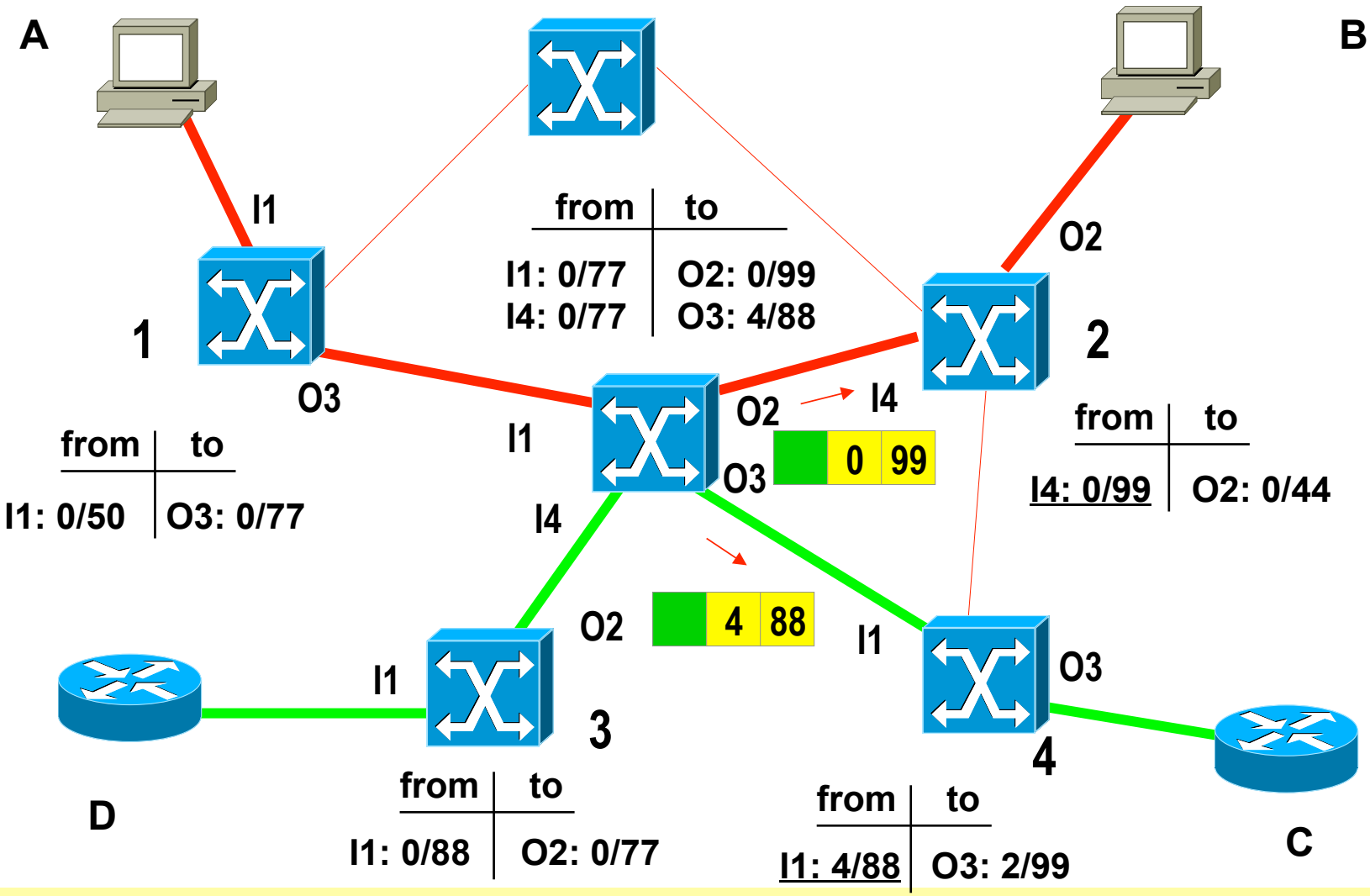
Cell Forwarding / Label Swapping 1



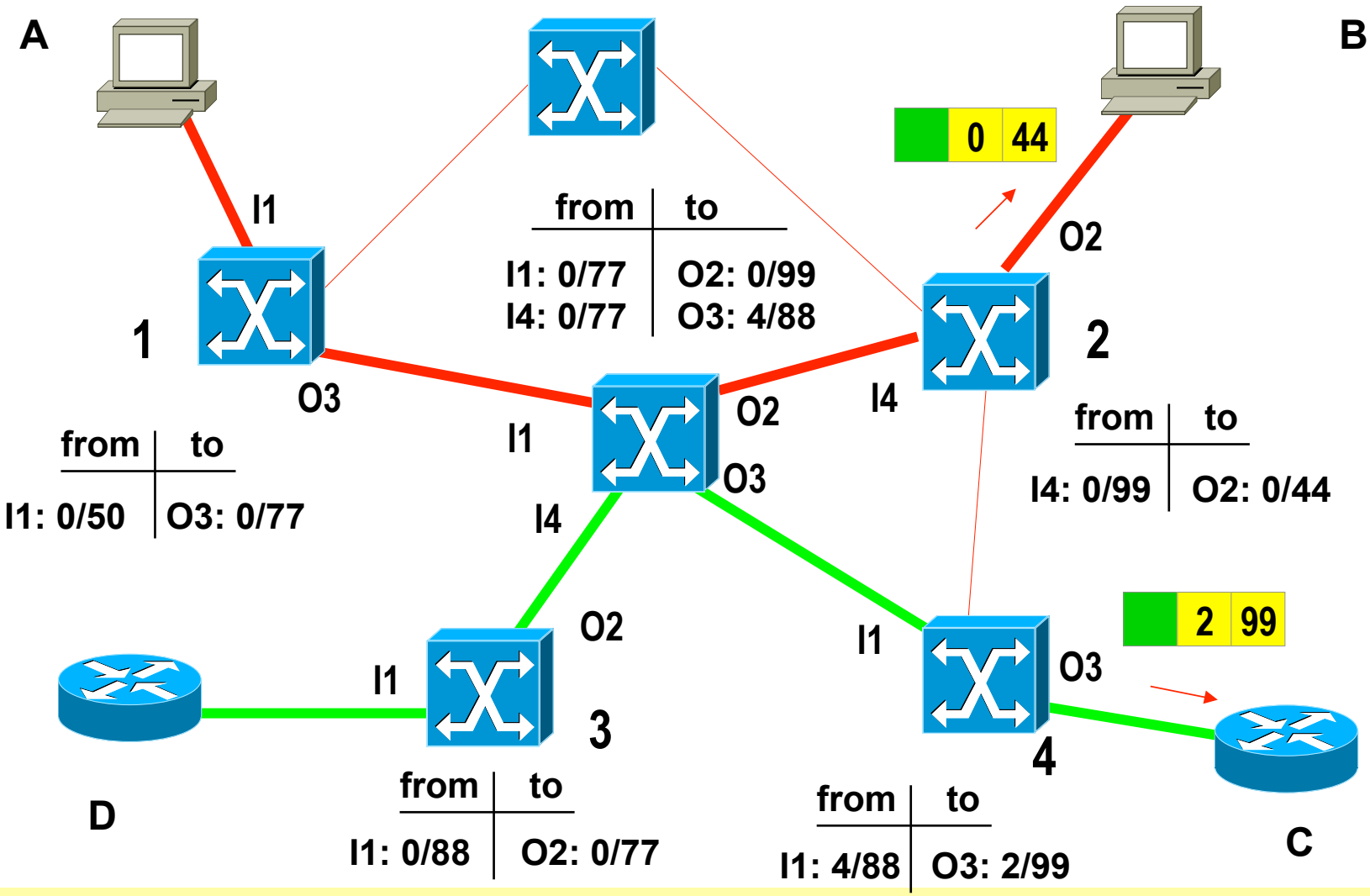
Cell Forwarding / Label Swapping 2



Cell Forwarding / Label Swapping 3



Cell Forwarding / Label Swapping 4



ATM Usage

- **Public and private networks**
  - LAN, MAN, WAN
- **Backbone high-speed networks**
  - Public (Telco's) or private
- **Original goal: World-wide ATM network**
  - But Internet technology and state-of-the art Ethernet are more attractive today
- **New importance as backbone technology for mobile applications**
  - Cellular networks for GSM, GPRS, UMTS, ...
- **But trend to an “All IP Network”**
  - maybe will finally kill ATM

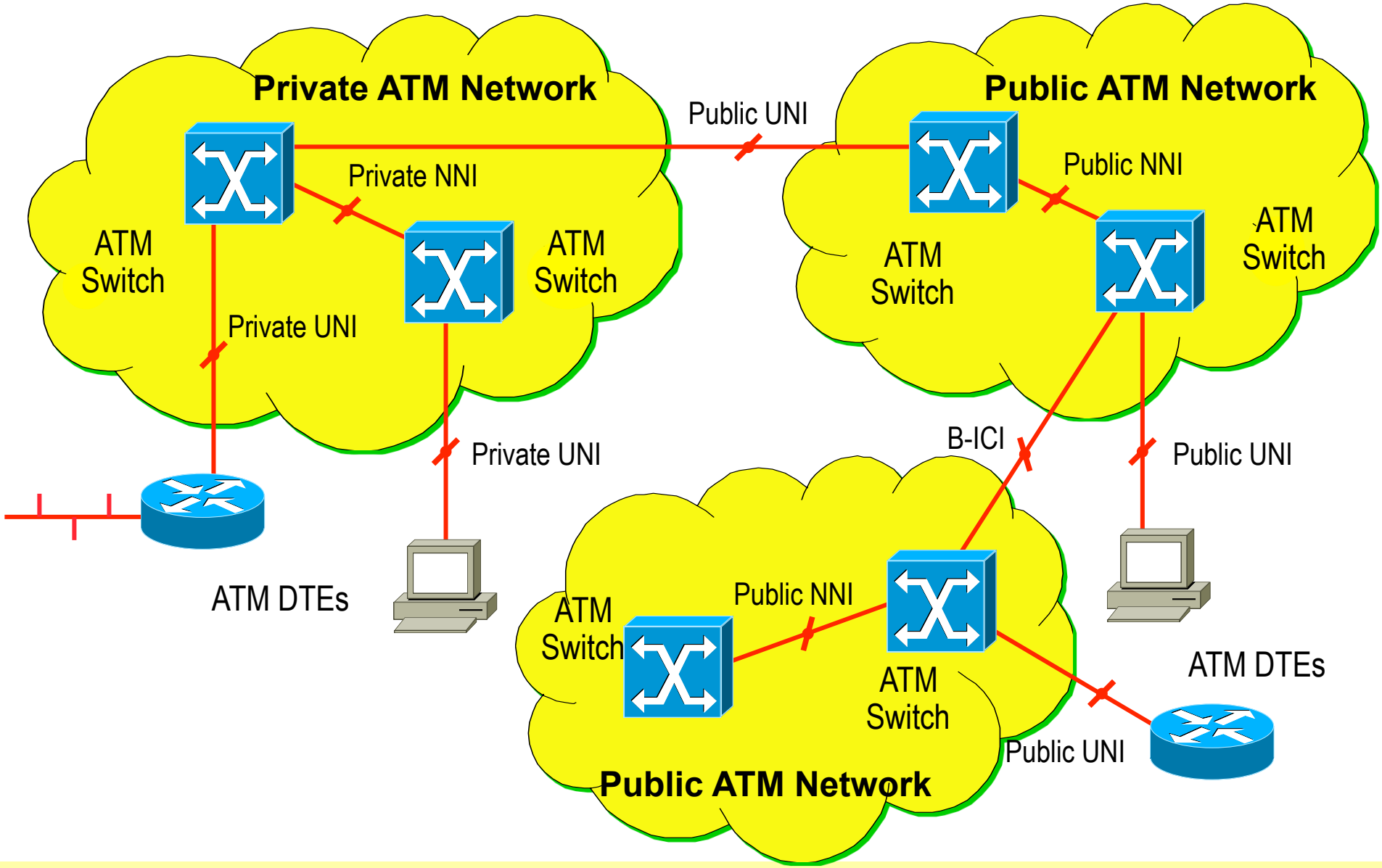
Who Did It?

- **CCITT (now ITU-T) issued first recommendations for B-ISDN in 1988**
  - Recommendation I.121
  - Aspects and Terms only
- **Switch vendors founded ATM-Forum**
  - To accelerate development
  - Majority rule instead of consensus
  - Also pushed ITU-T standardization

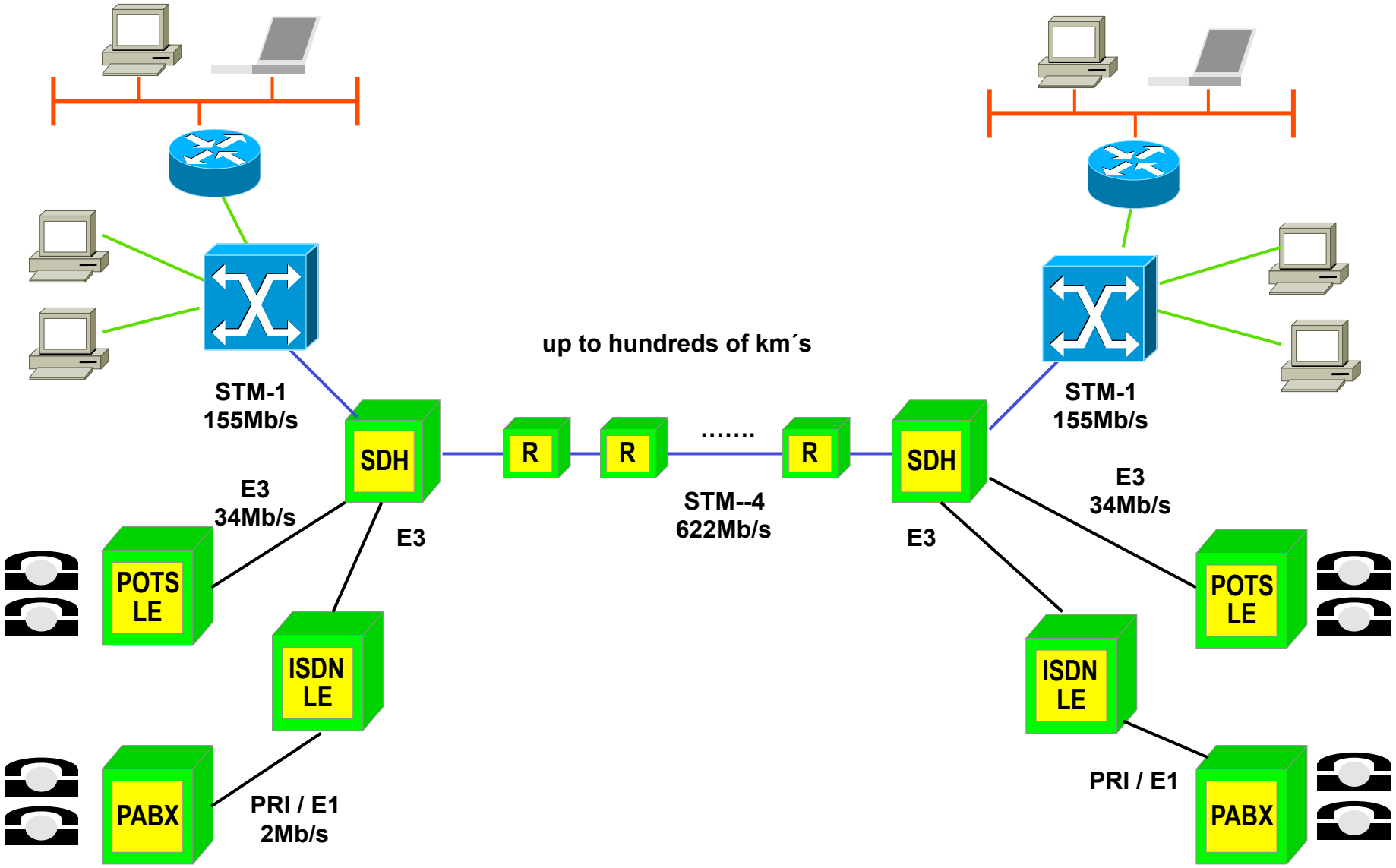
Public and Private Networks

- **ITU-T: Public ATM Networks**
  - Public UNI: E.164 addressing
  - Public NNI: Static routing
- **ATM-Forum: Private ATM Networks**
  - Private UNI: OSI NSAP like addressing
  - Private NNI: Dynamic routing (PNNI)

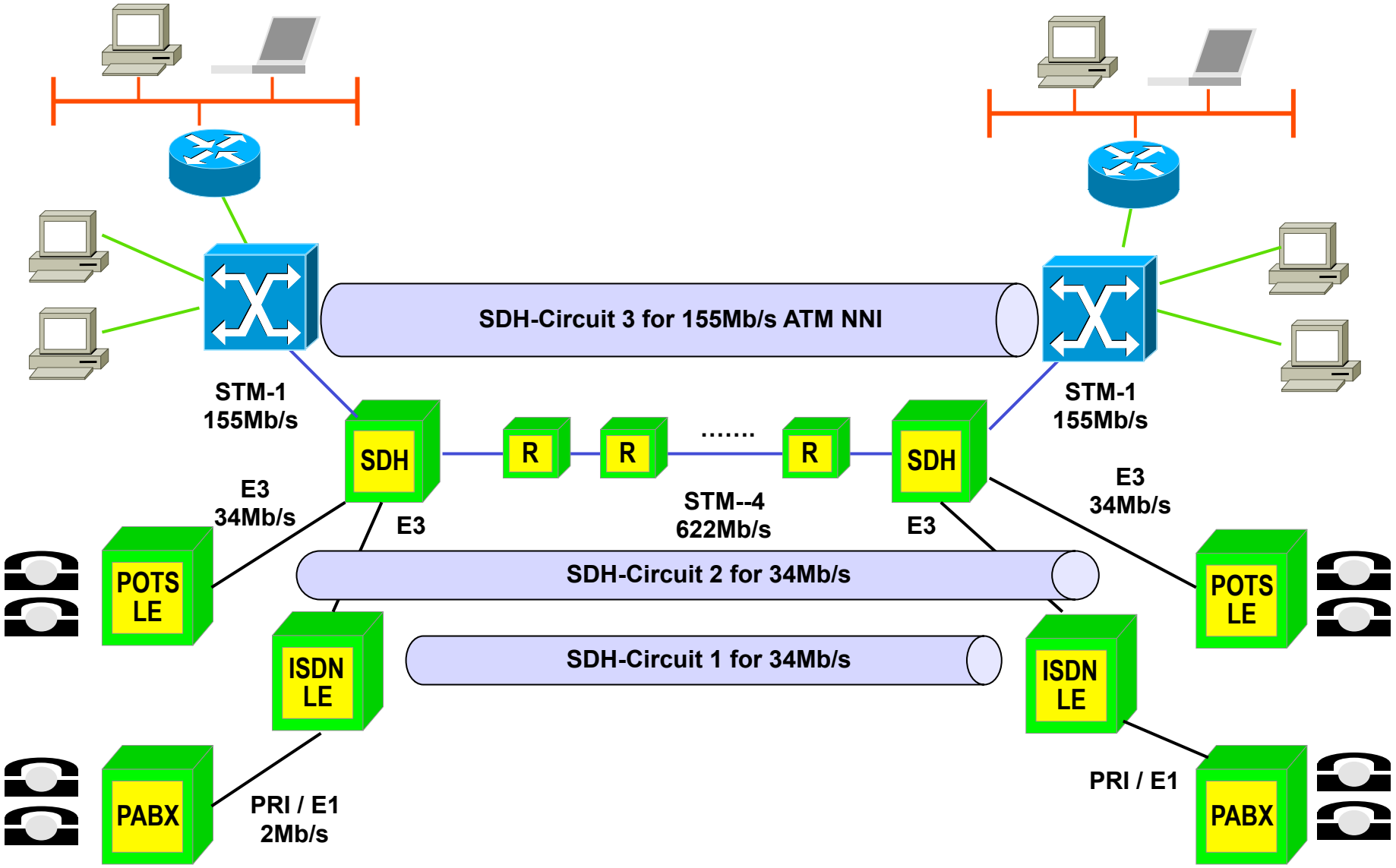
UNI and NNI Types



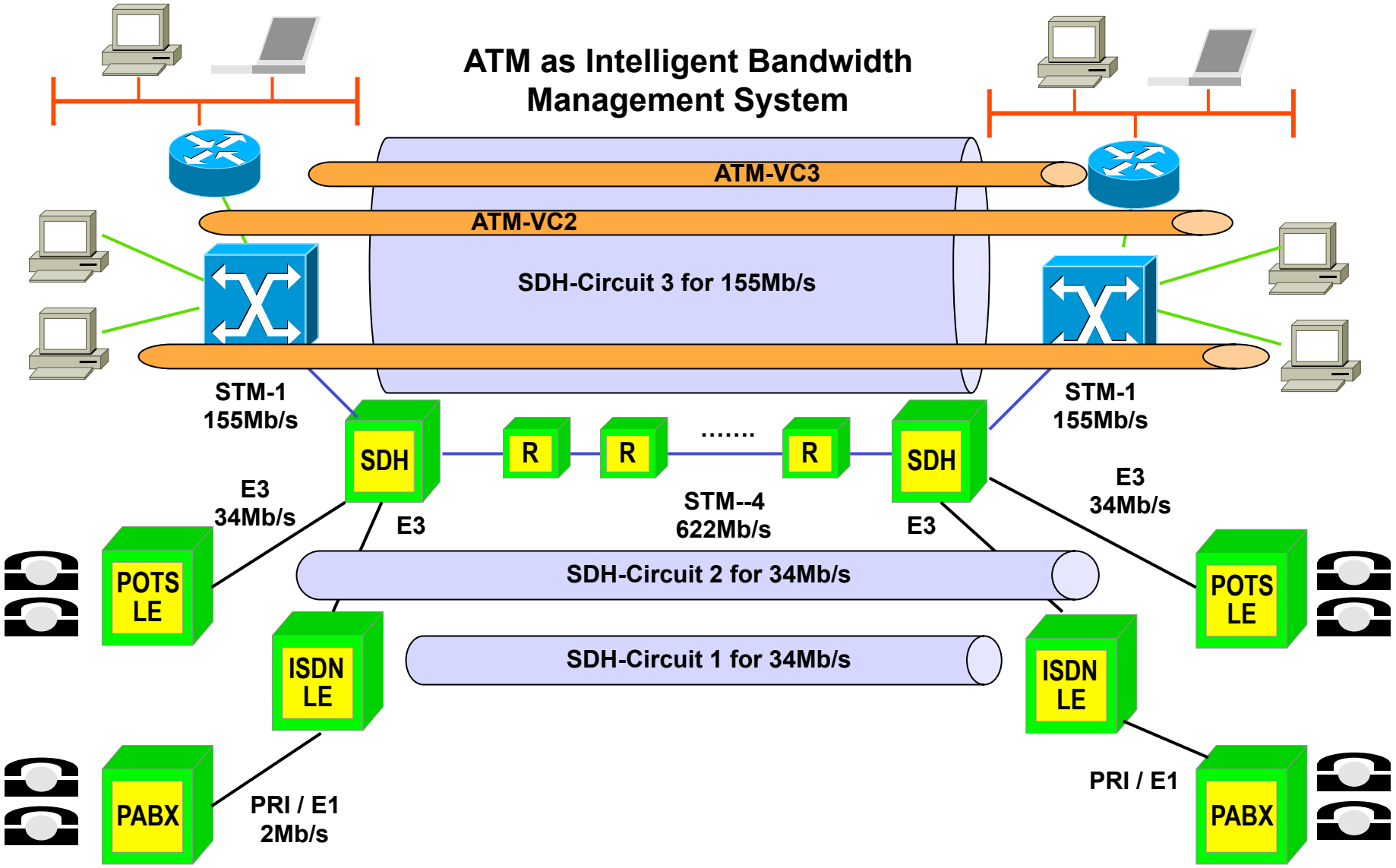
ATM as WAN Technology based on SDH



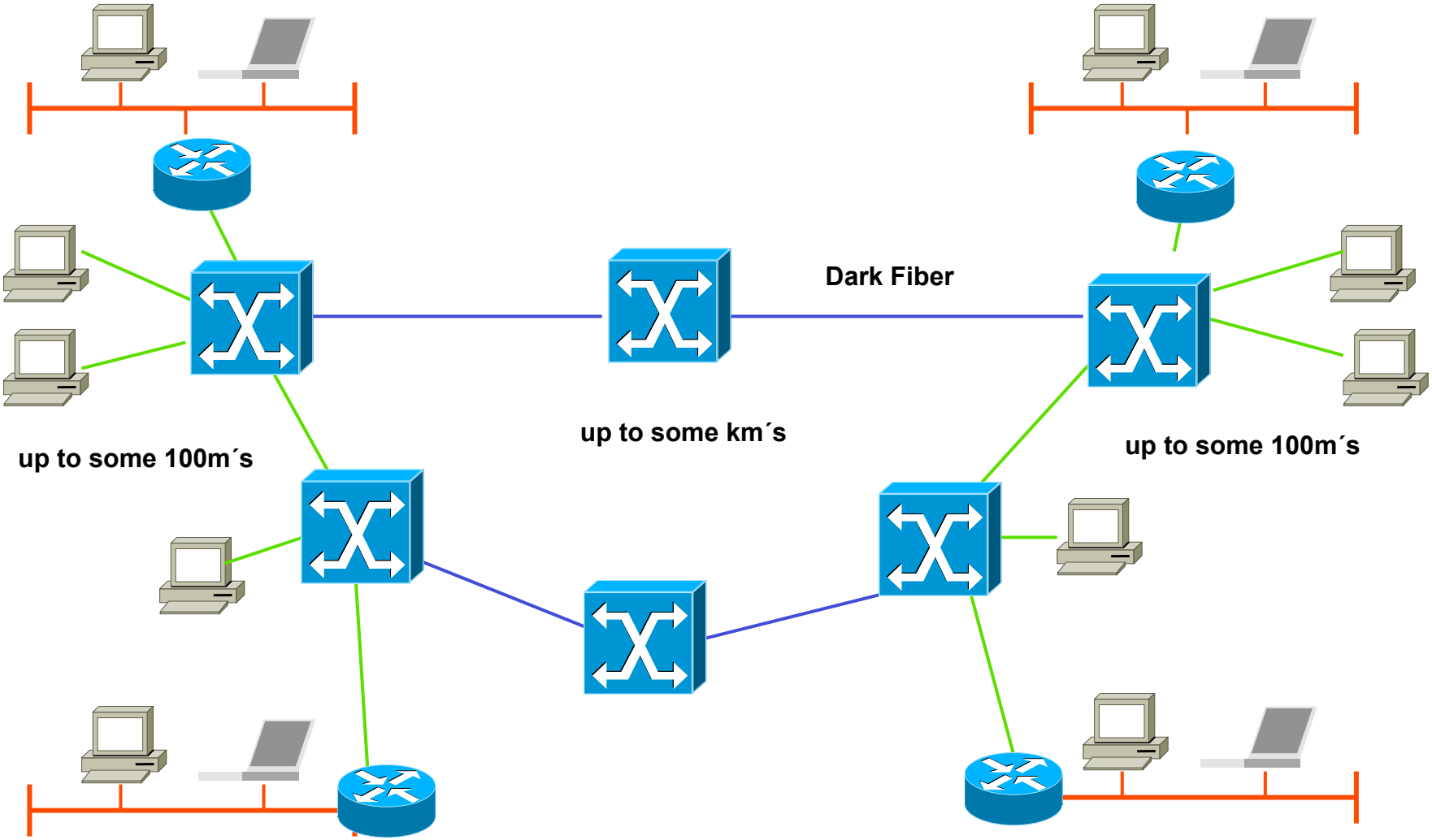
SDH Circuits (Timeslots of S-TDM)



ATM-VCs inside SDH-Circuit



ATM as LAN/ MAN Technology based on Dark Fiber? -> killed by Ethernet & Ethernet Switching



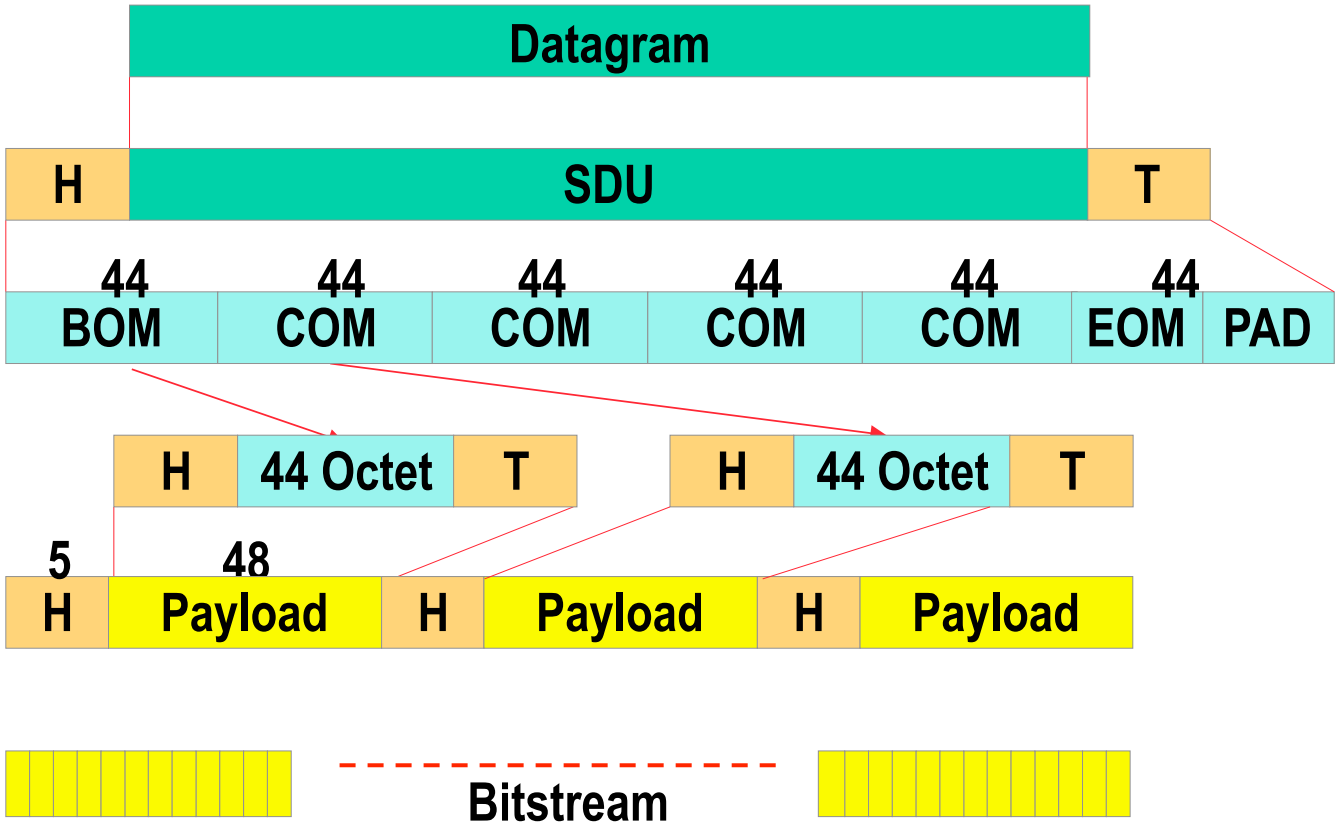
The ATM Cell

- **53 Byte Cells**
  - No technical reason
  - Agreement only
- **The payload must be encapsulated within predefined AAL frames**
  - Framing, Protection, etc
  - ATM Adaptation Layer
    - Several Types AAL1, AAL2, AAL3/4, AAL5

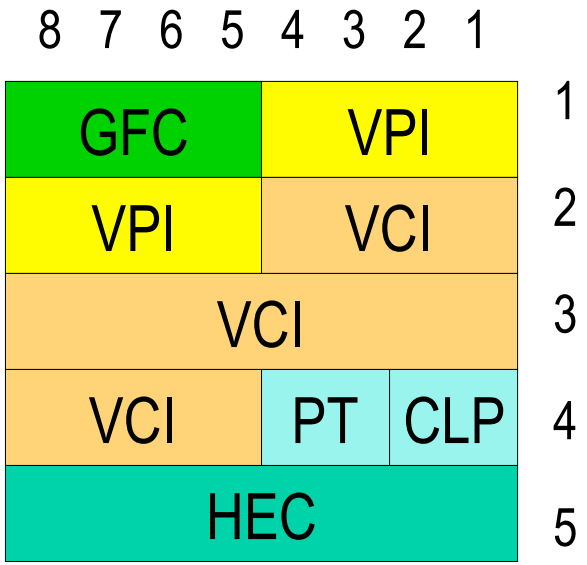
Segmentation / Reassembling (SAR)

- **Cells are much smaller than data packets**
  - Segmentation and Reassembly is necessary in ATM DTEs (!!!)
  - ATM DCEs are not involved in that

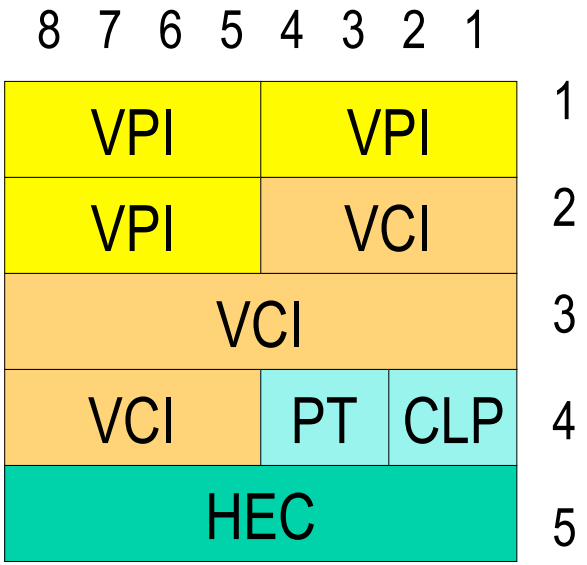
Example for AAL3/AAL4:



Cell Format



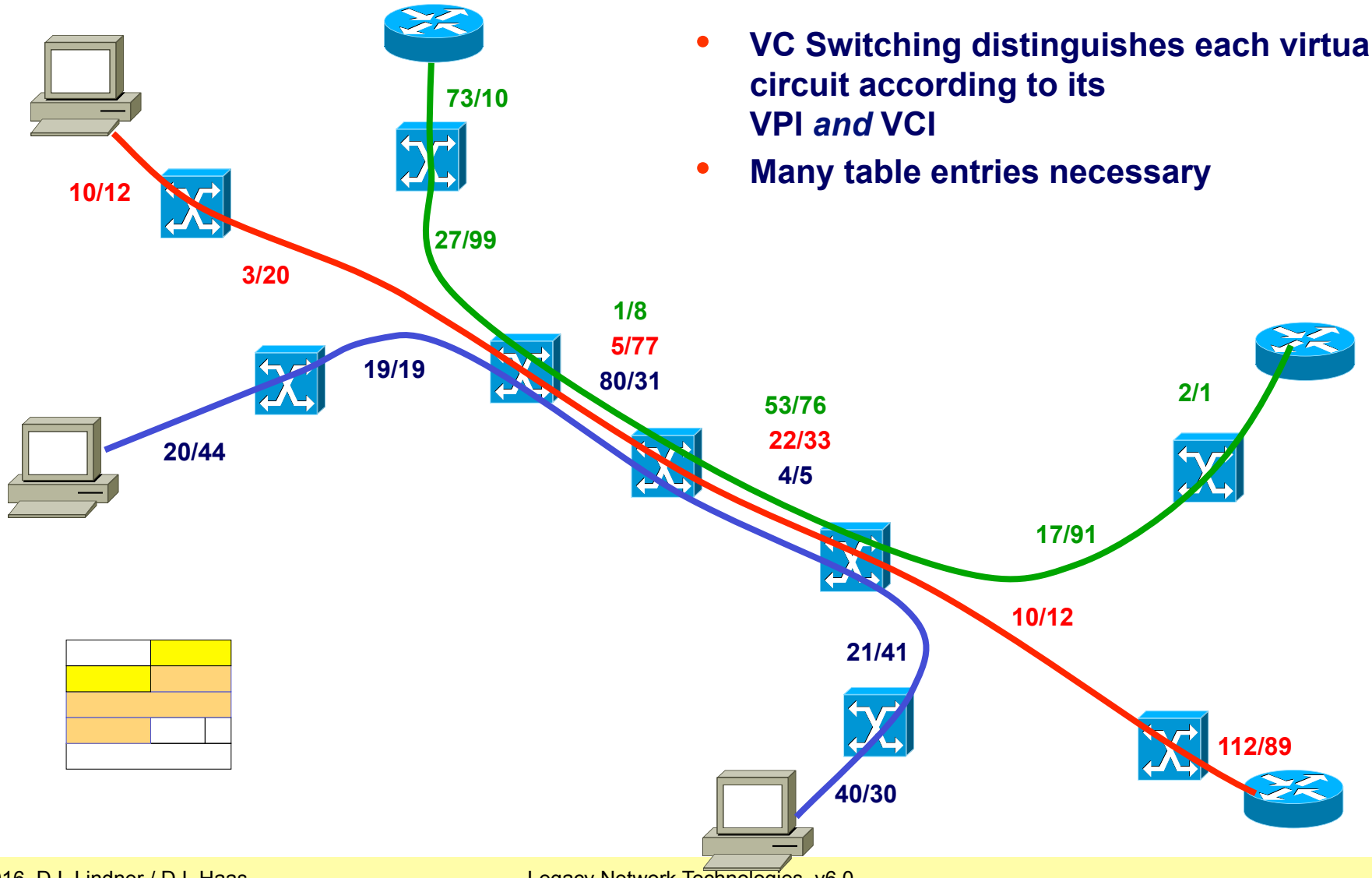
UNI Header



NNI Header

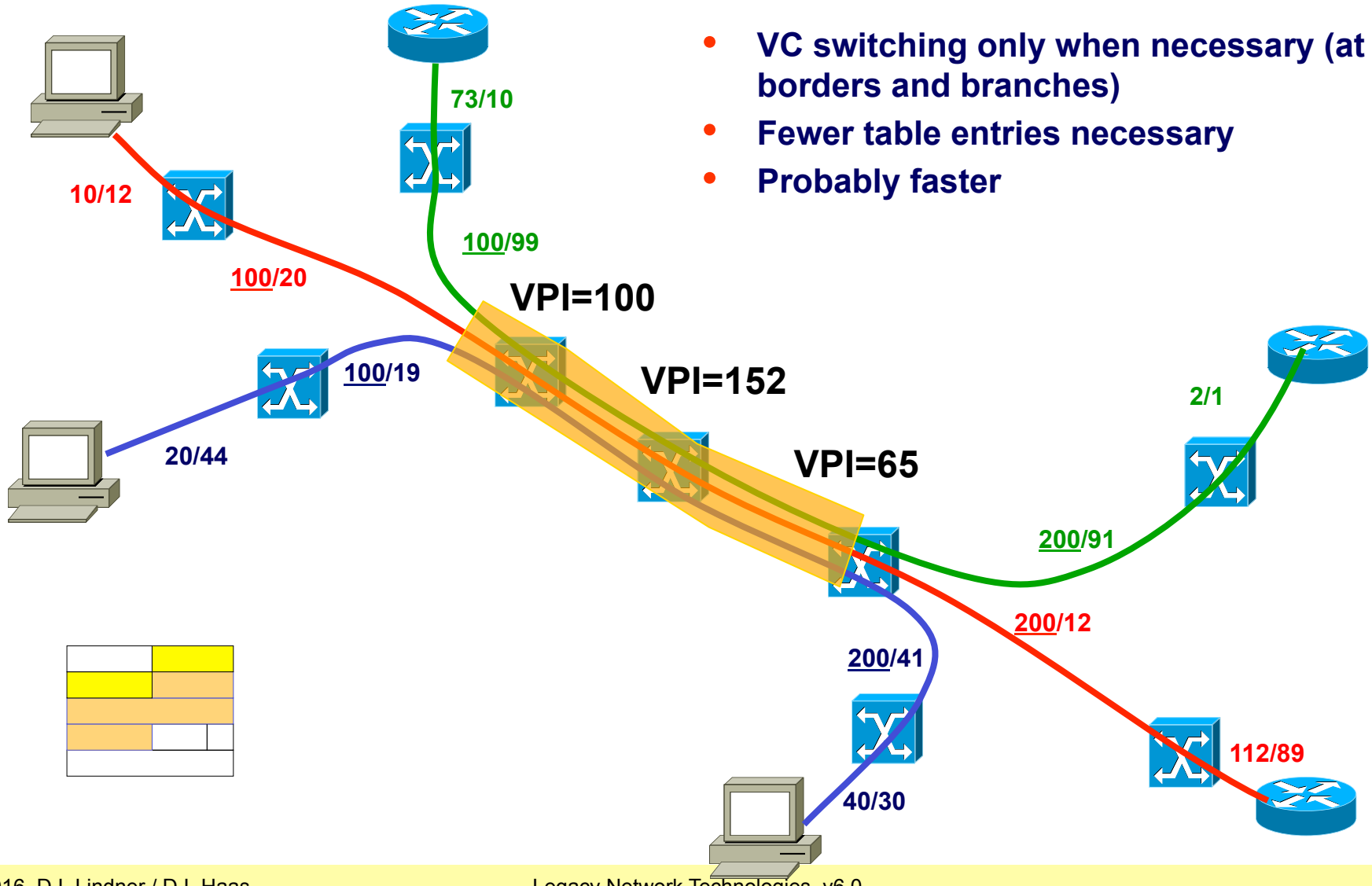
- **Two slightly different formats**
  - UNI … 8 bits for VPI
  - NNI … 12 bits for VPI

VC Switching



- VC Switching distinguishes each virtual circuit according to its VPI *and* VCI
- Many table entries necessary

VP and VC Switching



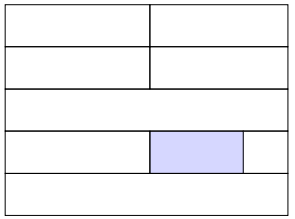
- VC switching only when necessary (at borders and branches)
- Fewer table entries necessary
- Probably faster

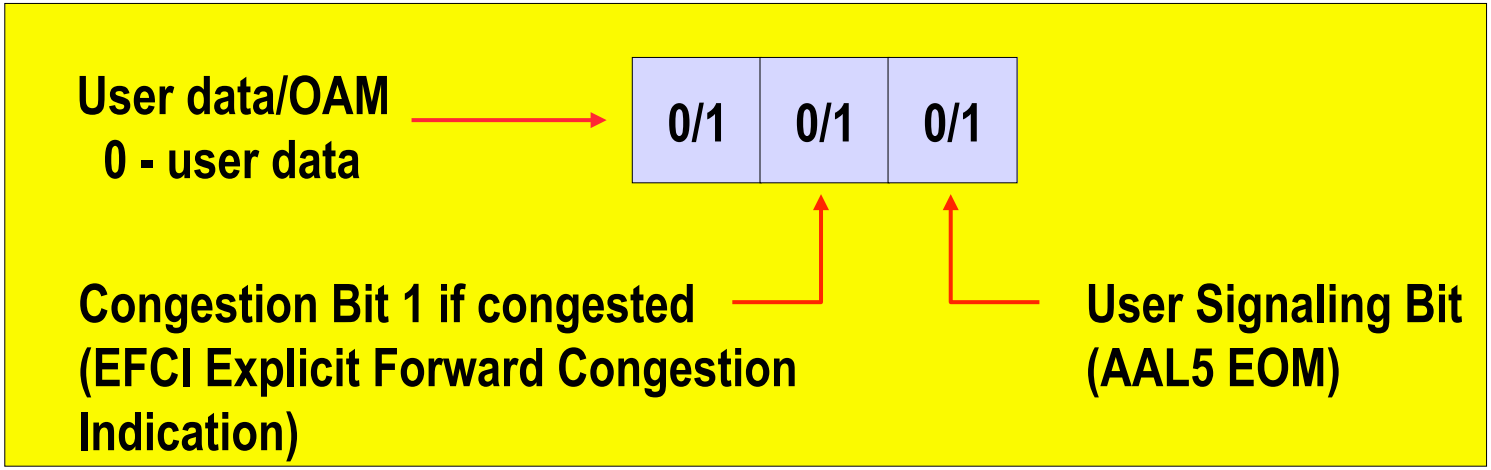
Reserved VPI/VCI Values

VPI	VCI	Function
0	0- 15	ITU-T
0	16 - 31	ATM Forum
0	0	Idle Cell
0	3	Segment OAM Cell (F4)
0	4	End-to-End OAM Cell (F4)
0	5	Signaling
0	16	ILMI
0	17	LANE
0	18	PNNI

Cell Format: Payload Type

- **Payload Type (3 bits)**
  - Used by AAL5 to flag end of block
  - Used to signal congestion





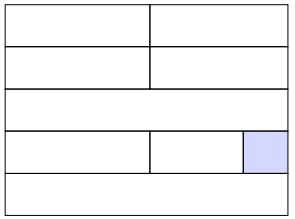
Value	OAM Type
100	OAM link associated cell
101	OAM end-to-end cell
110	Resource management cell
111	Reserved

(OAM = Operation, Admin, Management)

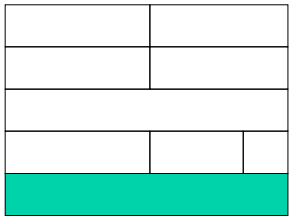
RM cell (Flow control in ABR)

Cell Format: CLP and HEC

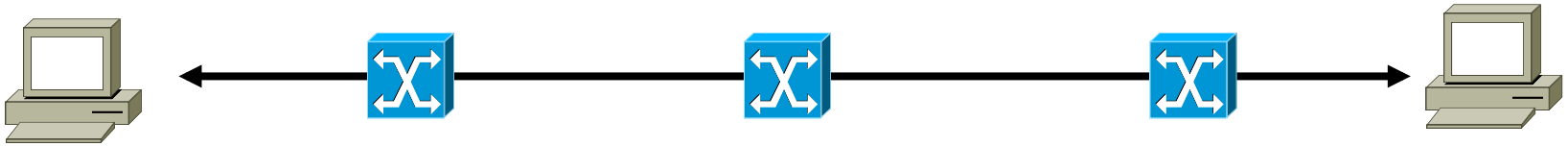
- **Cell Loss Priority (CLP)**
  - Similar to the DE-bit in Frame Relay
  - Normal transmission: CLP = 0
  - Low priority, might be discarded: CLP = 1



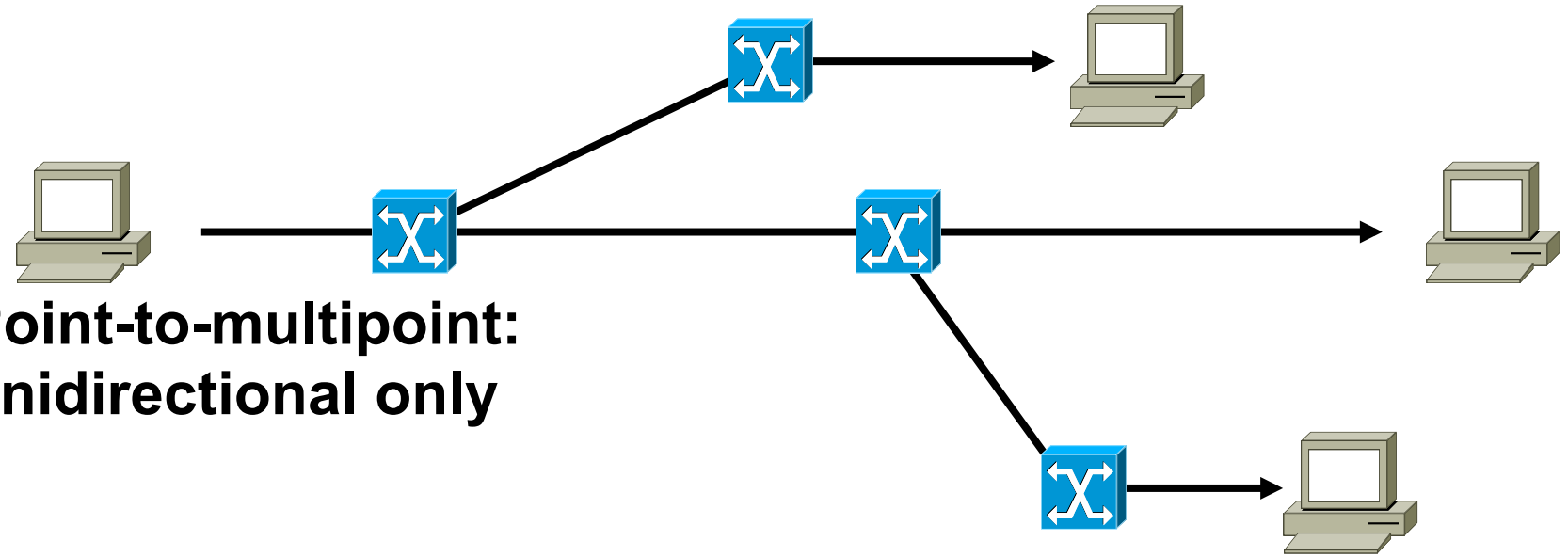
- **Header Error Check (HEC)**
  - Allows the correction of single-bit errors in the cell header
  - Allows the detection of most multi-bit errors
  - Also used for determining cell boundaries on some types of physical link connections
  - Cell delineation
    - Another term for frame synchronization performed at the physical layer



Connection Types

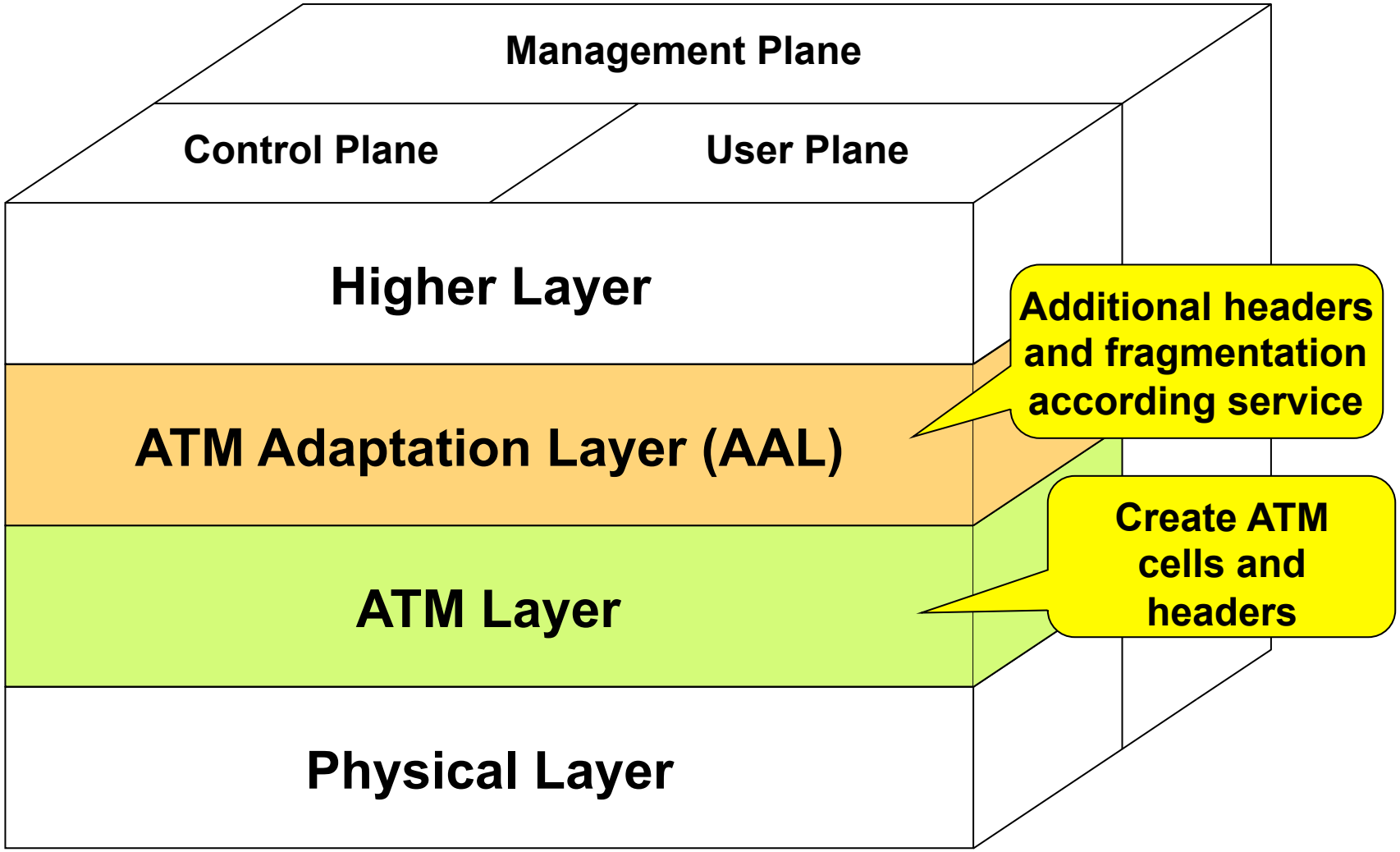


Point-to-point:
unidirectional or bidirectional

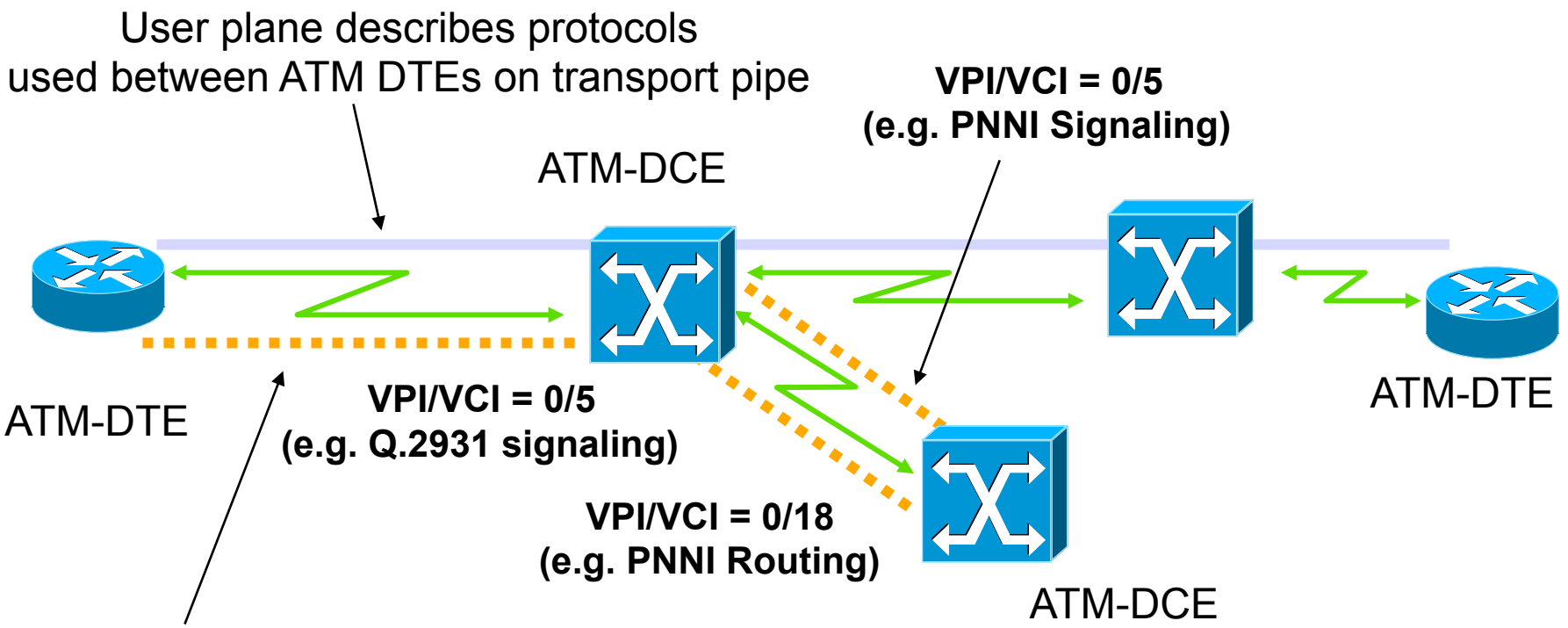


Point-to-multipoint:
unidirectional only

ATM Reference Architecture (Overview)



Control Plane <-> User Plane

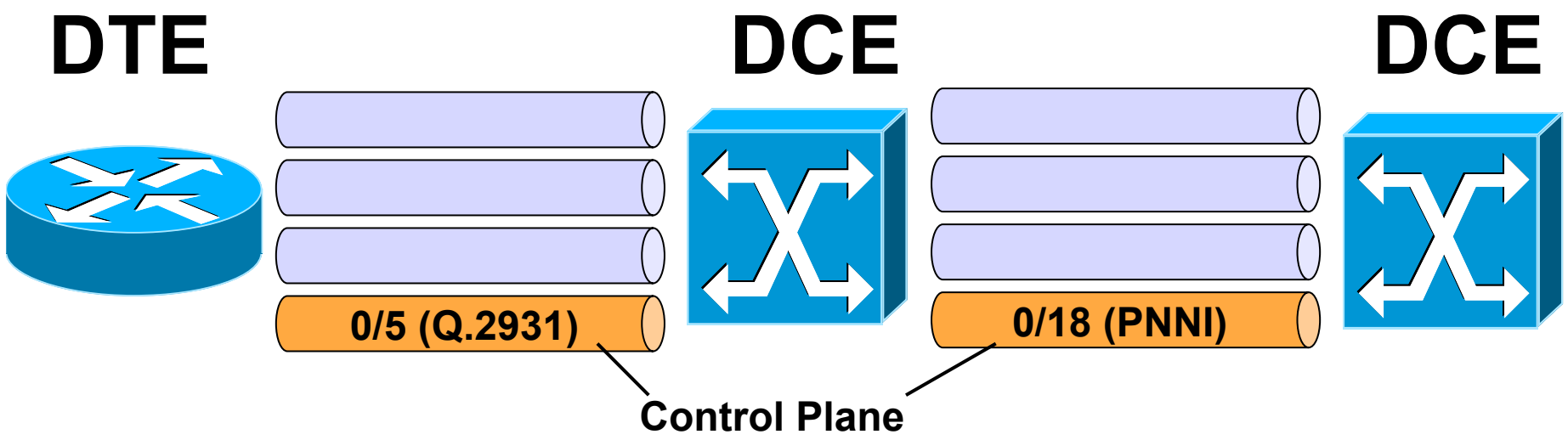


Physical access link

Virtual circuit
for user data

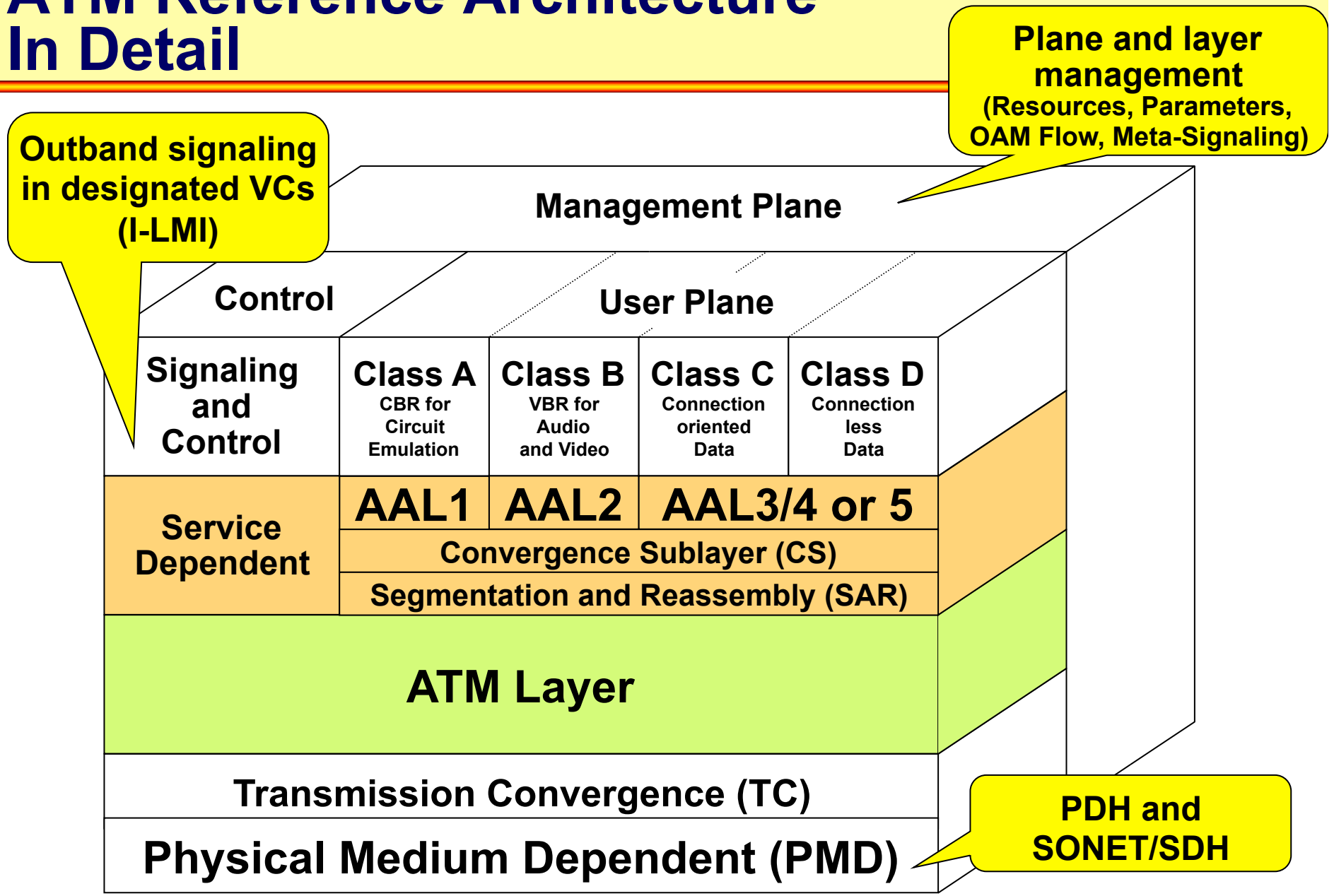
Virtual circuit
for signaling / ILMI / routing

Control Plane



- Signaling through dedicated virtual circuit = "Outband Signaling"

ATM Reference Architecture In Detail



Physical Layer

- **Transmission Convergence (TC) allows simple change of physical media**
  - PDH, SDH, SONET
  - HEC and cell delineation
- **Physical Medium Dependent (PMD) cares for (e. g.)**
  - Line coding
  - Signal conversions

Physical Layer: Interface Examples

Standard	Speed	Medium	Comments	Encoding	Connector	Usage
SDH STM-1	**155,52**	**Coax**	**75 Ohm**	**CMI**	**BNC**	**WAN**
PDH E4	**139,264**	**Coax**	**75 Ohm**	**CMI**	**BNC**	**WAN**
PDH DS3	**44,736**	**Coax**	**75 Ohm**	**B3ZS**	**BNC**	**WAN**
PDH E3	**34,368**	**Coax**	**75 Ohm**	**HDB3**	**BNC**	**WAN**
PDH E2	**8,448**	**Coax**	**75 Ohm**	**HDB3**	**BNC**	**WAN**
PDH J2	**6,312**	**TP/Coax**	**110/75 Ohm**	**B6ZS/B8ZS**	**RJ45/BNC**	**WAN**
PDH E1	**2,048**	**TP/Coax**	**120/75 Ohm**	**HDB3**	**9pinD/BNC**	**WAN**
PDH DS1	**1,544**	**TP**	**100 Ohm**	**AMI/B8ZS**	**RJ45/RJ48**	**WAN**
SDH STM-4	**622,08**	**SM fiber**		**SDH**	**SC**	**LAN/WAN**
SDH STM-1	**155,52**	**SM fiber**		**SDH**	**ST**	**LAN/WAN**
SDH STM-1	**155,52**	**MM fiber**	**62,5 um**	**SDH**	**SC**	**LAN/WAN**
SDH STM-4	**622,08**	**SM fiber**		**NRZ**	**SC (ST)**	**LAN**
SDH STM-4	**622,08**	**MM (LED)**		**NRZ**	**SC (ST)**	**LAN**
SDH STM-4	**622,08**	**MM (Laser)**		**NRZ**	**SC (ST)**	**LAN**
SDH STM-1	**155,52**	**UTP5**	**100 Ohm**	**NRZI**	**RJ45**	**LAN**
SDH STM1	**155,52**	**STP (Type1)**	**150 Ohm**	**NRZI**	**9pinD**	**LAN**
FIber Channel	**155,52**	**MM fiber**	**62,5 um**	**8B/10B**		**LAN**
TAXI	**100**	**MM Fiber**	**62,5 um**	**4B/5B**	**MIC**	**LAN**
SONET STS1	**51,84**	**UTP3**		**NRZI**	**RJ45**	**LAN**
ATM 25	**25,6**	**UTP3**		**NRZI**	**RJ45**	**LAN**

ATM Layer

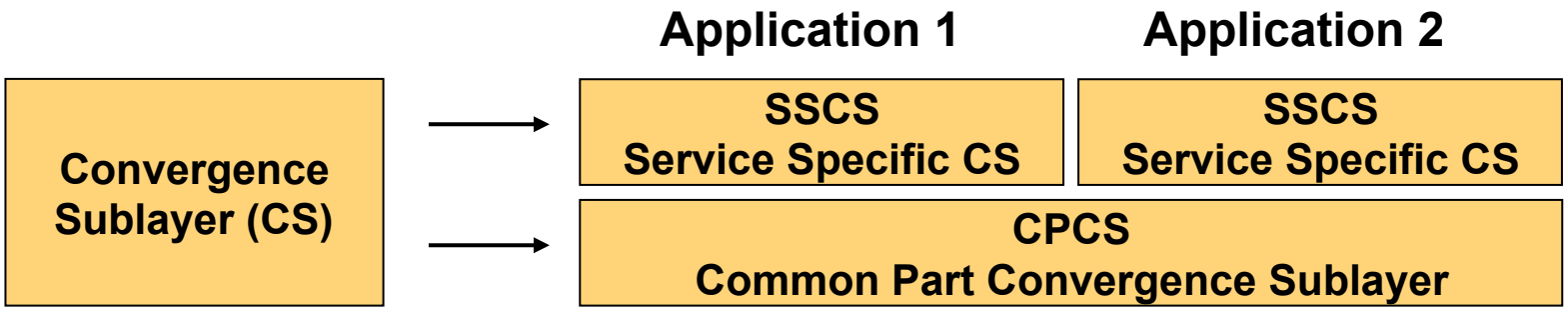
- **Multiplexing and demultiplexing of cells according VPI/VCI**
- **Switching of cells**
  - "Label swapping"
  - Note: origin of MPLS
- **Error management: OAM cells**
- **Flow Control**
- **QoS negotiation and traffic shaping**

Adaptation Layers

- **ATM only provides bearer service**
- **ATM cannot be used directly**
- **Applications must use adaptation layers to access the ATM layer**
- **Consist of SAR and CS**
  - Part of DTEs only
  - Transparent for switches (DCEs)

Adaptation Sublayers

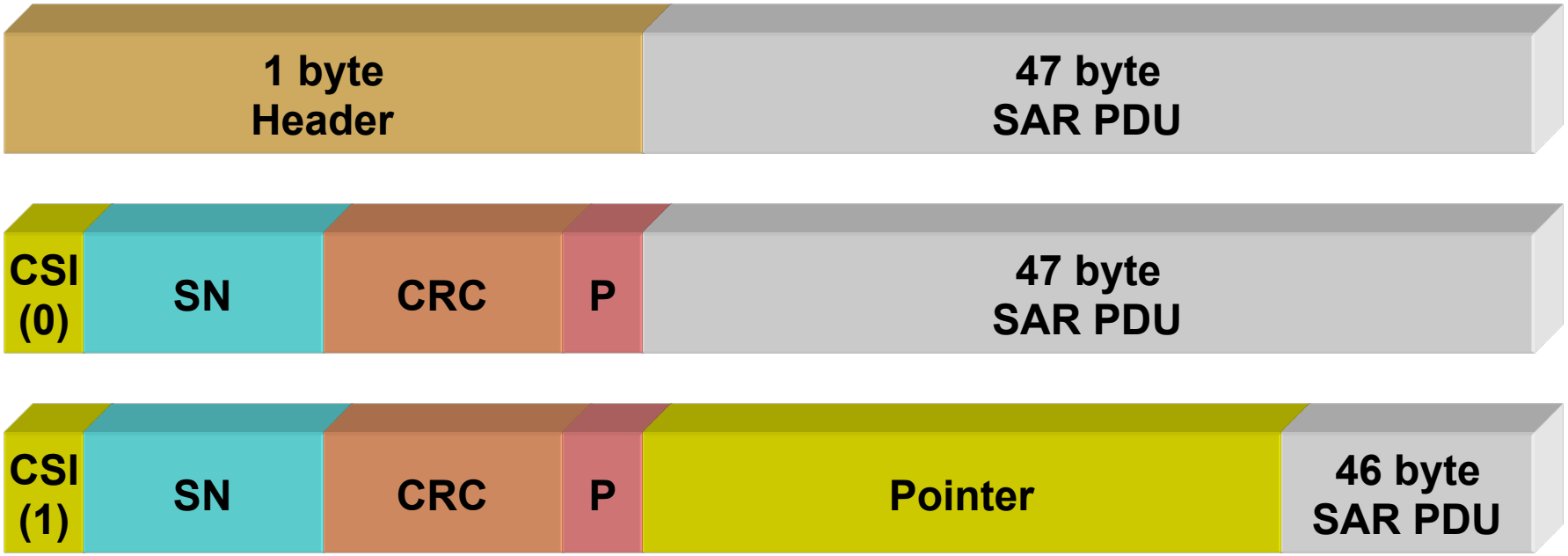
- **Convergence Sublayer (CS)**
  - Service dependent functions (clock recovery, message identification)
  - Adds special information (e. g. Frame Relay header)
- **Segmentation and Reassembly (SAR)**
  - You name it...



AAL1

- **Constant Bit Rate (CBR)**
- **Circuit Emulation**
- **Expensive**
  - Over provisioning like leased line necessary
  - Queuing prefers AAL1 cells over all other traffic (in case of congestion)

AAL1



CSI …. Convergence Sublayer Indication (1 bit) – "1" if pointer exists
SN ….. Sequence Number (3 bits)
CRC ... Cyclic Redundancy Check (3 bits)
P ……. Parity (1 bit)

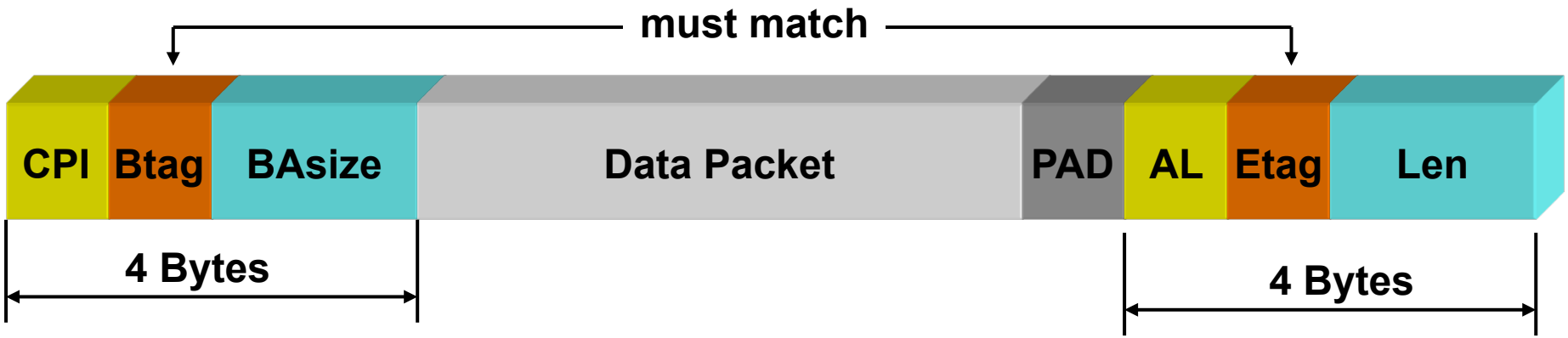
AAL2

- **Analog applications that require timing information but not CBR**
  - Variable Bit Rate (VBR)
  - Compressed audio and video
- **Relatively new (1997/98)**
  - Original standard withdrawn and later reinvented for mobile systems

AAL3 + AAL4

- **AAL3 designed to carry connection-oriented packets**
  - Such as X.25 or Frame Relay
- **AAL4 designed to carry connection-less datagrams**
  - Such as IP or IPX
- **Because of similarity both adaptation layers were combined to AAL3/4**

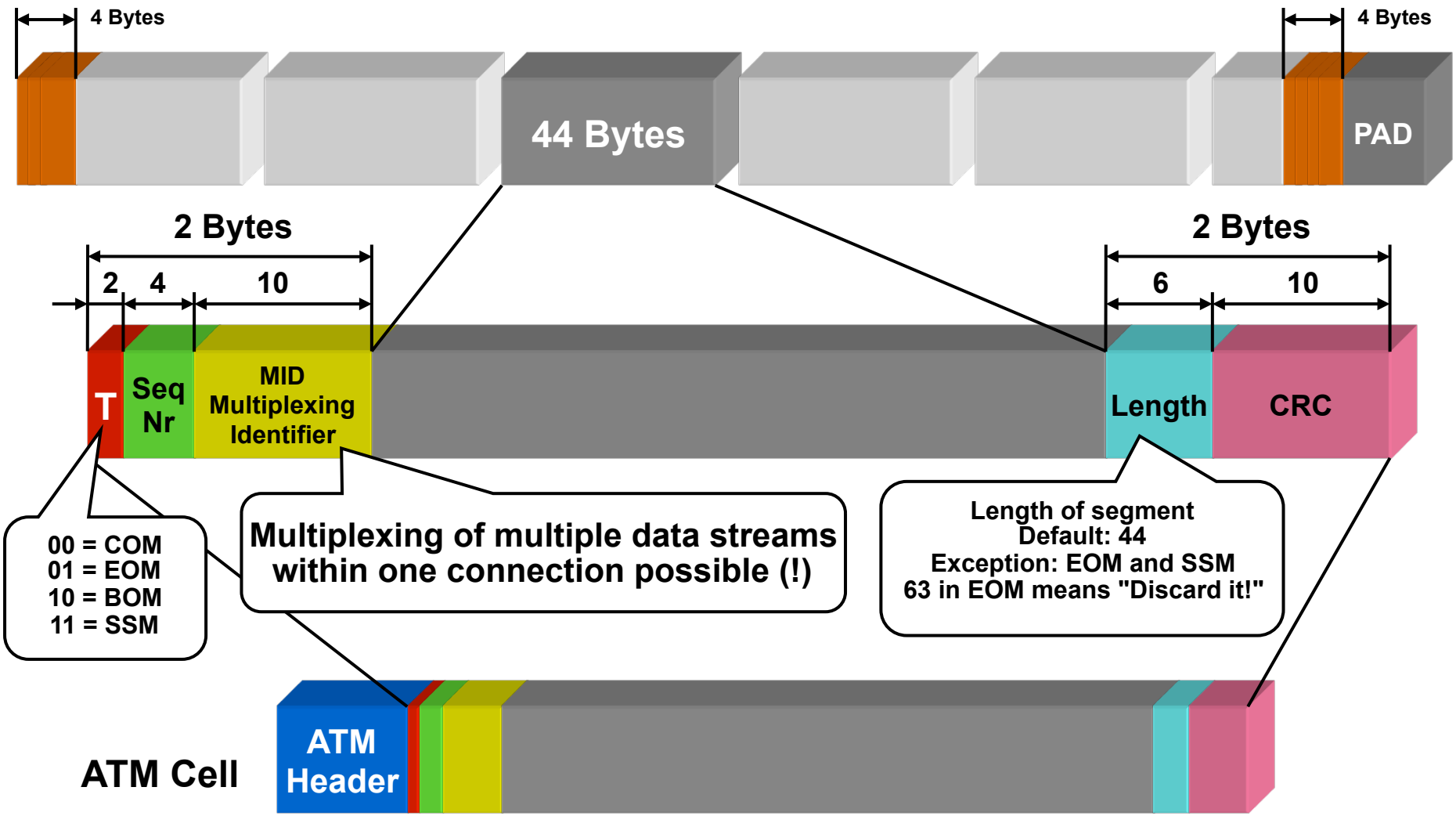
AAL3/4 – Step 1: CS



CPI ..... Common Part Indicator (1Byte)
Btag..... Beginning tag (1 Byte)
BAsize... Buffer allocation size (2 Bytes)

PAD..... for 32 bit alignment
AL..... Alignment (1 Byte)
Etag..... Ending tag (1 Byte) – must match Btag
Len ..... Length of SAR PDU

AAL3/4 – Step 2: SAR



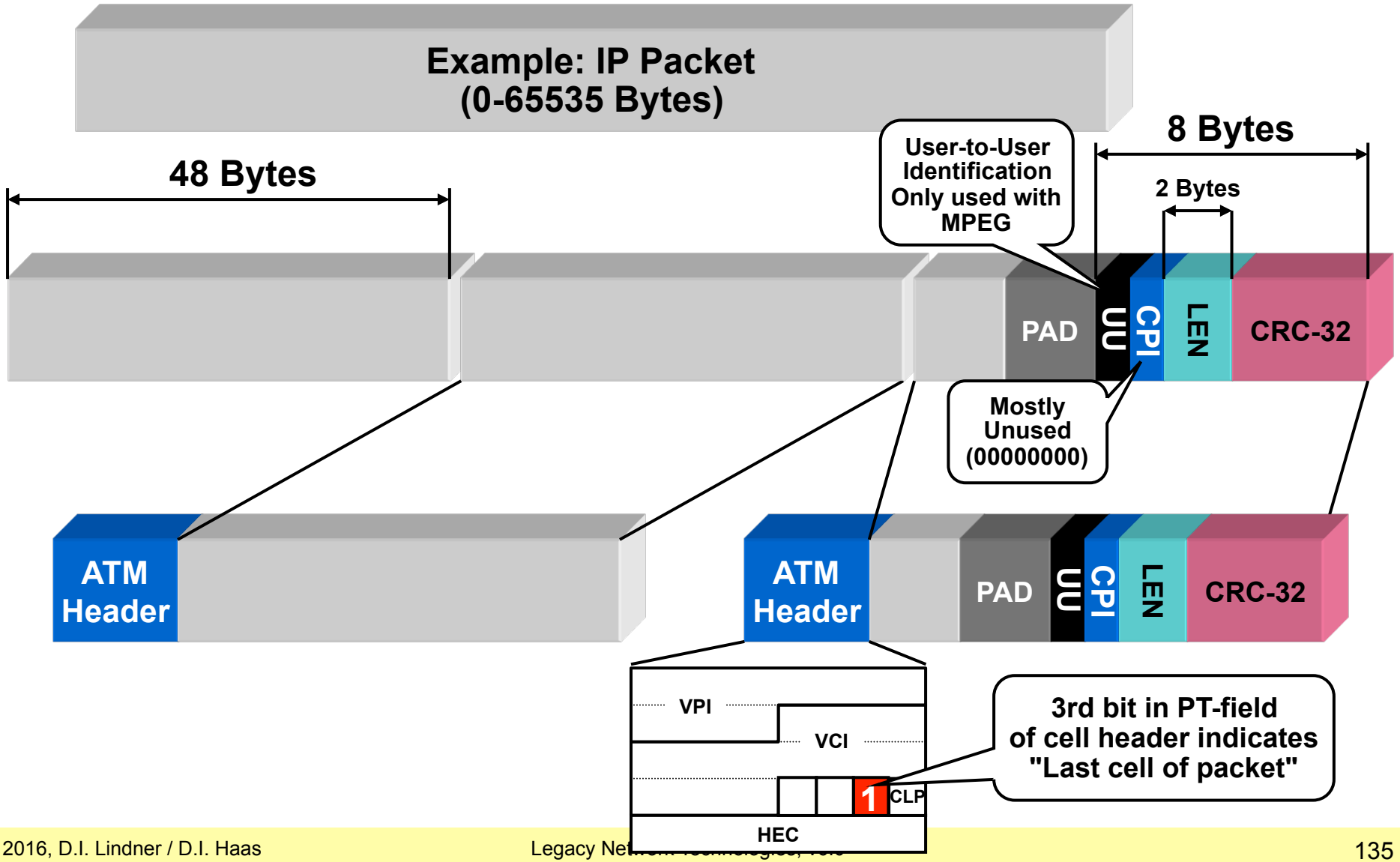
AAL3/4

- **Can multiplex different streams of data on the same ATM connection**
  - Up to 210 streams using the same VPI/VCI
- **But too much overhead**
  - Sequence numbers unnecessary when not interleaving
  - One CRC for whole packet would be sufficient
  - Length unnecessary
  - Nearly totally replaced by AAL5

AAL5

- **Favorite for data communication**
  - AAL 5 simulates connectionless data interface
  - Allows simple migration to ATM
- **Smallest overhead**
  - Convergence Layer:
    8 byte trailer in last cell
  - SAR Layer:
    just marks EOM in ATM header (PT)

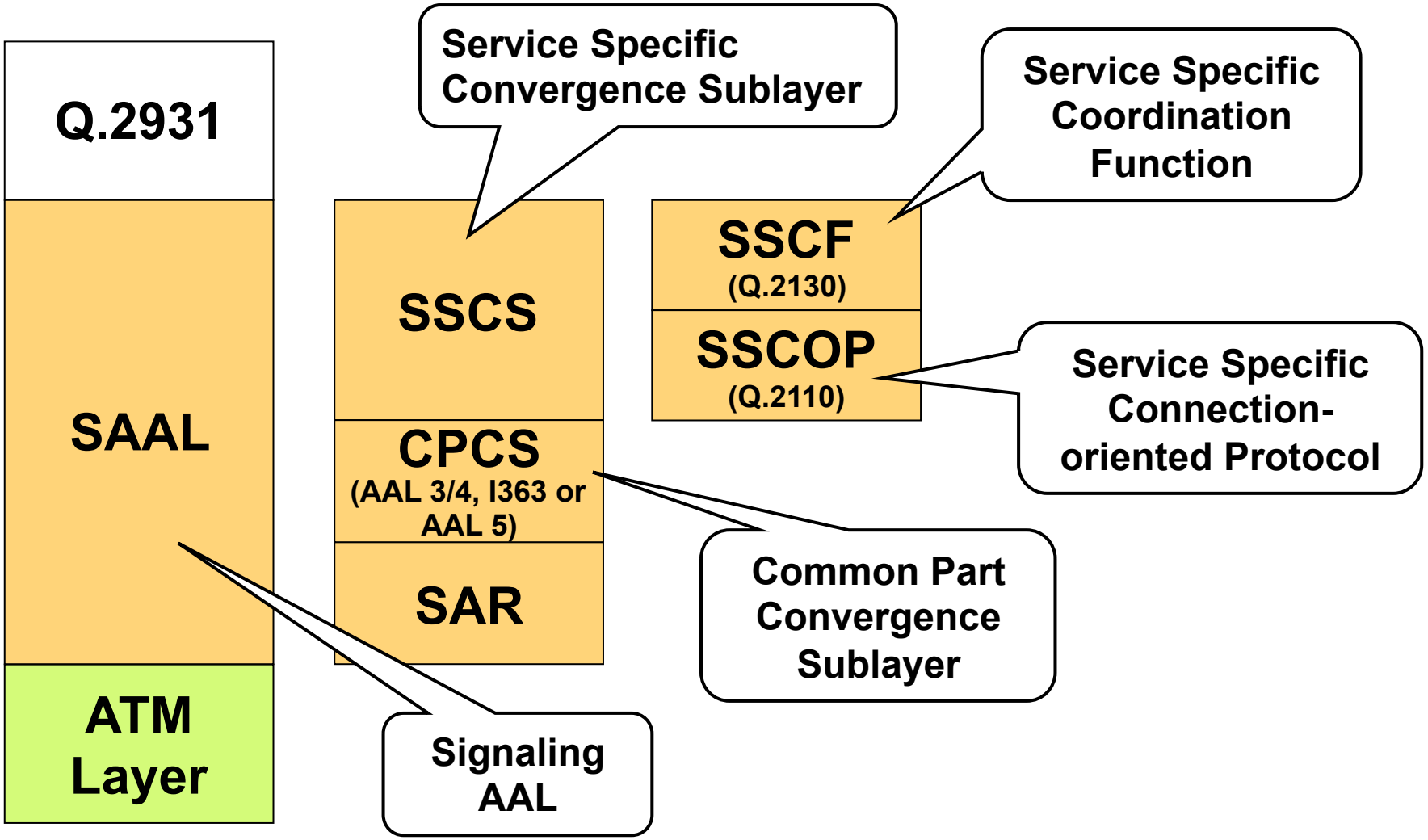
AAL5 Segmentation



Signaling

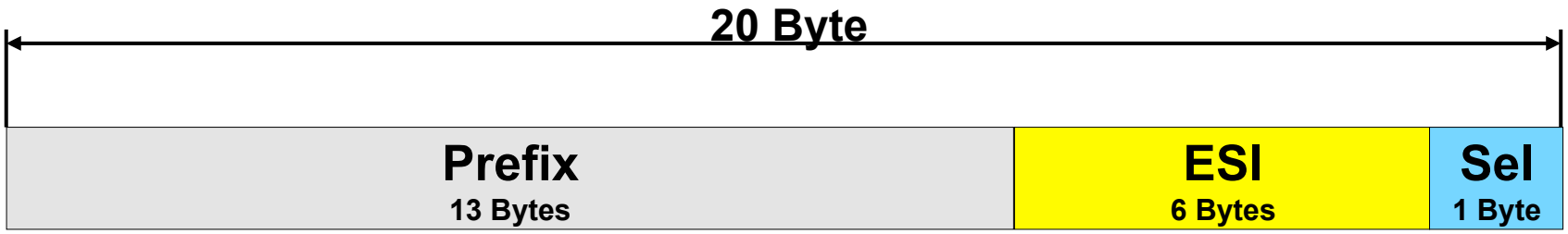
- **ATM Forum UNI signaling specification**
  - UNI 3.0, 3.1 and 4.0 standardized
    - UNI 2.0 PVC
    - UNI 3.0 PVC+SVC, CBR+VBR+UBR
    - UNI 4.0 = UNI 3.0 +ABR, QoS Negotiation
- **Based on ITU-T Q.2931 (B-ISDN)**

Signaling Layers

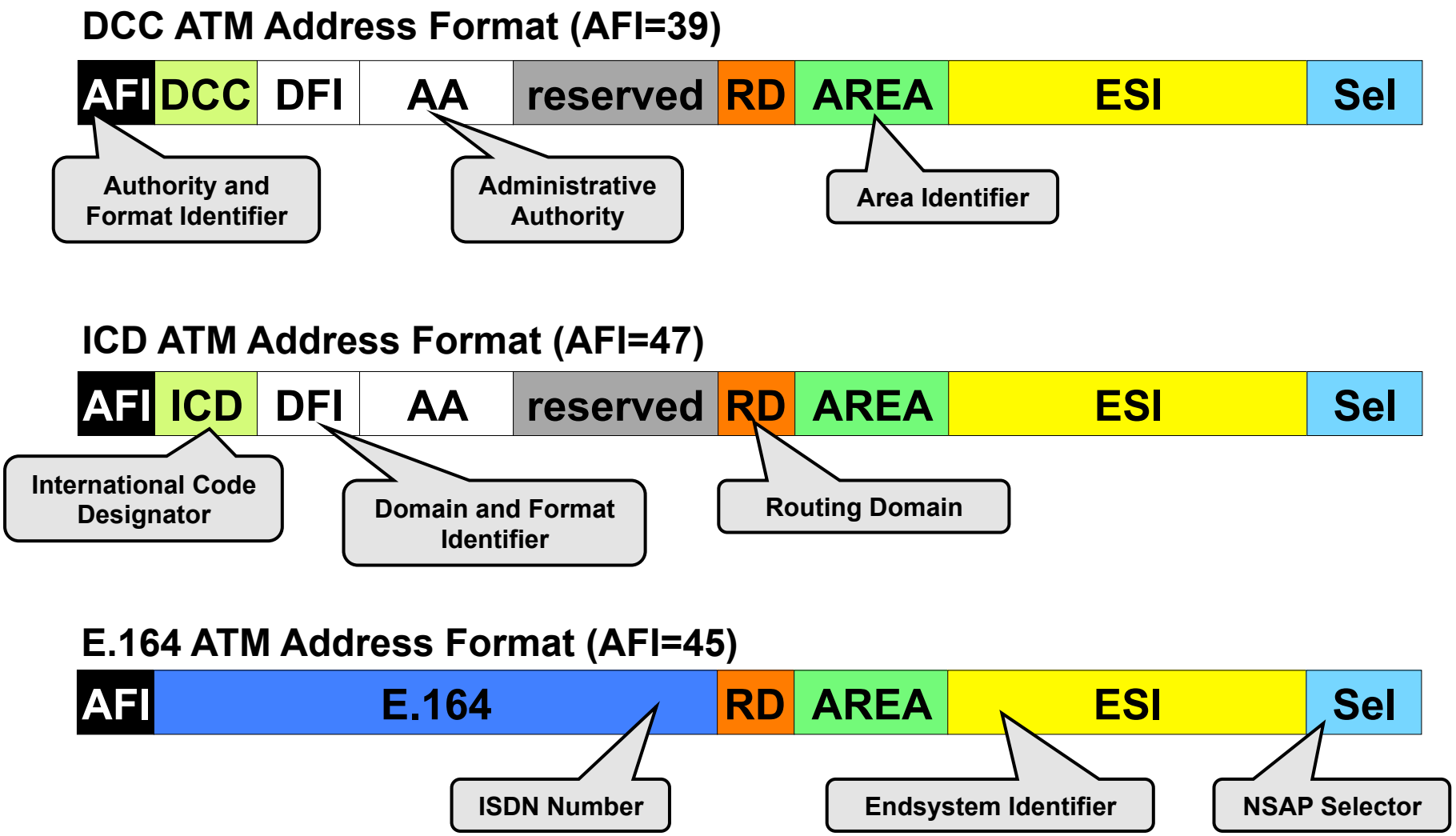


ATM Addresses

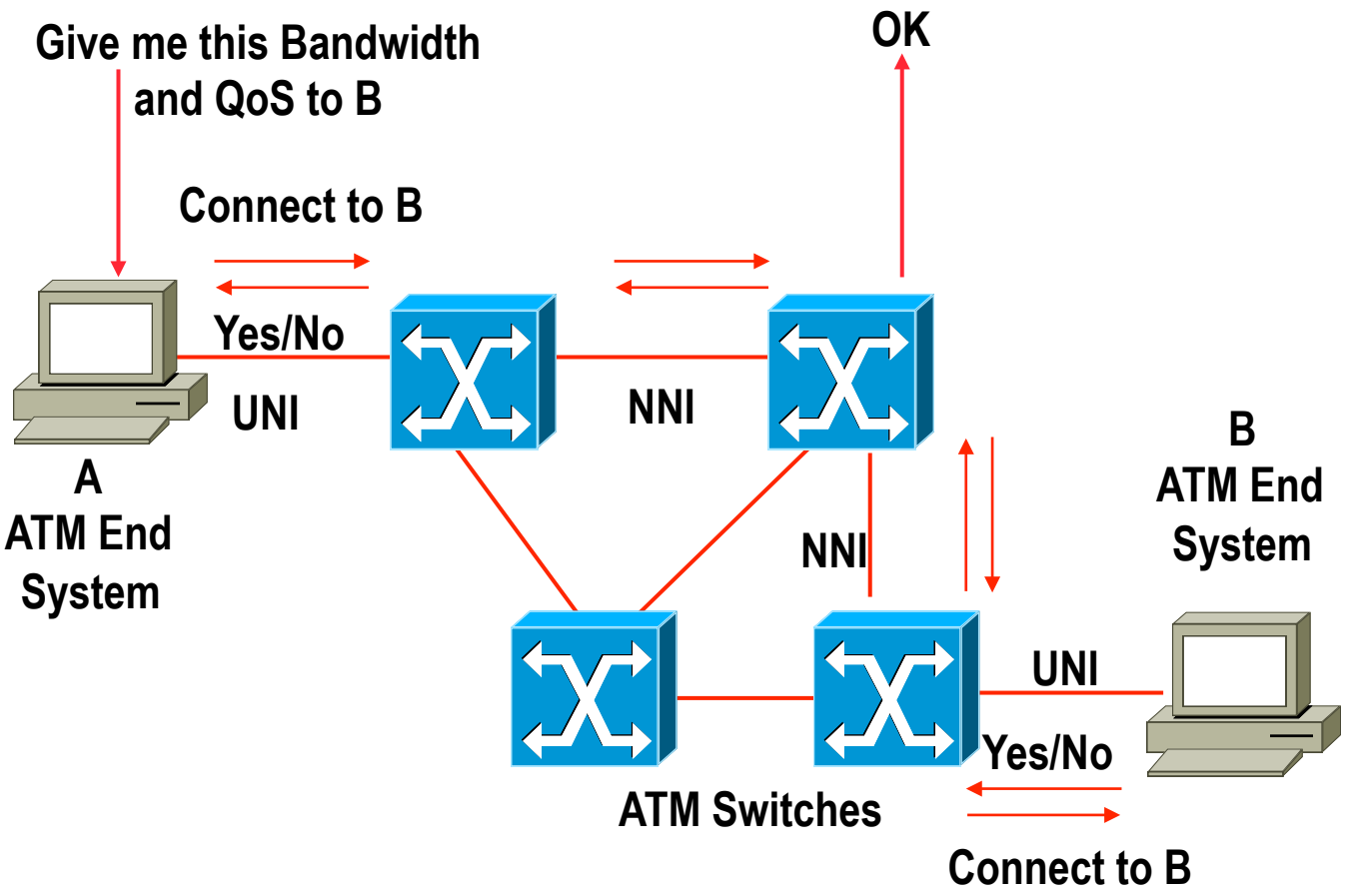
- **Different types of ATM addresses**
- **All have 20 byte length**
- **All consist of three main parts**
  - Prefix (Basically topology information)
  - End System Identifier (ESI)
  - NSAP Selector (Selects application)



ATM Address Flavors



ATM Goal: Bandwidth on Demand with QoS Guarantees



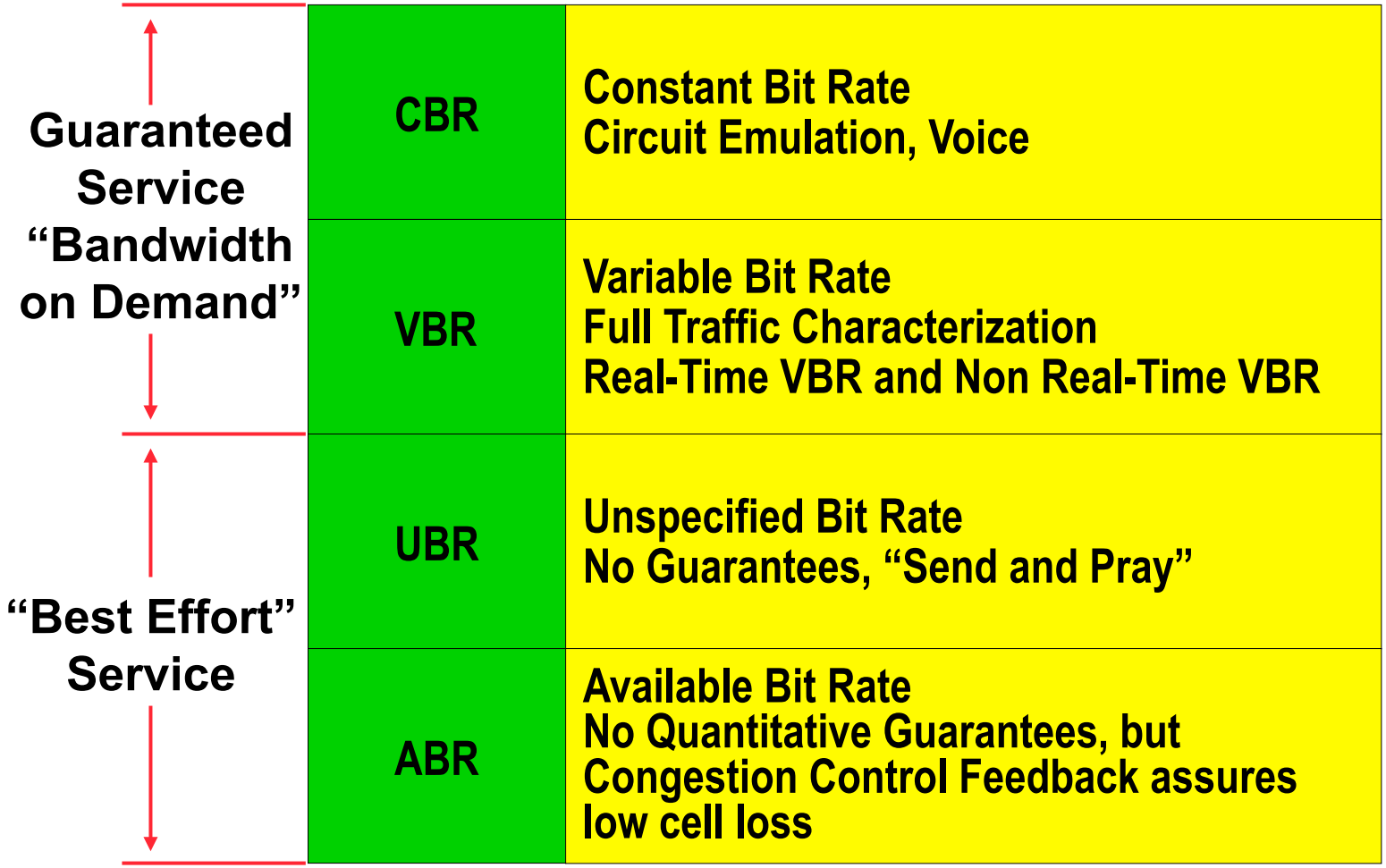
ATM Traffic Management Basics

- **The ATM network establishes**
  - A separate traffic contract with the user for each VC
- **The elements for a traffic contract are**
  - ATM service class
    - Framework that defines which of the following parameters are relevant for a certain traffic class
  - ATM traffic parameters
    - Specify characteristics of the traffic (cell flow) which is generated by an ATM end system
  - ATM QoS parameter
    - Performance parameters expected by an ATM end system from the ATM network when generated traffic is within the contracted parameters; some of these parameters are negotiated like ptpCDV, maxCDT, CLR

Traffic and QoS Parameters

- **ATM traffic parameters**
  - Peak Cell Rate (PCR)
  - Cell Delay Variation Tolerance (CDTV)
  - Sustainable Cell Rate (SCR)
  - Maximum Burst Size (MBS)
  - Minimum Cell Rate (MCR)
- **ATM QoS parameters**
  - Cell Transfer Delay (CTD)
  - Cell Delay Variation (CDV)
  - Cell Loss Ratio (CLR)
  - Cell Error Rate (CER)

Service Classes



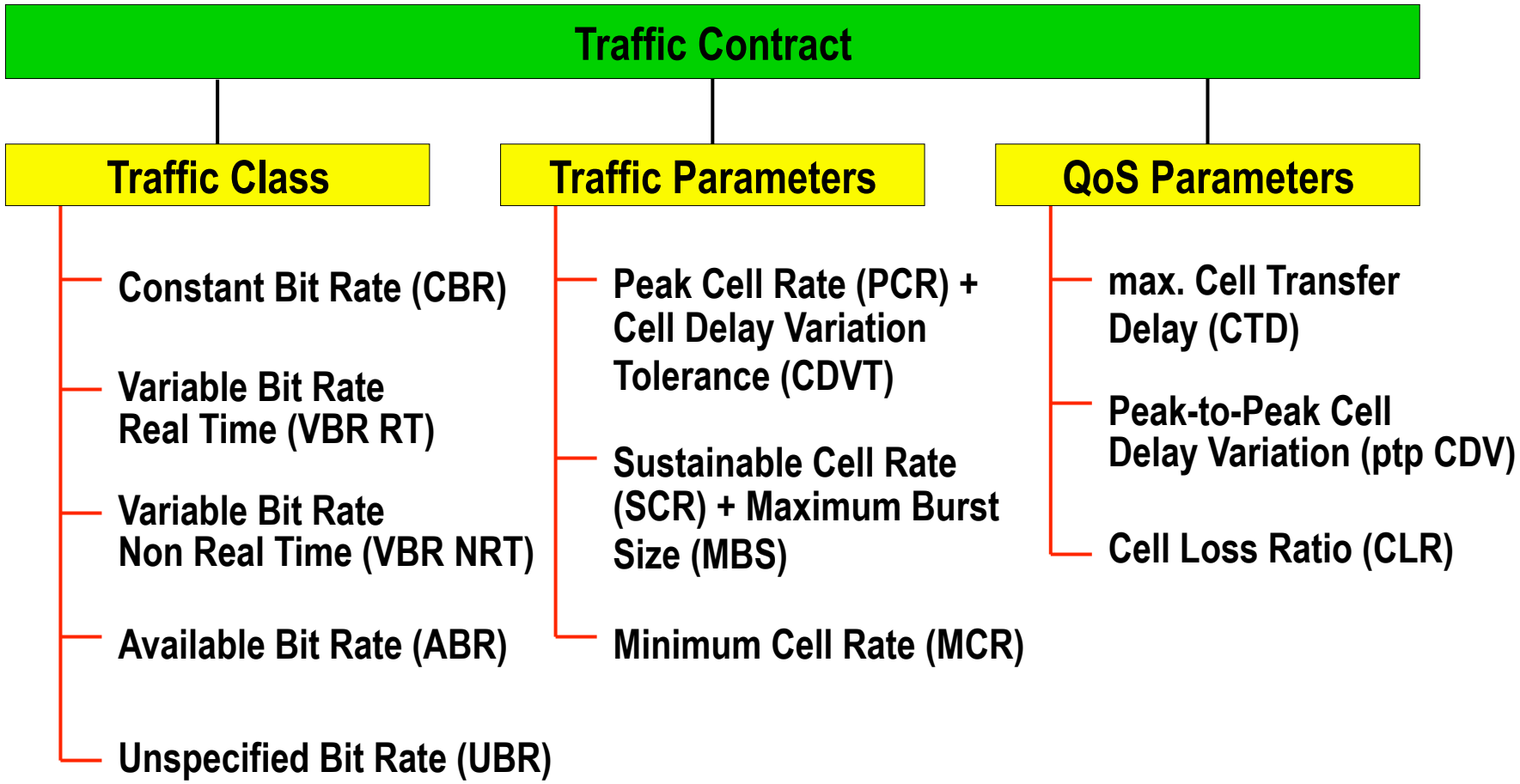
Service Classes

- **CBR Service**
  - Used for very strict bandwidth traffic
  - Minimal delay, minimal delay variation, minimal loss
  - Traffic parameter is peak cell rate (PCR)
  - For example digital leased line emulation
- **VBR Service**
  - Variable bandwidth traffic
  - Useful for video and compressed voice applications
  - Traffic parameters are sustainable (average) cell rate (SCR), PCR, and maximum burst size (MBS)
  - Guaranteed service if source conforms to parameters

Service Classes

- **ABR Service**
  - Useful for computer applications
  - Variable bandwidth traffic
  - Traffic parameter is minimum cell rate (MCR)
  - Includes feedback control
- **UBR Service**
  - “Best effort” service
    - No real guarantees
  - Useful for computer applications
  - Variable bandwidth traffic
  - No traffic parameters

Traffic Contract



Traffic Contract per Service Class

- **Specified for each service class**

ATTRIBUTE	CBR	rt-VBR	nrt-VBR	ABR	UBR
PCR & CDVT	Specified			Specified	
SCR, MBS, CDVT	n/a	Specified		n/a	
MCR	n/a			Specified	n/a
max CTD & ptp CDV	Specified		Unspecified	Unspecified	
CLR	Specified			Optional	Unspecified

CLR = Cell Loss Ratio
CTD = Cell Transfer Delay
CDV = Cell Delay Variation
MBS = Maximum Burst Size

PCR = Peak Cell Rate
CDVT = CDV Tolerance
SCR = Sustainable CR
MCR = Minimum CR

ATM as an Intelligent Bandwidth Management System