WAN Technologies
(to interconnect IP routers)

Mario Baldi

www.baldi.info

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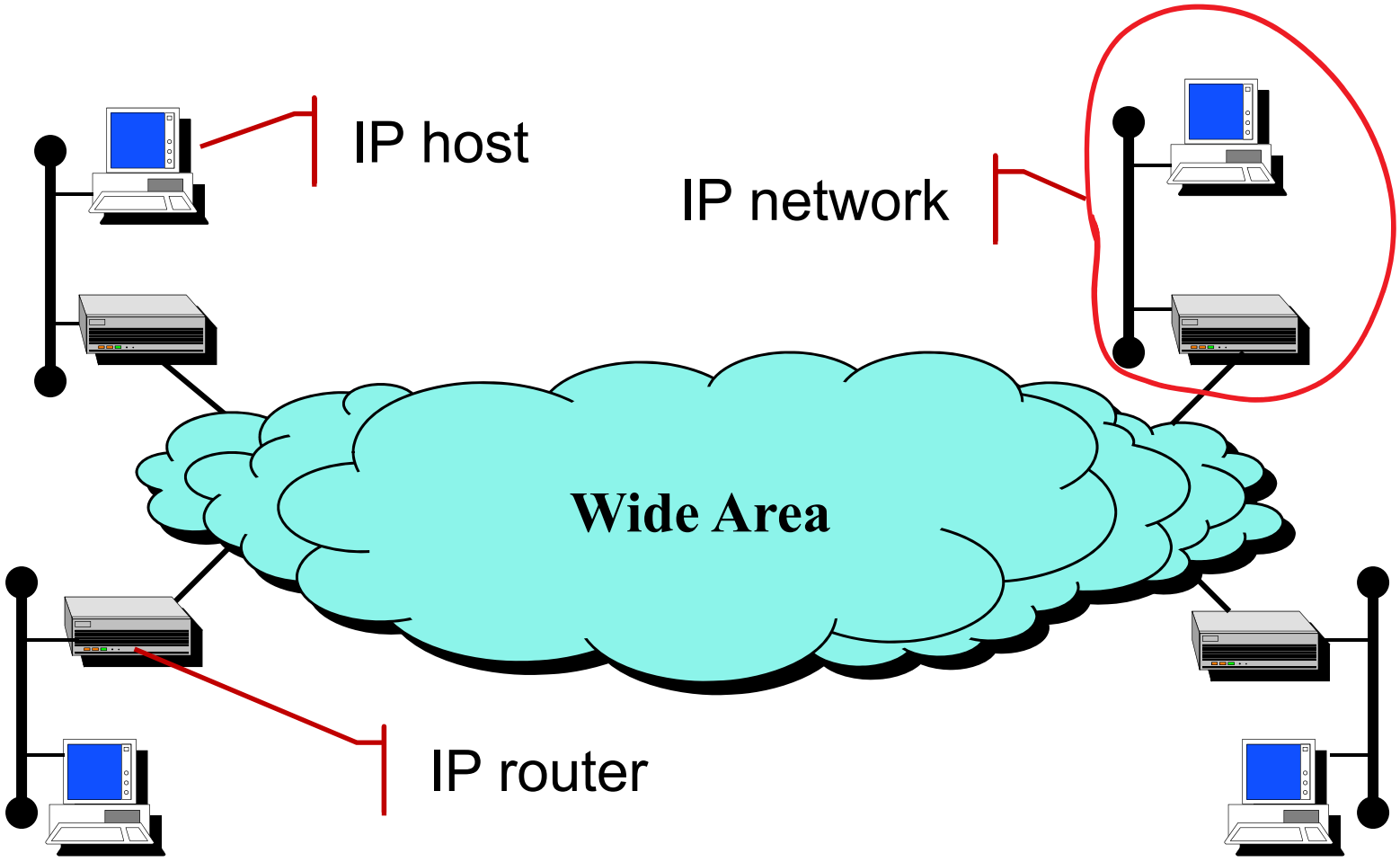
The Context



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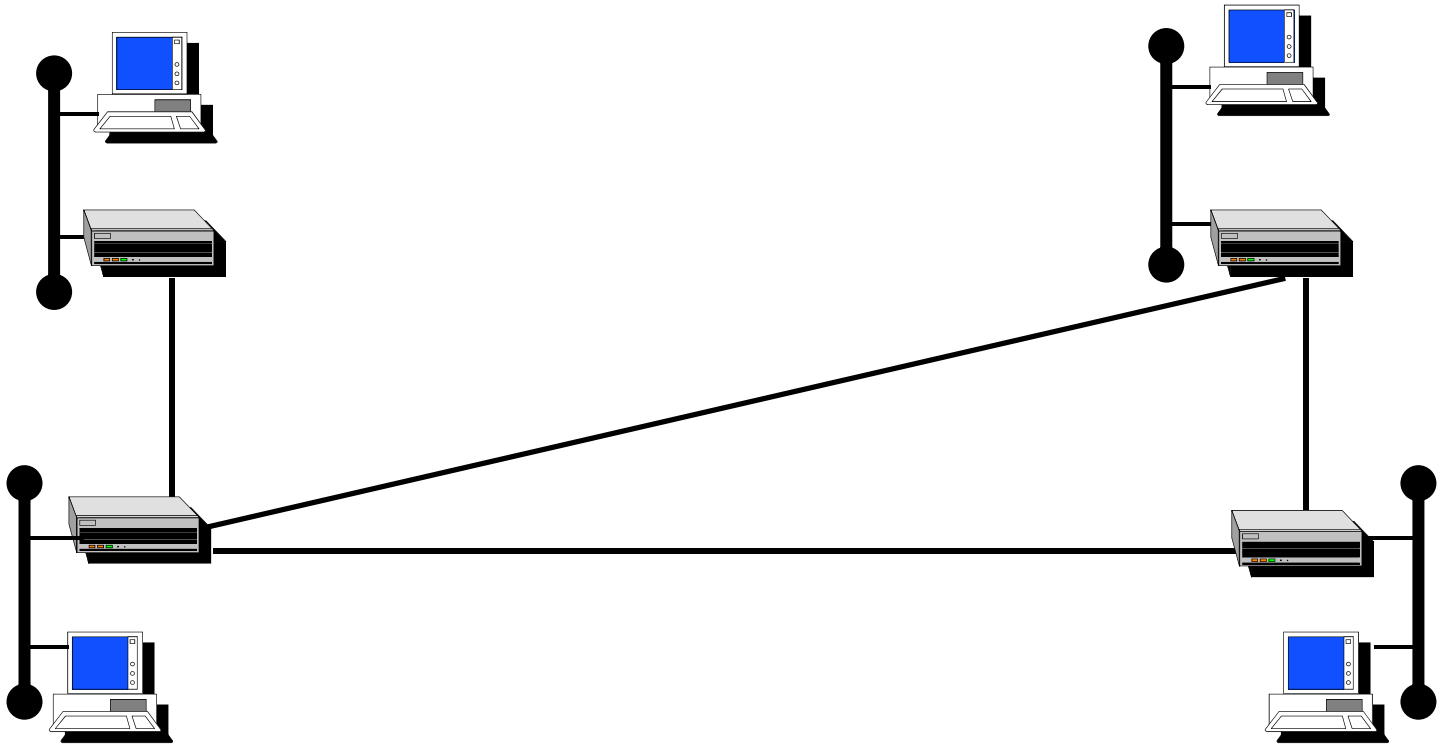
Why Not Just Cables?

- Expensive!
- Time consuming
- To lay
- To modify



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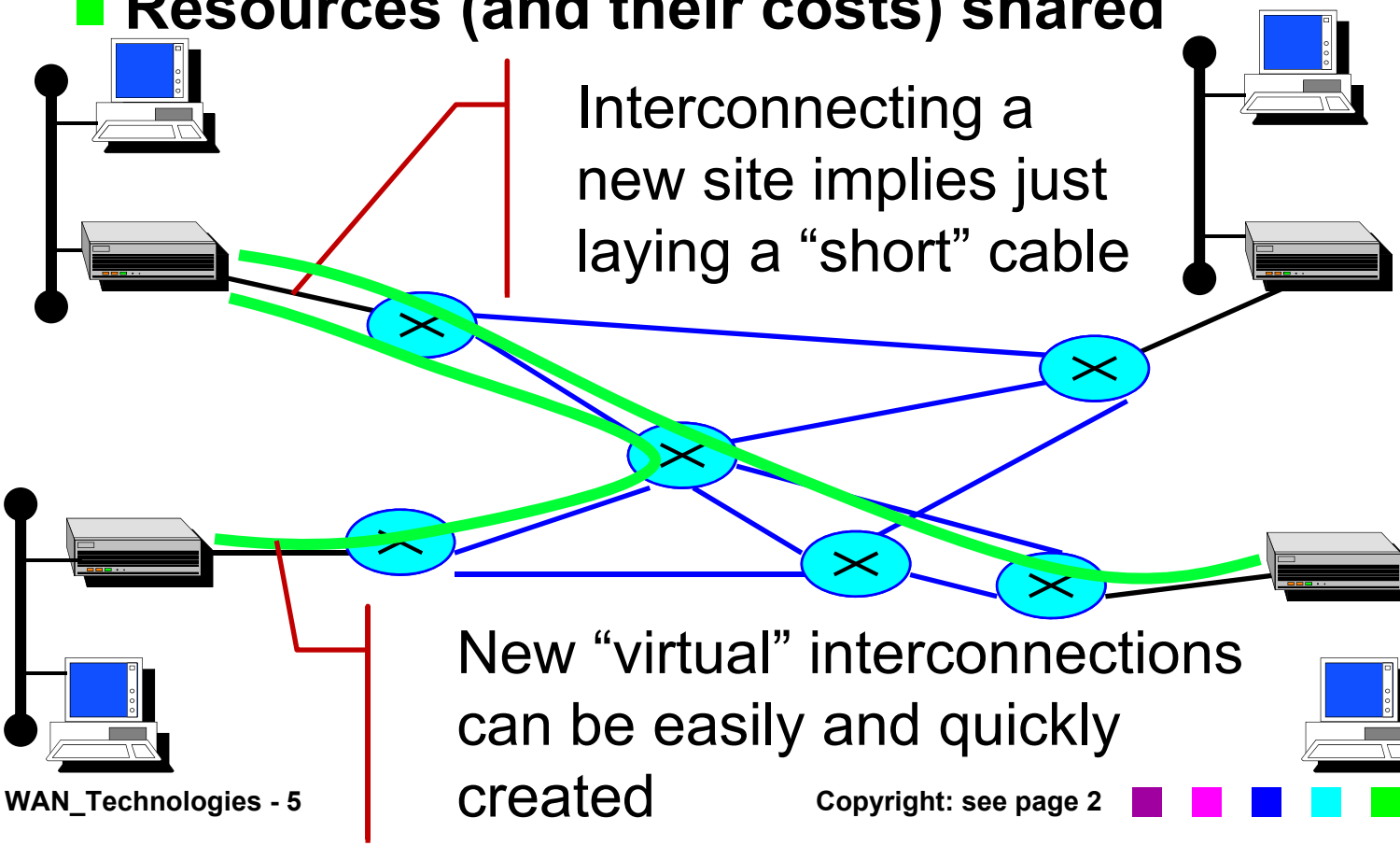
Use a Network

- **Cables are laid once**
- **Interconnectivity can be configured**
- **Resources (and their costs) shared**



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And before building new ones

- Reuse existing technologies
- Specifically, existing networks

They are

- “Dead”: there is no new development
- Old: designed tens of years ago with various purposes in mind
  - Not for interconnecting IP routers
    - With one exception (frame relay)
- … but huge investments

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Commonly Deployed Technologies

- Circuit switching
  - ISDN
  - PDH
  - SONET/SDH
- Frame Relay
- ATM

Dead and old, but still heavily used

→ relevant!

[also optical networks, which are a (relatively) new technology]

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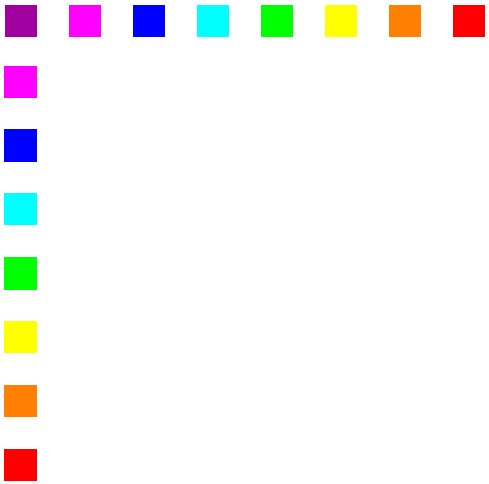

Circuit Switching Technologies

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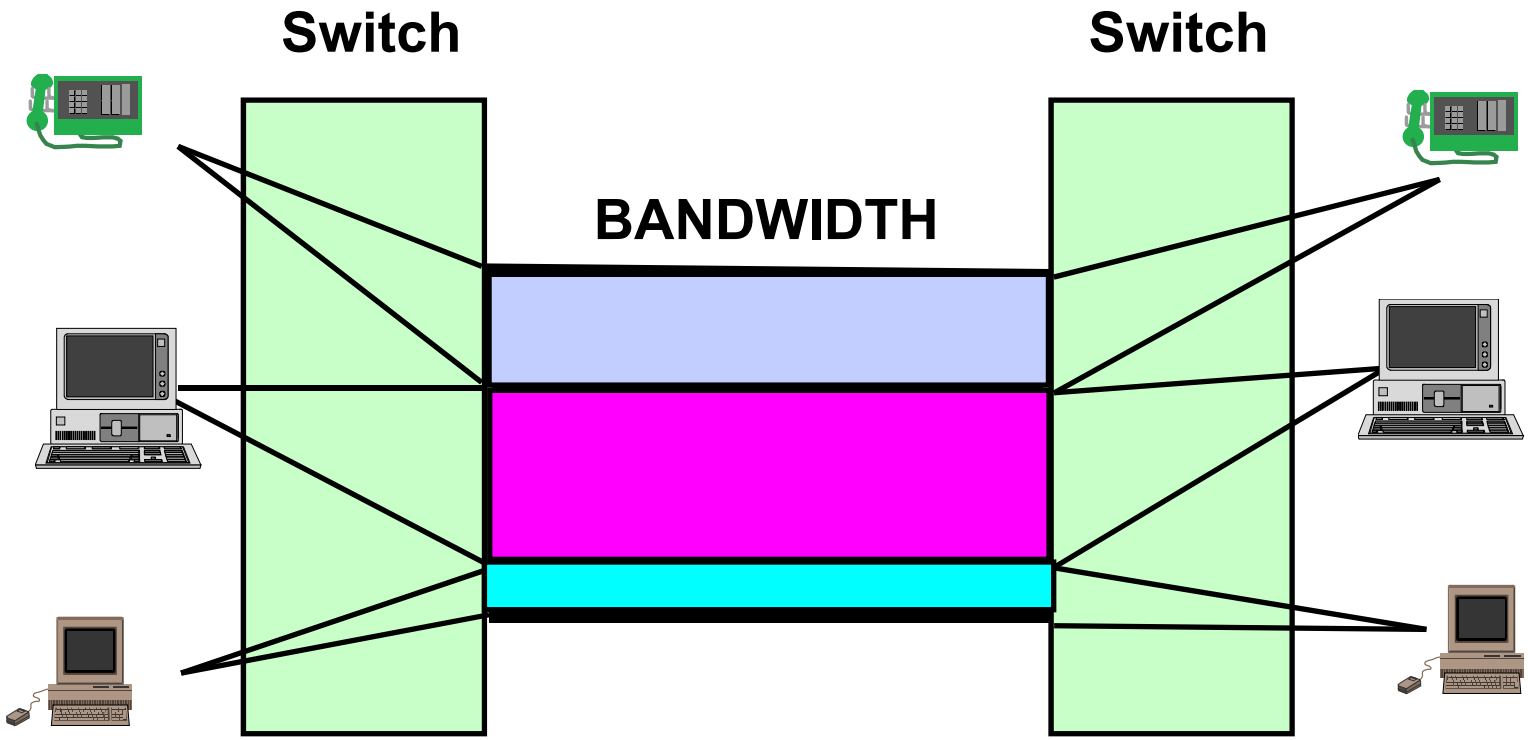
TDM: Time Division Multiplexing



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Interconnections based on TDM

- TDM (Time Division Multiplexer)
  - divide the total bandwidth in sub-bands
- Each network user (e.g., router) can “see” only its assigned sub-band as a synchronous channel with *fixed* bit rate
- Routers can use a channel as the equivalent of a physical link
- In reality at any given time the link carries traffic of only one user

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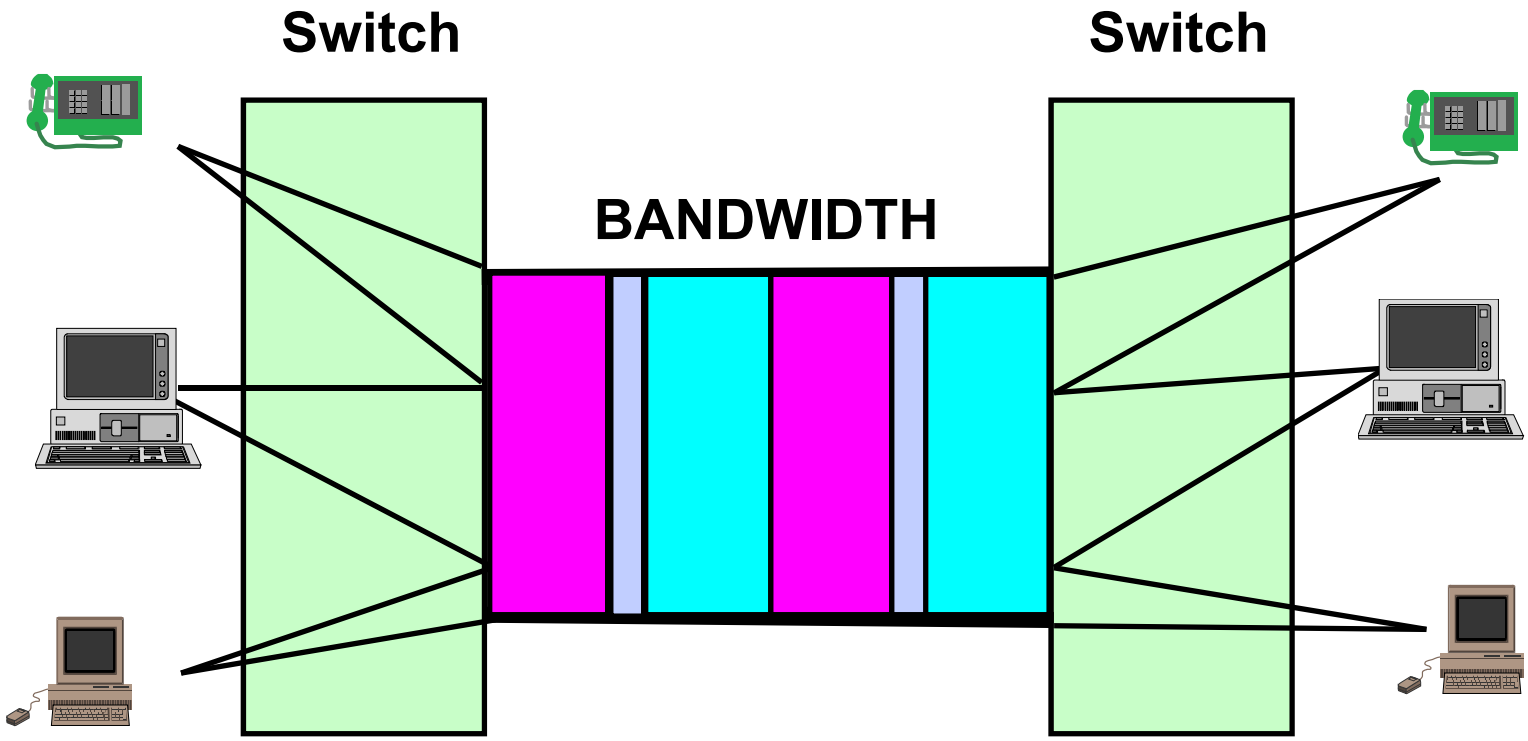
TDM: Time Division Multiplexing

Take turns



at *predefined*, *recurring* time instants → time rules

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Good service without flexibility (by design)

- Deterministic performance
  - Delay
  - Jitter
  - Bandwidth
- Fixed rate
- Bandwidth not actually used by a user (in a certain interval of time) cannot be used by other services and it is wasted
  - Higher costs
  - Particularly for bursty traffic
    - E.g., data traffic

Designed for voice traffic

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Standard Channel Hierarchies

- Standardized channel speeds
- Standardized transmission speeds
  - And corresponding equipment
    - Transmitters
    - Receivers
    - Cables
      - Copper
      - Fibers
- How to combine multiple low speed channels into a high speed signal transmitted on a link
  - Multiplexing and demultiplexing

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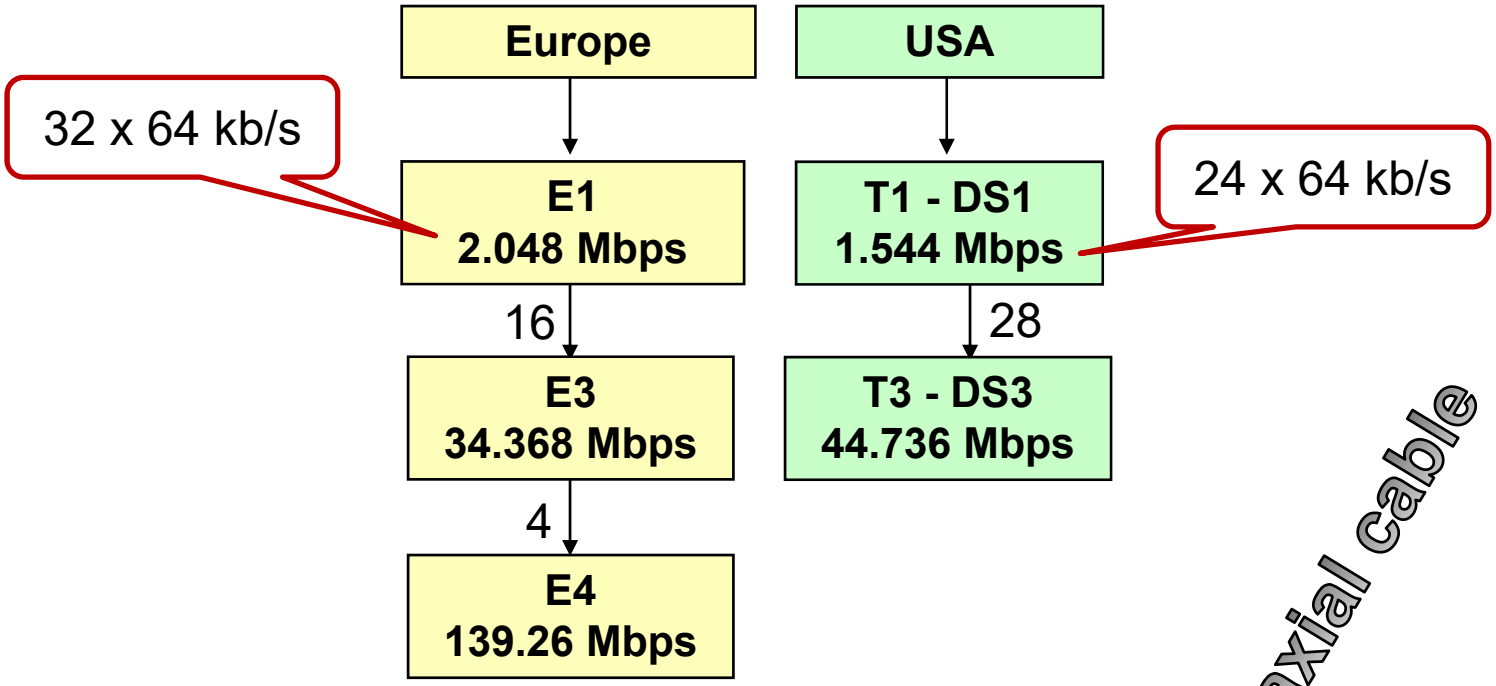
PDH: Plesiochronous Digital Hierarchy

- Looser synchronization requirements



- Limited transmission speeds
- High overhead

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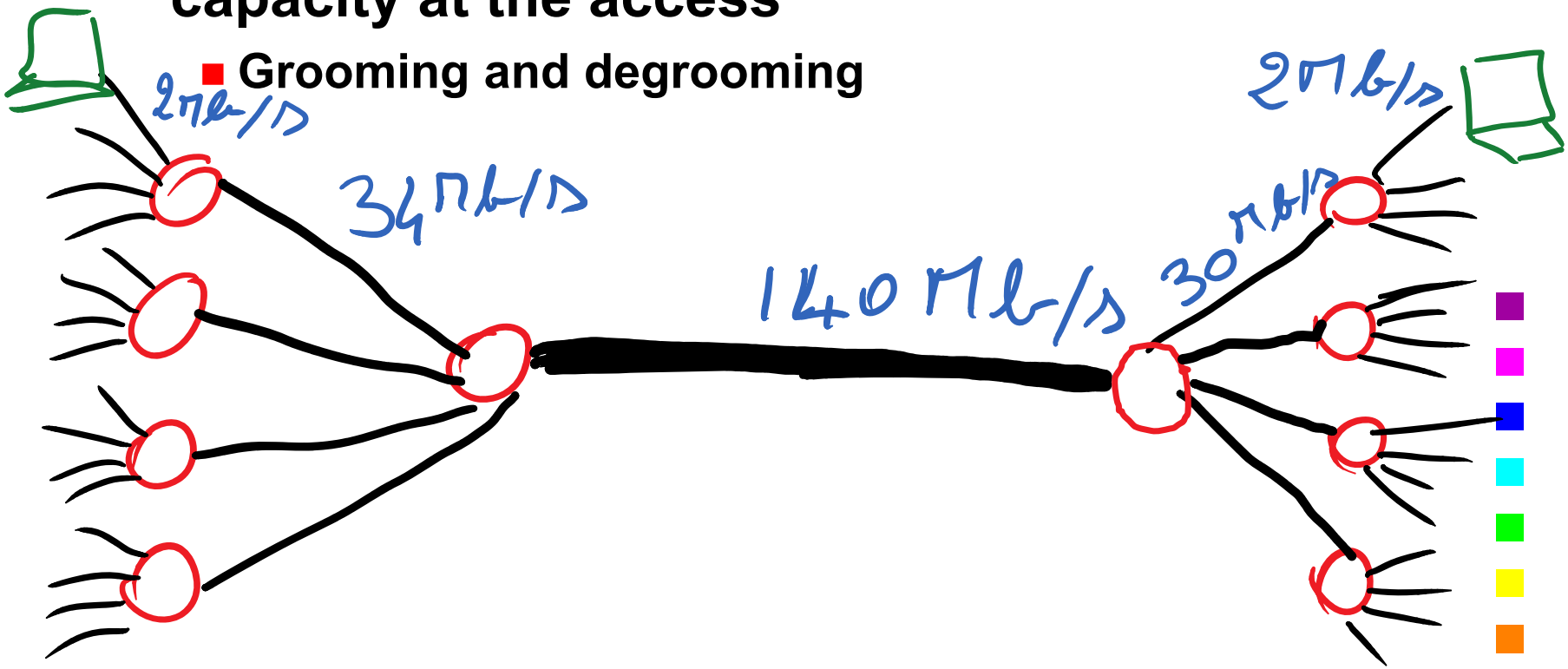
Why a hierarchy?

- Hierarchy: how to combine multiple lower rate frames into higher rate frame
- Higher capacity links in the backbone, lower capacity at the access
  - Grooming and degrooming



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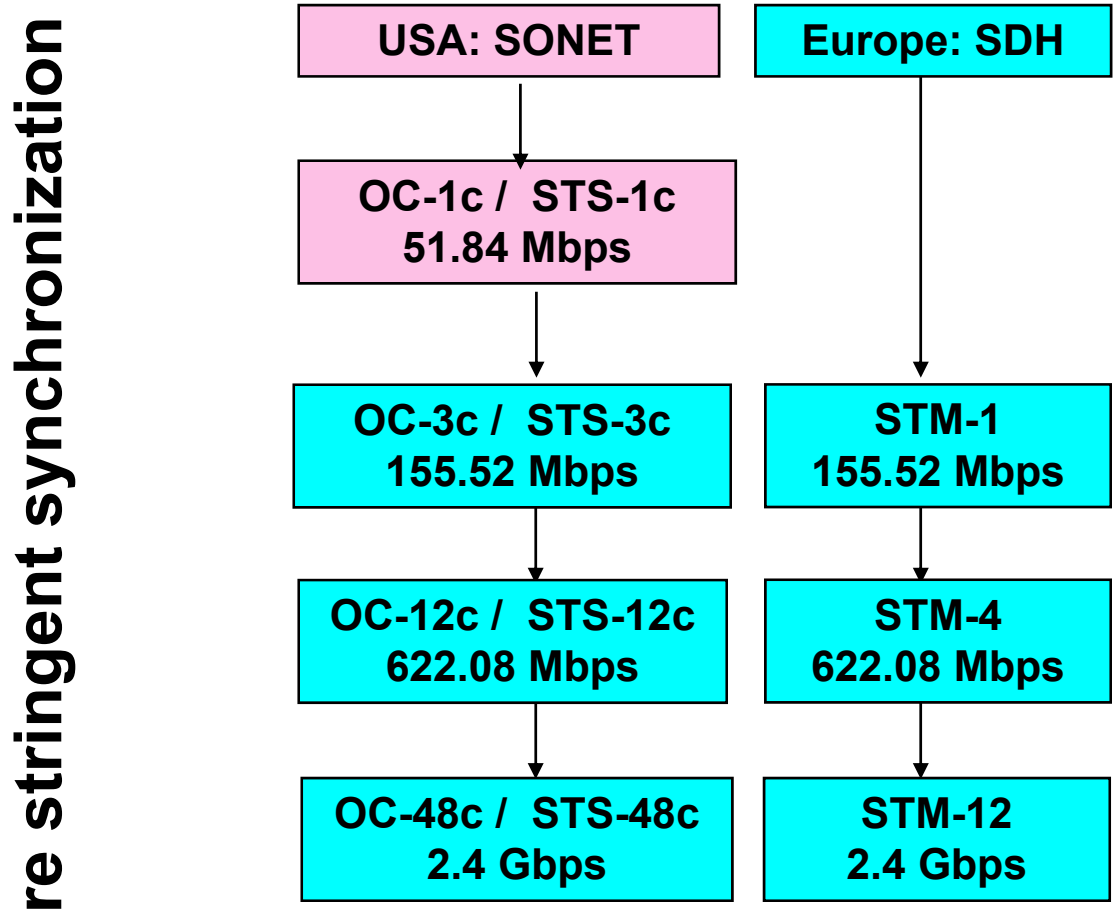
SDH: Synchronous Digital Hierarchy
SONET: Syncronous Optical Network



- Higher transmission speeds
- Lower overhead

Optical fiber

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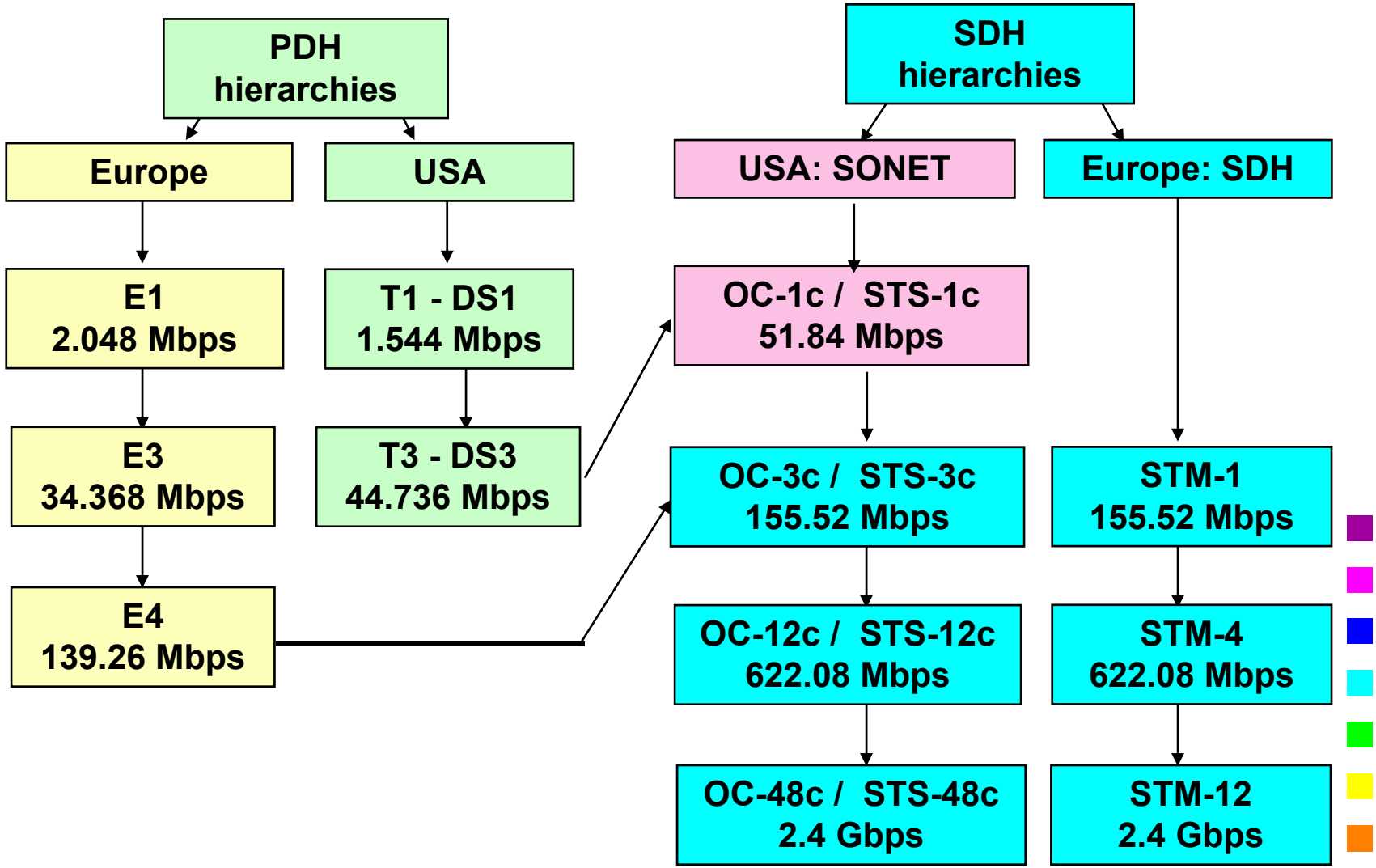
Interoperability



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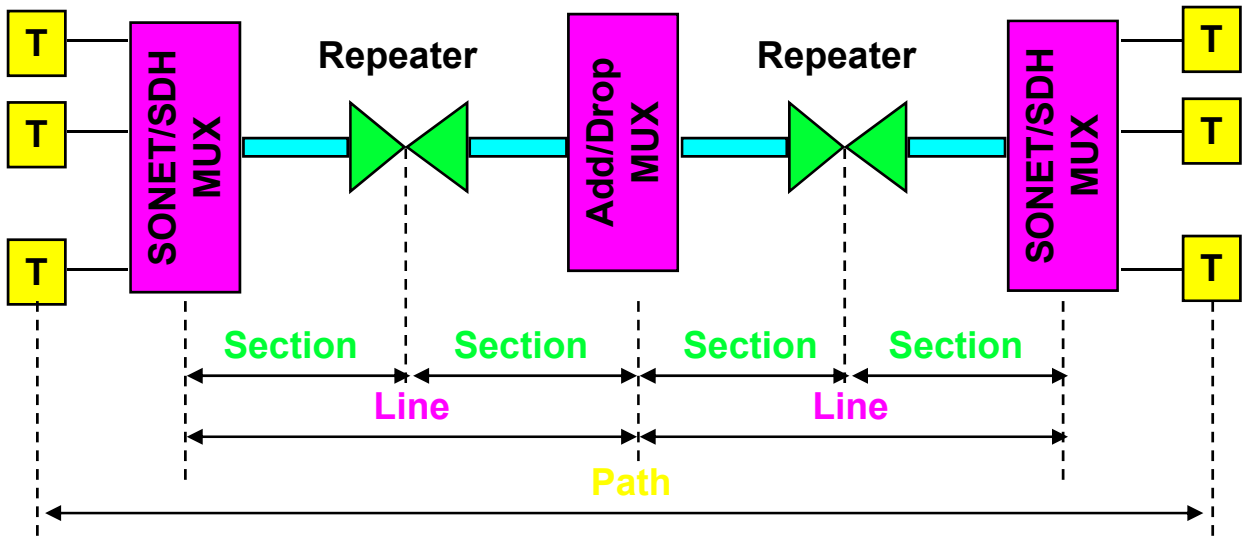
Physical architecture

- **Section:** fiber optic between repeaters
- **Line:** sequence of sections between devices oeprating at line level
- **Path:** end-to-end connection



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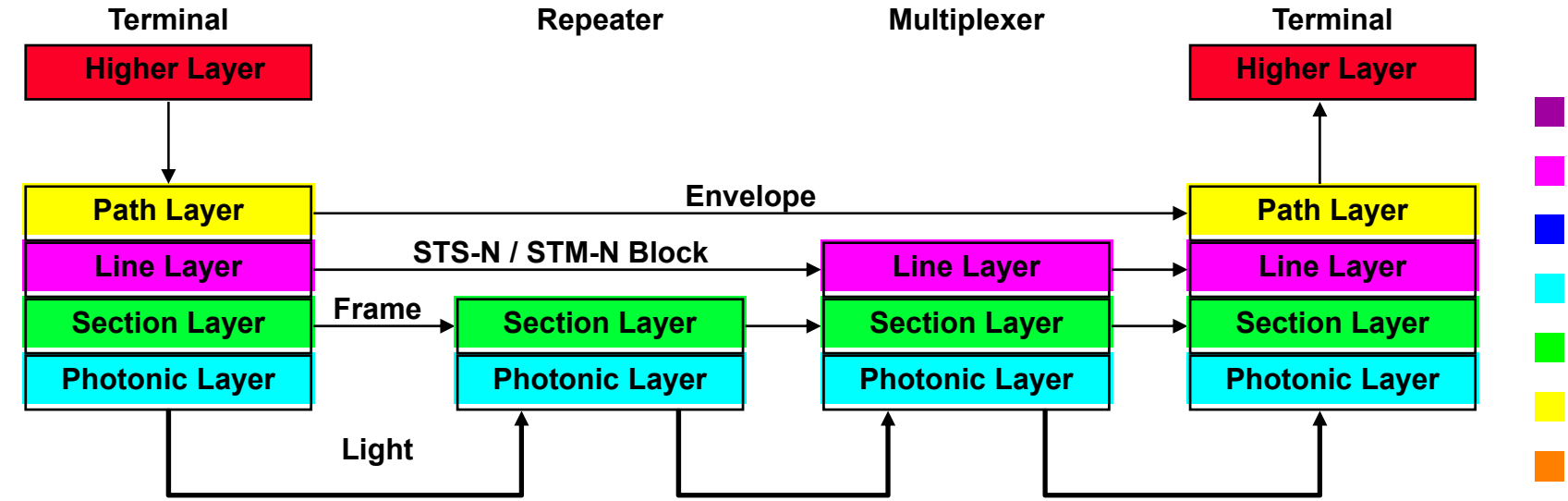
Protocol architecture

- Multiple layers
  - Complex protocol architecture
- Monitoring functionalites
- Fast fault recovery
  - 50 ms
  - Ring topology



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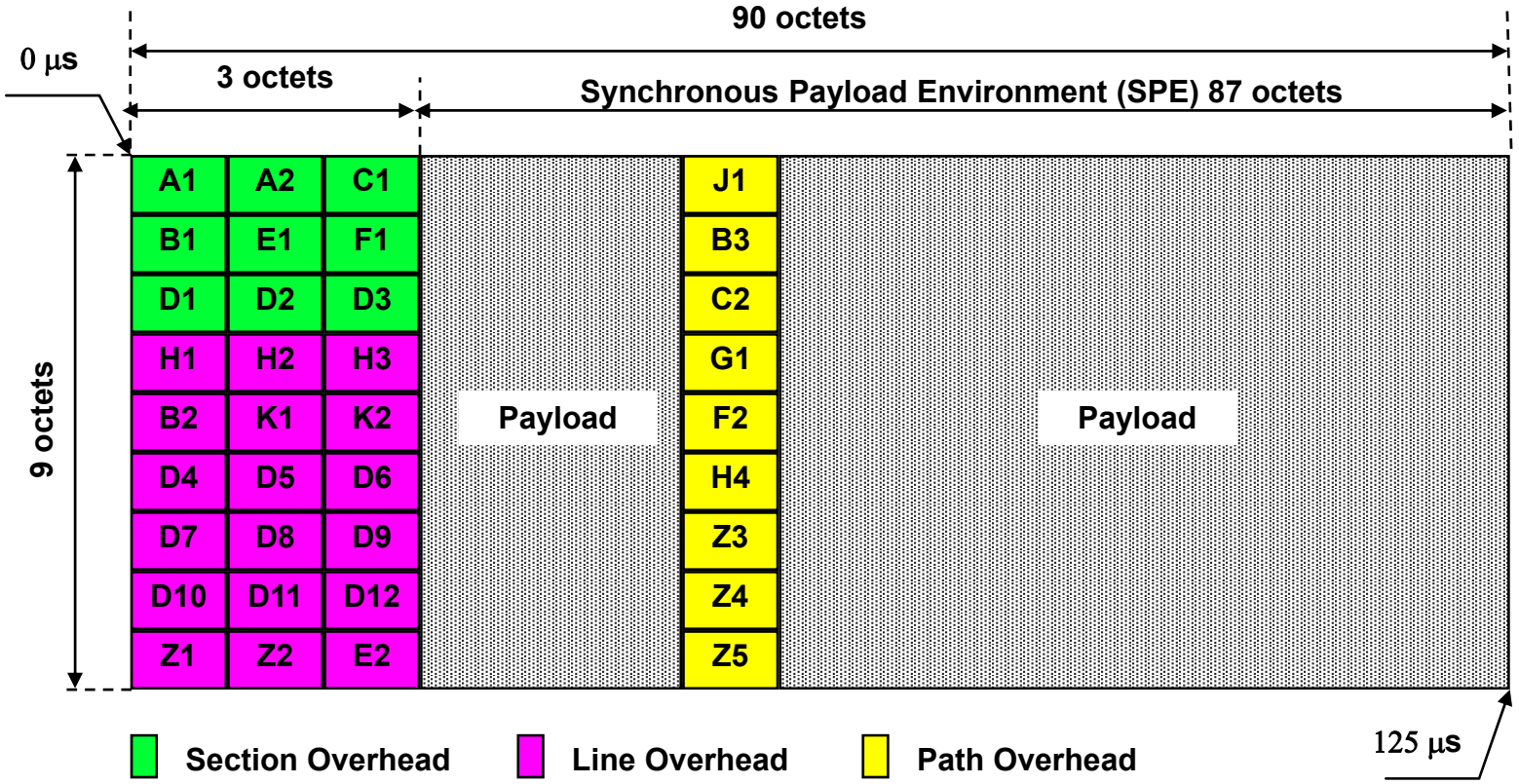
Frame format

STS-1: 810 bytes transmitted in 125 μs → 51.84 Mbps



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Frames

- In packet switching
  - Frame contains bytes of a single communication
  - Destination (source) identified in the header
  - Frames are transmitted asynchronously
    - Whenever there is data to transmit
    - Whenever a link is free
  - Statistical multiplexing
- In circuit switching
  - Frame contains bytes of multiple communications
  - Destination (source) identified by the position
  - Frames are transmitted synchronously
    - Back-to-back
    - Independently of whether there is data to transmit

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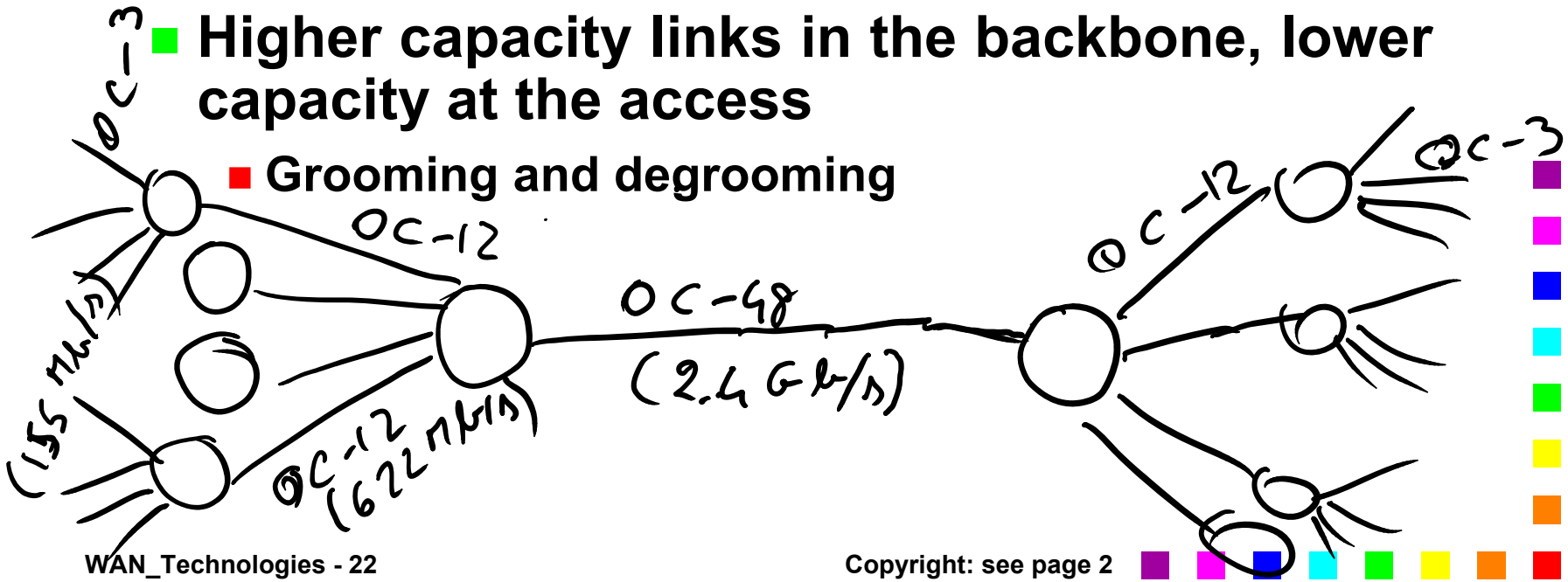
What do we do with them?

- Same duration (125 µs) at any bit rate
  - 1 byte carries one 64kb/s channel
- More bytes per frame at higher rates
- Hierarchy: how to combine multiple lower rate frames into higher rate frame
- Higher capacity links in the backbone, lower capacity at the access
  - Grooming and degrooming



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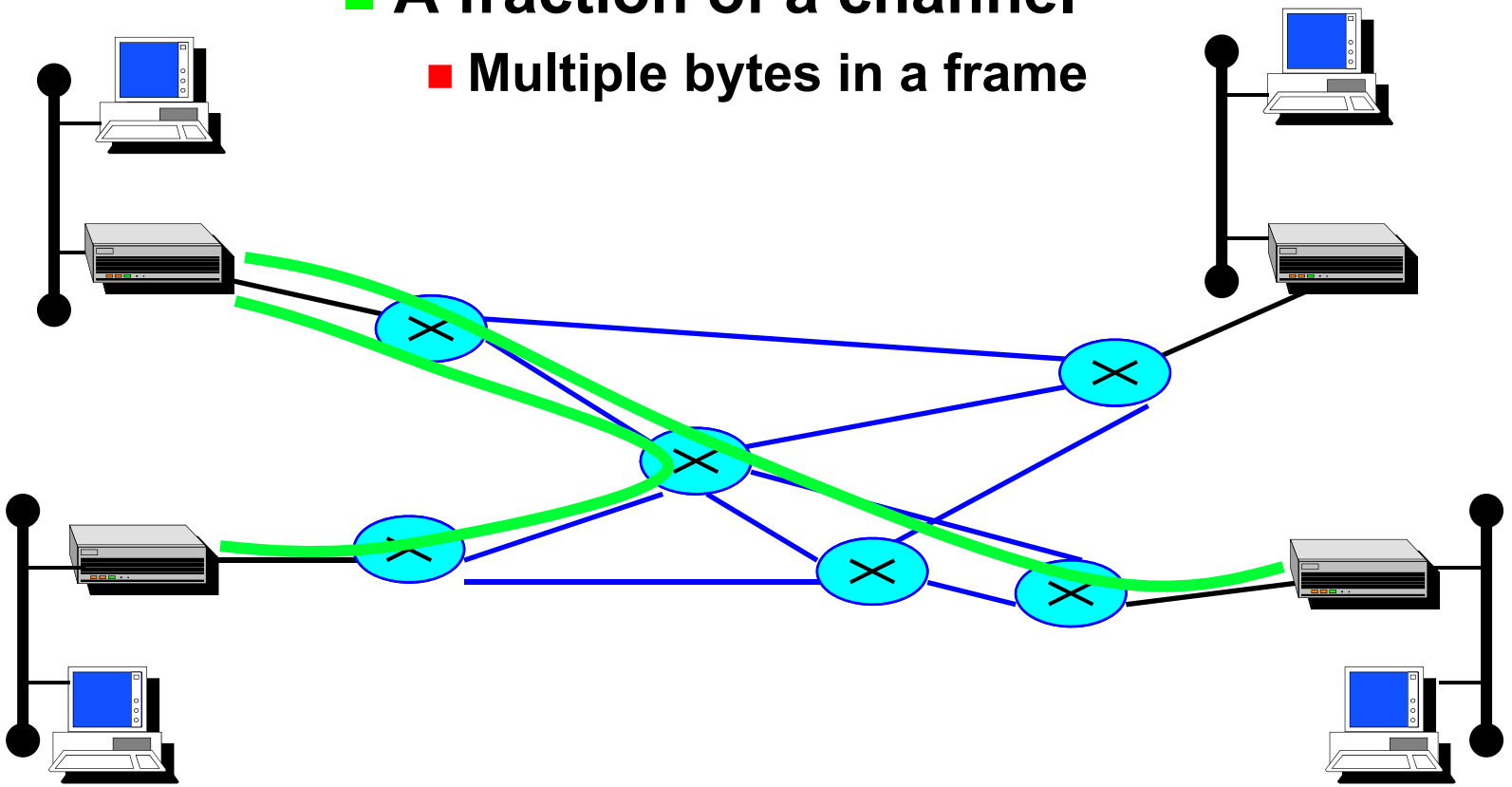
How do we connect routers?

- One channel between two routers
  - All bytes in a frame
- A fraction of a channel
  - Multiple bytes in a frame



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But this is not the way it was meant to be used

- Voice
- Integrated services

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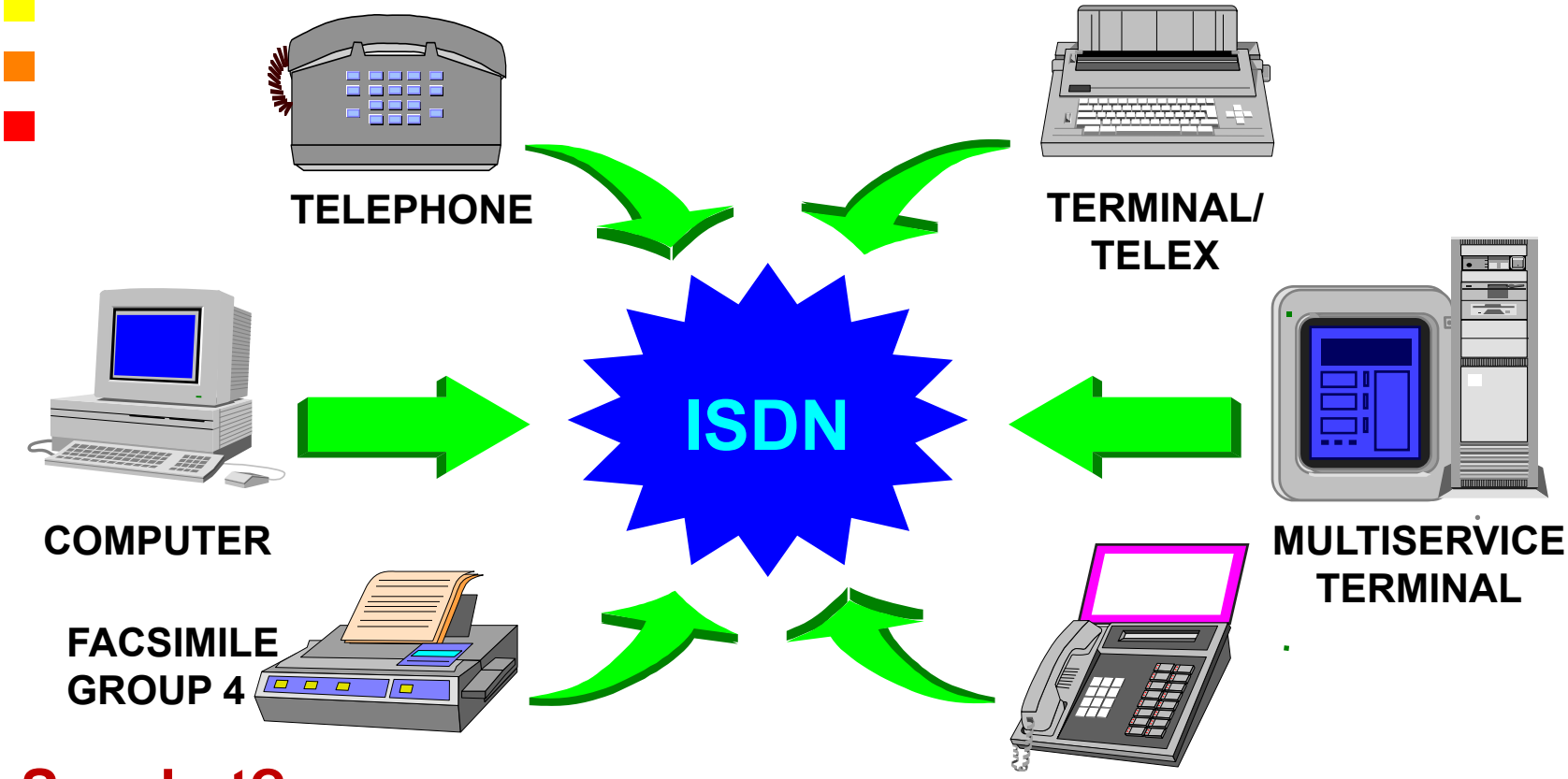
ISDN -
Integrated Service Digital Network



So what?

Now it is normal, but back then it was a big step forward

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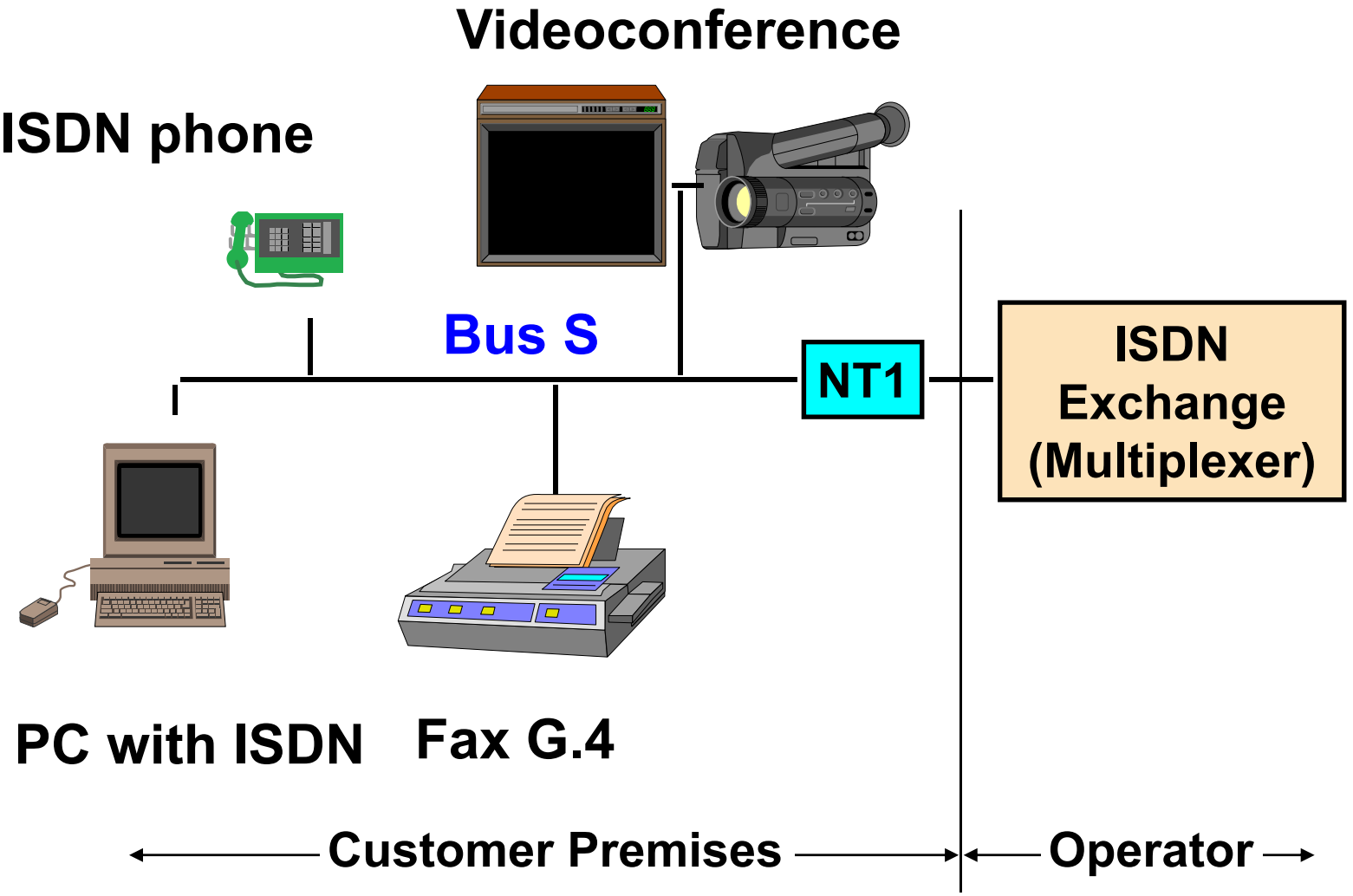
ISDN Access Interface



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ISDN Access Interface

- Data + voice
- The user terminal becomes digital
- 2B + D or base access
  - 2 data channels at 64 kbps
  - 1 signaling channel at 16 kbps
  - total 144 kbps up to user's premises
- 30B + D or primary access
  - 30 data channels at 64 kbps
  - 1 signaling channel at 64 kbps
  - total 2 Mbps up to user's premises

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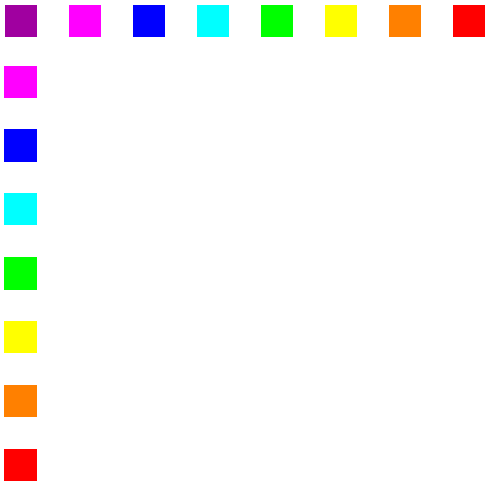

Packet Switching Technologies

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Packet-based multiplexing/switching

- If a source has no traffic, bandwidth is not wasted
  - Statistical multiplexing

- The same network infrastructure can statistically accommodate more communications
  - Cost of communicating is lower
  - Service is not deterministic

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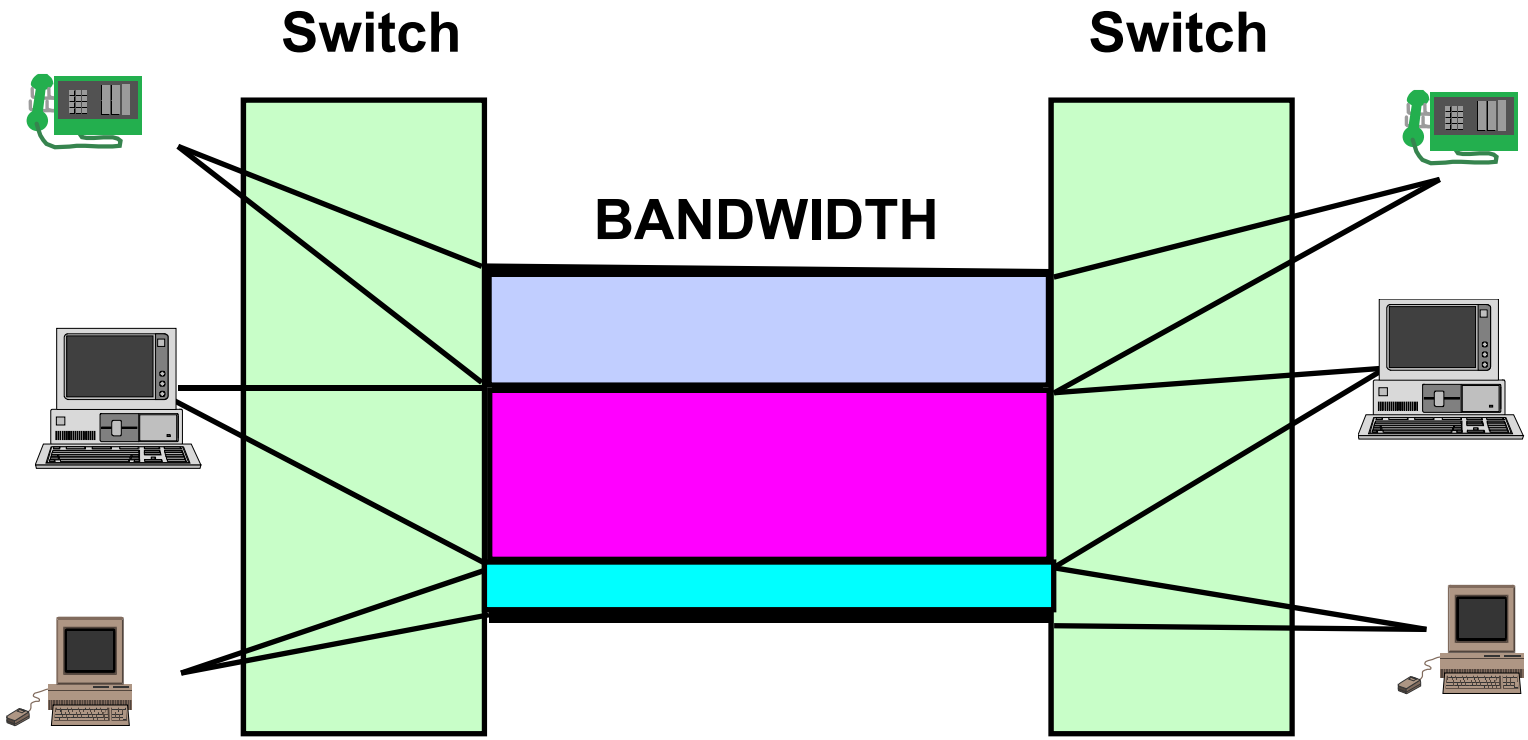
Statistical Multiplexing



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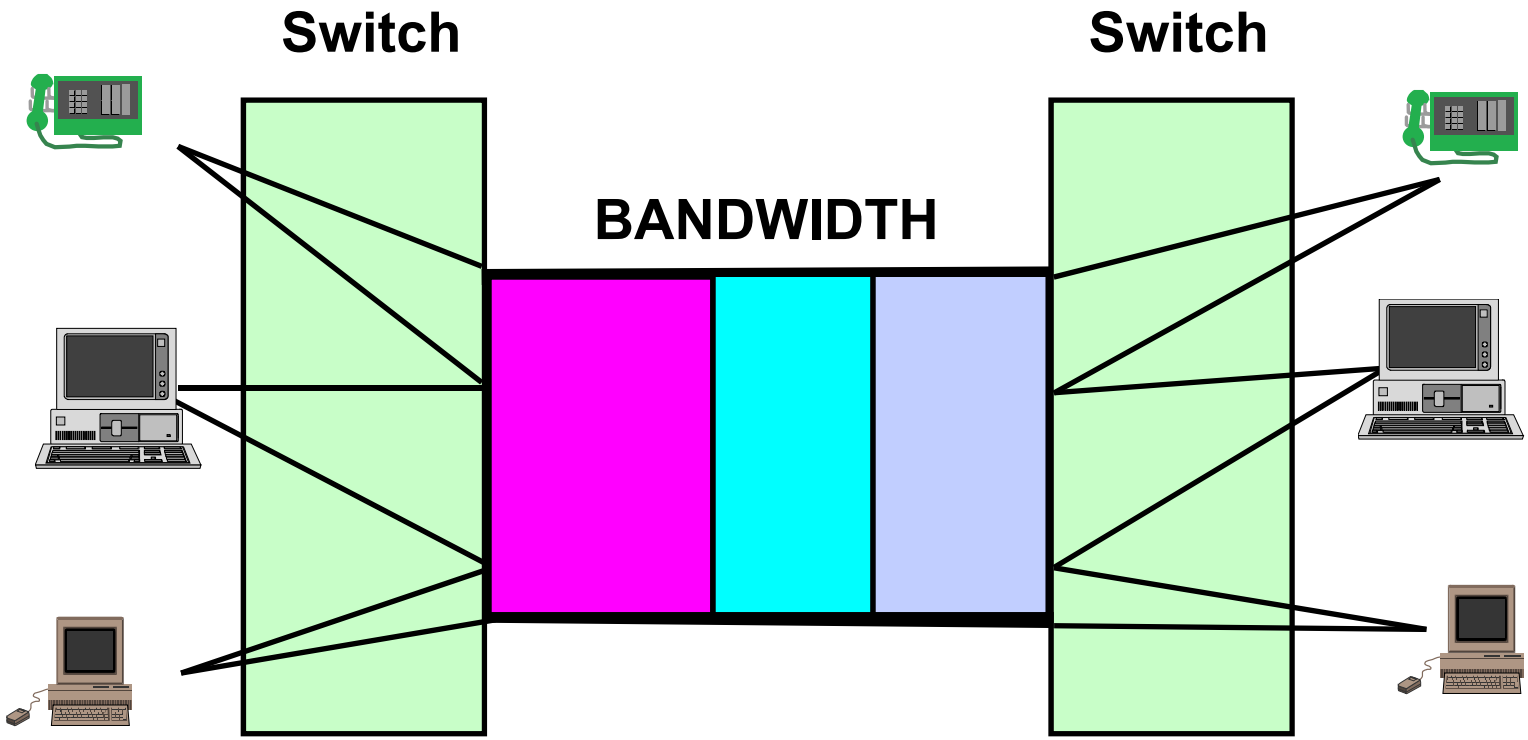
Statistical Multiplexing

Take turns



opportunistically, i.e., as soon as link is available

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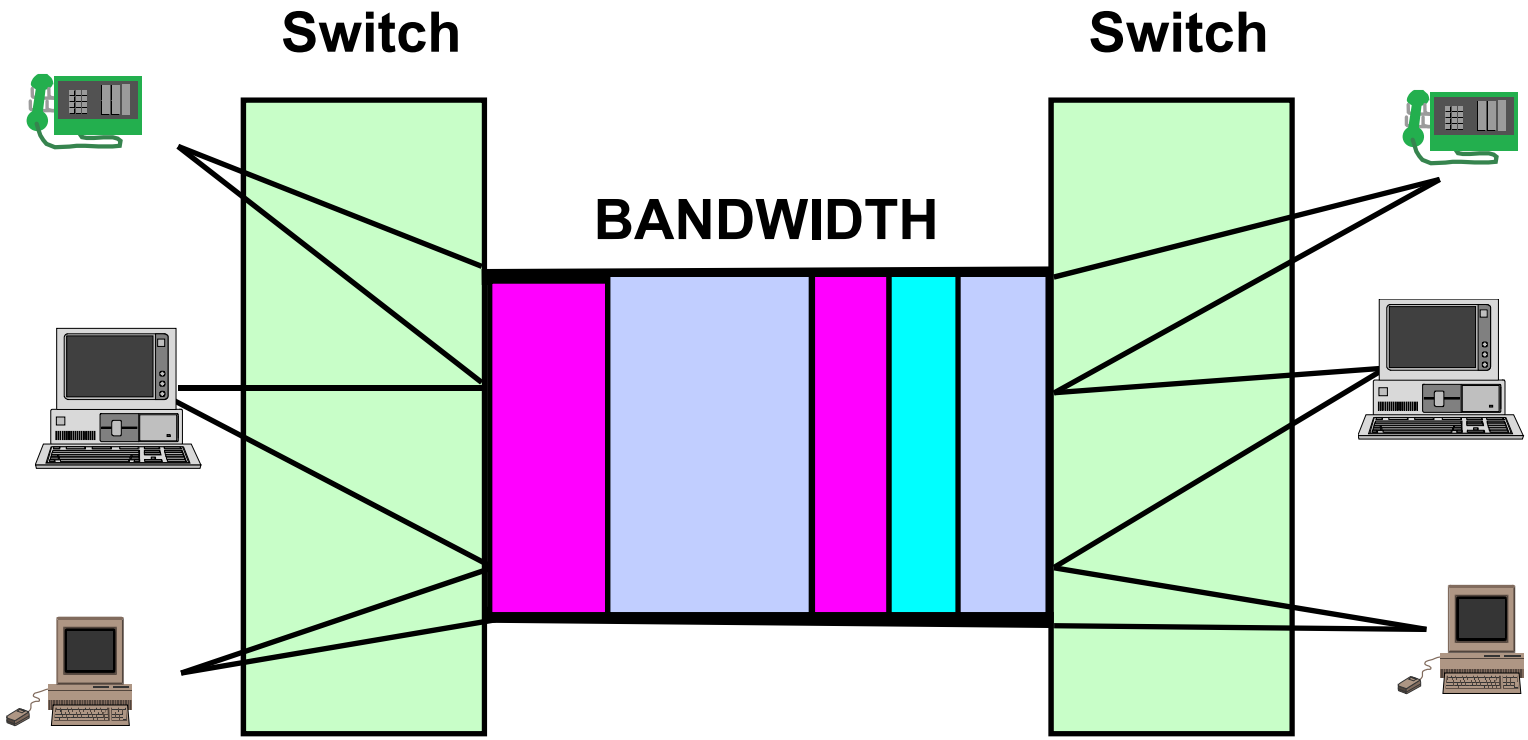
Statistical Multiplexing

If one is using less, others can use more



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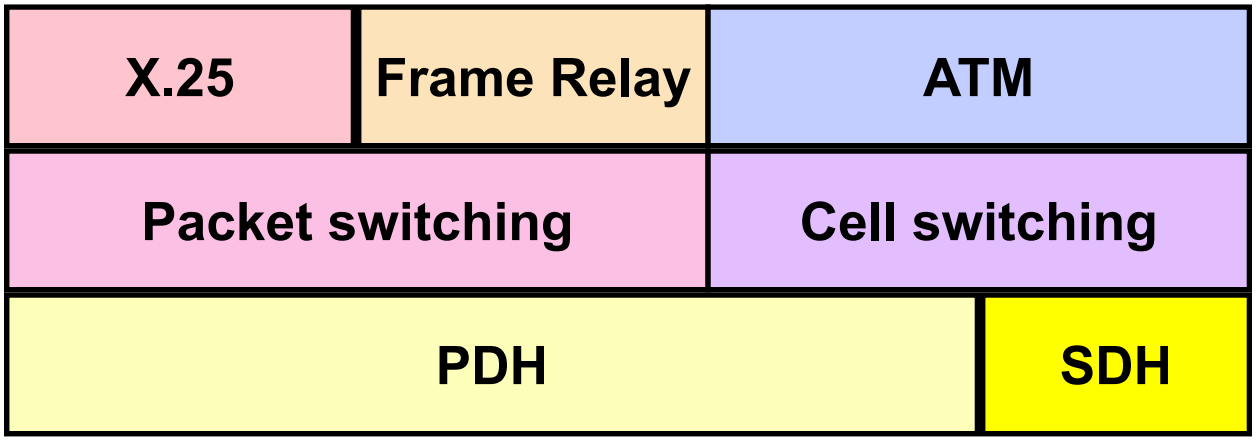
Building packet switching on top of circuit switching

Use circuits through a circuit network to interconnect packet/frame switches/routers



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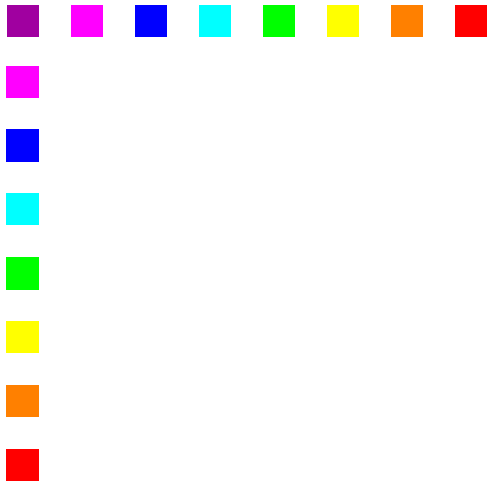

Frame Relay

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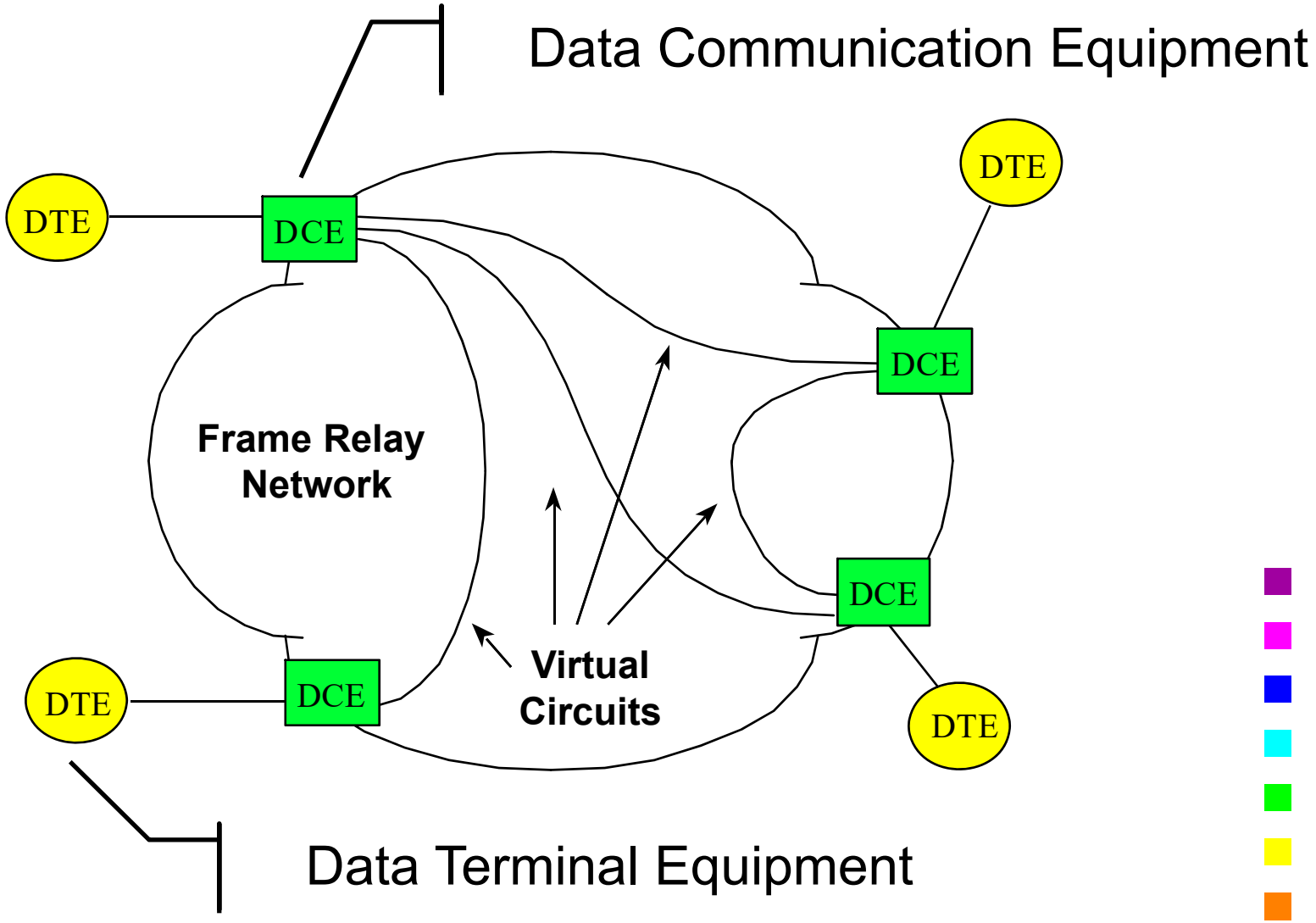
Frame Relay Network Architecture



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Frame Relay standard

- Standard for DCE-DTE interfaces
  - Multiple logical connections through a single access link
  - Similarly to X.25
- Layer 2 only
  - Switches do not need to process 2 headers (layer 2 and layer 3) like in the previous X.25
  - X.25 does have a layer 3

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Core-Edge Approach

- Error correction: re-transmission only at the network edge, not in the intermediate nodes (core)
  - X.25 corrects errors at each hop
- Requires reliable links
- Takes advantage of fast links
- Small latency:
  - 2 ms per frame relay node
  - from 5 to 20 ms per X.25 node

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Frame Relay applications

- Interconnection of Intermediate Systems (router, bridge, gateway) through WANs
  - All commercial devices offer FR interfaces
  - Physical layer is common (PDH)
  - Data-link layer is implemented in software
- It is possible to specify the bandwidth required by/provided to the customer
- Variable transit times
  - Problematic with voice/video transmission

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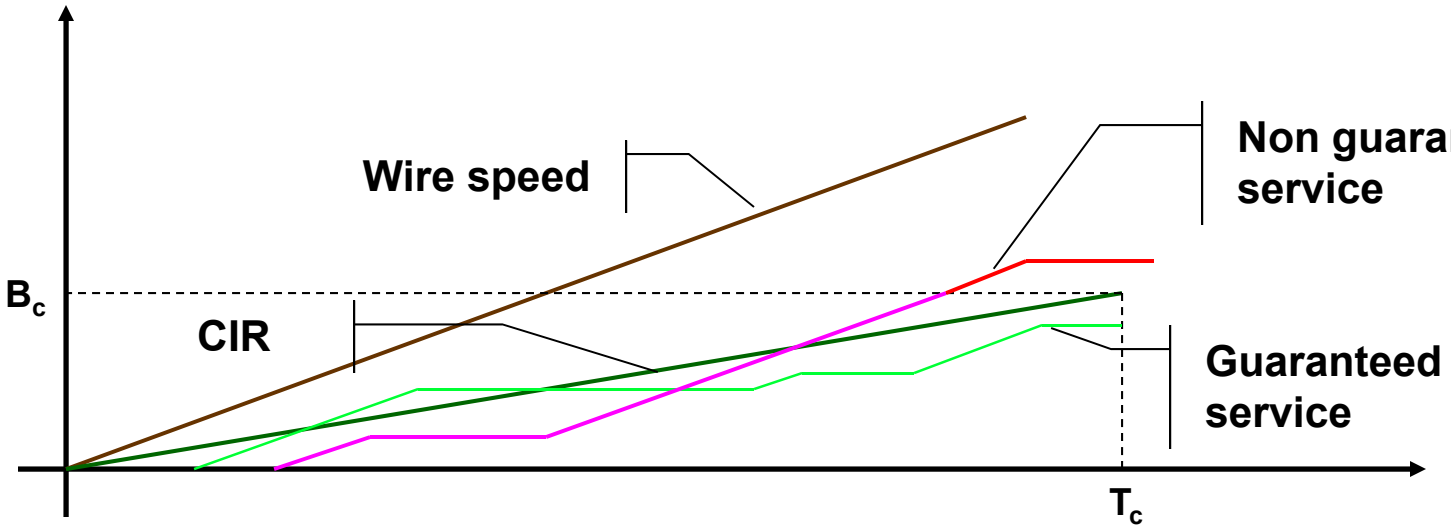
CIR: Committed Information Rate

- B_c: committed burst size
  - Maximum burstiness
- $T_c = B_c / CIR$
  - Interval of time where CIR is applied
  - It is possible to transmit up to B_c bit at wire speed of the access link in each time interval T_c



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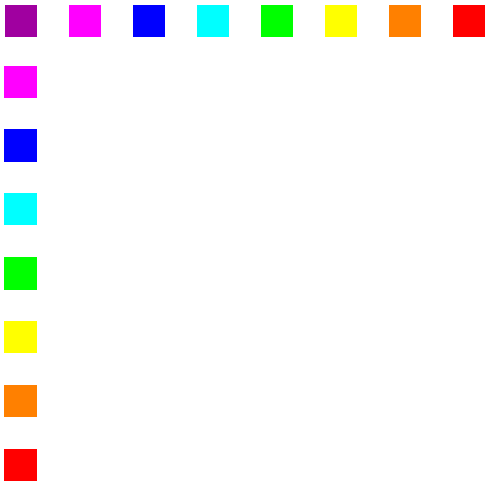

Asynchronous Transfer Mode (ATM)

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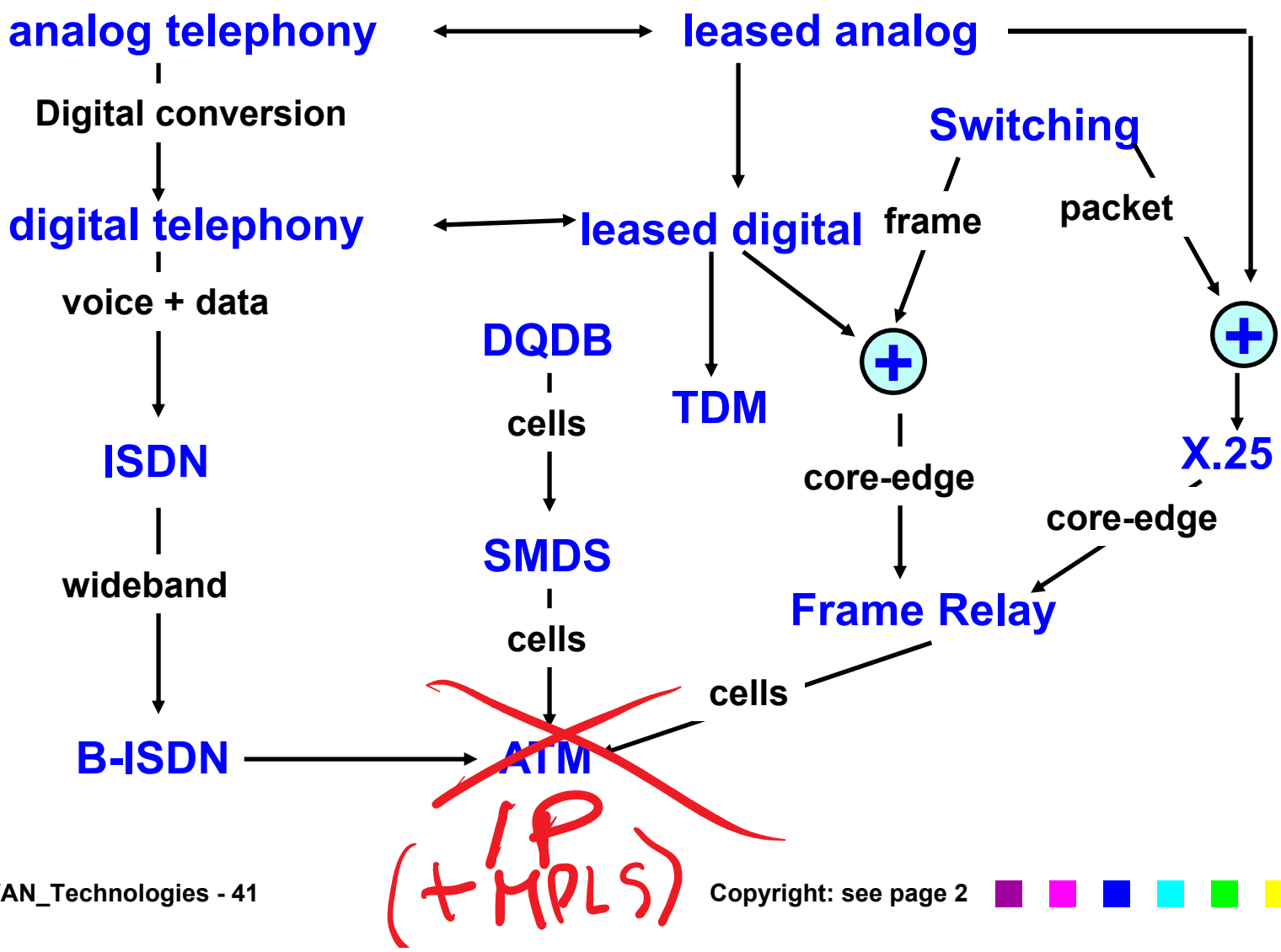
Relationships among different technologies



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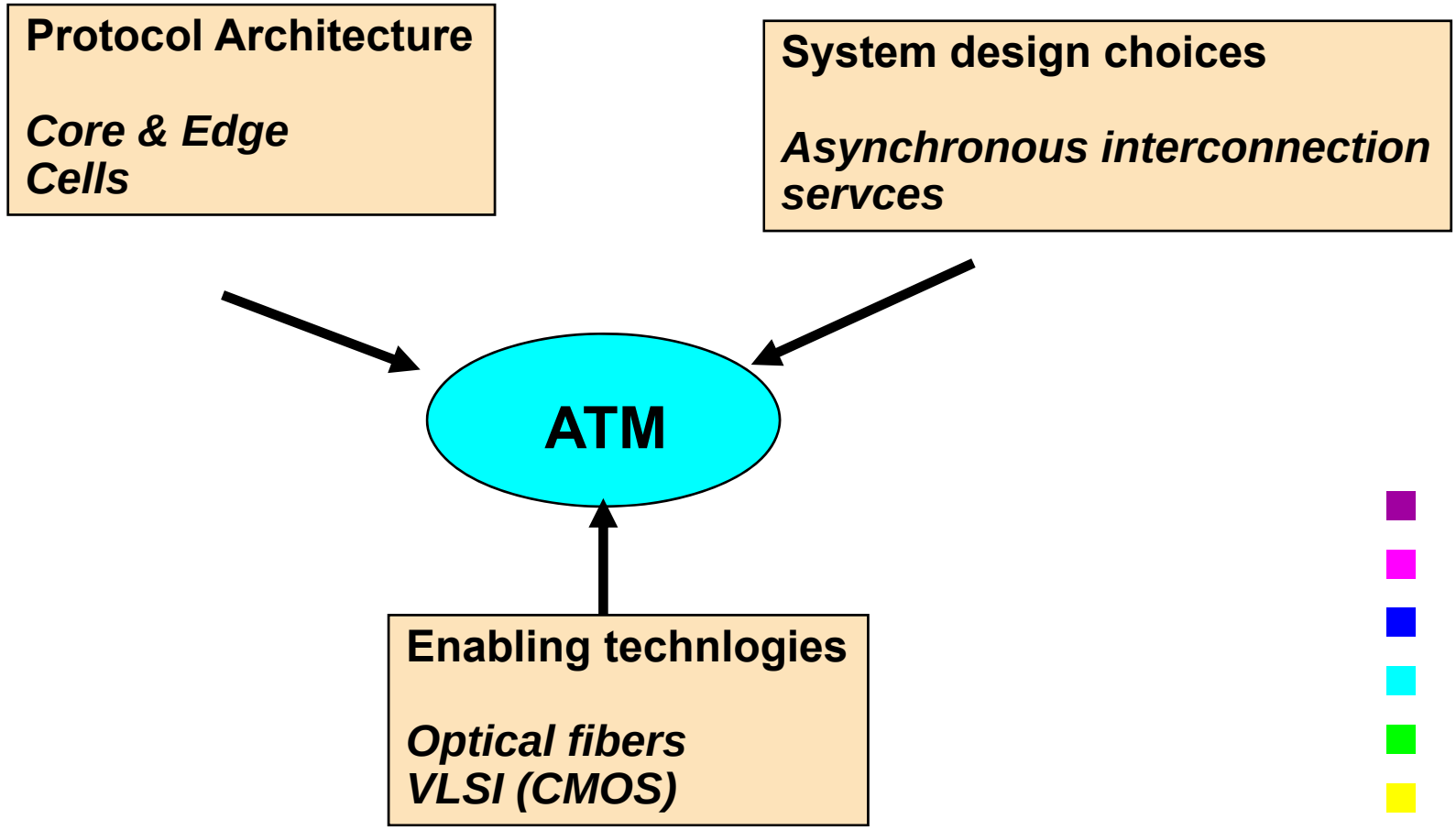
Distinguishing Factors



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General features

- Switching of small, fixed length data units: *cells*
  - 53 bytes
- Fast links (with low bit error rate)
  - ≥ 150 Mb/s
- Low latency
  - Good for data, voice and video
- For deployment in both LAN and WAN
- Selected for implementing the B-ISDN

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General features

- Sophisticated signaling:
  - Multiparty or point-to-point connections
- Sophisticated mechanisms for flow control
  - Sliding window is not efficient on *long, fat pipes*
- Dynamic bandwidth allocation
  - Bandwidth management
- Fine granularity in bandwidth allocation
- Support for “bursty” traffic
- Adaptability for applications that are sensible to time or data loss

Anything else?!?!

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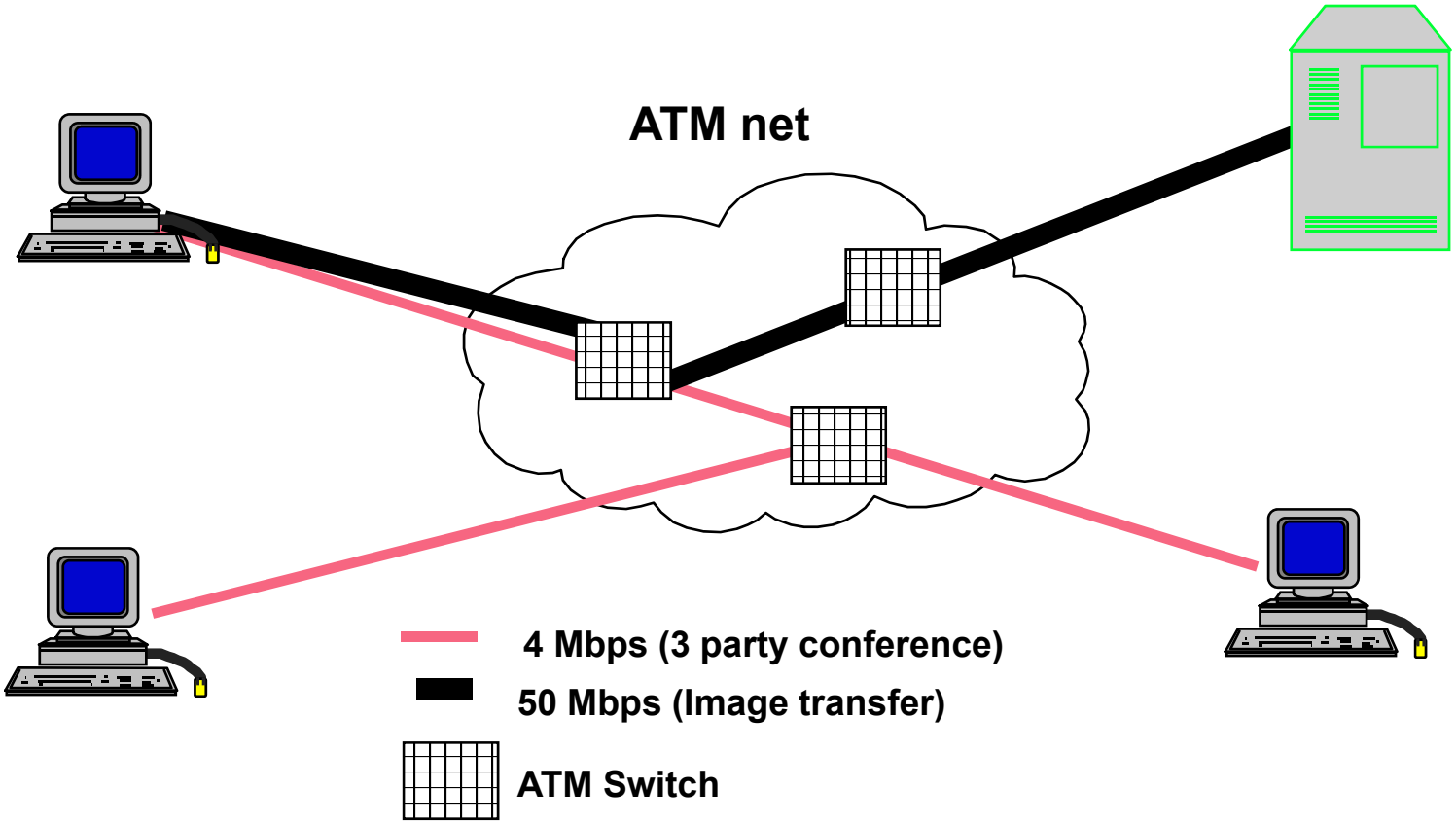
Virtual channels



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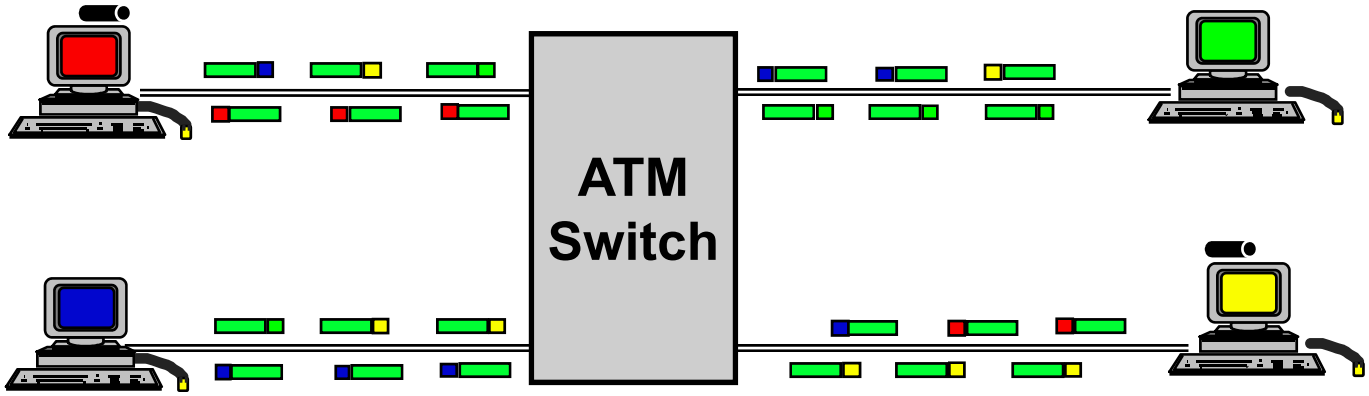
Cell switching



5	48

Cell = 53 bytes

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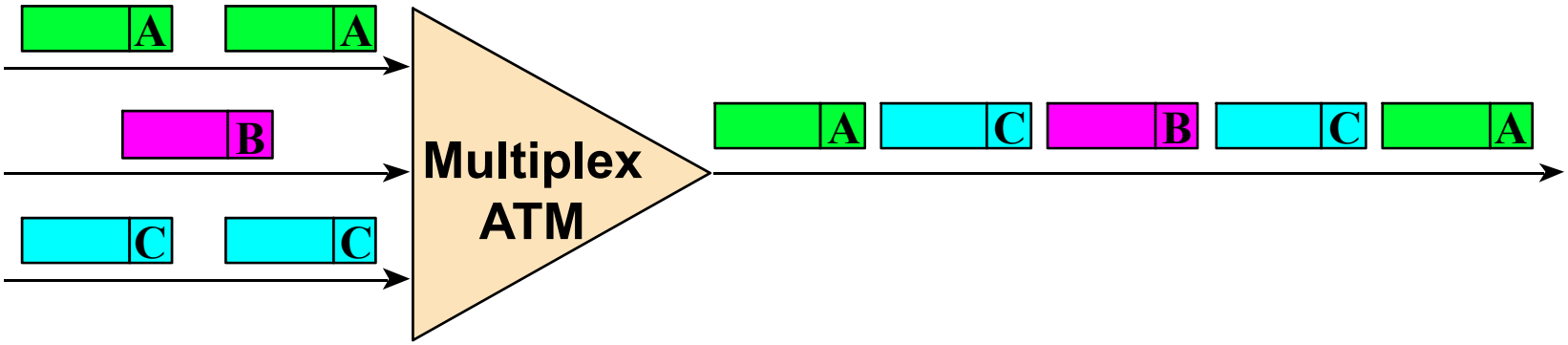
Statistical multiplexing



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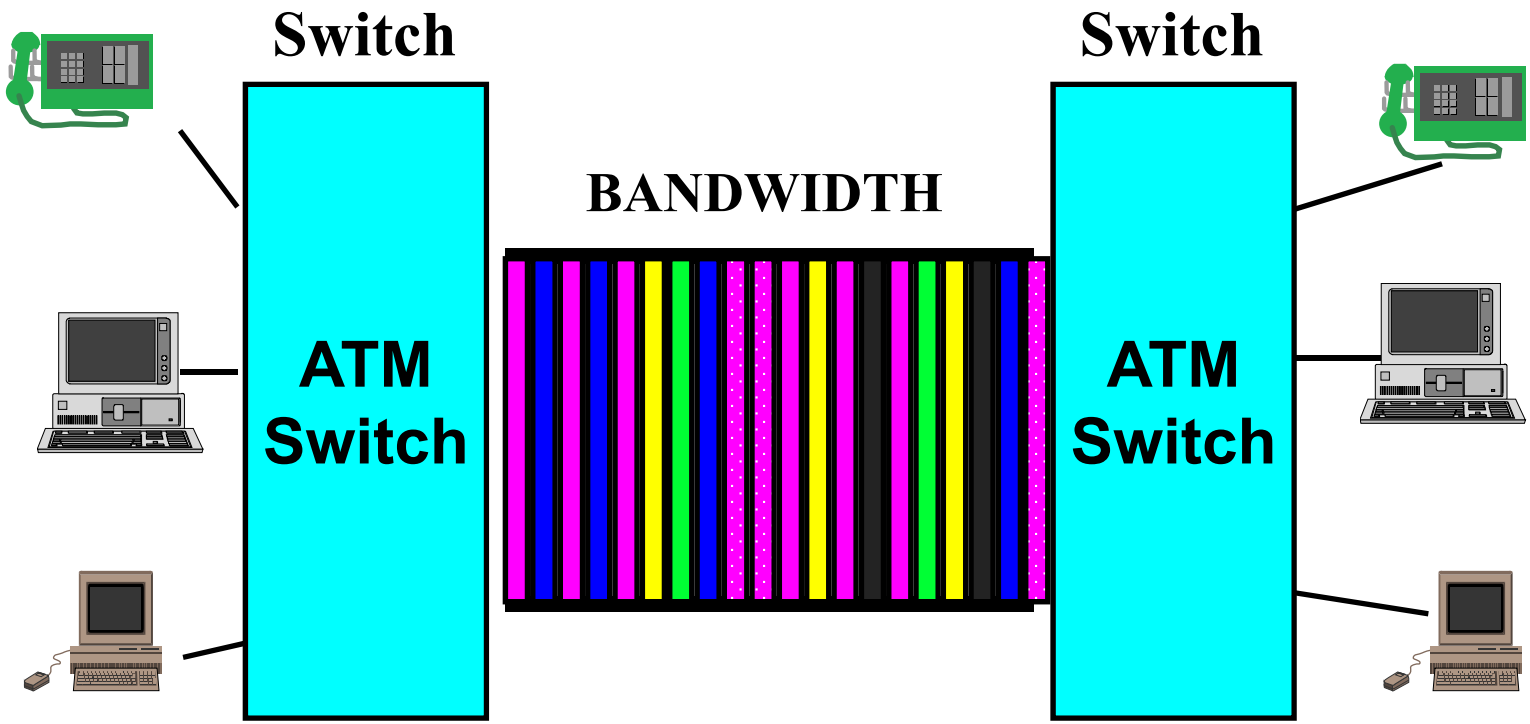
ATM technology



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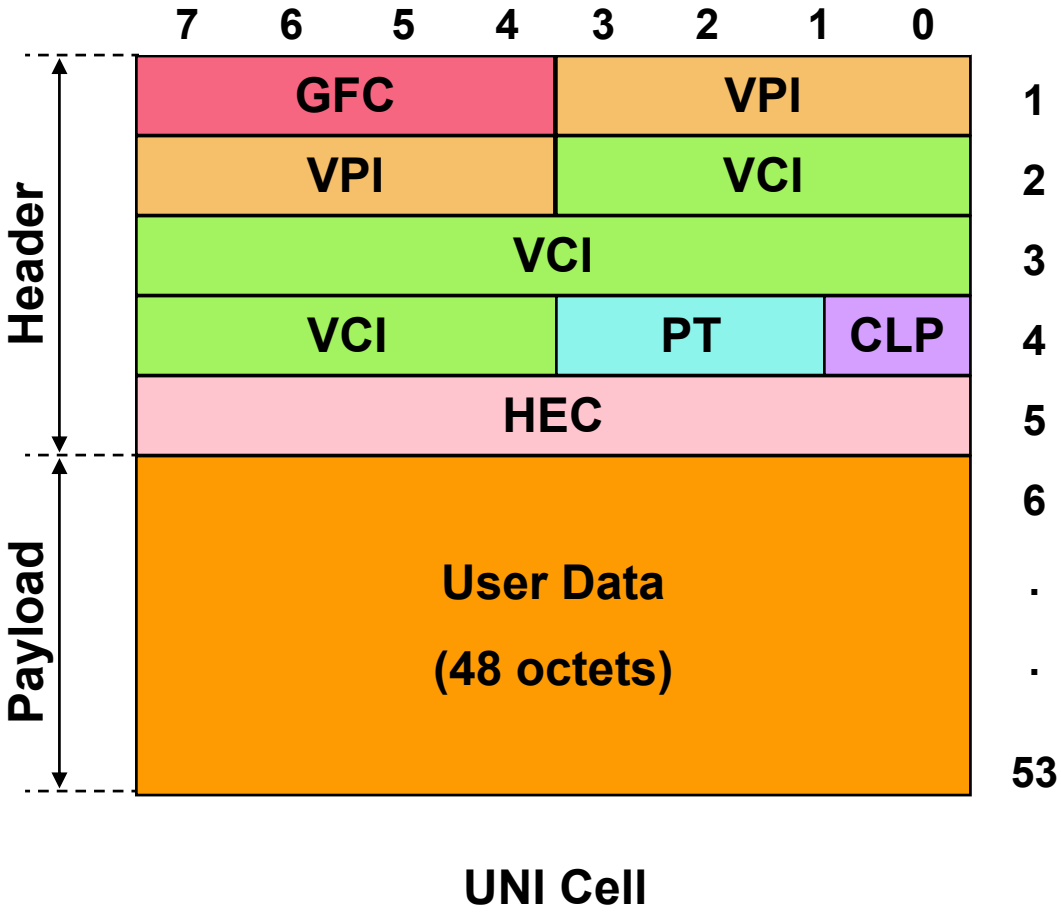
ATM Cell



UNI Cell

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Header Field Names

- GFC: General Flow Control
- VPI: Virtual Path Identifier
- VCI: Virtual Channel Identifier
- PT: Payload Type
- CLP: Congestion Loss Priority
- HEC: Header Error Control

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A couple more details

- Cells are transmitted back-to-back, poossibly inserting empty ones
- Each cell carries an indentifier of the circuit
  - VCI/VPI: Virtual Channel/Path Identifier
- Error correction:
  - *Core-edge approach as in* frame relay
- Flow control more sophisticated than sliding windows, to take into account:
  - Different types of traffic
  - The“memory” of the channel

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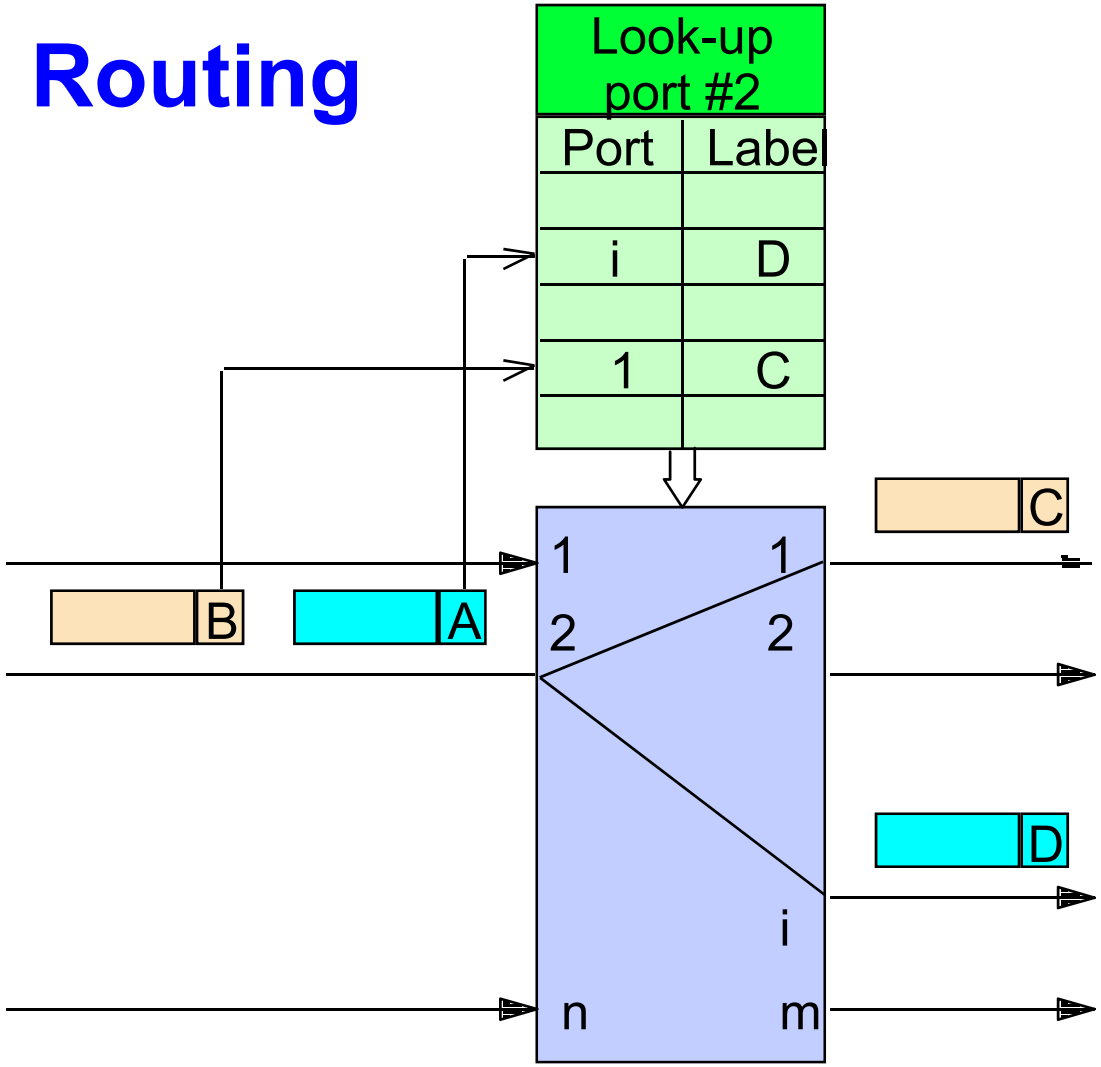
Cell Routing



VCI/VPI changes each time an ATM switch is traversed

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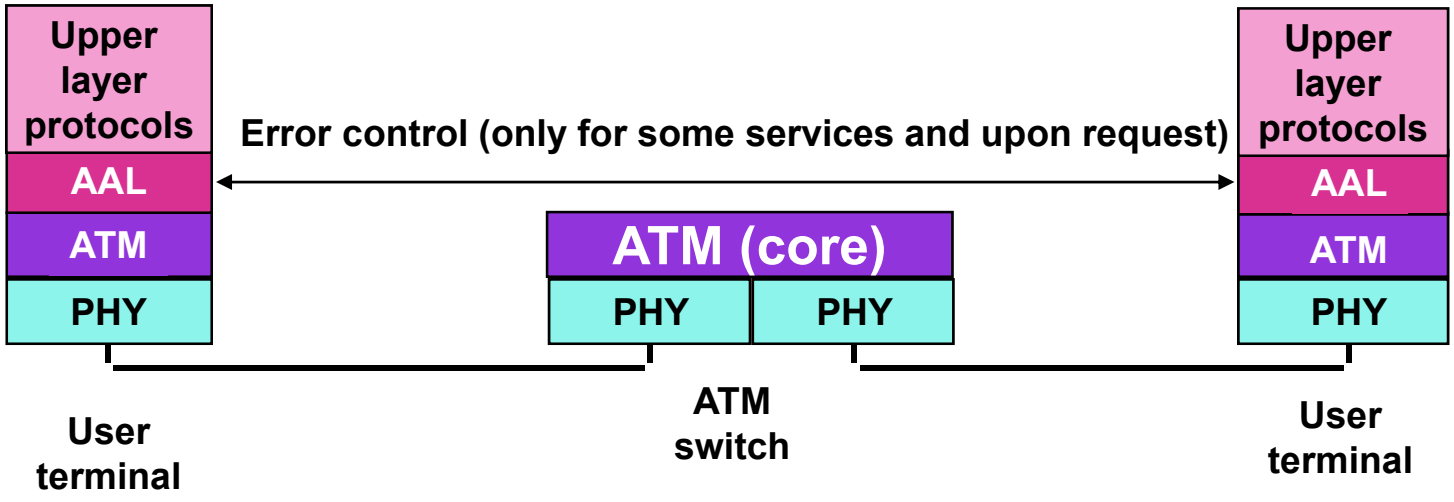
Core-Edge Principle

- Nodes execute only basic functionalities (switching and multiplexing)
  - ATM Layer (L1-L2 OSI stack)
- Additional functionalities for the different services are implemented at the edge



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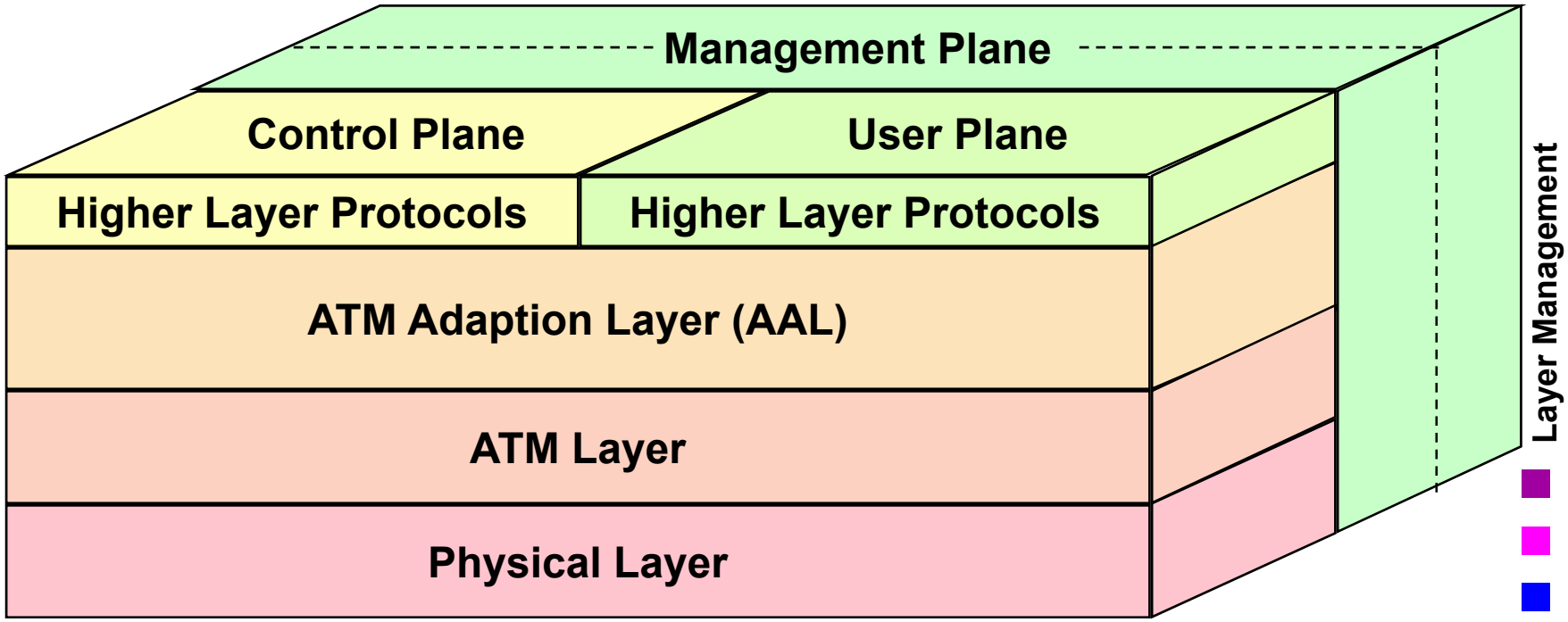
B-ISDN/ATM Reference Model



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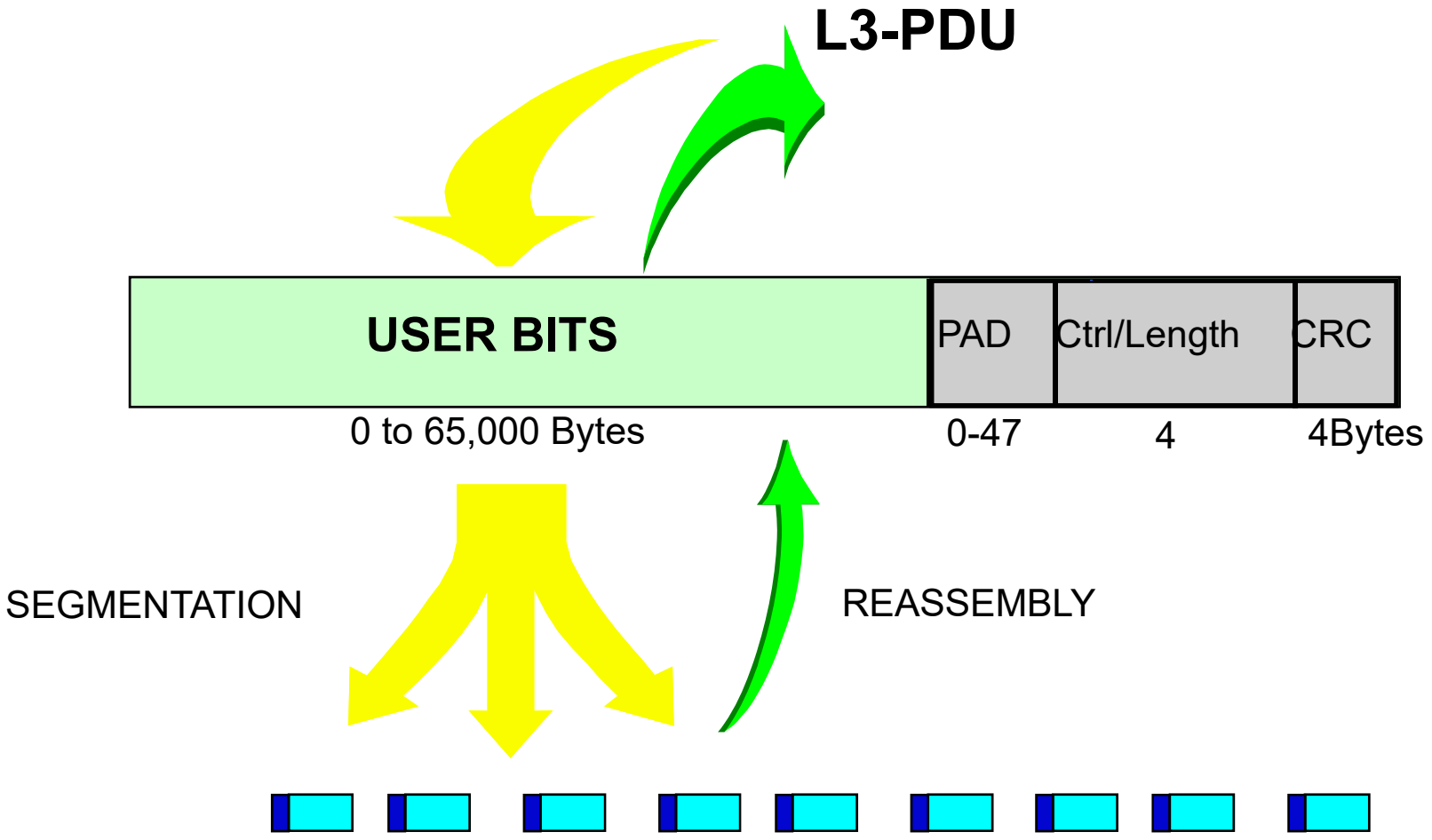
AAL 5 Segmentation and Reassembly



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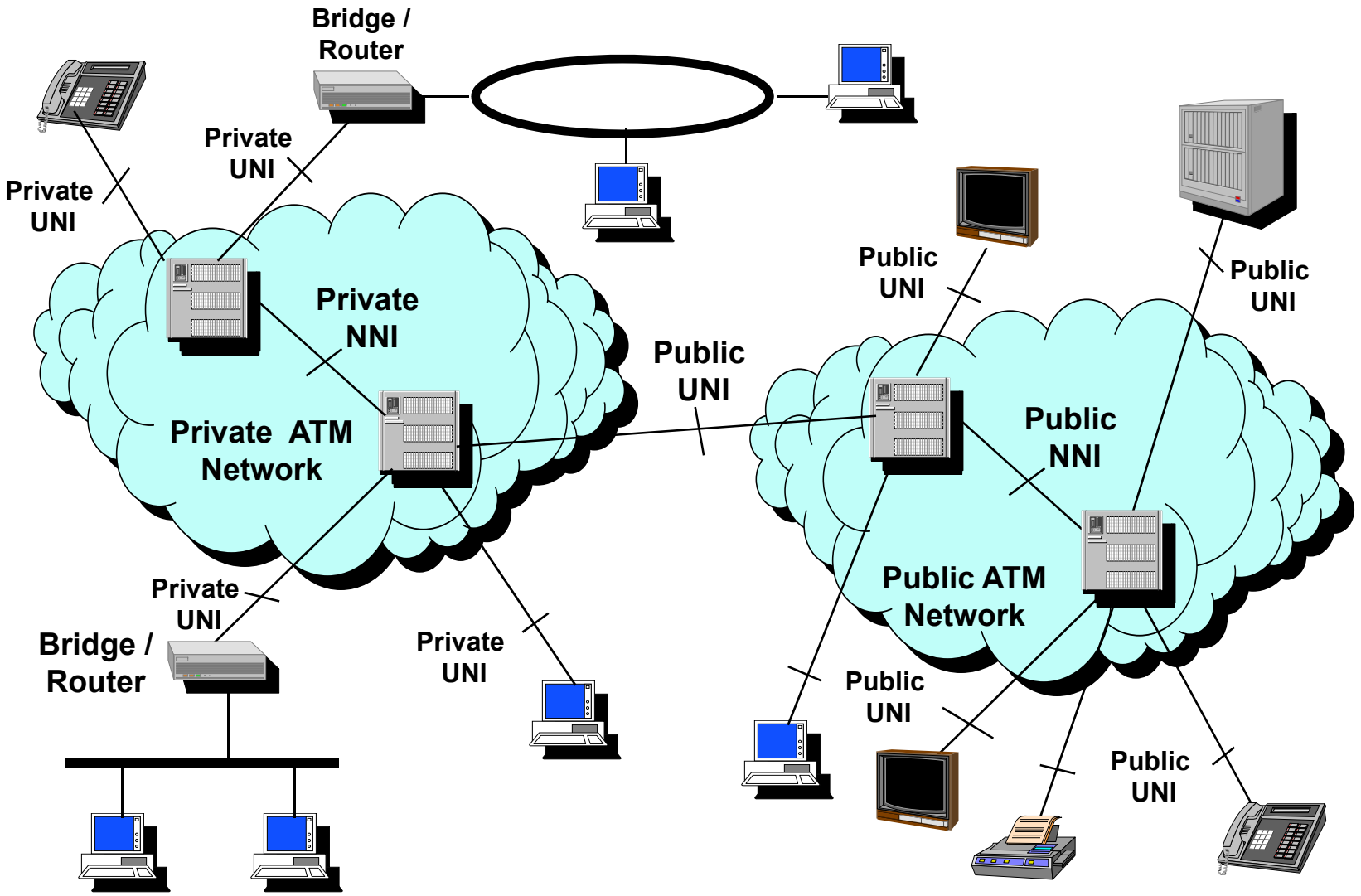
The Vision



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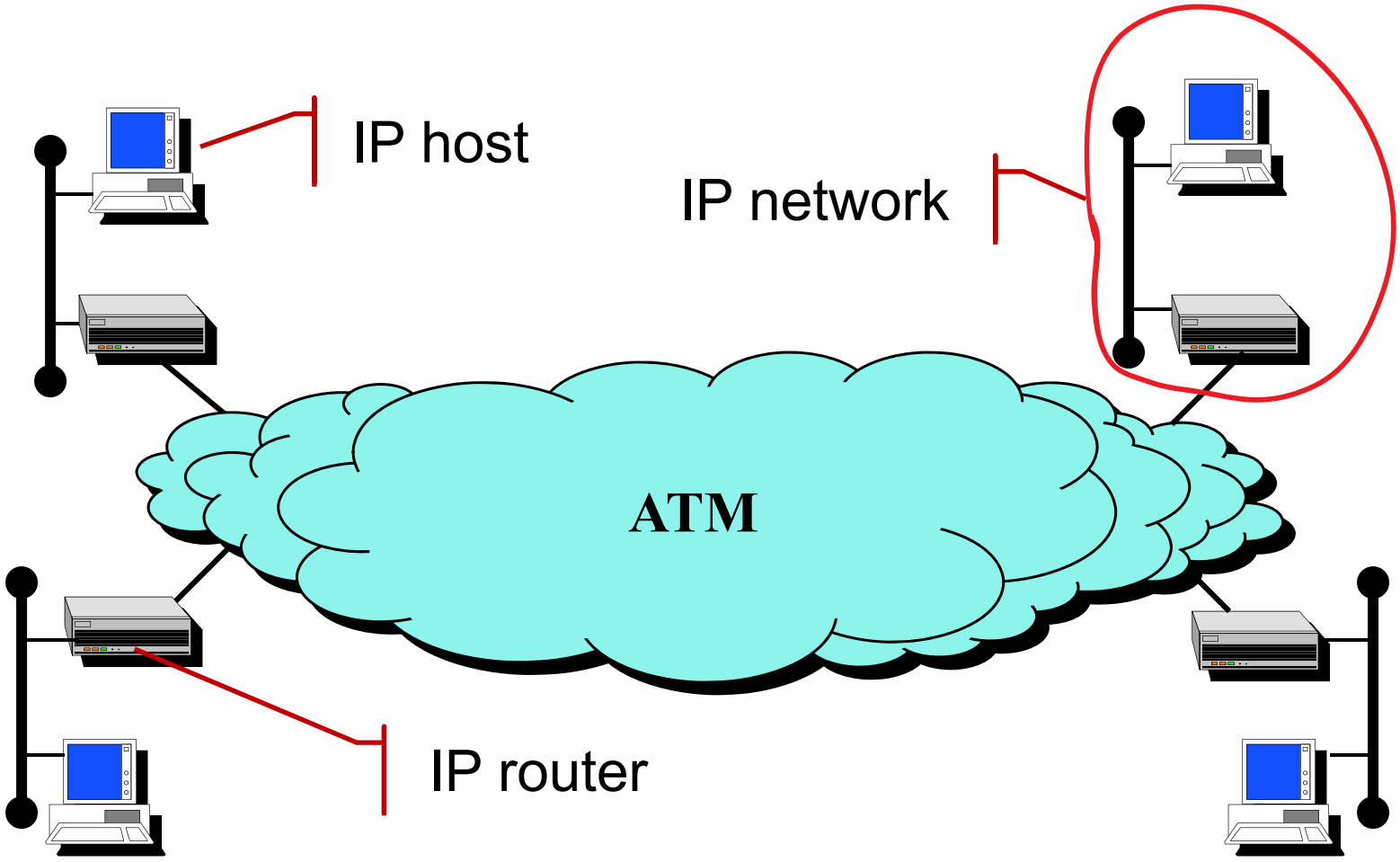
Reality



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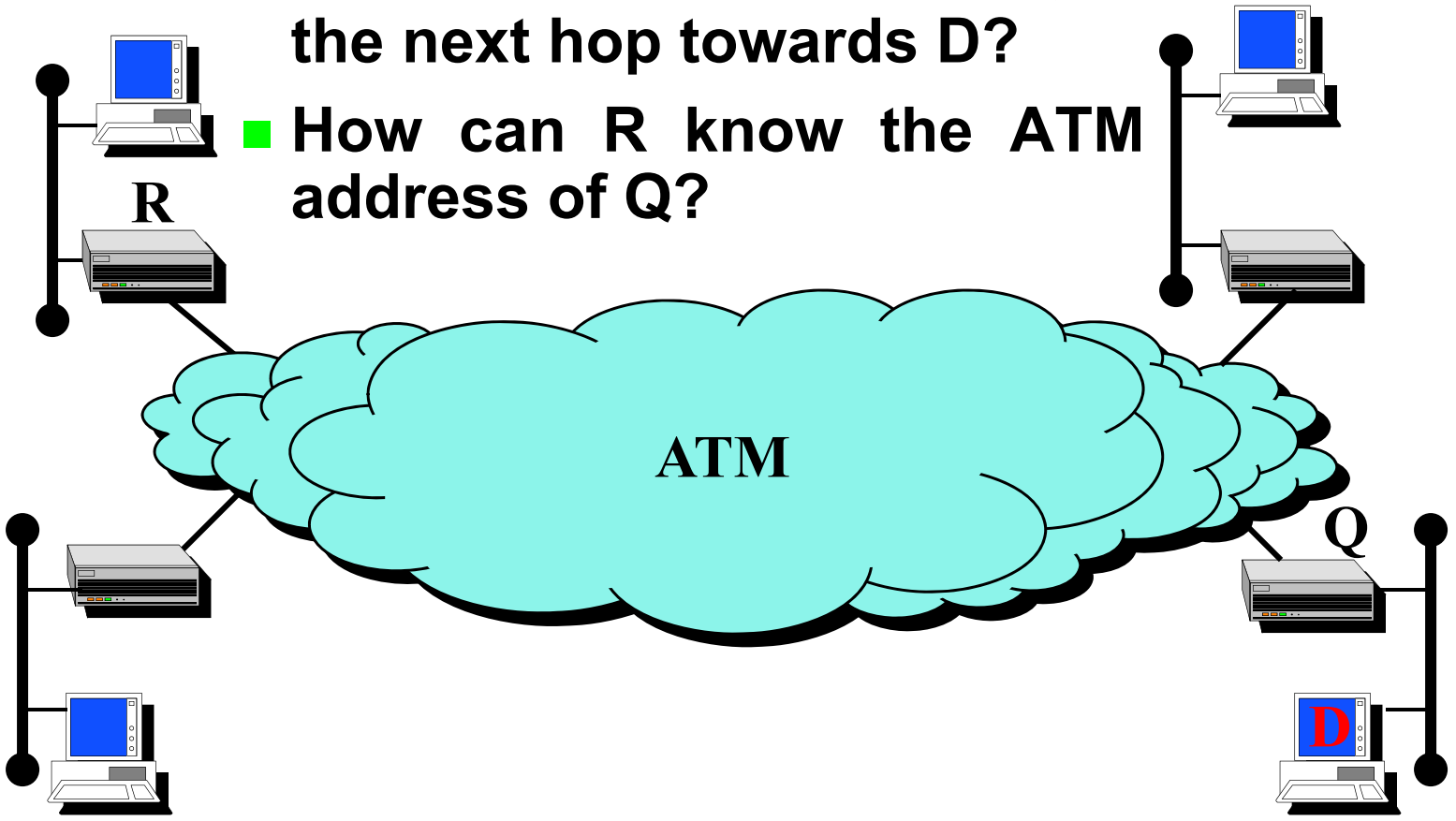
A problematic solution

- How can R know that Q is the next hop towards D?
- How can R know the ATM address of Q?



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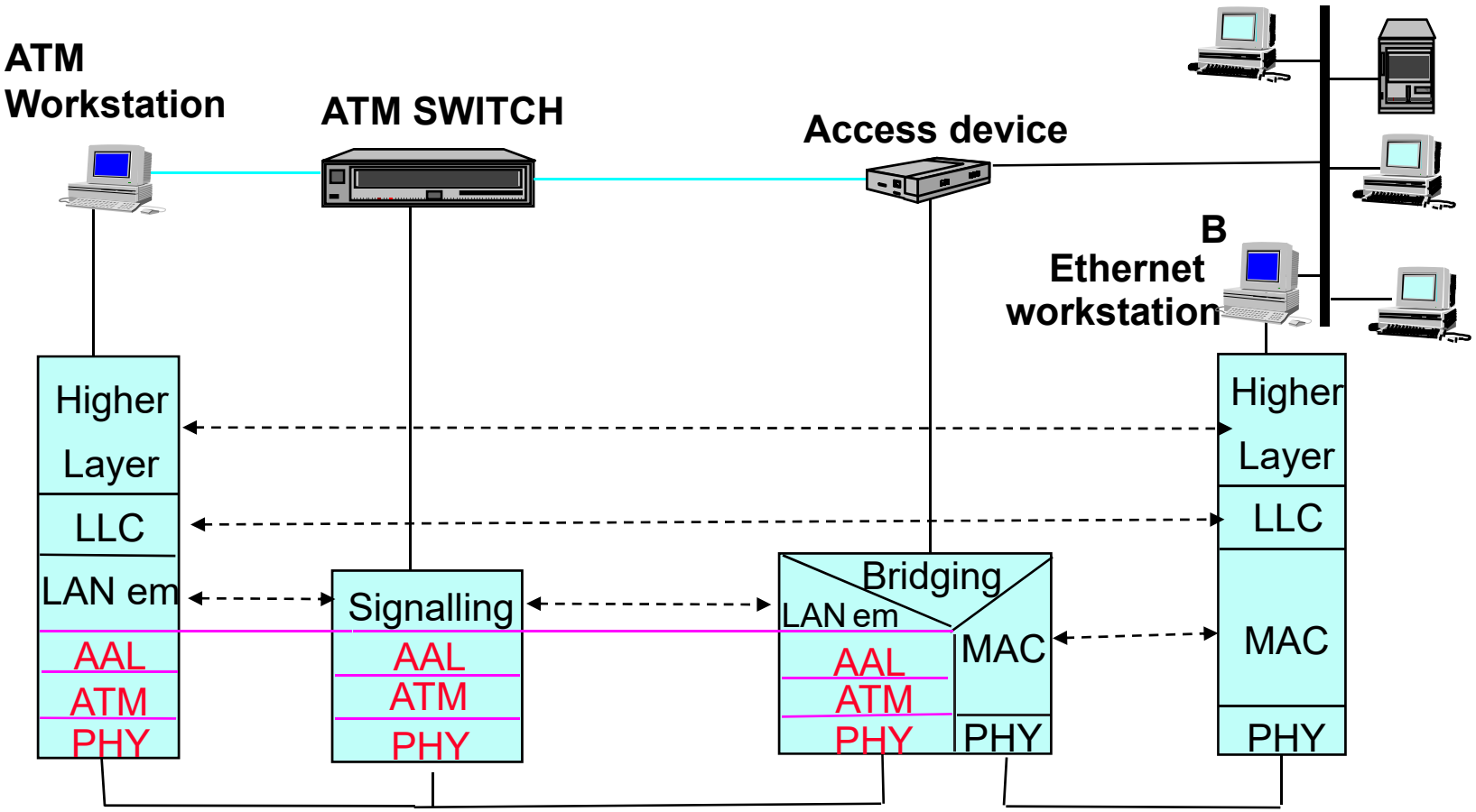
ATM LAN Emulation



Access devices operate as bridges

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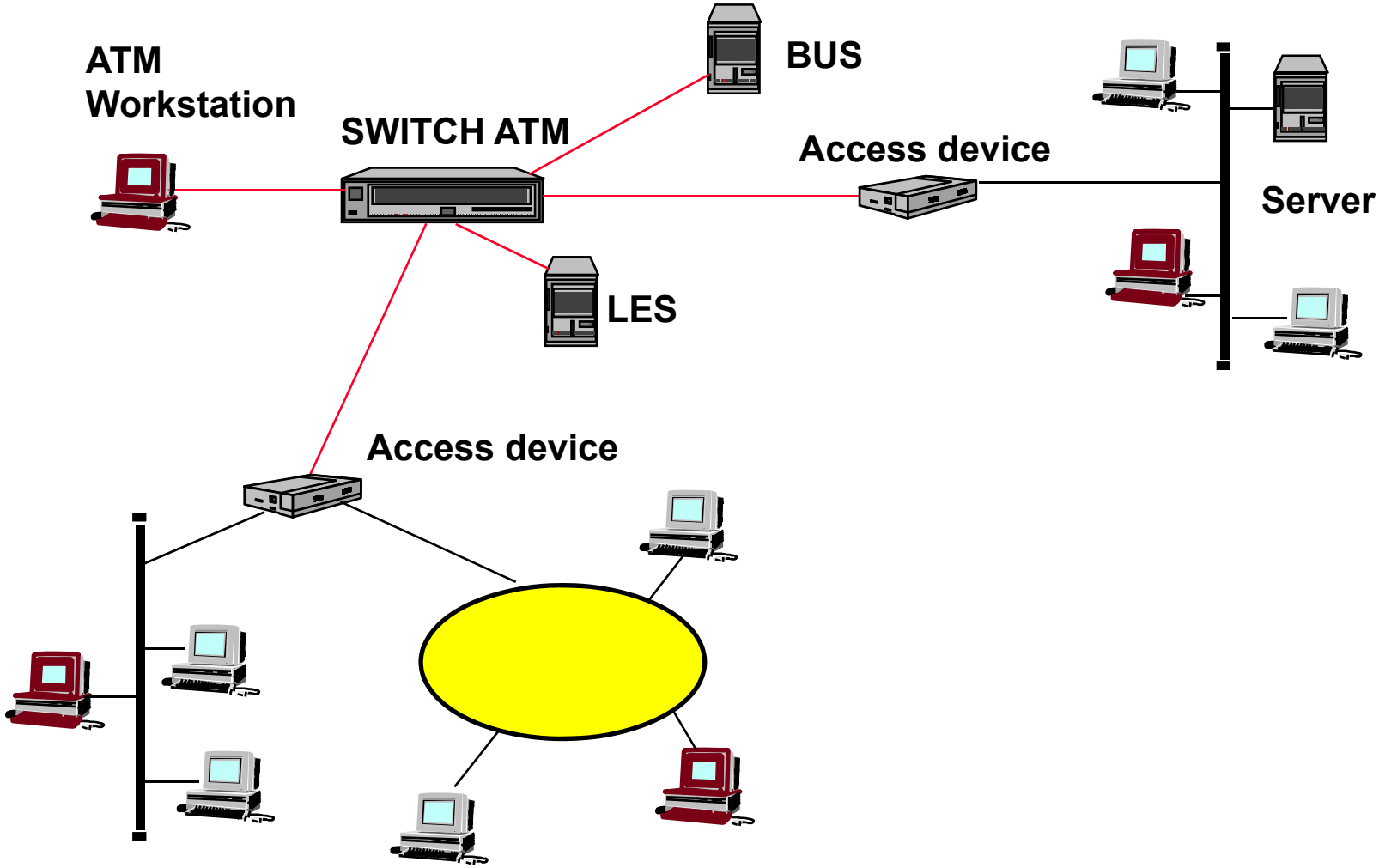
ATM LAN Emulation



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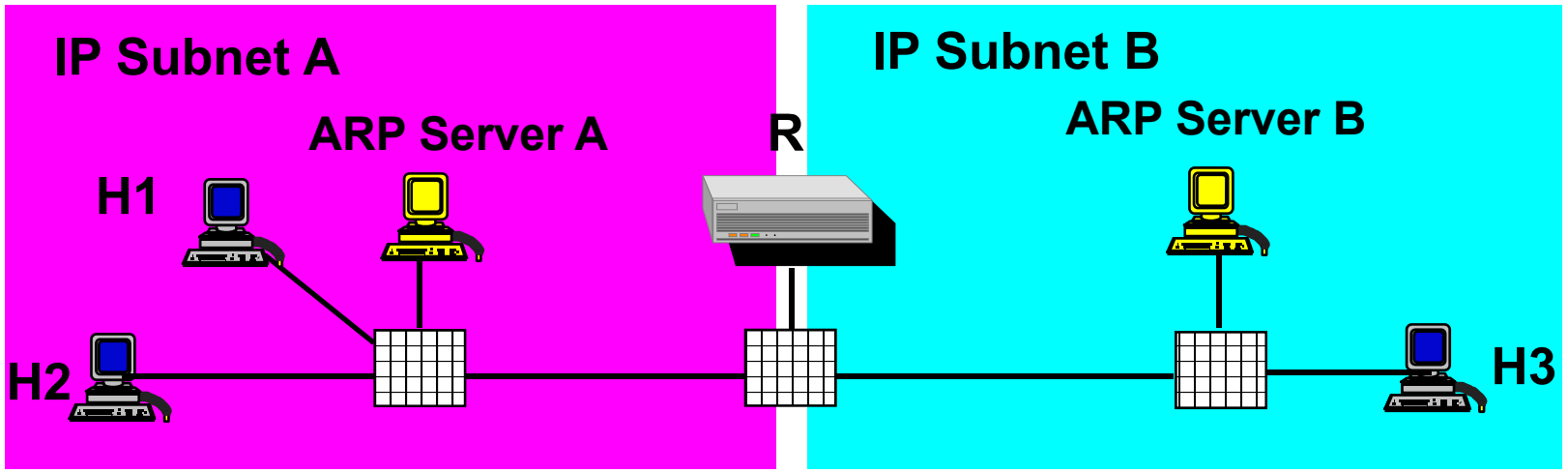
IP over ATM: Classical model

- Direct communication within a subnet
- Use router across subnets
- Emulate ARP for address resolution within the subnet
  - Find ATM address of destination or router
- It does not use ATM potential (performance)



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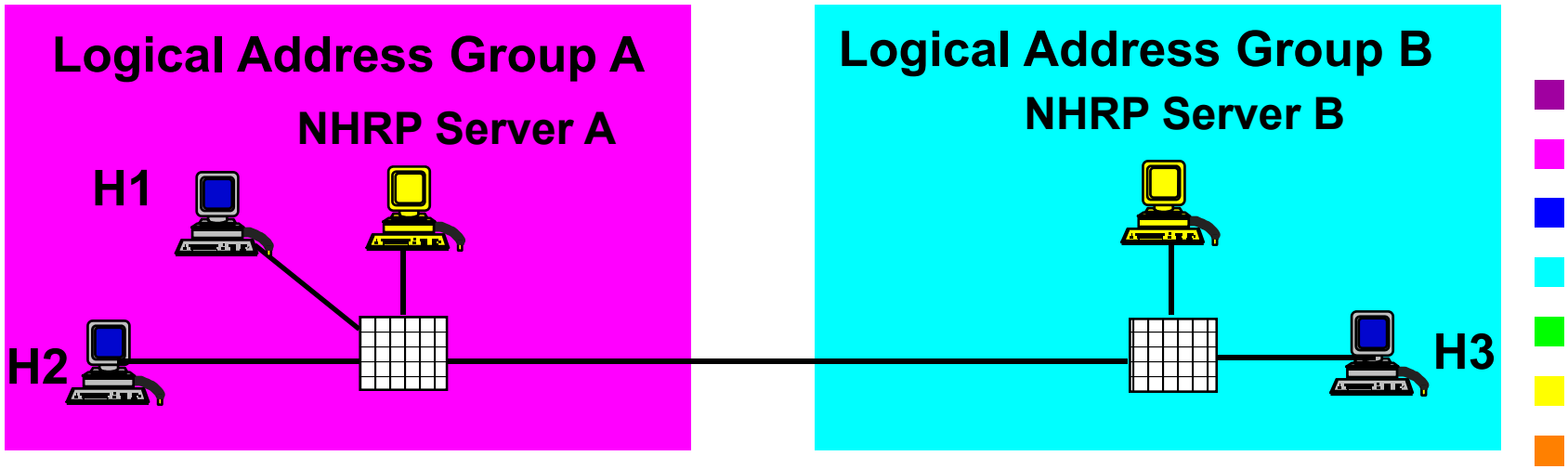
Advanced Solutions: Next Hop Resolution Protocol

- Source finds the ATM address of the best hop to a destination
  - Destination itself if it is on the ATM network
  - A router connected out of the ATM network if the destination is not on the ATM network
- Complex



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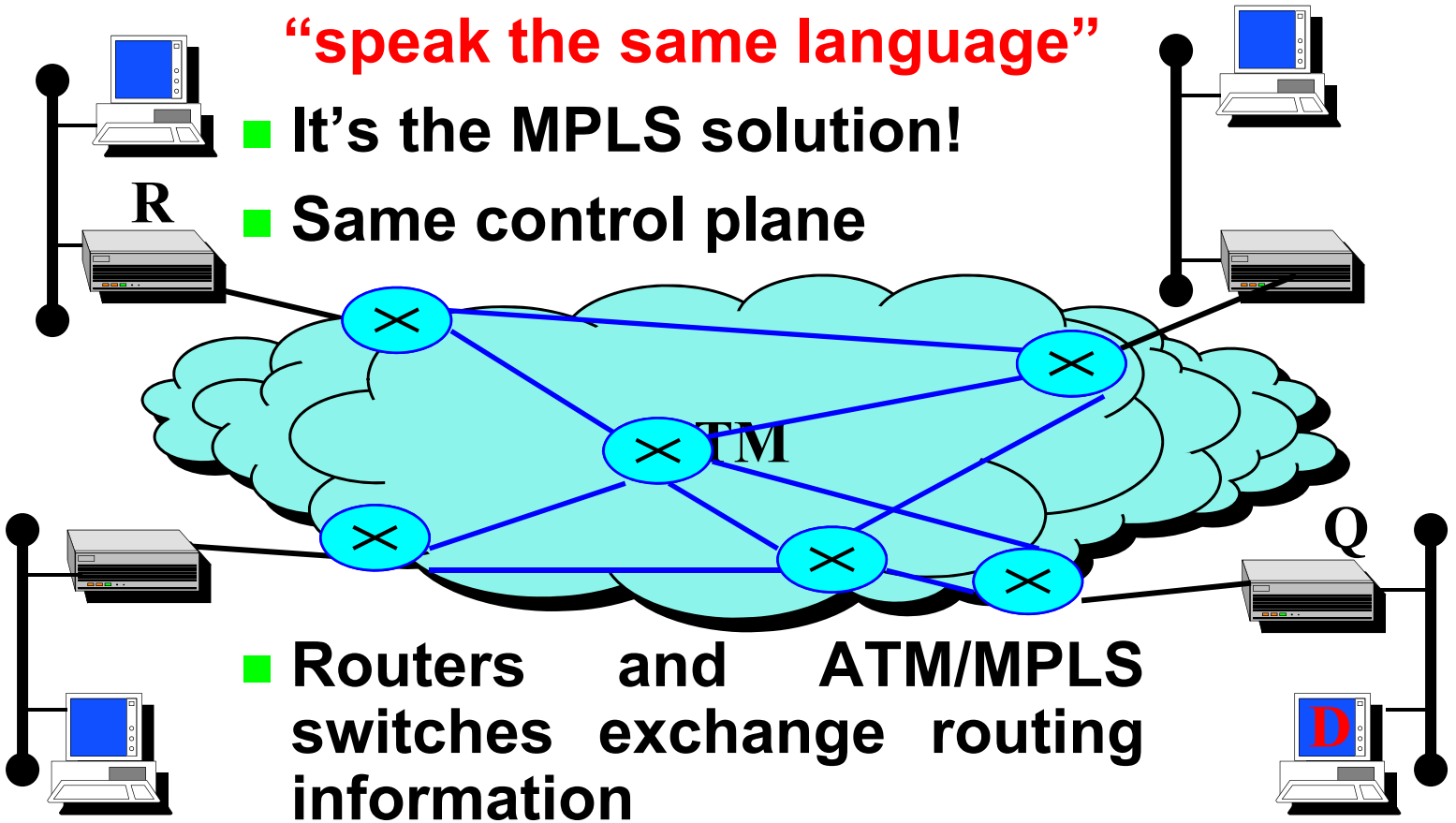
Only one good way out

Routers and ATM switches "speak the same language"

- It's the MPLS solution!
- Same control plane



- Routers and ATM/MPLS switches exchange routing information
- Destinations are identified with IP addresses

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