THE UNIVERSITY OF SYDNEY

Lecture 9

WAN Technologies

ELEC 3506/9506
Communications Networks

Dr Wibowo Hardjawana
School of Electrical and Information Engineering

THE UNIVERSITY OF SYDNEY

Topics of the Day

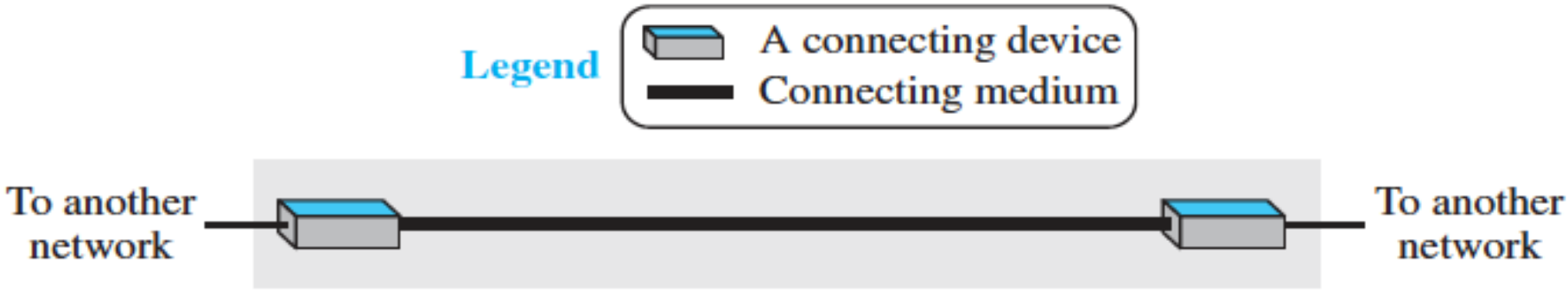
- WAN (Wide Area Network) Overview
- Dial-up Service
- xDSL (Digital Subscriber Line)
- SDH/SONET (Synchronous Optical Network)
- ATM (Asynchronous Transfer Mode)
- Cable Networks
- MPLS

THE UNIVERSITY OF SYDNEY

LAN vs WAN

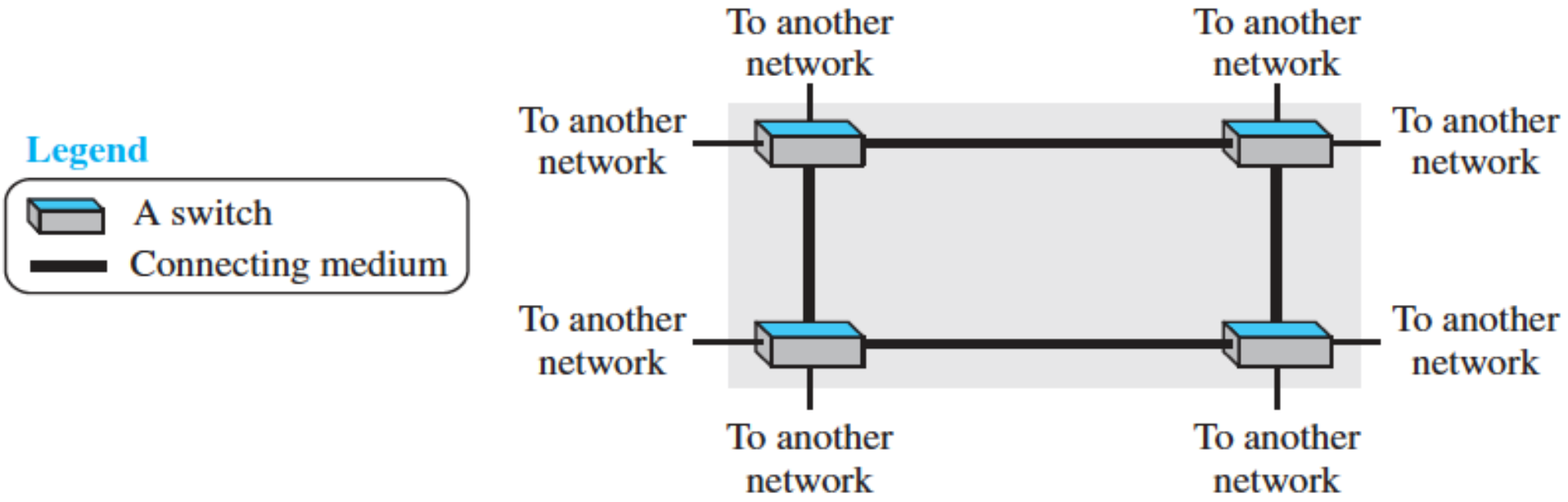
- Local area network (LAN)
  - Interconnects hosts (computer, laptop, cellular phone, workstation….)
  - Usually privately owned
  - Typically spans a single office, building, or campus
- Wide area network (WAN)
  - Interconnects connecting devices (switches, routers, modem)
  - Normally run by communication companies and leased by an organization that uses it
  - Spans across large geographic areas: a town, a state, a country, or even the world
  - LANS are usually connected to WANs
  - Two types: Point-to-Point and Switched

Point-to-Point WAN



- Point-to-point WAN: a network that connects two communication devices through a transmission media (cable or air)

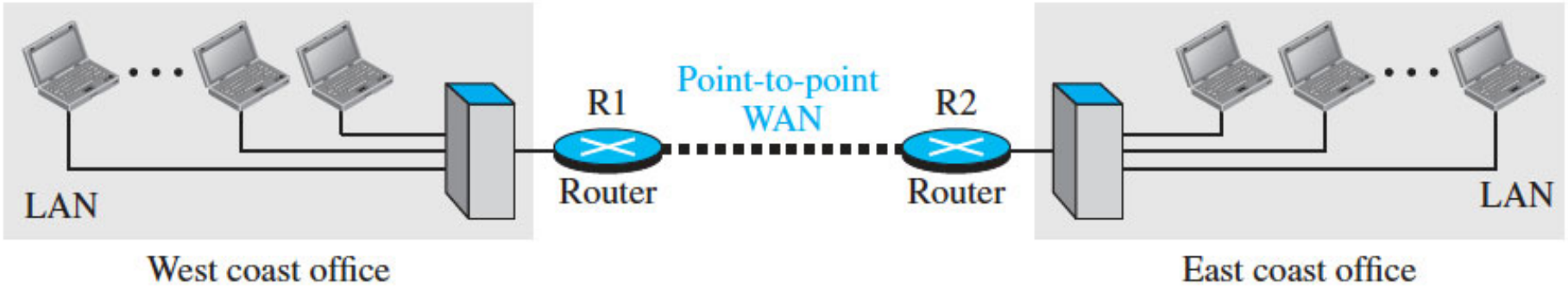
Switched WAN



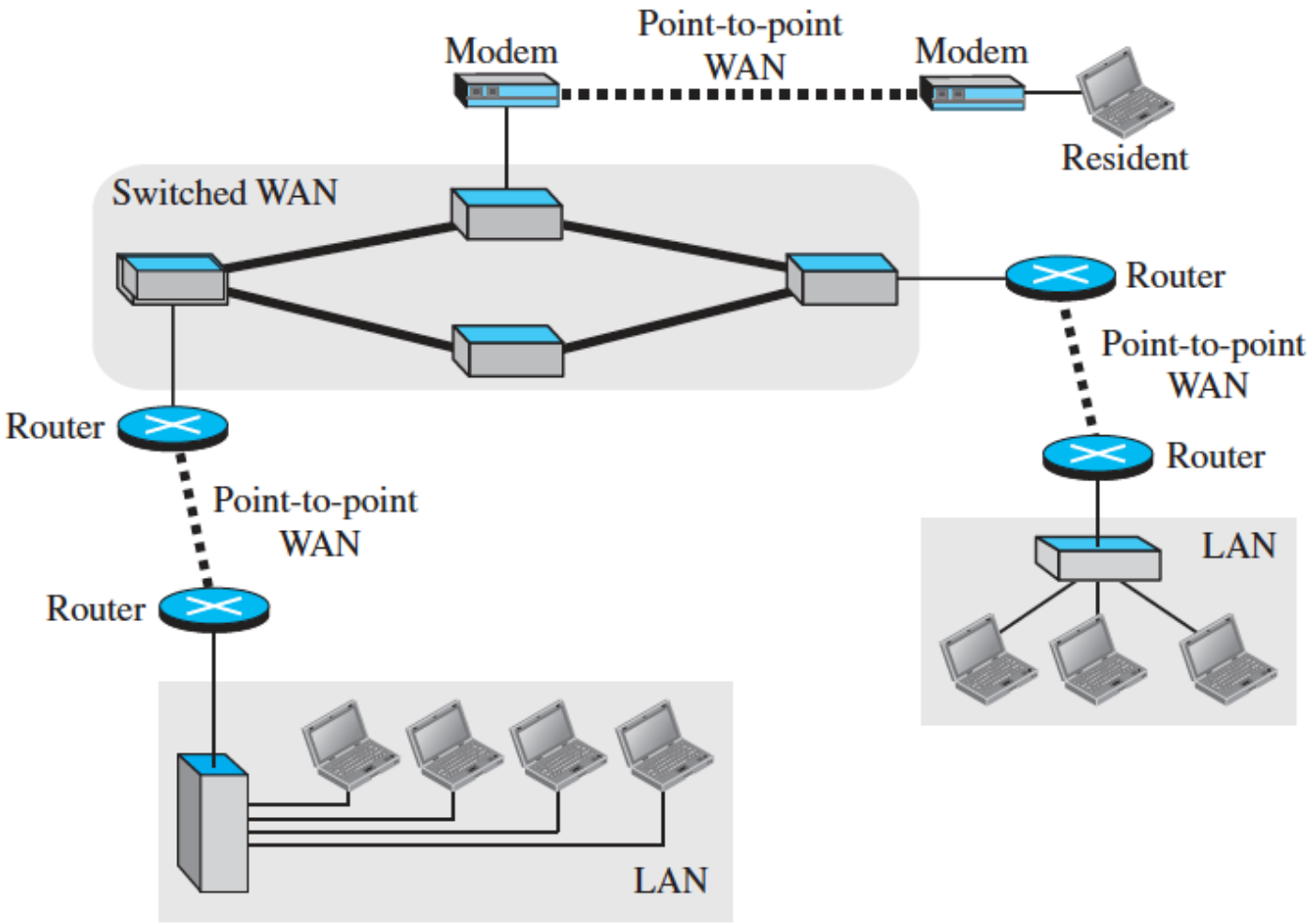
- Switched WAN: a network with more than two ends
- Used in the backbone of global communication

Internetwork

- LANs and WANs are connected to one another (internetwork)



Internetwork



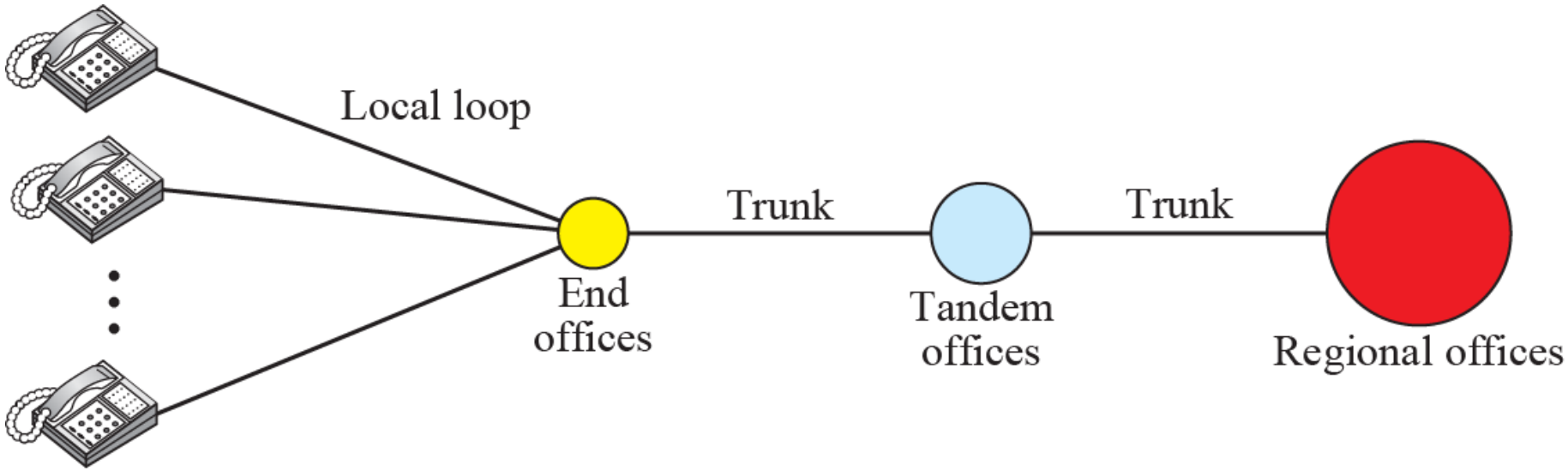
THE UNIVERSITY OF SYDNEY

Accessing the Internet

- To access the Internet, a user needs to be physically connected to an Internet Service Provider (ISP)
- The physical connection is normally done through a point-to-point WAN. Possible ways include:
- Using telephone networks
  - Dial-up service: add a modem that converts data to voice
  - DSL service: upgrade telephone lines to provide higher speed Internet service. Allows simultaneous voice and data communications
- Using cable networks
- Using wireless networks
- Direct connection to the Internet

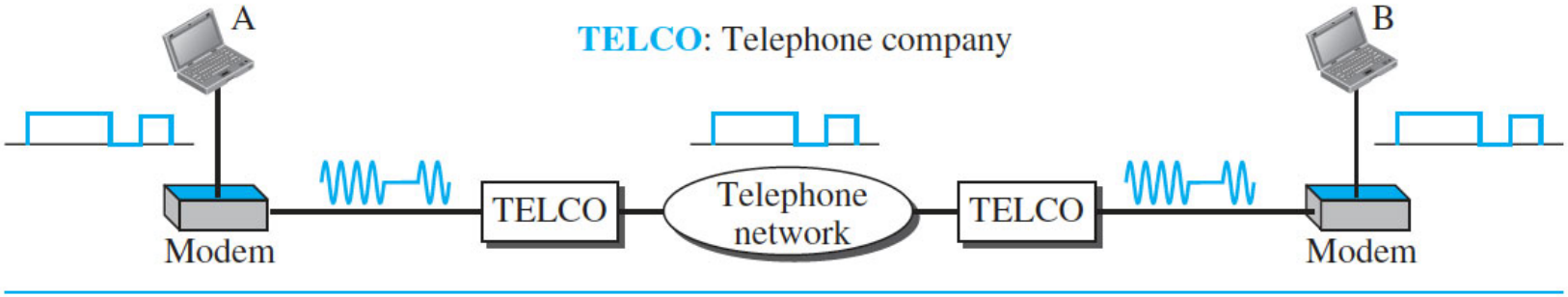
Telephone Networks

- Referred to as plain old telephone system (POTs)
- Local loops: twisted-pair cable connecting the subscriber telephone to the nearest end office
- Trunks: transmission media between offices, usually through optical fibers or satellite links
- Switching offices: connect several local loops or trunks; several levels of switching offices such as end offices, tandem offices, and regional offices



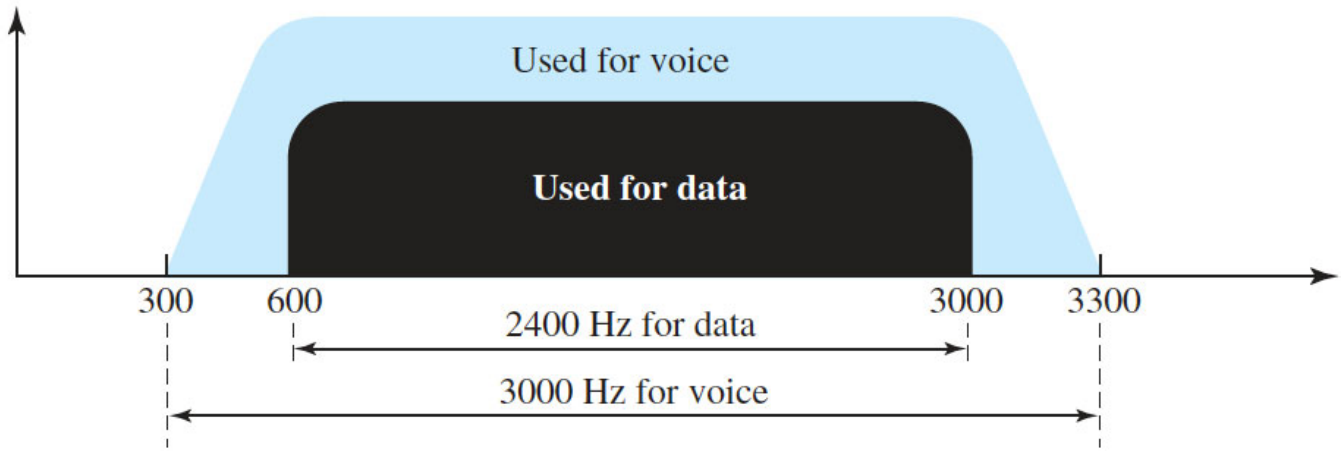
Dial-Up Service

- A form of Internet access that uses telephone network to establish a connection to an ISP by dialing a telephone number
- Uses a modem to convert data to voice
- Very slow; No simultaneous voice and data communications
- Modem: a signal modulator and demodulator
- Modulator: creates a bandpass analog signal from binary data
- Demodulator: recovers the binary data from the modulated signal



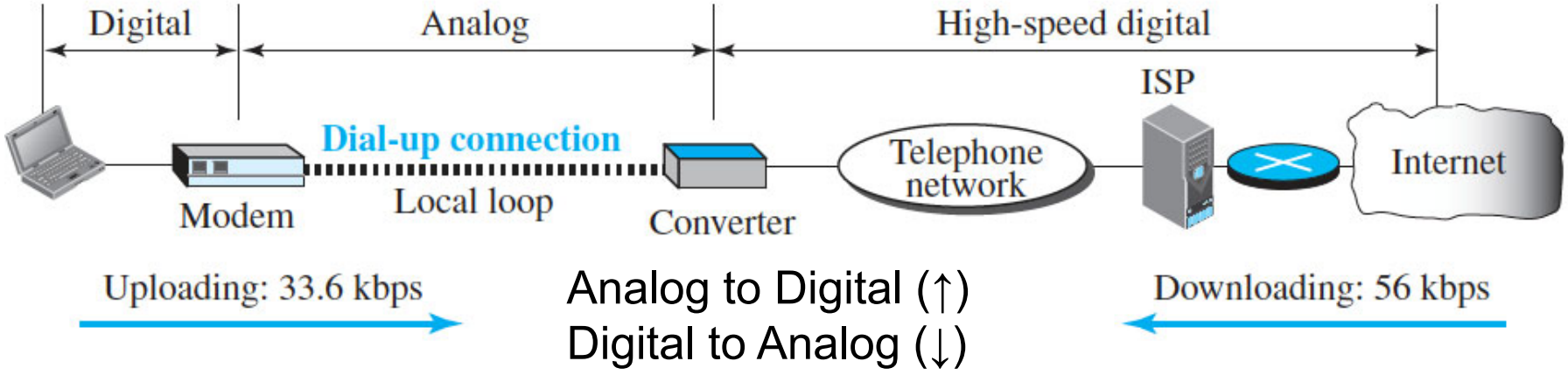
Telephone Line Bandwidth

- Traditional telephone lines use 3 kHz bandwidth for transmitting voice
- The effective bandwidth of telephone line being used for data transmission is 2.4 kHz
- Why smaller bandwidth for data transmission?



56K Dialup Modem

- Uploading (flow of data from PC to ISP): 33.6 kbps;
- Downloading (flow of data from the ISP to the PC): 56 kbps;
- Why asymmetric rate?
  - Uploading: analog signal must be sampled at the switching station or converter, which introduces quantization noise
  - Downloading: no sampling, signal is not affected by quantization noise



7 bits *8000 sample per sec=56 kbps
1 bit out of 8 bits is for control

THE UNIVERSITY OF SYDNEY

Digital Subscriber Line (DSL)

- A family of technologies for supporting high-speed digital communication over the existing telephone lines (xDSL):
  - ADSL : Asymmetric Digital Subscriber Line
  - SDSL : Symmetric Digital Subscriber Line
  - HDSL: High-bit-rate Digital Subscriber Line
  - VDSL : Very-high-bit-rate Digital Subscriber Line

- Allows simultaneous voice and data communications

THE UNIVERSITY OF SYDNEY

xDSL

- Asymmetric: downstream (ISP to user) has more bandwidth than upstream (user to ISP)
- Reflects the data requirements of home users
- Use the existing telephone lines (local loop)
- ADSL achieves much higher data rate than traditional dial up service. How?
  - Twisted-pair cable can actually handle bandwidths up to 1.1 MHz
  - But the filter at the end office of telephone company limits the bandwidth to 4 kHz (sufficient for voice)
  - By upgrading the filter, the entire 1.1 MHz is available for data and voice communications
- Multiple xDSL technologies

xDSL Bandwidth Portion

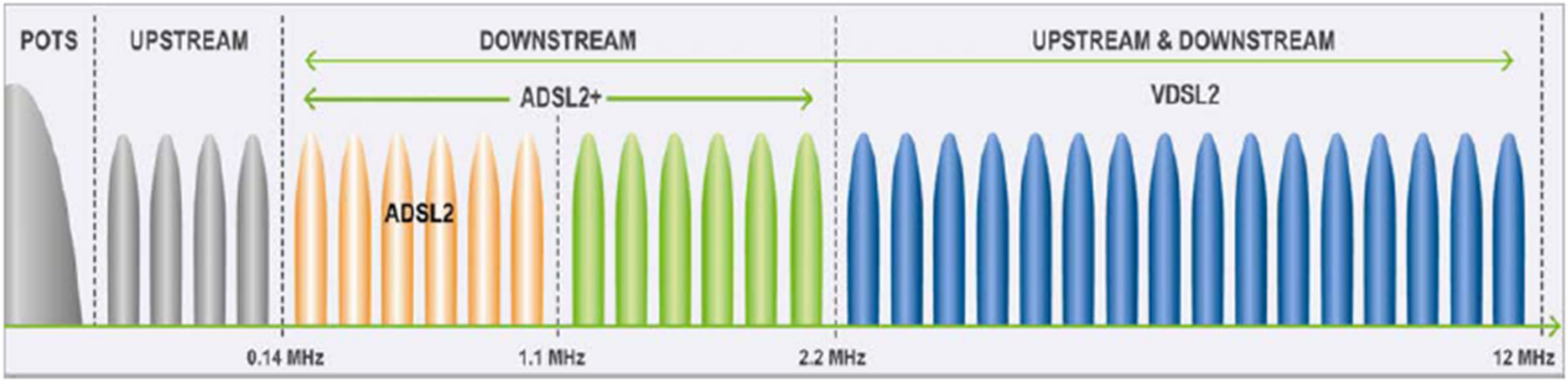


Image Source : https://en.wikipedia.org/wiki/VDSL

xDSL Bandwidth Portion

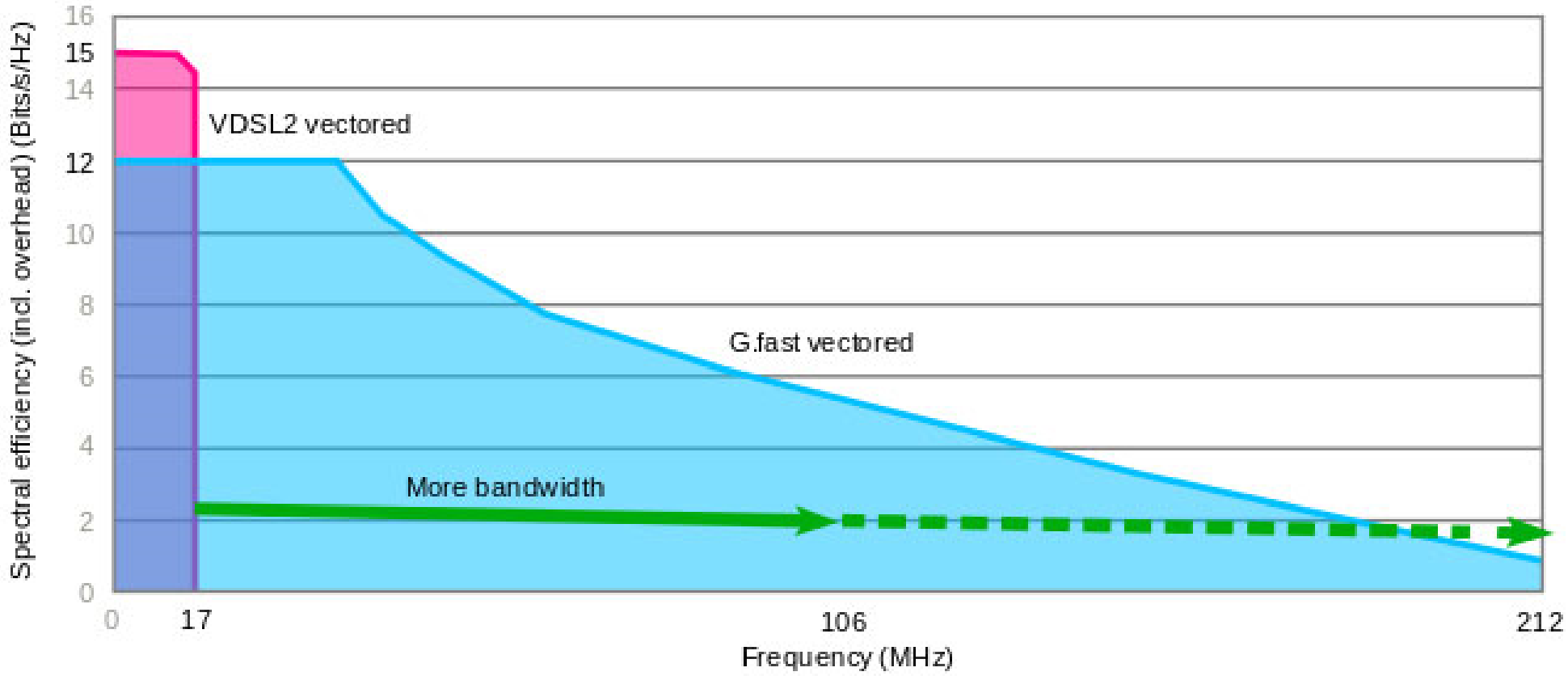


Image Source: https://arstechnica.com/information-technology/2016/10/xg-fast-dsl-does-10gbps-over-telephone-lines/

ITU-T/ETSI Standards

(European Telecommunications Standards Organization)

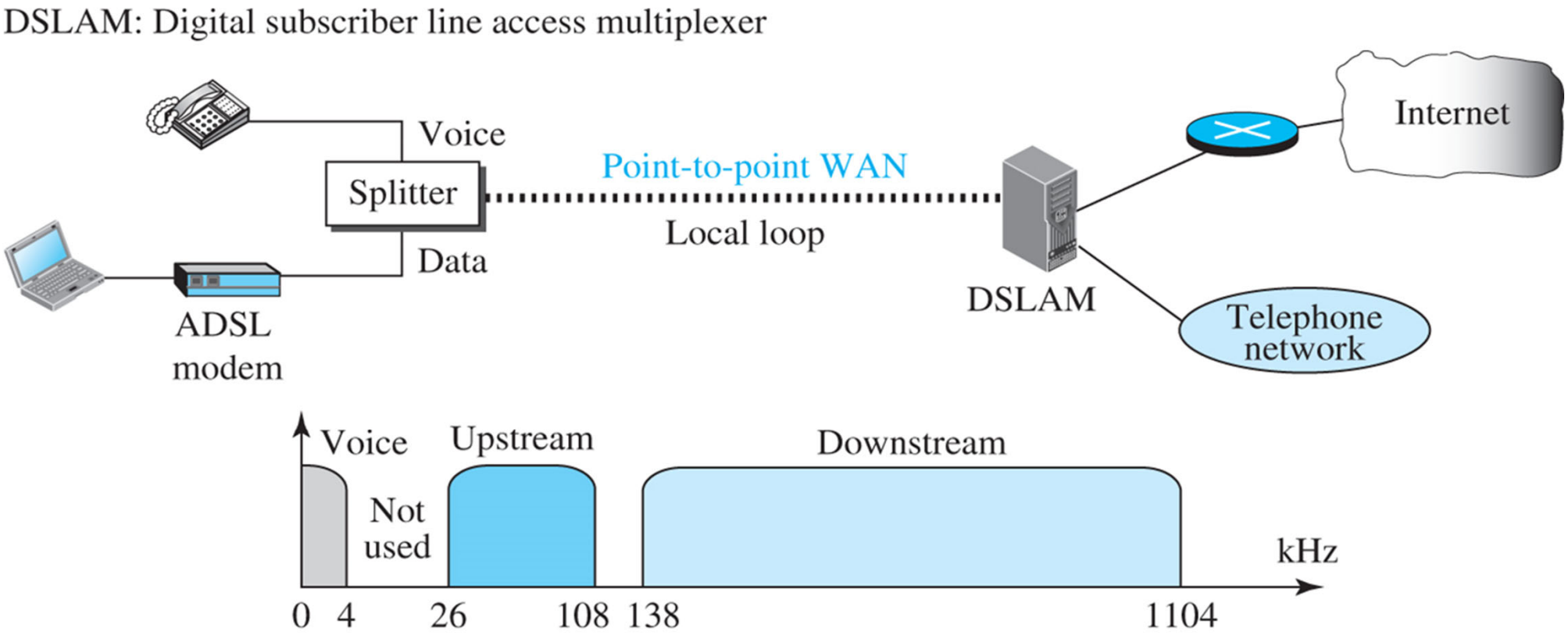
Technology	Standard	Yr. approved	Data rate	Applications
HDSL	G.991.1	1998	2048 kbit/s	1.5–2 Mbit/s symmetrical service
SHDSL	G.991.2	2001	768 kbit/s	HDSL on a single pair
ADSL	G.992.1	1999	6 Mbit/s / 640 kbit/s	Internet access, multimedia database access, and video distribution
ADSL2	G.992.3	2002	8 Mbit/s / 800 kbit/s	
ADSL2+	G.992.5	2003	16 Mbit/s / 800 kbit/s	
VDSL	G.993.1	2004	52 Mbit/s / 2.3 Mbit/s	Internet access, HDTV service
VDSL2	G.993.2	2006	100 Mbit/s	Internet access, HDTV service over longer loops with more users than VDSL
VDSL2 vectoring	G.993.5	2010	200 Mbit/s	
G.fast	G.9701	2014	1000 Mbit/s	Internet access, 4K TV service

HDTV: high-definition television
SHDSL: single-pair high-speed DSL

Yoshihiro Kondo, "G.fast Ultrafast Access Technology Standardization in ITU-T", *NTT Technical Review*

xDSL Architecture

- Voice and data signals are separated by Filter/Splitter



Bandwidth portions are different for different ADSL technologies

THE UNIVERSITY OF SYDNEY

xDSL Limiting Factors

- Limiting Factors
  - Line distance: signal strength degrades with distance
  - Wire gauge: increasing wire size, less signal attenuation
  - Bridging tap: undesired interference to DSL due to echoed signal

xDSL: Data Rate vs. Distance

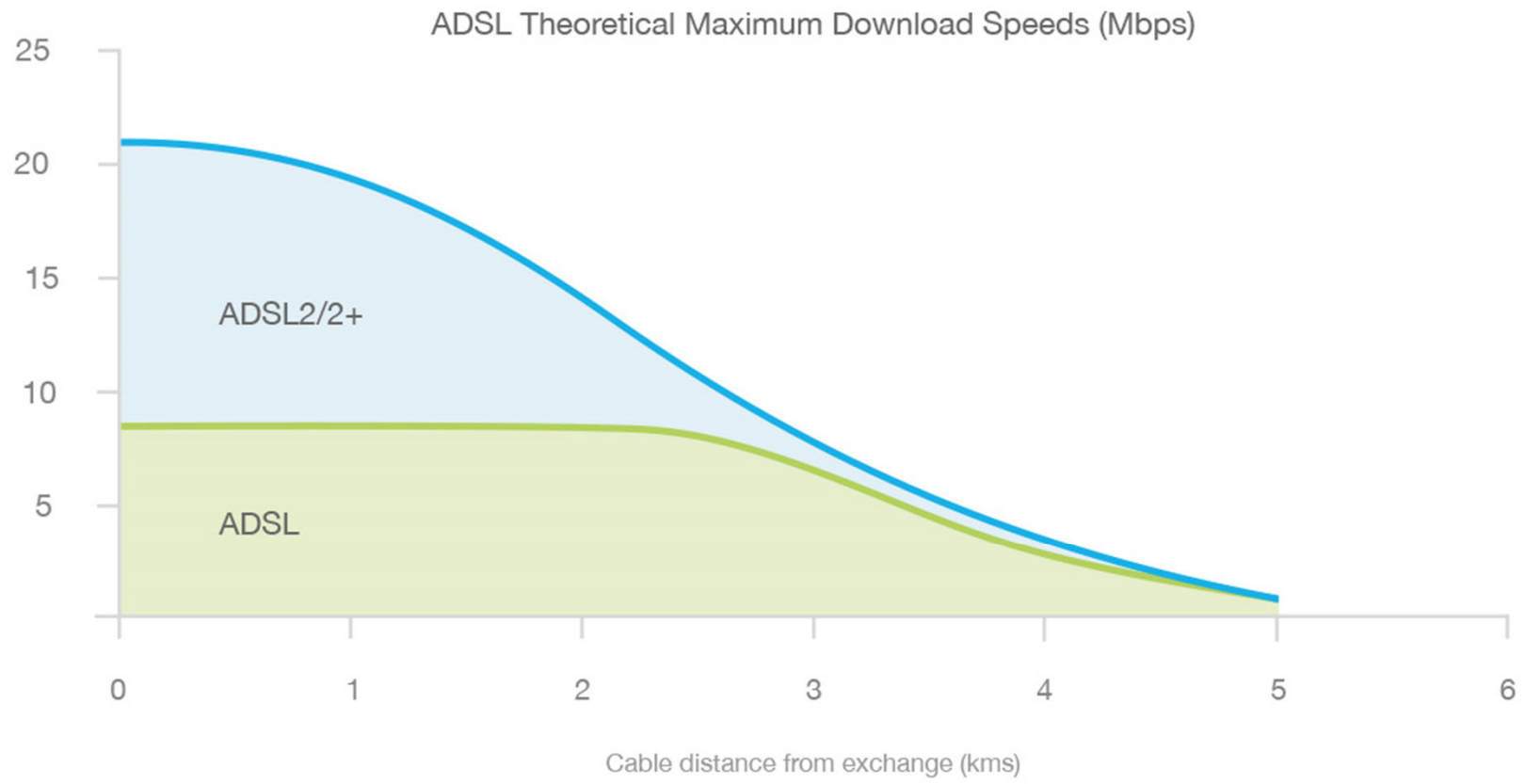


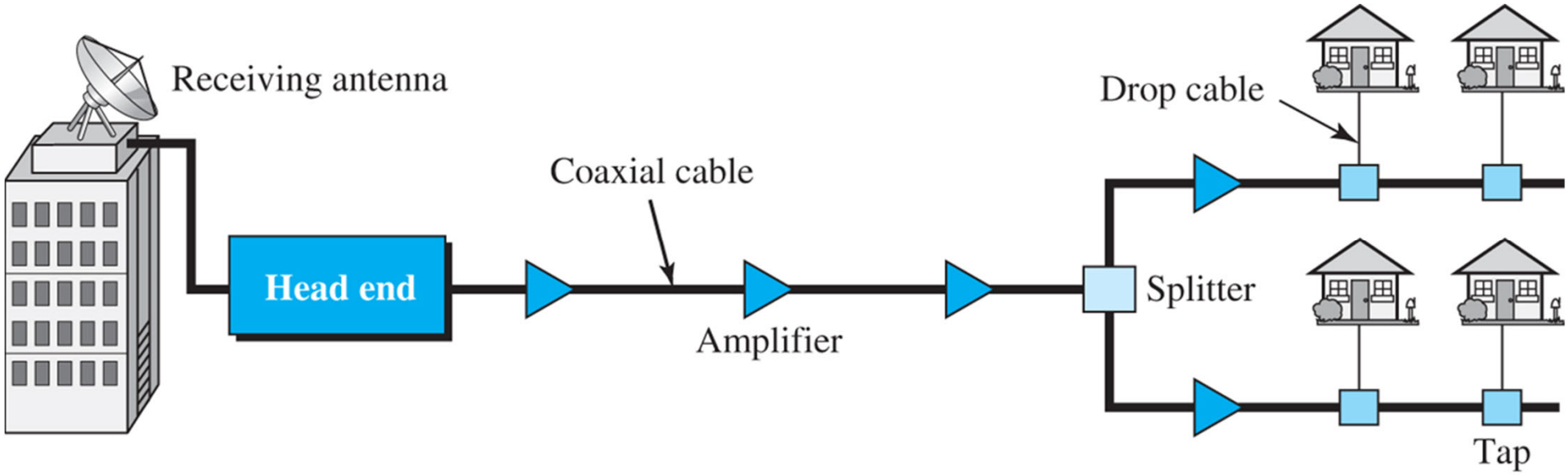
Image Source: *http://support.belong.com.au/adsl/join/what-is-the-difference-between-adsl2-and-adsl*

CABLE NETWORK

- Cable networks were originally created to provide access to TV programs for those subscribers who had no reception because of natural obstructions such as mountains.
- Later cable networks became popular with people who just wanted a better signal.
- In addition, cable networks enabled access to remote broadcasting stations via microwave connections.

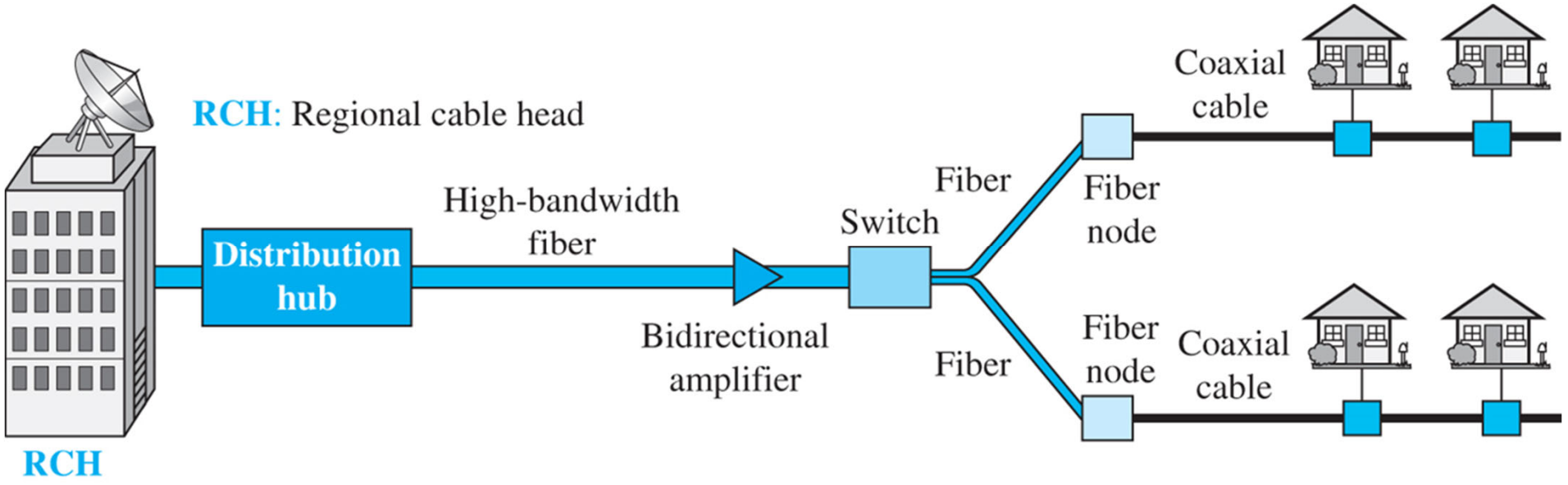
Traditional Cable Network

- Cable TV started distributing broadcast video signals to locations with poor or no reception in the late 1940s. I
- Community antenna TV (CATV) that received the signals from the TV stations and distributed them via coaxial cables.
- Head end performs the signal processing function, and amplifiers are used to strengthen the signal at the user-end



Hybrid Fiber-Coaxial Network (HFC)

- Second generation of cable networks, fiber-optic + coaxial cable
- The transmission medium from the cable TV office to a box, called the fiber node, is an optical fiber cable
- Fiber node through the neighborhood and into the house is still coaxial cable.



Cable TV for Data Transfer

- DSL uses the existing unshielded twisted-pair cable, which is very susceptible to interference.
- Coaxial cables, used in a cable network , alleviate this problem

THE UNIVERSITY OF SYDNEY

Sharing

- Both upstream and downstream bands are shared by the subscribers.
- The upstream data bandwidth is 37 MHz, and only six 6-MHz channels are available in the upstream direction.
- Subscriber shares these channels in time to send data in the upstream direction.
- When the users are a few, much higher data rate than xDSL (for the same distance and bandwidth); time-sharing reduces rates as the number of users increases

THE UNIVERSITY OF SYDNEY

SONET/SDH

- Fiber-optic cable: high bandwidth, suitable for high-data-rate technologies and for carrying large numbers of lower-rate technologies at the same time
- SONET (Synchronous Optical Network): Standardized protocols for fiber-optic networks
- SONET: developed by ANSI (American National Standards Institute)
- SDH (Synchronous Digital Hierarchy): Similar standard developed by ITU-T
- SONET/SDH uses synchronous time division multiplexing (TDM)
- All clocks in the system are locked to a master clock

THE UNIVERSITY OF SYDNEY

SONET/SDH Rates

- SONET defines a hierarchy of electrical signaling levels called synchronous transport signals (STSs)
- Each STS level supports a certain data rate, and the corresponding optical signals are called optical carriers (OCs)
- SDH specifies a similar system called a synchronous transport module (STM)
- The lowest level (STS-1) has data rate of 51.84 Mbps (base unit)
- OC-*n* has a rate *n* x 51.84 Mbps
- Facilitates multiplexing: *n* STS-1 channels can be multiplexed into one STS-*n* channel

THE UNIVERSITY OF SYDNEY

SONET/SDH Rates

STS	*OC*	*Rate (Mbps)*	*STM*
STS-1	OC-1	51.840	
STS-3	OC-3	155.520	**STM-1**
STS-9	OC-9	466.560	**STM-3**
STS-12	OC-12	622.080	**STM-4**
STS-18	OC-18	933.120	**STM-6**
STS-24	OC-24	1244.160	**STM-8**
STS-36	OC-36	1866.230	**STM-12**
STS-48	OC-48	2488.320	**STM-16**
STS-96	OC-96	4976.640	**STM-32**
STS-192	OC-192	9953.280	**STM-64**

THE UNIVERSITY OF SYDNEY

SONET/SDH Devices

- STS Multiplexer/De-multiplexer
  - Multiplexes signals from multiple electrical sources and creates the corresponding OC signal (OC=Optical Carrier)
  - Provide interface conversion between an electrical tributary network and the optical network
  - Mark the beginning points and endpoints of a SONET link
- Regenerator
  - Extends the length of the link
  - Demodulate OC-n to STS-n, regenerate the electrical signal, and modulates the electrical signal into OC-n signal
- Add/drop Multiplexer
  - Allow insertion and extraction of signals in the optical domain
- Terminal
  - A device that uses the services of a SONET network

SONET Devices

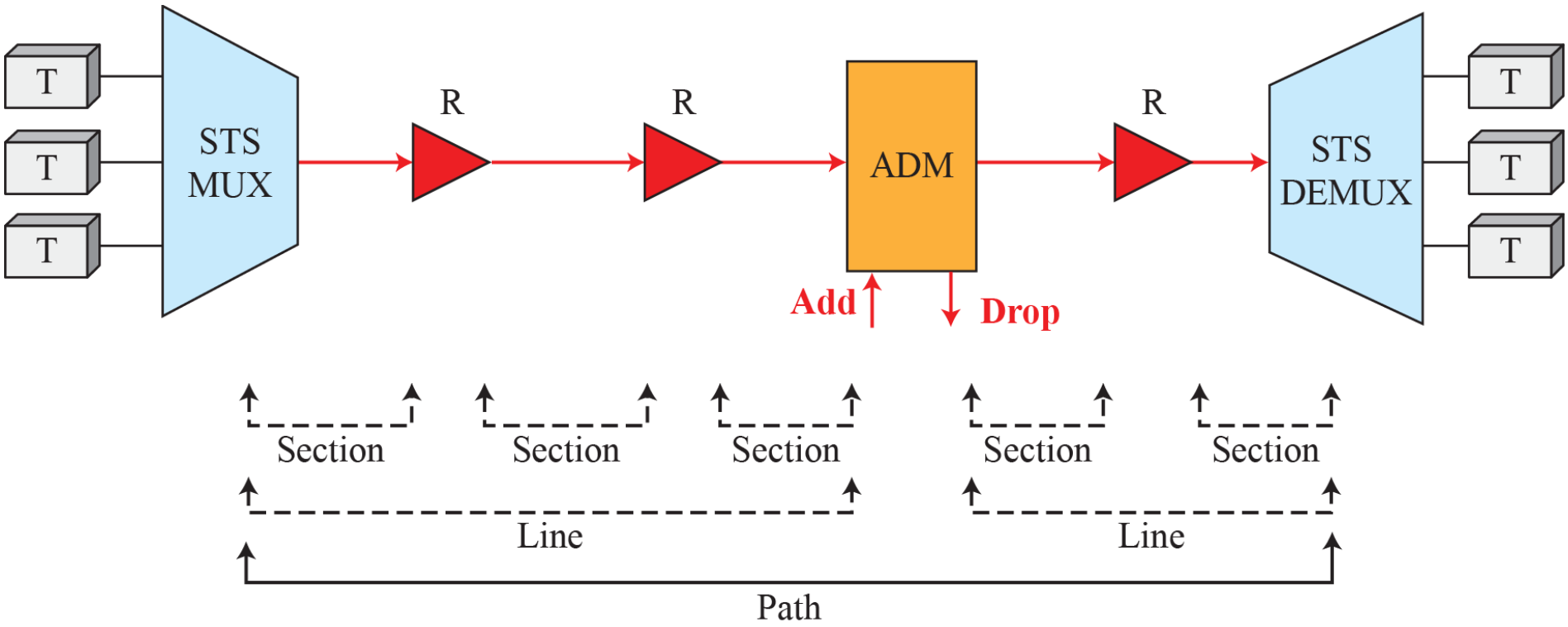
ADM: Add/drop multiplexer

STS MUX: Synchronous transport signal multiplexer

STS DEMUX: Synchronous transport signal demultiplexer

R: Regenerator

T: Terminal

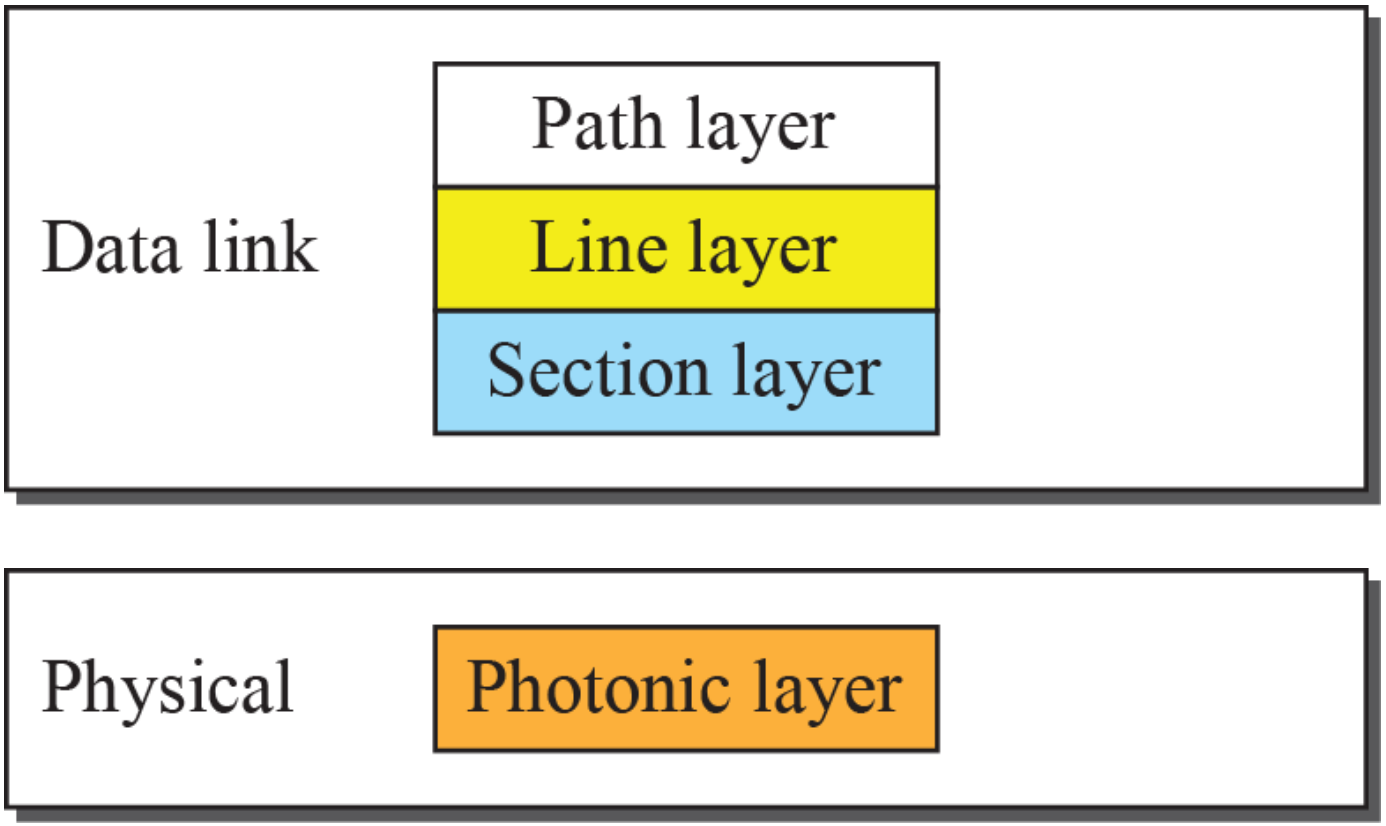


THE UNIVERSITY OF SYDNEY

SONET Connections

- Section:
  - optical link connecting two neighboring devices
- Line:
  - portion of the network between two multiplexers
- Path:
  - end-to-end portion of the network between two STS multiplexers

SONET Layers

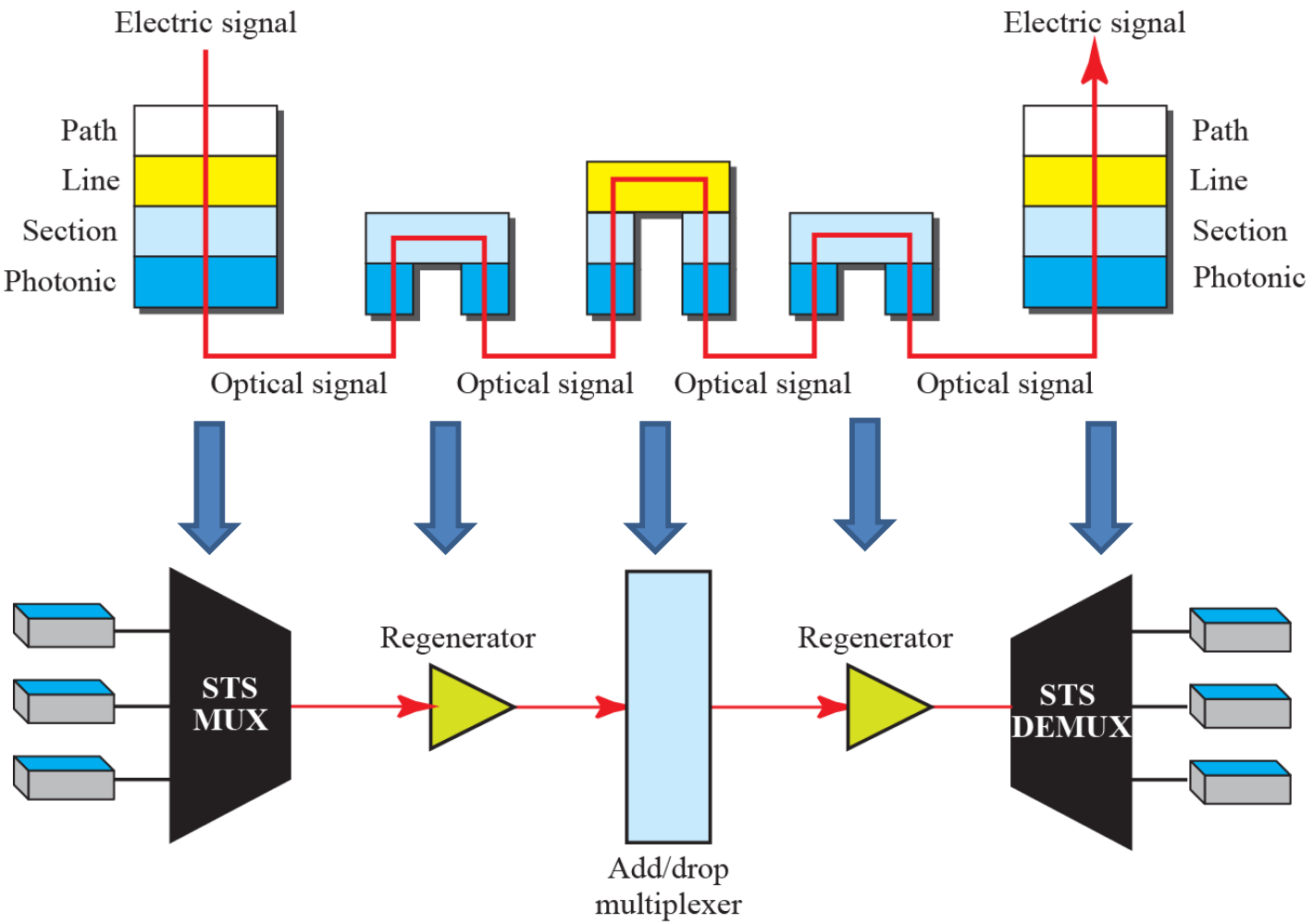


THE UNIVERSITY OF SYDNEY

SONET Layers

- Path layer:
  - Responsible for the movement of a signal from optical source to optical destination
  - STS multiplexers provide path layer functions
- Line layer:
  - Responsible for the movement of a signal across a physical line
  - STS multiplexers and add/drop multiplexers provide line layer functions
- Section layer:
  - Responsible for the movement of a signal across a physical section
- Photonic Layer:
  - Corresponds to the physical layer
  - Includes physical specifications for the optical fiber channel, the sensitivity of the receiver, multiplexing functions, and so on.

Device Layer Relationship of SONET

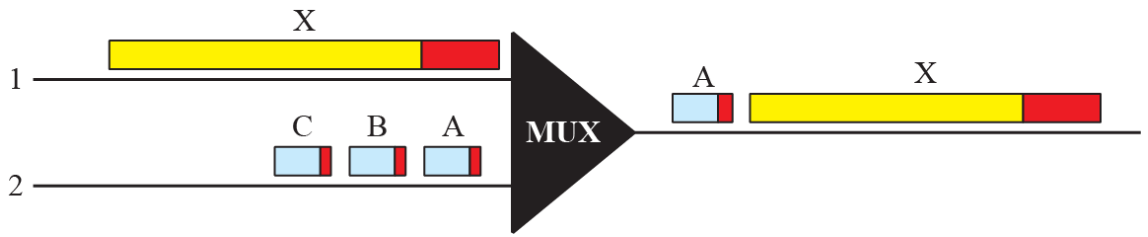


Asynchronous Transfer Mode (ATM)

- ATM (Asynchronous Transfer Mode): A switched wide area network that
  - Encodes data into small packets of fixed size (53 bytes), called cells, and
  - Uses asynchronous time-division multiplexing (TDM)
- ATM is a core protocol used over the SONET/SDH backbone of the public switched telephone network (PSTN)
- Designed for networks that must handle both traditional high-throughput data traffic (e.g., file transfers), and real-time, low-latency content such as voice and video
- Addresses the problems of frame-based networks (Frame Relay and X.25)

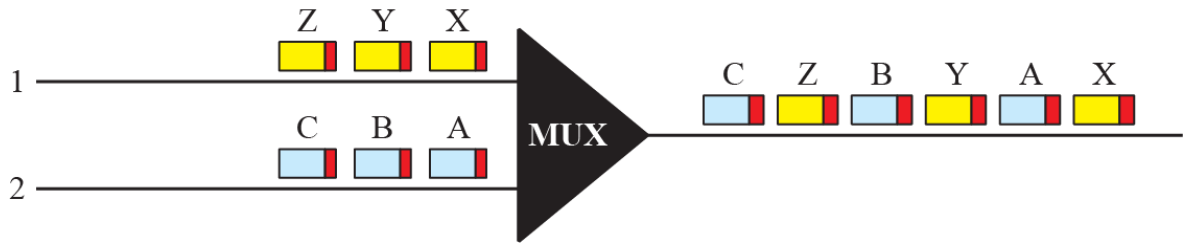
Problems of Frame Networks

- Before ATM, data communications at the data-link layer had been based on frame networks
- Different protocols use frames of varying size
- Internetworking among the different frame networks is slow and expensive
- Multiplexing using different frame sizes may create unacceptable delays and makes shared frame links unusable for audio and video information



Cell Networks

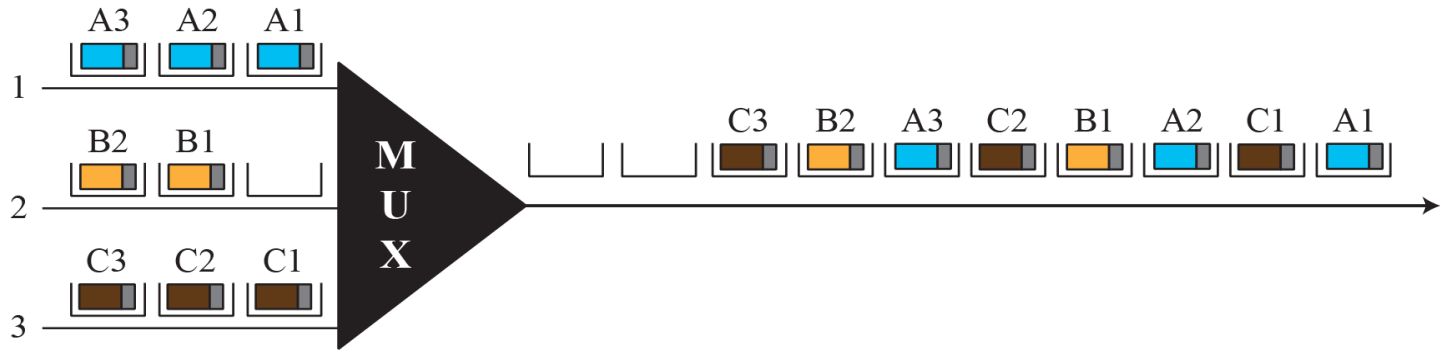
- The problems of frame internetworking can be solved by cell networking
- Cell networking: packet switching with fixed size packets (called *cells*)
- Cell: a small data unit of fixed size, the basic unit of data exchange
- As frames of different sizes and formats reach the cell network from a tributary network, they are split into cells
- Cells are then multiplexed and routed through the cell network
- Why cells?
  - Reduce mean delay and variation of delay
  - Enable continuous stream despite of interleaving, thus suitable for real-time applications (voice, video)



Asynchronous TDM

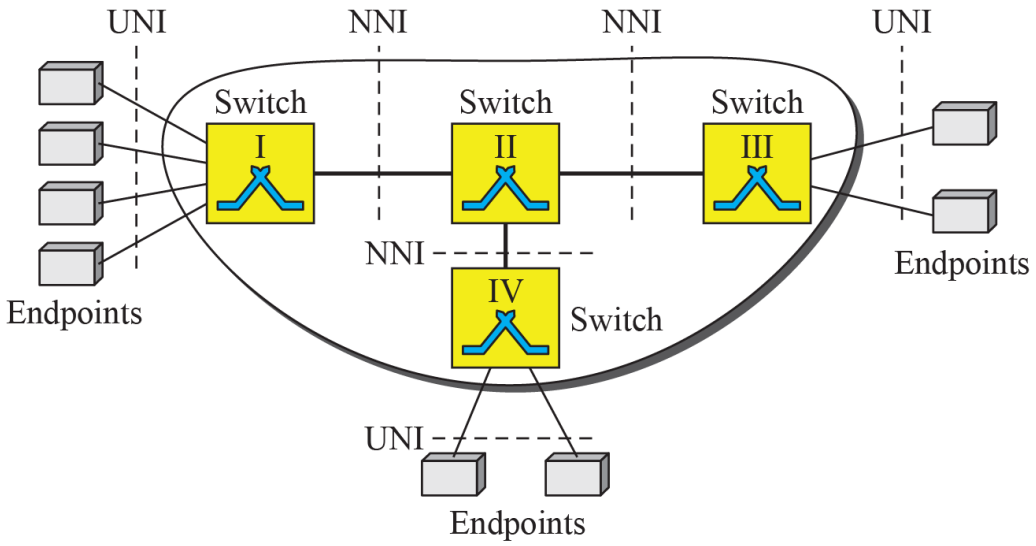
- ATM uses asynchronous time-division multiplexing (TDM)
- Rather than being preassigned, each slot is available to any of the attached input lines that has data/cells to send.
- More efficient use of channel than synchronous TDM

Asynchronous TDM



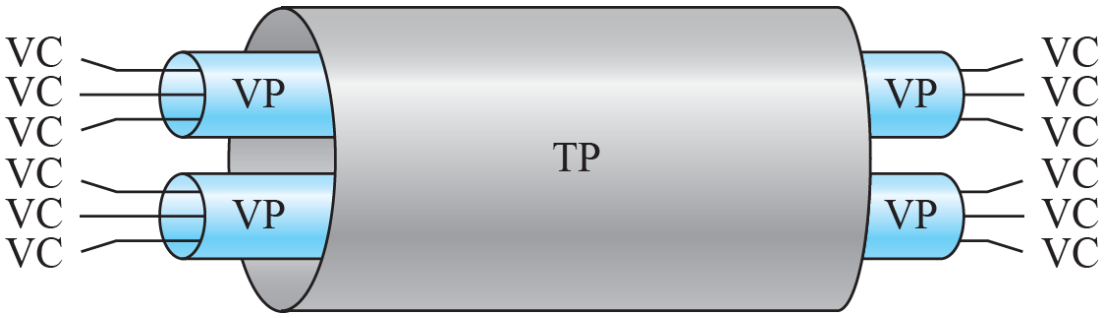
ATM Architecture

- User access devices (end points) connected through user- to-network interface (UNI) to switches inside the network
- Switches connected through network-to-network interfaces (NNIs)



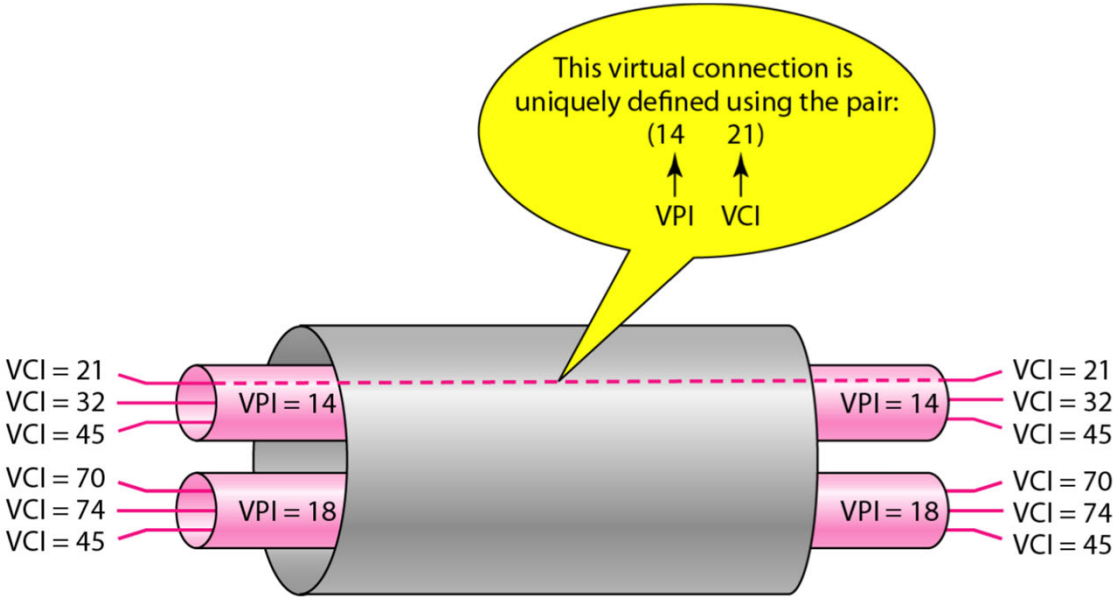
Virtual Connection

- Connection between two endpoints is identified by transmission path (TP), virtual path (VP), and virtual circuit (VC)
- TP: physical connection between an endpoint and a switch or between two switches
- VP: provides a set of connection between two switches. A TP is divided into several VPs.
- VC: logically connects two points. A combination of VCs forms VP



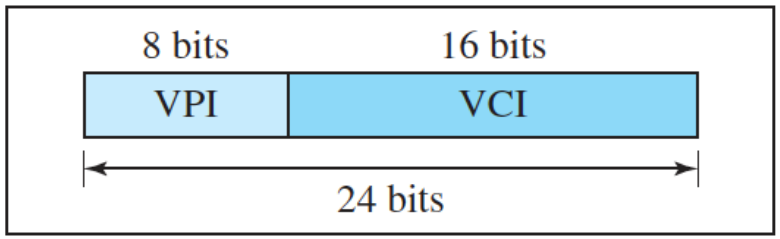
Virtual Connection Identifier

- Virtual connection identified by by a hierarchical identifier with two levels:
  - Virtual path identifier (VPI): defines the specific virtual path
  - Virtual circuit identifier (VCI): defines a particular VC inside the VP

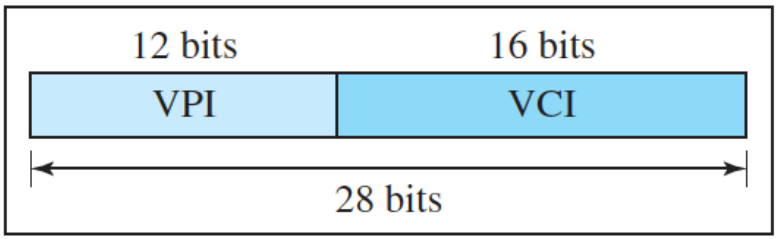


Virtual Connection Identifier

- The lengths of VPIs for UNIs and NNIs are different
  - 8 bits for UNI
  - 12 bits in NNI
- The length of VCI is the same in both UNI and NNI (16 bits)

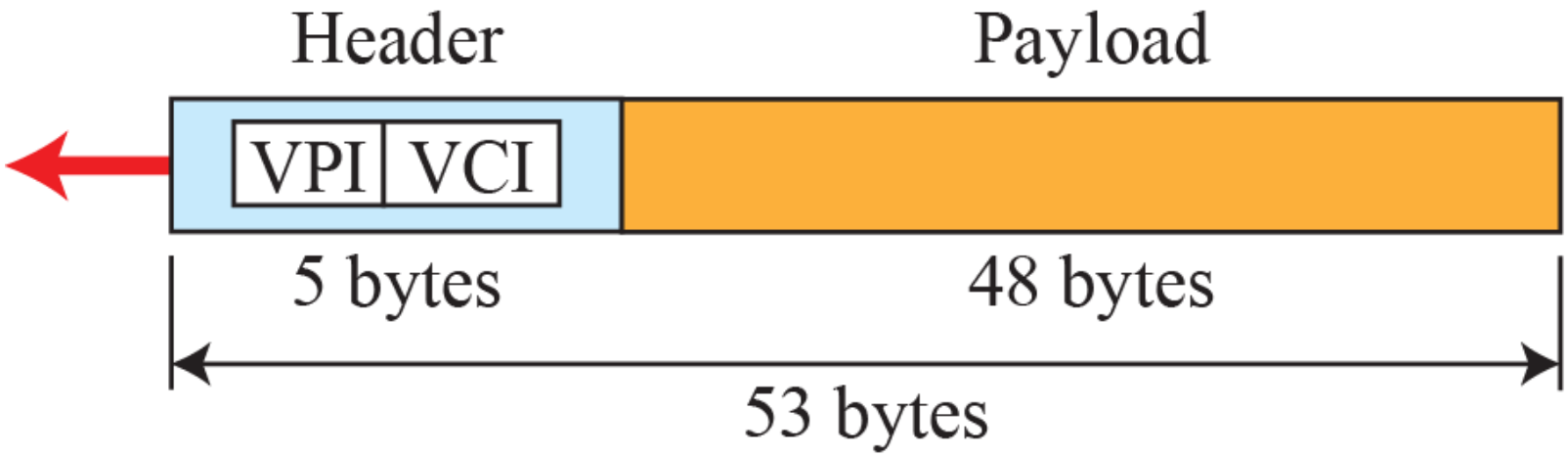


a. VPI and VCI in a UNI

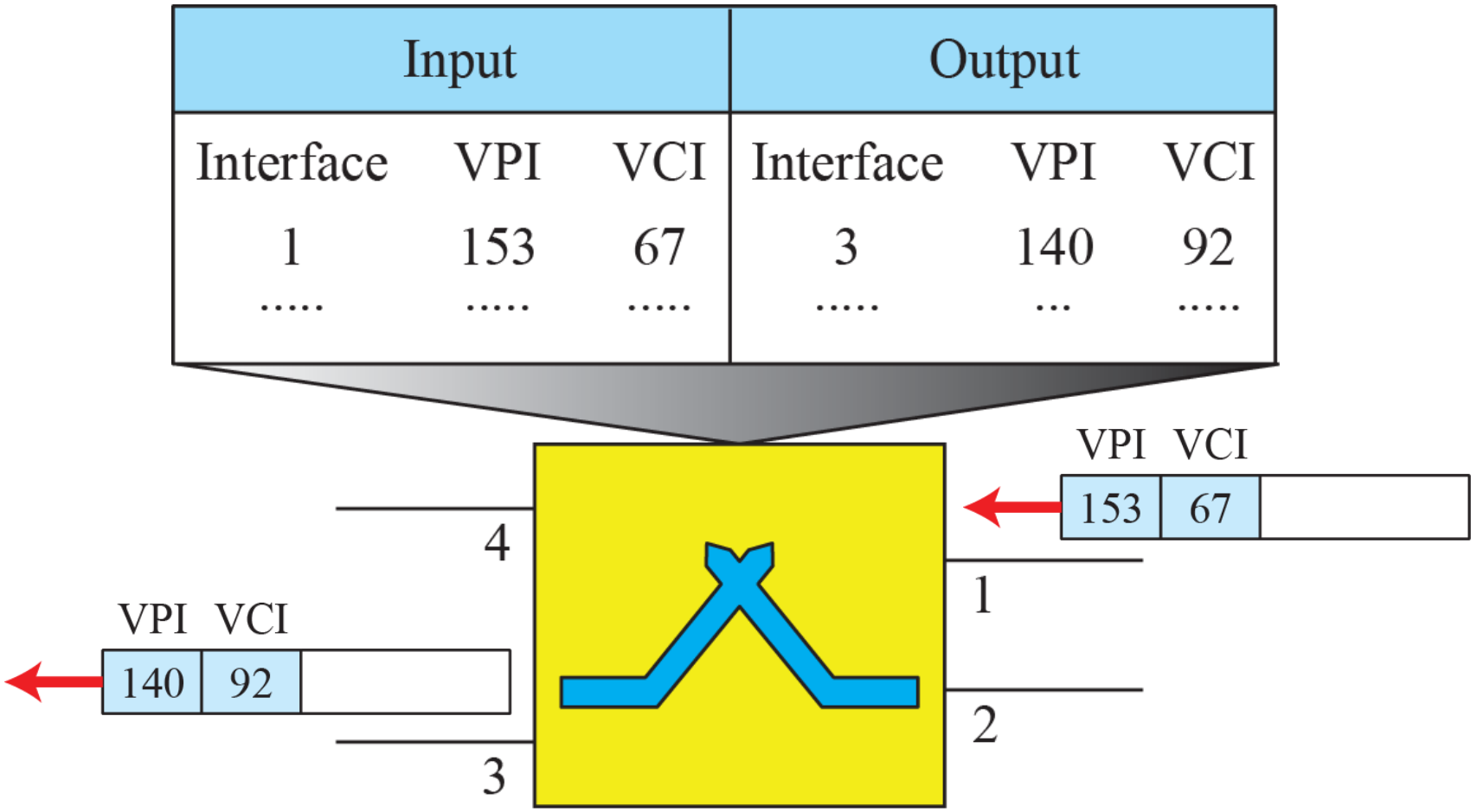


b. VPI and VCI in an NNI

ATM Cell



Cell Switching

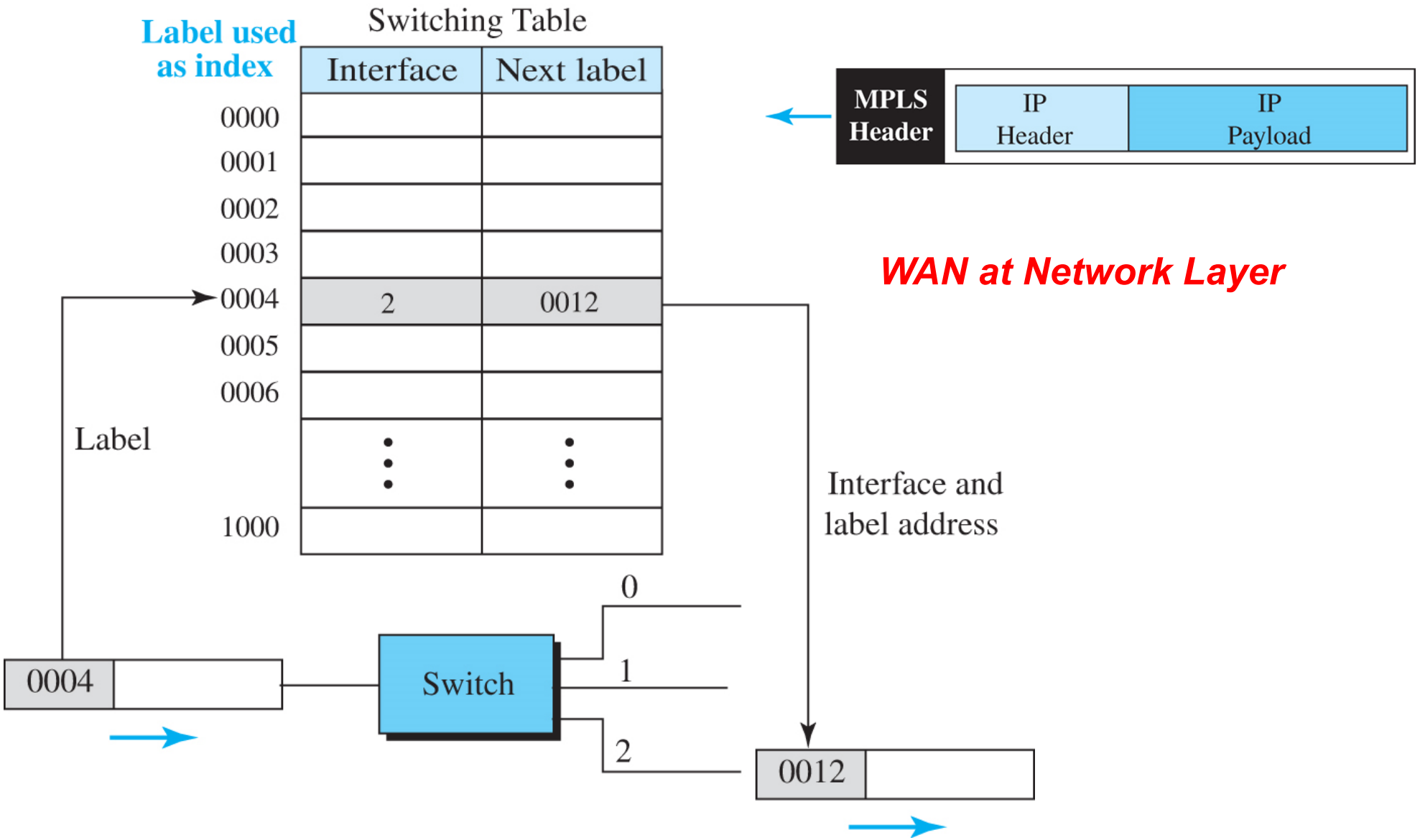


THE UNIVERSITY OF SYDNEY

Relationship Between Technologies

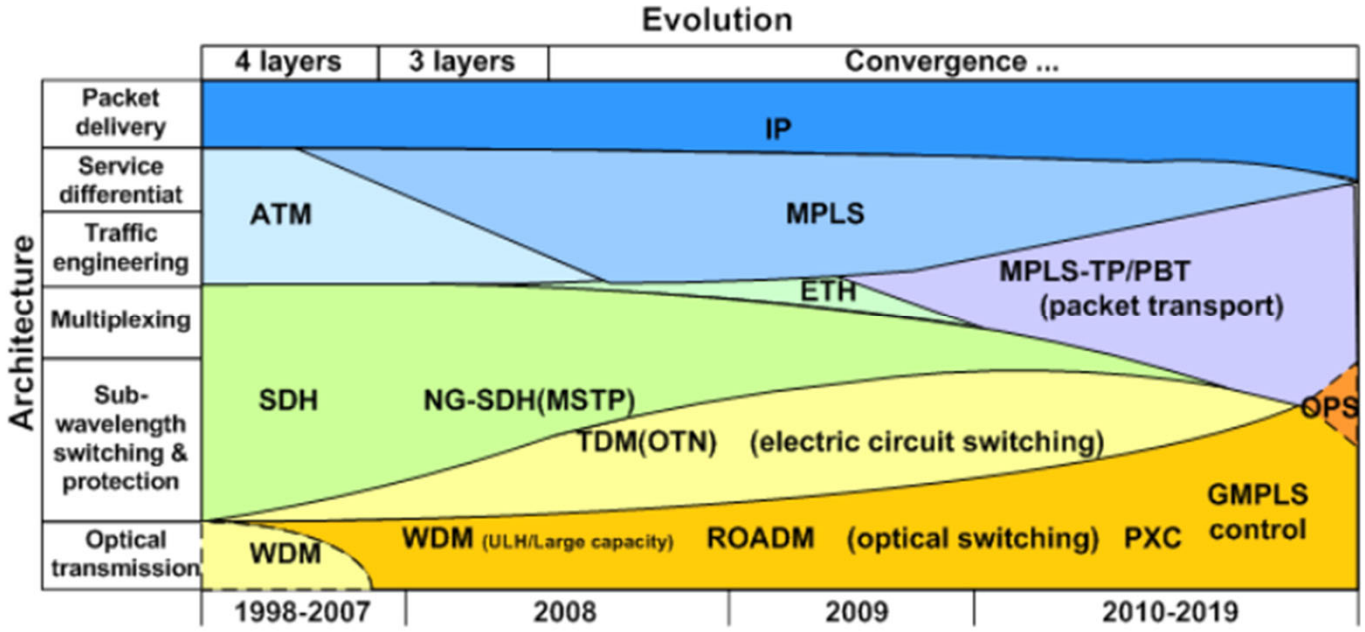
- ADSL → PHY layer
  - Access network: connects small LANs to an ISP
  - Carry another Layer-2 protocol
    - PPP (Point-to-Point Protocol)
    - To support IP
- SONET/SDH → PHY/Link layer
  - A transmission technology for optical networks
  - Acts as carriers/bearers for other network traffic
  - High transfer rate over long-distance scale
- ATM → switching technology
  - Does not care what kind of wire it is on
  - ATM and SONET can work together to enable high-speed connections

Multi-Protocol Label Switching (MPLS)



Other WAN Technologies

- X.25
- Frame Relay
- SDH/SONET
- ATM
- MPLS
- WDM



Recommended Reading

- Behrouz A. Forouzan, Data Communications and Networking with TCP/IP Protocol Suite, 6th ed., 2022, Chapters 5 and 7