Lecture 9: Wide Area Networks. The Internet

Acknowledgement: Materials presented in this lecture are predominantly based on slides from:

- Internet resources
- *Business Data Communications and Networking,* J. Fitzgerald, A. Dennis, 10/11th ed., 2013, John Wiley & Sons, Chapter 5
- *Computer Networking: A Top Down Approach,* J. Kurose, K. Ross, 7th ed., 2017, Addison-Wesley, Chapter 3

Lecture 9: Wide Area Networks. The Internet Overview

- Wide Area Networks vs the Internet
- Monash University WAN
- AARnet
- Dark Fibre Networks
- Submarine Communications Cables
- Circuit-switched and packet-switched WAN services.
- T-carrier and SONET/SDH services
- Metro Ethernet
- MPLS
- Architecture of the Internet
- Internet Access Technologies

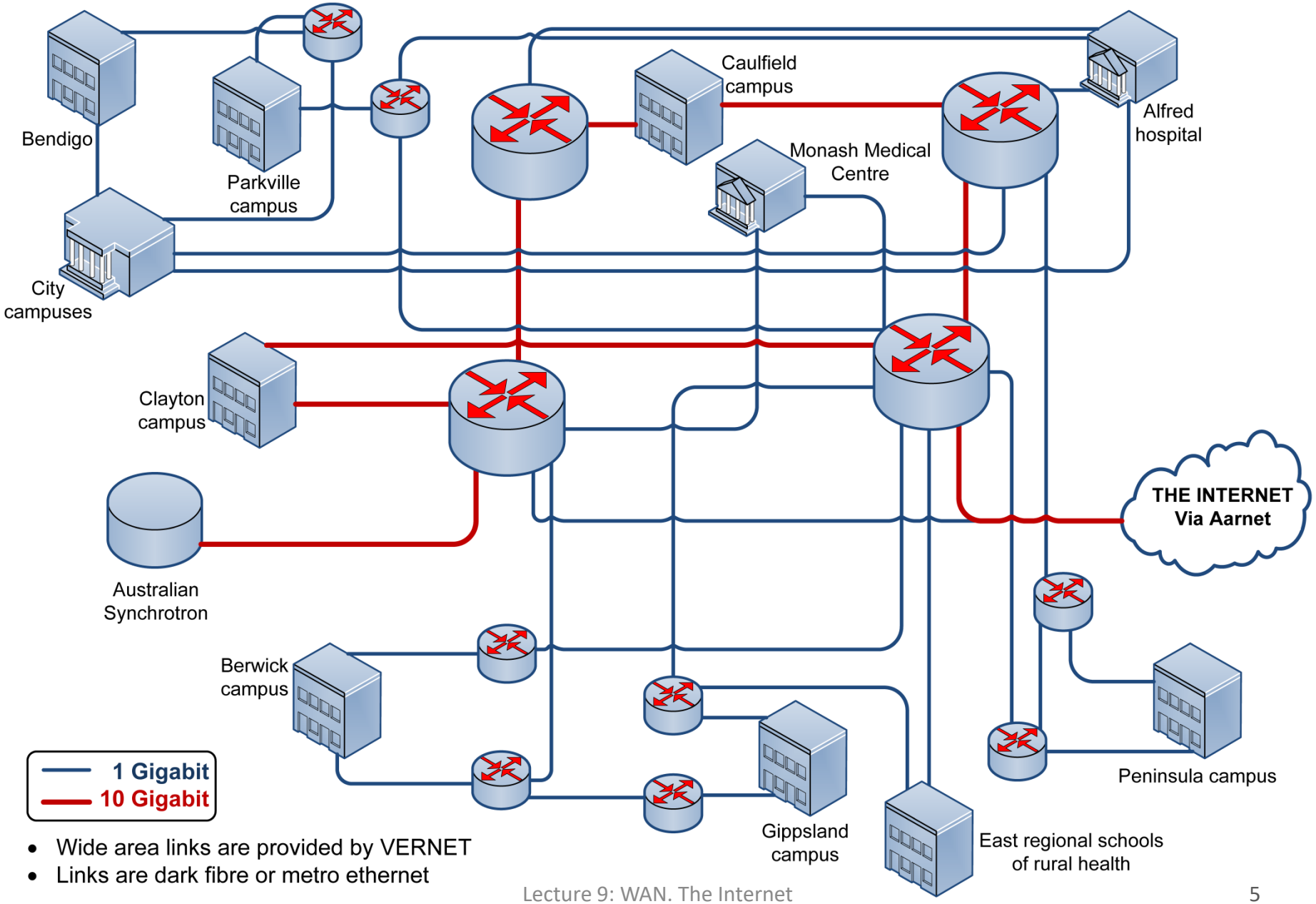
WANs vs the Internet

- Wide Area Networks (WANs)
  - Typically connect segments of the enterprise networks that are spread across long distances
  - Most organizations lease circuits or data transfer services from the common carriers like Telstra or Optus in Au, China Telecom, or AT&T in the USA
  - Are governed by enterprises and organizations
- The Internet is (what is it?) an overarching network of networks, publically available to everybody from individuals to big organizations
- WANs typically guarantee a level of service (speed and security), the Internet does not guarantee anything.

Monash University WAN

- Monash Network is a typical example of a network that spans large geographic area and is run by the university.
- The network consists of more than 2000 network devices servicing over 40,000 data points in 150 buildings on 20 sites.
- In addition to a fixed data network Monash University also provides a wireless service for staff, students and authorised visitors.
- The wireless service currently provides access for more than 3500 concurrent users every day.
- The university relies heavily on the entire network for the delivery of academic and administrative services.
- The Monash network is connected to the Internet via separate 1 Gigabit and 10 Gigabit high quality dark fibre links to AARNet.
- Work is currently in progress to enable dual 10 Gigabit links.

Overview of the Monash ITS Network Infrastructure



- Wide area links are provided by VERNET
- Links are dark fibre or metro ethernet

Monash Network Topology

- The design is based around ***precincts*** or sub-networks.
- Each precinct is served by two **route switches** for resilience.
- Each precinct comprises a group of buildings based on a combination of campus geography and optical fibre distribution.
- Additionally, the **central servers** have their own dual precinct **route switches.**
- The design ensures a solid routed core with resilient load-sharing paths to the servers, and the building distribution switch located in each building.
- From each Precinct switch, there are dual gigabit connections via single mode (SM) fibre to building distribution switches (BDS).
- Each BDS in turn resiliently connects to floor Ethernet switches (FES).
- A high degree of resilience is therefore achieved from core to edge, providing a gigabit connection to the desktop.

Australian Academic and Research Network (AARnet)

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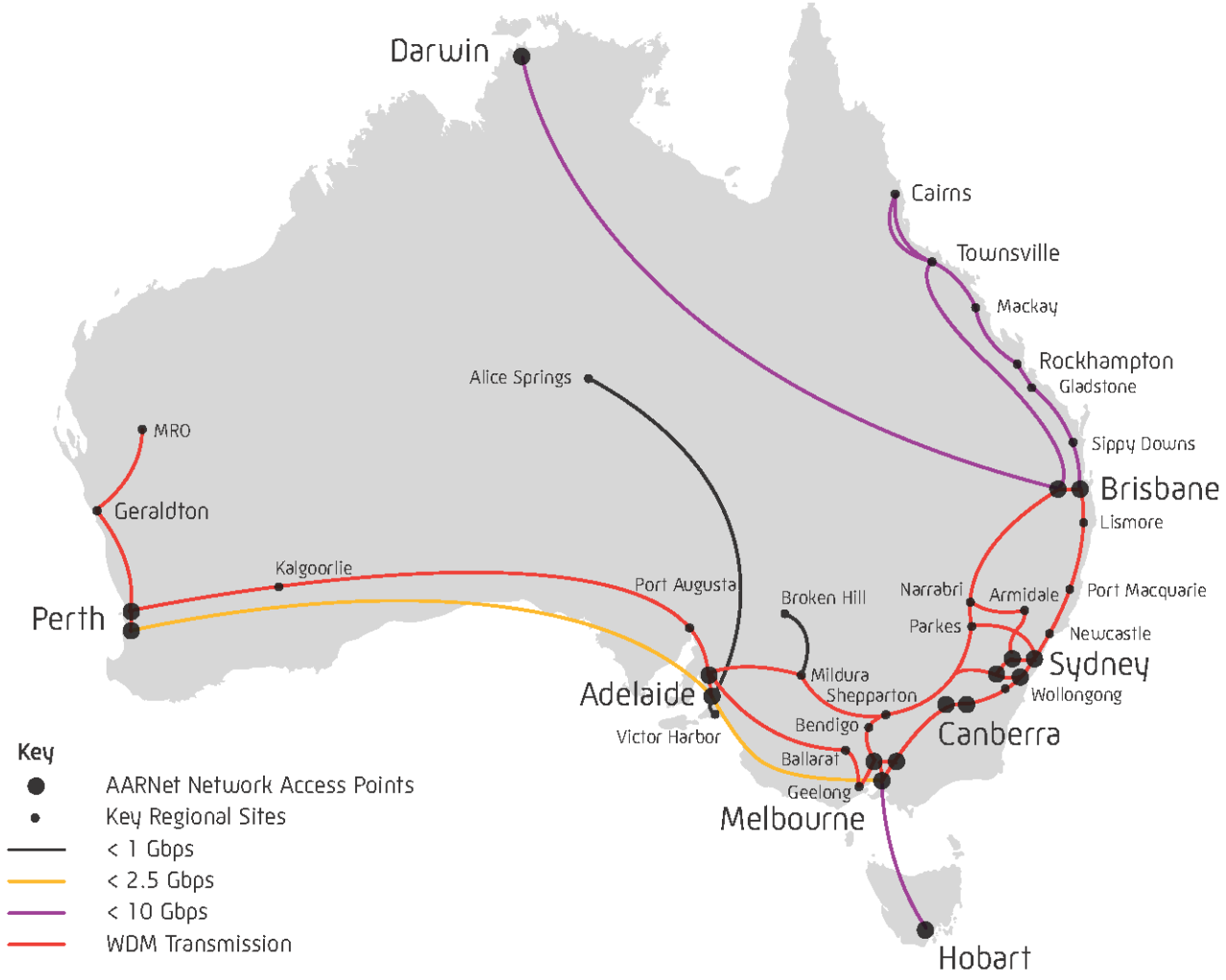


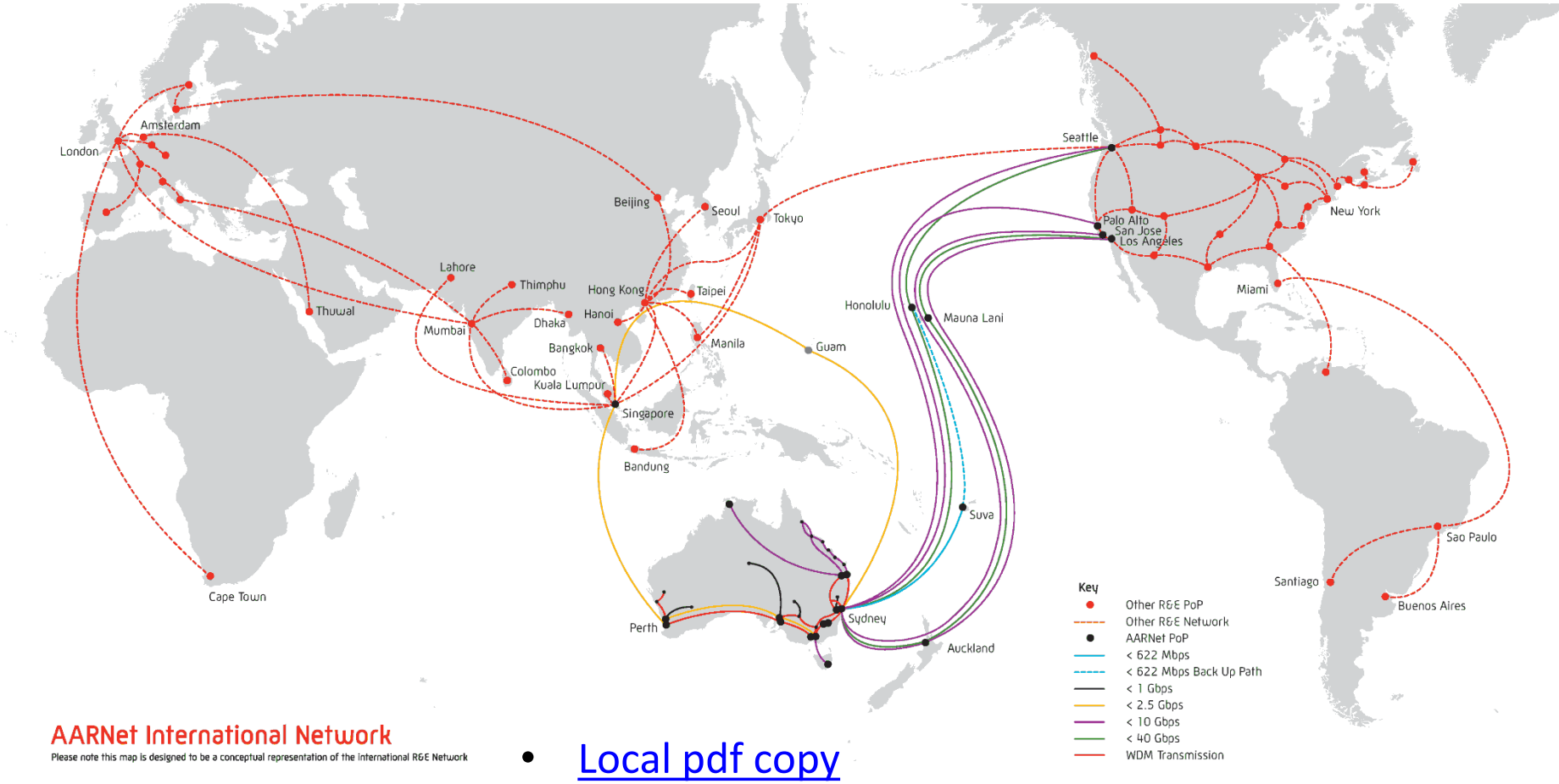
- AARnet is an example of a WAN owned and operated by an independent organization

Note

- Access Points aka PoPs (Points of Presence)
- Fibre optics connections of different speed.

Wavelength Division Multiplexing

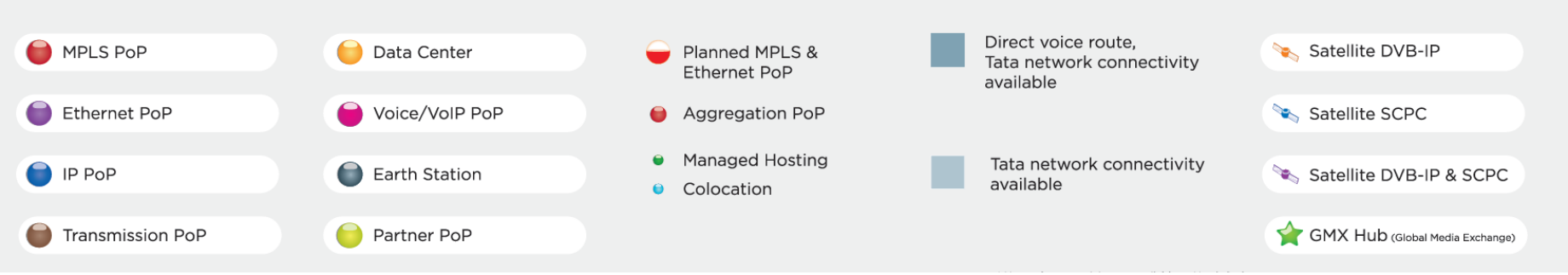
AARnet International presence



- [Local pdf copy]
- http://www.tein3.net/Pages/home.aspx
- R&E – Research and Education Networks

WAN Infrastructure

- WAN Infrastructure (also used by the Internet) is provided by (big) telecommunication companies
- Tata Communications as an example (local copy)
- Services are provided at PoPs (Points of Presence)



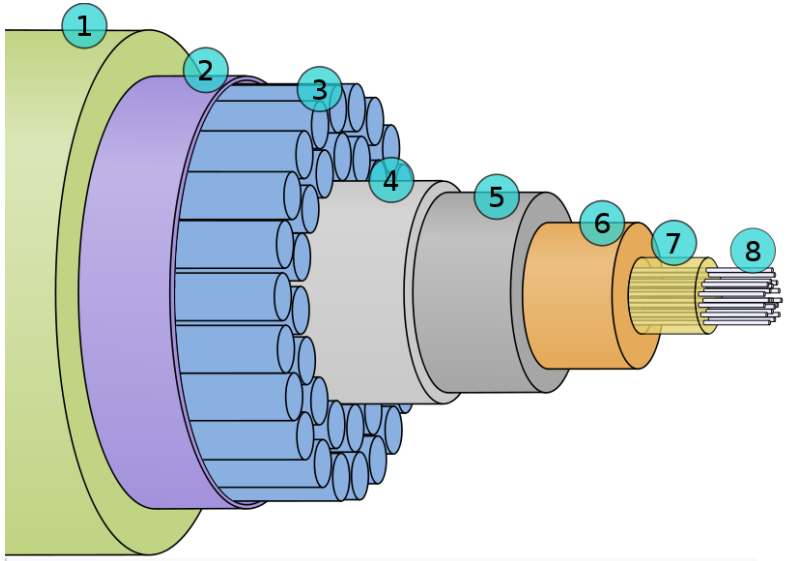
- Note IP, Ethernet, MPLS PoPs
- Communications links include: Terrestrial and submarine optical fibre cables and satellite links

More telcos

- http://www.optus.com.au/network/satellite
- http://info.singtel.com/business
- China telecom
- http://www.cogentco.com/en/network/network-map
- http://www.level3.com/
- http://enterprise.vodafone.com/home/
- http://www.sprint.com/

Submarine Communications Cables

- A submarine communications cable is a cable laid on the sea bed between land-based stations to carry telecommunication signals across stretches of ocean.
- Modern cables for the deep-see sections are typically 25 millimetres in diameter and weigh around 1.4 kilograms per metre
- Larger and heavier cables are used for the shallow-water sections.
- Submarine cables link all the world's continents (except Antarctica).
- First commercial cable across the English Channel was laid in 1853. First Australian cables in early 1870s.
- In 2012 operators had successfully demonstrated long-term, error-free transmission at 100 Gbps across Atlantic Ocean



A cross section of a modern submarine communications cable.
1 – Polyethylene
2 – Mylar tape
3 – Stranded steel wires
4 – Aluminium water barrier
5 – Polycarbonate
6 – Copper or aluminium tube
7 – Petroleum jelly
8 – Optical fibers

Submarine Communications Cables

- AJC - (Australia-Japan Cable)
- Southern Cross - (Australia, New Zealand, Fiji, United States)
- APCN 2 - (*Asia-Pacific Cable Network 2*) (Japan, Korea, Philippines, Taiwan, China, Hong Kong, Malaysia, Singapore)
- APNG-2 - (Australia-Papua New Guinea)
- APG - (*Asia-Pacific Gateway*)
- SEA-ME-WE 5 – (*South East Asia-Middle East-Western Europe*)
- C-J FOSC - (*China-Japan Fibre Optic Submarine Cable*)
- CUCN - (*China-US Cable Network*) (Korea-US-China-Japan-Guam)

MAN/WANs Network Classification

Circuit-Switched Networks (based on POTS)

- Use regular dial-up phone lines and a modem
  - A modem used to call another modem
  - Once a connection is made, data transfer begins
  - Was (is ?) popular with shop payments

Dedicated-Circuit Networks

- Leased full duplex circuits from common carriers e.g. dark fibre

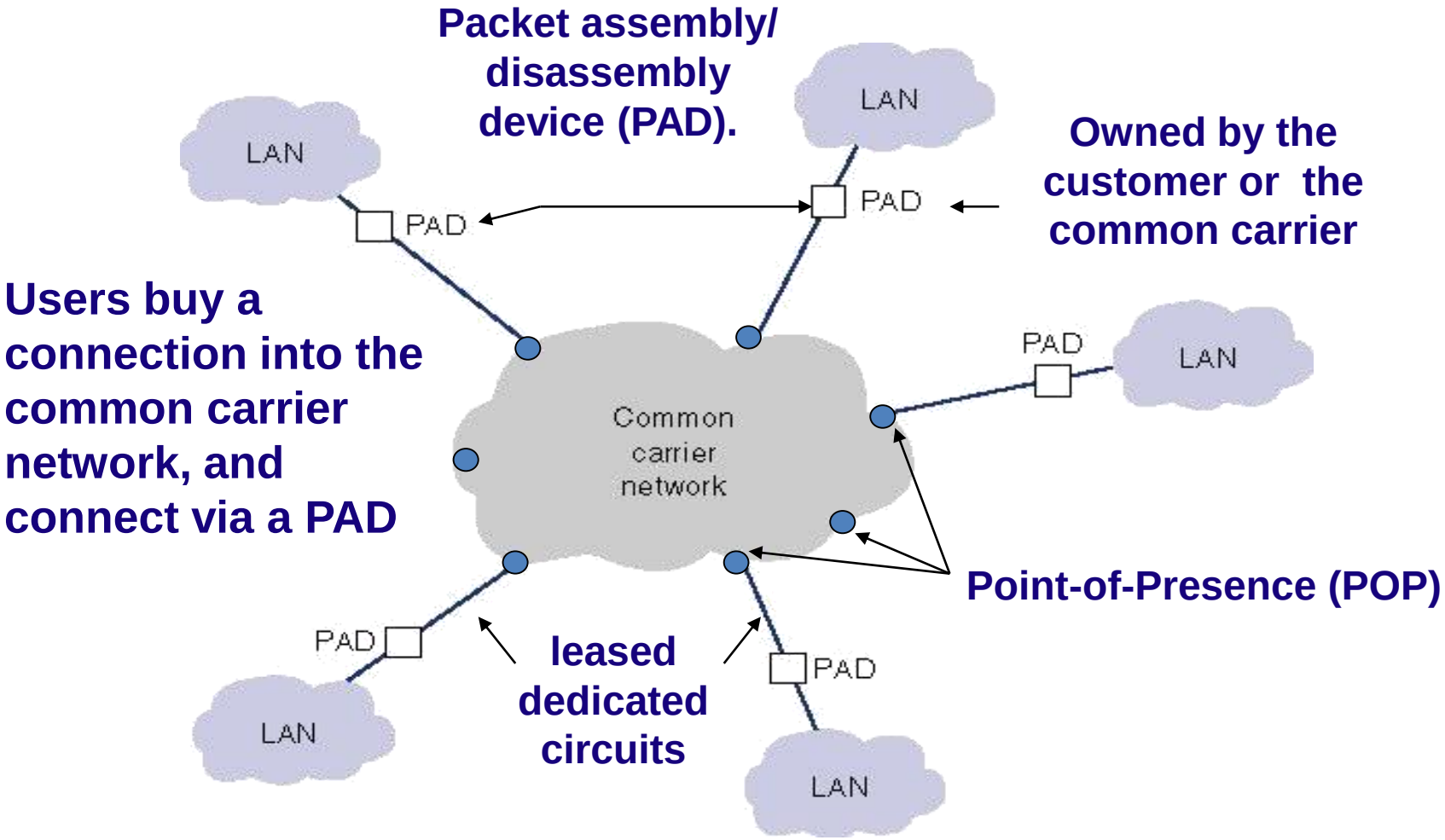
Packet-Switched Networks

- Enable multiple connections to exist simultaneously between computers over the same physical circuits
- User pays a fixed fee for the connection to the network plus charges for packets transmitted

Dark Fibre Networks

- Dark fibre or **unlit fibre** is an unused optical fibre, available for lease in fibre-optic communications.
- A dark fibre network is a privately operated optical fibre network that is run directly by its operator over dark fibre leased or purchased from another supplier, rather than by purchasing bandwidth or leased line capacity.
- Dark fibre networks may be used for private networking, or as the Internet access or the Internet infrastructure networking.
- Dark fibre networks are generally only available in high-population-density areas where fibre has already been laid, as the civil engineering costs of installing fibre to new locations is often prohibitive.
- For these reasons, dark fibre networks are typically run between data centers and other places with existing fibre infrastructure.

Basic Architecture of Packet Switched Services



Data Rates of Packet Switched services

- Users specify the rates per connection via negotiations
  - **Committed information rate** (CIR)
    - Guaranteed by the service provider
    - Packets sent at rates exceeding the CIR are marked discard eligible (DE)
      - discarded if the network becomes overloaded
  - **Maximum allowable rate** (MAR)
    - Sends data only when the extra capacity is available

T-Carrier Services

- (Old) Most commonly used dedicated digital circuits in North America
- Users can lease the transmitting capacity in terms of T-c services
- Units of the T-Carrier hierarchy:
  - DS-0 (64 Kbps); Basic unit of T-1, bound into groups of 24
  - T-1, also called DS-1 (1.544 Mbps)
    - Allows 24 simultaneous 64 Kbps channels which transport data or voice messages using PCM (pulse coded modulation)
  - T-2 (6.312 Mbps) multiplexes 4 T-1 circuits
  - T-3 (44.376 Mbps); 28 T-1 capacity
  - T-4 (274.176 Mbps); 178 T-1 capacity (672 DS-0 channels)

Synchronous Optical Network (SONET) Synchronous Digital Hierarchy (SDH)

- Standards for optical fiber transmission in Gbps range
  - SDH, ITU-T standard (updated by OTN standard)
  - SONET, ANSII
  - can be easily interconnected
- Hierarchy
  - Begins with OC-1 (optical carrier level 1) at 51.84 Mbps
  - Each succeeding SONET hierarchy rate is defined as a multiple of OC-1

SONET/SDH Digital Hierarchy

SONET Designation	SDH Designation	Speed
OC-1		51.84 Mbps
OC-3	STM-1	155.52 Mbps
OC-12	STM-4	622.08 Mbps
OC-24	STM-8	1.244 Gbps
OC-48	STM-16	2.488 Gbps
OC-192	STM-64	9.953 Gbps
OC-768	STM-256	39.813 Gbps
OC-3072	STM-1024	159.25 Gbps

Packet Switched Service Protocols

- Frame Relay popular some time ago
- IP/MPLS (Multi Protocol Label Switching)
- Ethernet Services, e.g. Metro Ethernet

Several common carriers announced they will stop offering all but Ethernet and Internet services soon

Metropolitan-area Ethernet (1)

- Metro Ethernet is a metropolitan area network (MAN) based on (fibre optics) Ethernet standards.
- It is commonly used to connect subscribers to a larger service network or the Internet.
- Businesses use metro Ethernet to connect their own offices to each other.
- An Ethernet interface is much cheaper than a SONET/SDH interface of the same bandwidth.
- An Ethernet-based access network can be easily connected to the customer network, due to the prevalent use of Ethernet.
- The Metro Ethernet network have a hierarchy of: core, distribution (aggregation), and access.
- The core in most cases is an existing IP/MPLS backbone but may migrate to newer forms of Ethernet transport in the form of 10Gbit/s, 40Gbit/s, or 100Gbit/s speeds or even possibly 400Gbit/s to Terabit Ethernet network in the future.

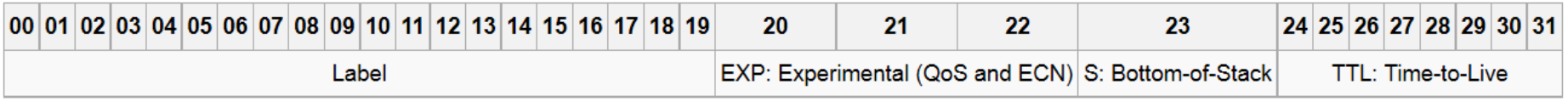
Metropolitan-area Ethernet (2)

- Ethernet on the MAN can be used as pure Ethernet, Ethernet over SDH, Ethernet over MPLS, or Ethernet over DWDM (Dense Wavelength Division Multiplexing).
- Pure Ethernet-based deployments are cheaper but less reliable and scalable and thus are usually limited to small scale or experimental deployments.
- SDH-based deployments are useful when there is an existing SDH infrastructure already in place, its main shortcoming being the loss of flexibility in bandwidth management due to the rigid hierarchy imposed by the SDH network.
- MPLS-based deployments are costly but highly reliable and scalable and are typically used by large service providers

Multi Protocol Label Switching (MPLS)

- MPLS is a scalable, protocol-independent packet transport method belonging to the family of packet-switched networks.
- In an MPLS network, data packets are assigned labels.
- Packet-forwarding decisions are made solely on the contents of this label, without the need to examine the packet itself.
- This allows creation of end-to-end circuits across any type of transport medium, using any protocol.
- MPLS operates at a layer considered to lie between traditional definitions of layer 2 (data link layer) and layer 3 (network layer)
- It can be used to carry many different kinds of traffic, including IP packets, native SONET/SDH, and Ethernet frames.

MPLS header



- MPLS works by prefixing packets with an MPLS header, containing one or more labels forming a stack
- Each label stack entry contains four fields:
  - A 20-bit label value. A label with the value of 1 represents the router alert label.
  - a 3-bit *Traffic Class* field for QoS (quality of service) priority (experimental) and ECN (Explicit Congestion Notification).
  - a 1-bit *bottom of stack* flag. If this is set, it signifies that the current label is the last in the stack.
  - an 8-bit TTL (time to live) field.

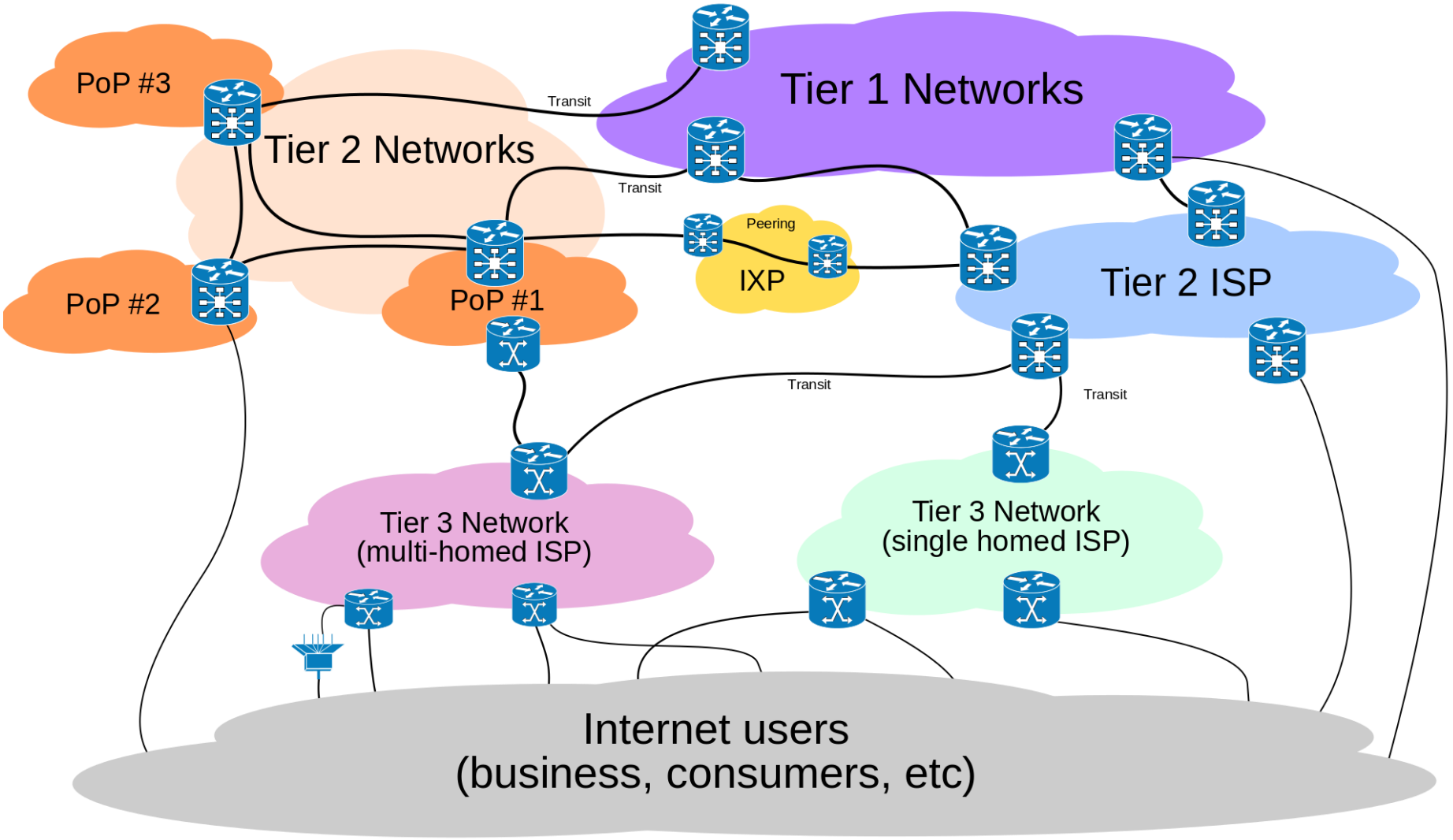
MPLS and IP

- MPLS works in conjunction with IP and its routing protocols, such as the Interior Gateway Protocol (IGP).
- MPLS is standardized by the IETF in RFC 3031.
- It is deployed to connect as few as two facilities to very large networks.
- For example, in the retail sector, it is not uncommon to see deployments of 2000 to 5000 locations to communicate transaction data to a headquarters data center.
- In practice, MPLS is mainly used to forward IP protocol data units (PDUs) and Virtual Private LAN Service (VPLS) Ethernet traffic.
- Major applications of MPLS are traffic engineering, MPLS VPN and MPLS VPLS.

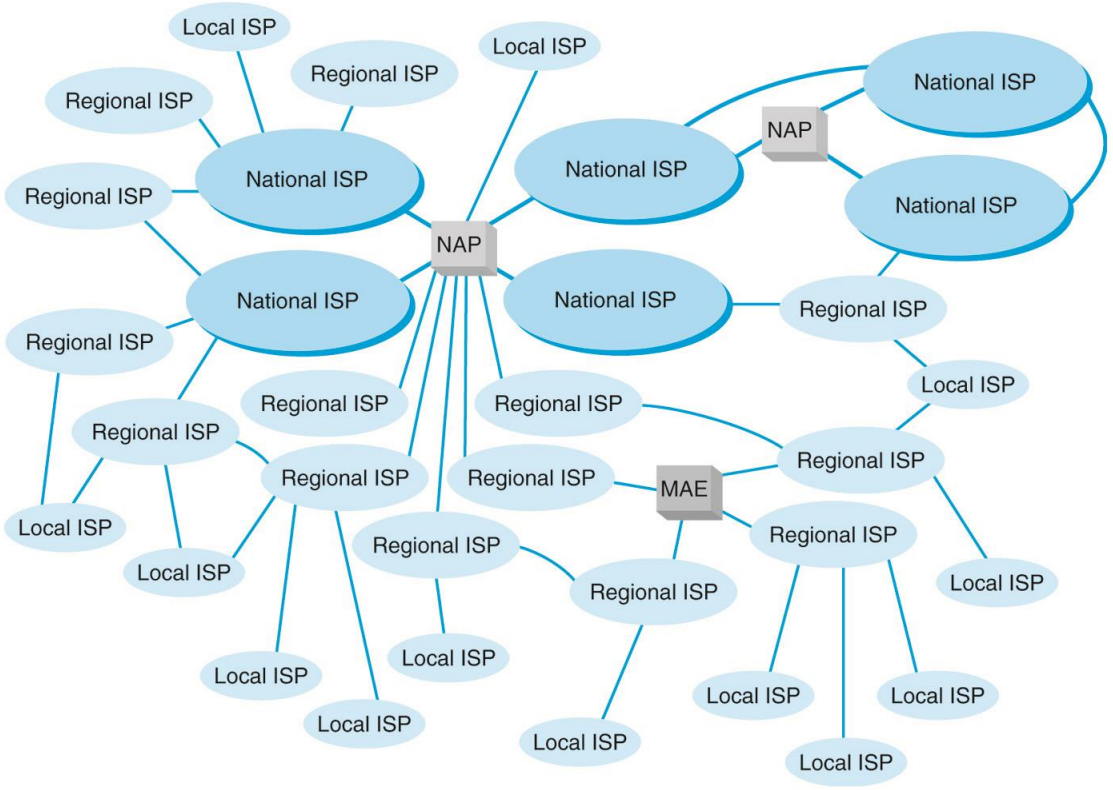
Architecture of the Internet

- Internet is a hierarchical network of autonomous networks
- In order to manage the huge traffic and enormous number of users, (in the USA) the Internet Service Providers (ISPs) are organized in three tiers:
  - National Internet Service Providers (tier 1 ISPs)
  - Regional ISPs (tier 2 ISPs)
  - Local ISPs (tier 3 ISPs)
- The ISPs interchange traffic at
  - Network Access Points (NAP)
  - Metropolitan Area Exchange (MAE)

3-Tier view of the Internet



Basic Architecture – USA Example



- Regional ISPs provide services to their customers and to **local ISPs** (tier 3 ISPs) who sell Internet **access to individuals**.

- **National Internet service providers** (tier 1 ISPs) are responsible for large Internet networks and connect together and exchange data at **network access points** (about a dozen NAPs in USA)
- National ISPs provide services for their customers and also to **regional ISPs** (tier 2 ISPs)
- Regional ISPs rely on the national ISPs to transmit their messages to national ISPs in **other countries.**

MAEs, Regional ISPs, …

- **Metropolitan Area Exchange** (MAE) is a smaller versions of NAP and typically link a set of regional ISPs whose networks come together in major cities.
- Today there are about 50 MAEs in the United States.
- Some **large universities and corporations** that can be considered local ISPs (Indiana University provides Internet access for about 40,000 individuals) have direct connections into the Chicago NAP.
- **Regional and local ISPs** often have several connections into other national, regional, and local ISPs to provide backup connections in case one Internet connection fails (hence, they are not dependent on just one higher-level ISP.)

Peering, charging, …

- In general, ISPs at the same level do not charge one another for transferring messages they exchange across a NAP or MAE.
- A national tier 1 ISP does not charge another national tier 1 ISP to transmit its messages. This is called **peering.** (see previous figure)
- It is peering that makes the Internet work and has led to the belief that the Internet is free.
- However, higher-level ISPs normally charge lower-level ISPs to transmit their data (e.g., a national will charge a regional and a regional will charge a local).
- Each of the ISPs are **autonomous systems** and are responsible for running its own **interior routing protocols** and for exchanging routing information via the BGP **exterior routing protocol** at NAPs and MAEs and any other connection points between individual ISPs.

Connecting to an ISP

- Each of the ISPs is responsible for running its own network that forms part of the Internet.
- ISPs make money by charging customers to connect to their part of the Internet.
- Local ISPs charge individuals for internet access
- National and regional ISPs (and sometimes local ISPs) charge larger organizations for higher-speed access.
- Each ISP has one or more **points of presence** (POP).
- A POP is simply the place at which the ISP provides services to its customers.
- To connect into the Internet, a customer must establish a circuit from his or her location into the ISP POP.
- The customer must pay for both Internet access (paid to the ISP) and
- for the circuit connecting from their location to the POP usually paid to the local exchange carrier, or to the ISP if it can provide a circuit.

Internet Governance

- No one organization operates/runs the Internet
- Closest thing: Internet Society (ISOC)
  - Open membership professional society
  - Over 175 organizational and 8000 individual members in over 100 countries
  - Mission: “Open development, evolution and use of the Internet for the benefit of the people in the world.”
- ISOC work areas
  - Public policy: Involves in debates in copyright, censorship, privacy
  - Training and education programs
  - Standards

ISOC Standard Bodies

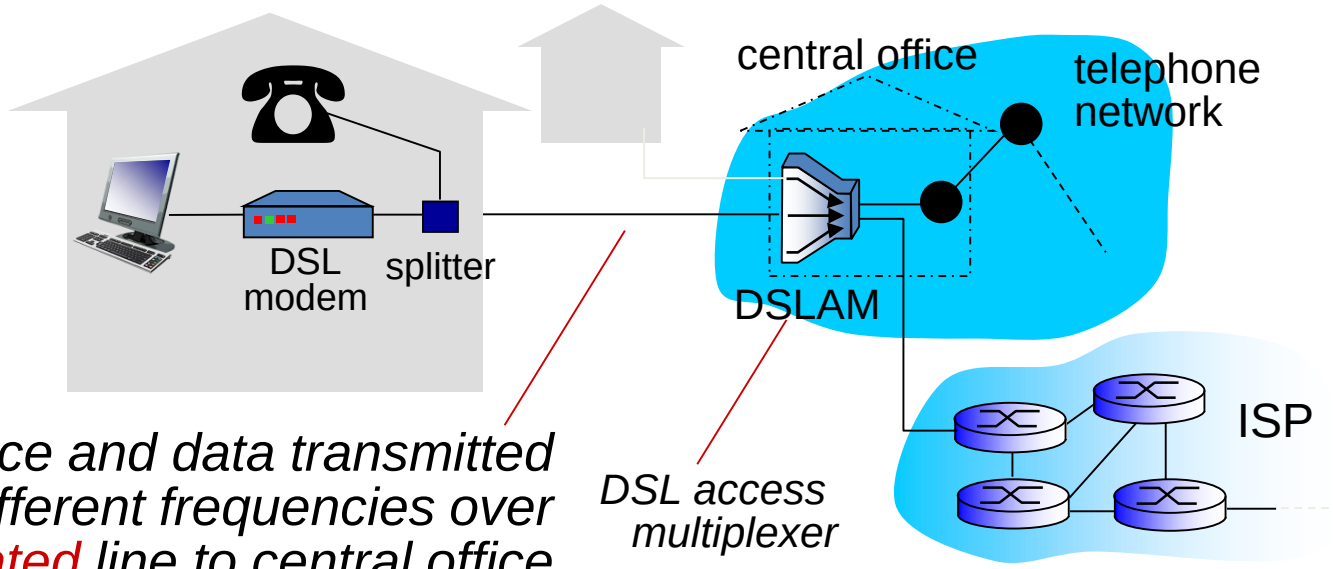
- Internet Engineering Task Force (IETF)
  - Concerned with evolution of Internet architecture and smooth operation of Internet
  - Work through groups (organized by topics)
  - Request For Comments (RFC): basis of Internet standards
- Internet Engineering Steering Group (IESG)
  - Responsible for management of the standard process
  - Establishes and administers rules in creating standards
- Internet Architecture Board (IAB)
  - Provides strategic architectural oversight, guidance
- Internet Research Task Force (IRTF)
  - Focus on long-term specific issues

Internet Access technologies

The “last mile” connection

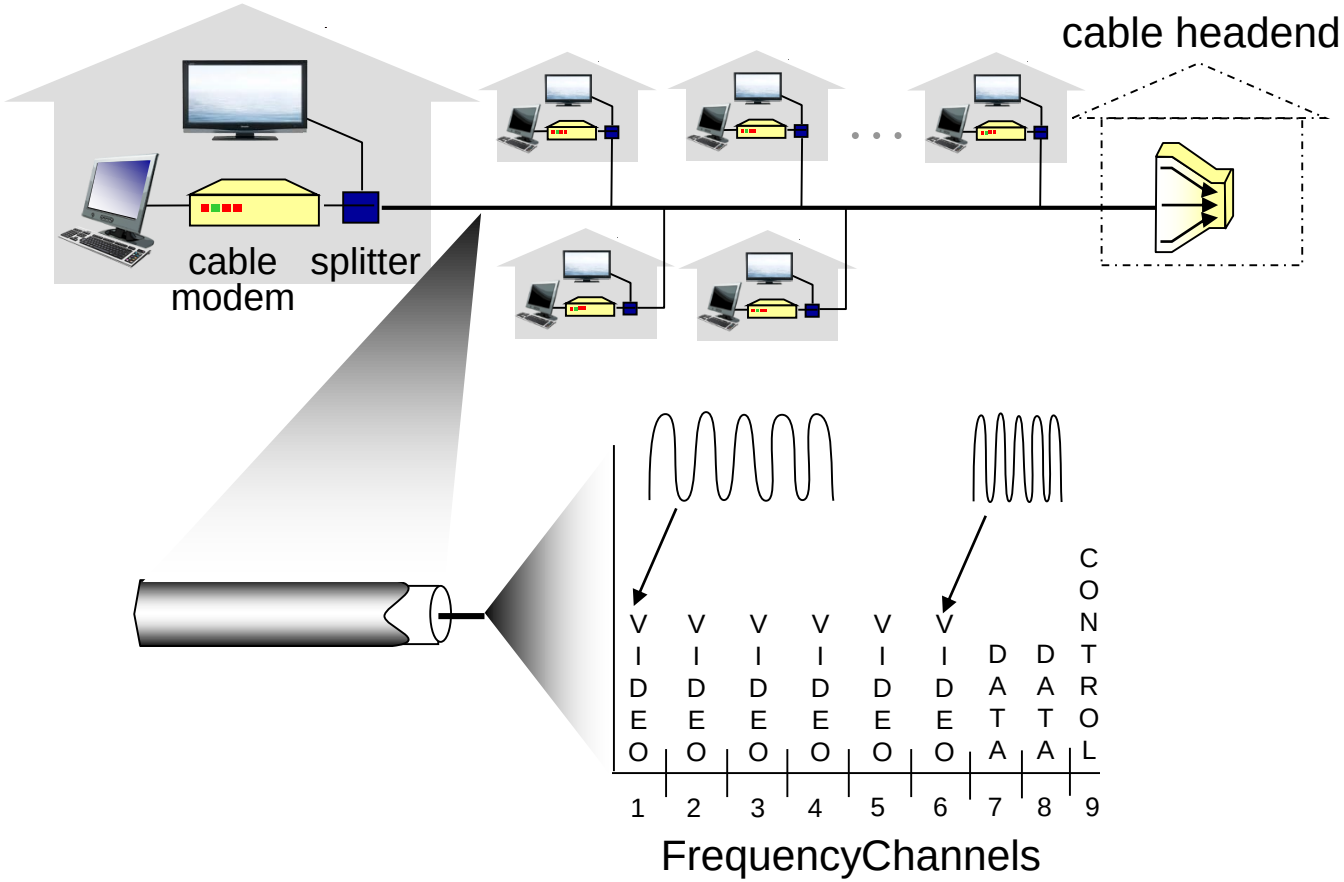
- Digital Subscriber Lines (DSL) based on existing telephone lines
- Cable modems – based on the existing coaxial cable TV network
- Fibre to the X – use the fibre optic cable to provide the Internet access to individual premises, houses,…
- Wireless Access (WiFi, LTE)

Access net: digital subscriber line (DSL)



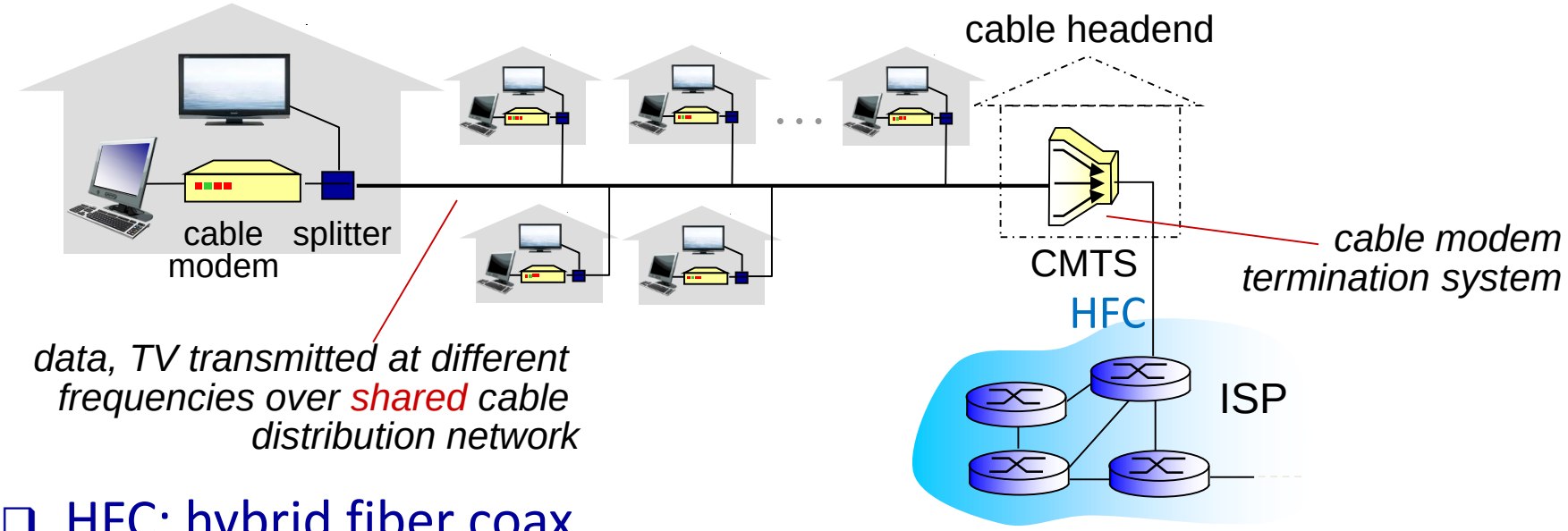
- use *existing* telephone line to central office DSLAM
  - data over DSL phone line goes to Internet
  - voice over DSL phone line goes to telephone net
- < 2.5 Mbps upstream transmission rate (typically < 1 Mbps)
- < 24 Mbps downstream transmission rate (typically < 10 Mbps)

Access net: cable network



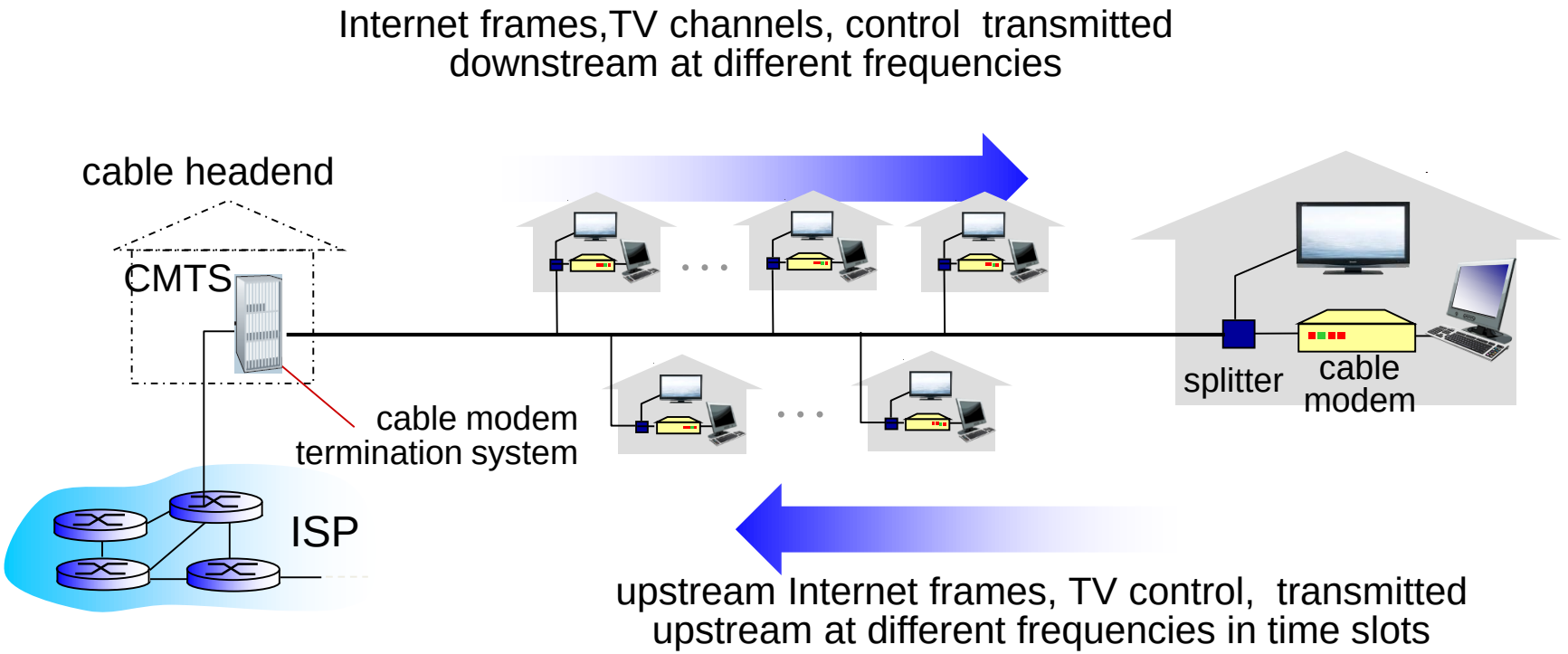
frequency division multiplexing: different channels transmitted in different frequency bands

Access net: cable network



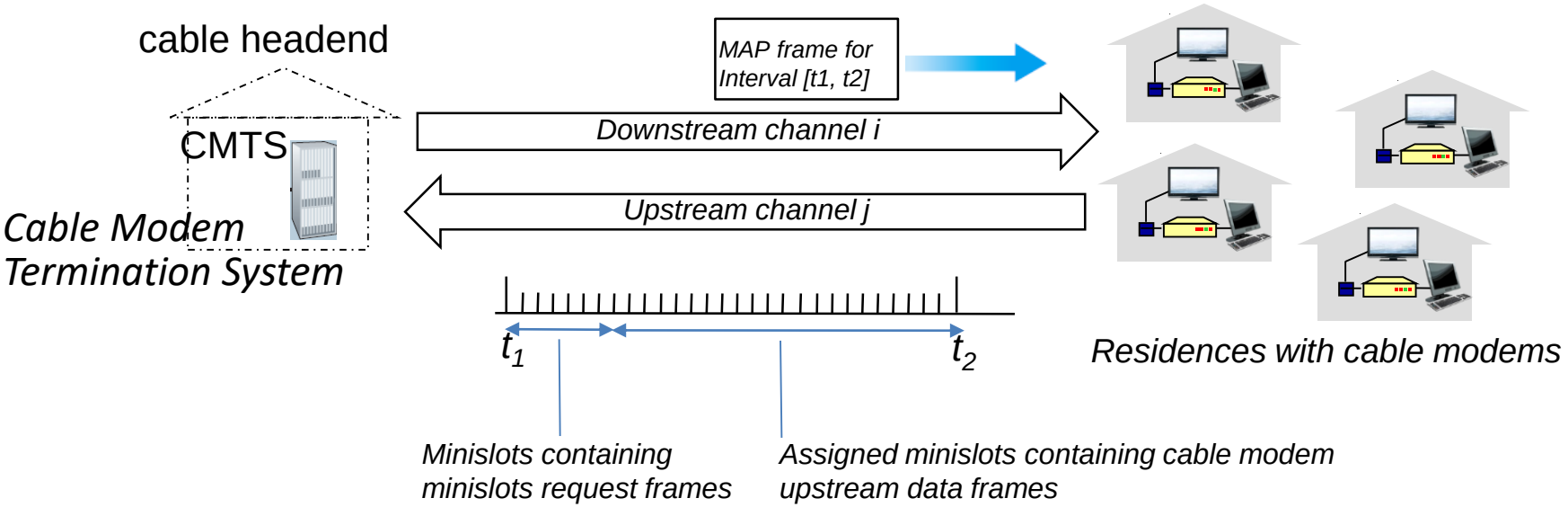
- HFC: hybrid fiber coax
  - asymmetric: up to 40Mbps downstream transmission rate, 2 Mbps upstream transmission rate (old data! x5 now)
- network of **coaxial and fiber optics** cables attaches homes to ISP router
  - homes *share access network* to cable **headend**
  - unlike DSL, which has dedicated access to central office

Cable access network



- *multiple* 40Mbps downstream (broadcast) channels
  - single CMTS transmits into channels
- *multiple* 30 Mbps upstream channels
  - *multiple access: all* users contend for certain upstream channel time slots (others assigned)

Cable access network



DOCSIS: data over cable service interface spec

- FDM over upstream, downstream frequency channels
- TDM upstream: some slots assigned, some have contention
  - downstream MAP frame: assigns upstream slots
  - request for upstream slots (and data) transmitted random access (binary backoff) in selected slots

Optical Fibre Networks (the last mile)

- Existing “last mile” connections for individual users, namely ADSL and “Cable Modems” aka HFC, have being replaced by the fibre optics based networks commonly known as: **Fiber to X (FTTX)**
- FTTX is a generalization for several configurations of fibre deployment, arranged into two groups:
- FTTP/FTTH/FTTB (Fiber laid all the way to the premises/home/ building)
- FTTC/N (fiber laid to the cabinet/node, with copper wires completing the connection).
- **FTTP** exists in the R&D appartments
- 80% of China's broadband connections (end of 2016) are by Fiber making China the world leader in FTTP.

Fibre to the X

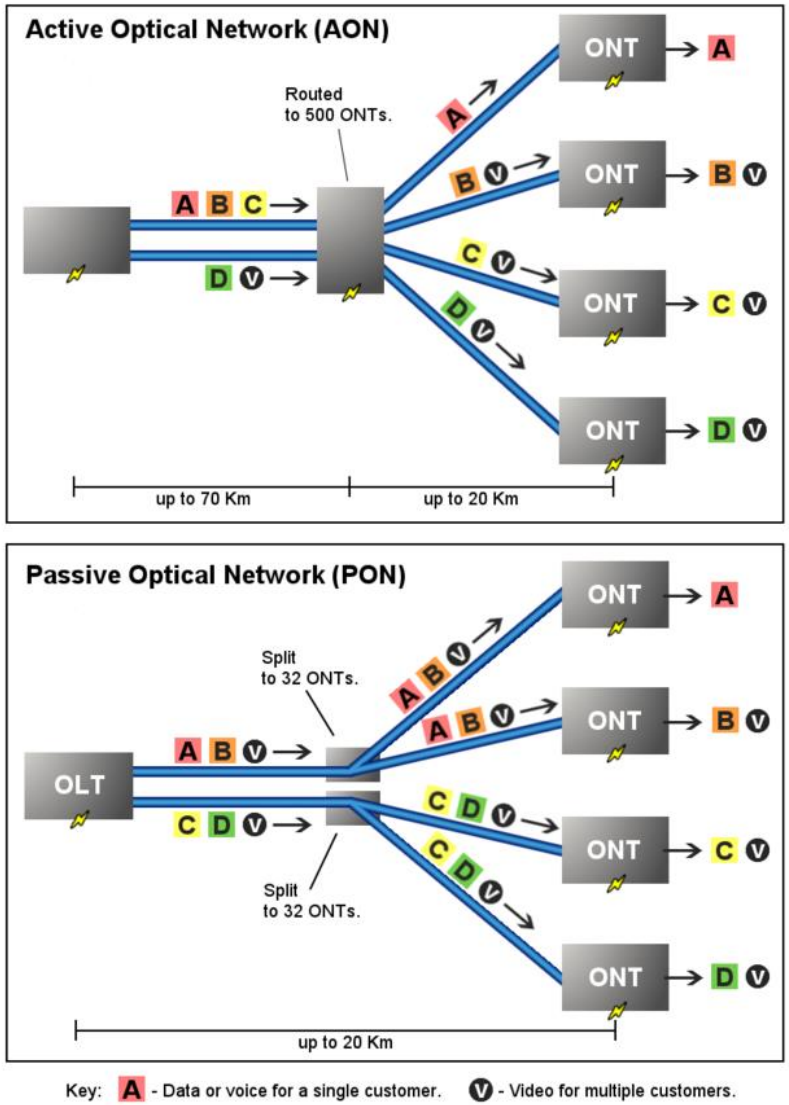
- **FTTN** (*fiber-to-the-node):* Fiber is terminated in a street cabinet, possibly miles away from the customer premises, with the final connections being copper.
- **FTTC** (*fiber-to-the-curb*): similar to FTTN, but the street cabinet or pole is closer to the user's premises, typically within 300 m, within range for high-bandwidth copper technologies such as wired Ethernet, WiFi or IEEE 1901 power line networking
- **FTTP** (*fiber-to-the-premises*):
  - **FTTB** (*fiber-to-the-building, -business, or -basement*): Fiber reaches the boundary of the building, such as the basement in a multi-dwelling unit, with the final connection to the individual living space being made as in FTTC
  - **FTTH** (*fiber-to-the-home*): Fiber reaches the boundary of the living space, such as a box on the outside wall of a home.
  - Passive optical networks and point-to-point Ethernet are architectures that deliver **triple-play** services over FTTH networks.

Optical distribution networks

- **Direct fiber**
  - The simplest optical distribution network architecture is direct fiber: each fiber leaving the central office goes to exactly one customer.
  - Such networks can provide excellent bandwidth but are about 10% more costly due to the fiber and central office machinery.
  - Direct fiber is generally favored by new entrants and competitive operators.
- **Shared fiber**
  - More commonly, each fiber leaving the central office is actually shared by many customers.
  - It is not until such a fiber gets relatively close to the customers that it is **split into individual** customer-specific fibers.
  - The split is performed by
    - **Active optical network (AON)**
    - **Passive optical network PON)**

Active and Passive Optical Networks

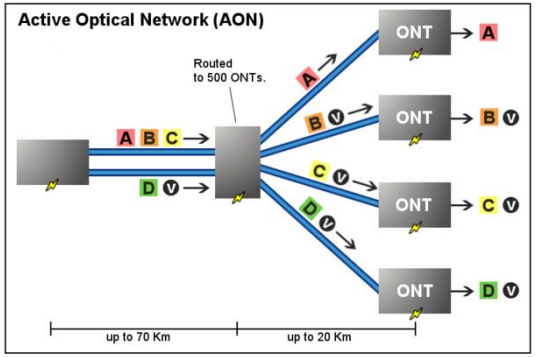
- AON is a star network with a single electrically powered splitter/router delivering multicasting traffic over, say 20 km, to a significant number (say 500) of customers.
- A PON is also a star network but with multiple splitters housed in the same cabinet without power supply.
- Note the smaller distance and the smaller number of customers (e.g. up to 32)
- ONT – optical network terminal

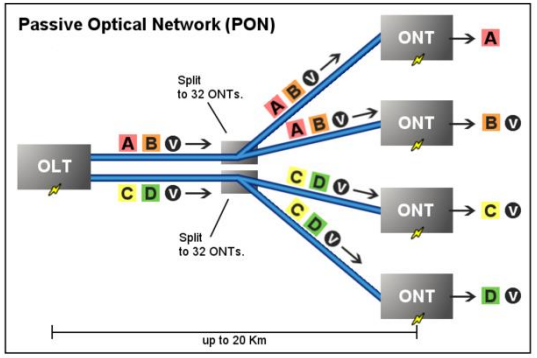


AONs and PONs

Active optical network (AON)

- AON uses **optical Ethernet switches** to distribute the signal, incorporating the customers' premises and the central office into a large switched Ethernet network.
- Such networks are identical to Ethernet computer networks used in businesses and academic institutions.
- Each switching cabinet can handle up to 1,000 customers, although
- Speeds of 1Gbit/s are becoming commercially available.





Key: A - Data or voice for a single customer. V - Video for multiple customers.

Passive optical network PON)

- PONs use **unpowered optical splitters** that enable a single optical fiber to serve up to 128 customers.
- A PON reduces the fiber and central office equipment required compared with point-to-point architecture.
- Downstream signal coming from the central office is broadcast to each customer premises sharing a fiber.
- Encryption is used to prevent eavesdropping.
- Upstream signals are combined using a multiple-access protocol, usually time division multiple access (TDMA).