Network Technologies

ITS 413 – Internet Applications and Technologies

Contents

- Review of Access and Backbone Networks
  - LANs, ADSL, ATM, MPLS, …
- Optical Network Technologies
  - SONET/SDH
  - IP over optical networks
- Example and Future Networks
  - Abilene, GEANT2, TransPac, Thailand Internet

Aim

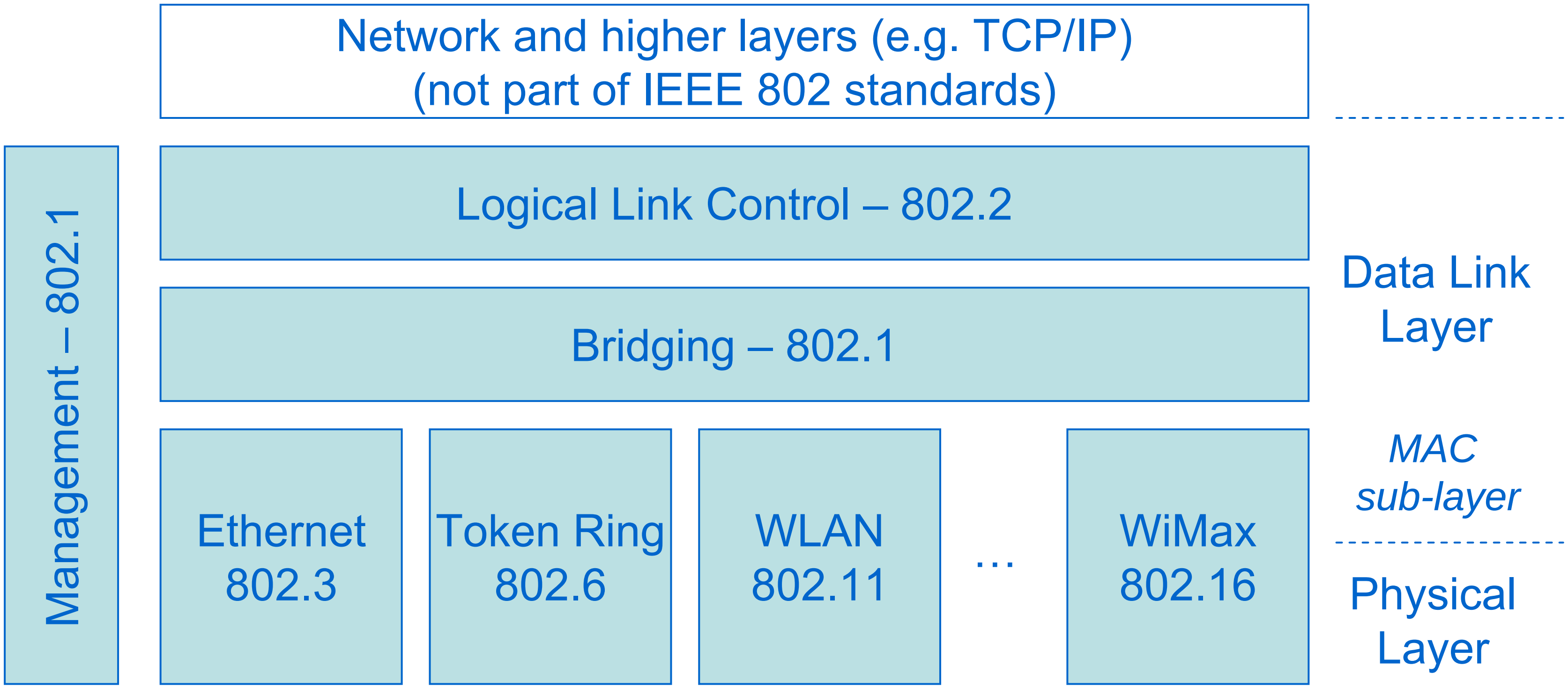
- Focus on fixed, wired technologies (wireless is covered in next topic)
- Some topics are new, some topics you should know
  - We do not go into detail of most topics, for example:
    - You will know ‘what it is and does’ but may not know ‘how it works’
- Aim:
  - Introduce (and refresh) basics of different network technologies
    - Learn the role of different technologies
  - Provide basis for understanding functionality and performance of higher layer protocols (e.g. IP, TCP) and applications

Ethernet Technologies

Network Technologies

IEEE 802 Standards

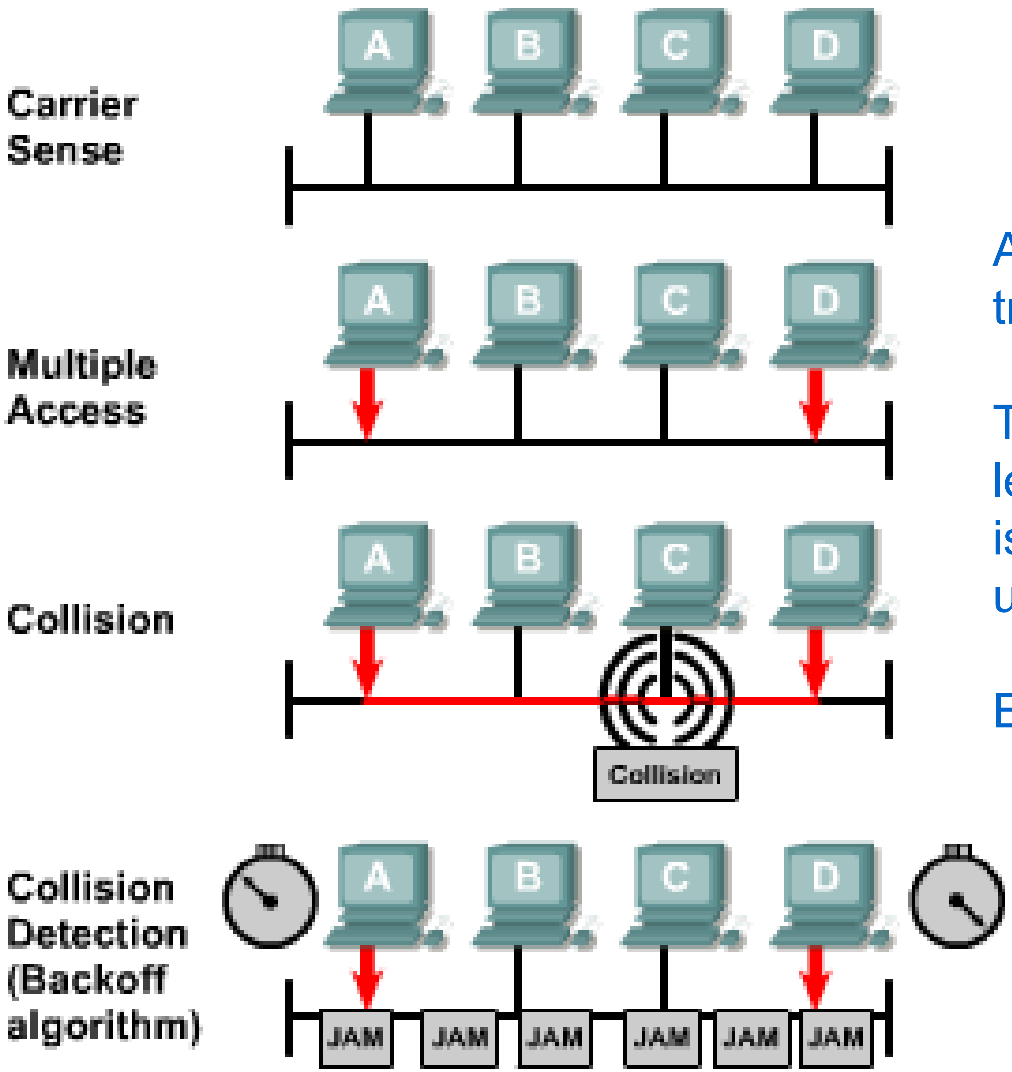
Standards for local and metropolitan area networks



Ethernet Networks

- Dominant technology for Local Area Networks (LANs)
  - Standardised in IEEE 802.3
  - Invented in mid-1970's
  - Ethernet was 10Mb/s over half-duplex connections
    - CSMA/CD used to avoid collisions
  - Fast Ethernet at 100Mb/s (most common today)
    - Full duplex connections to avoid collisions
    - Switched networks
  - Use copper, unshielded twisted pair (UTP)
  - Move from copper/UTP to optical fibre: Gigabit and 10GB Ethernet
- Success due to:
  - Simplicity and ease of maintenance
  - Ability to incorporate new technologies
  - Reliability
  - Low cost of installation and upgrade

Carrier Sense and Collisions



Aim: only 1 user transmits at a time

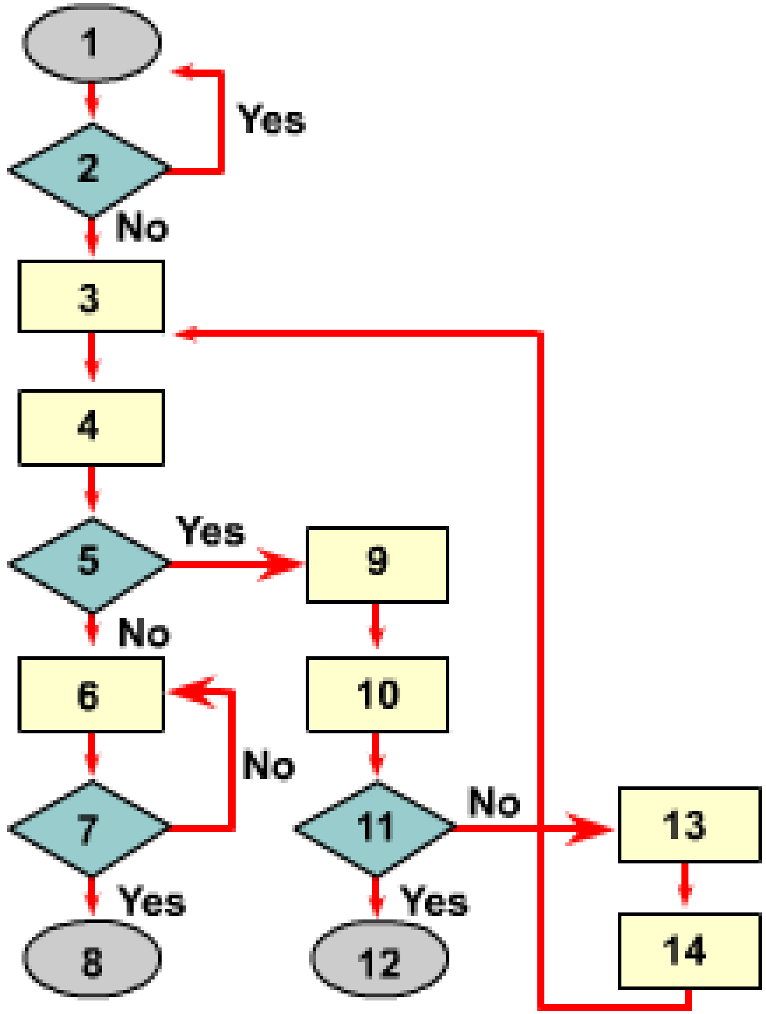
Total bandwidth (B) less overheads (O) is shared between N users:

Each user: (B-O)/N

Source:
Cisco Systems,
CCNA1 Module 6

Ethernet CSMA/CD Basic Rules

1. Host wants to transmit
2. Is carrier sensed?
3. Assemble frame
4. Start transmitting
5. Is a collision detected?
6. Keep transmitting
7. Is the transmission done?
8. Transmission completed
9. Broadcast jam signal
10. Attempts = Attempts + 1
11. Attempts > Too many?
12. Too many collisions; abort transmission
13. Algorithm calculates backoff
14. Wait for t microseconds

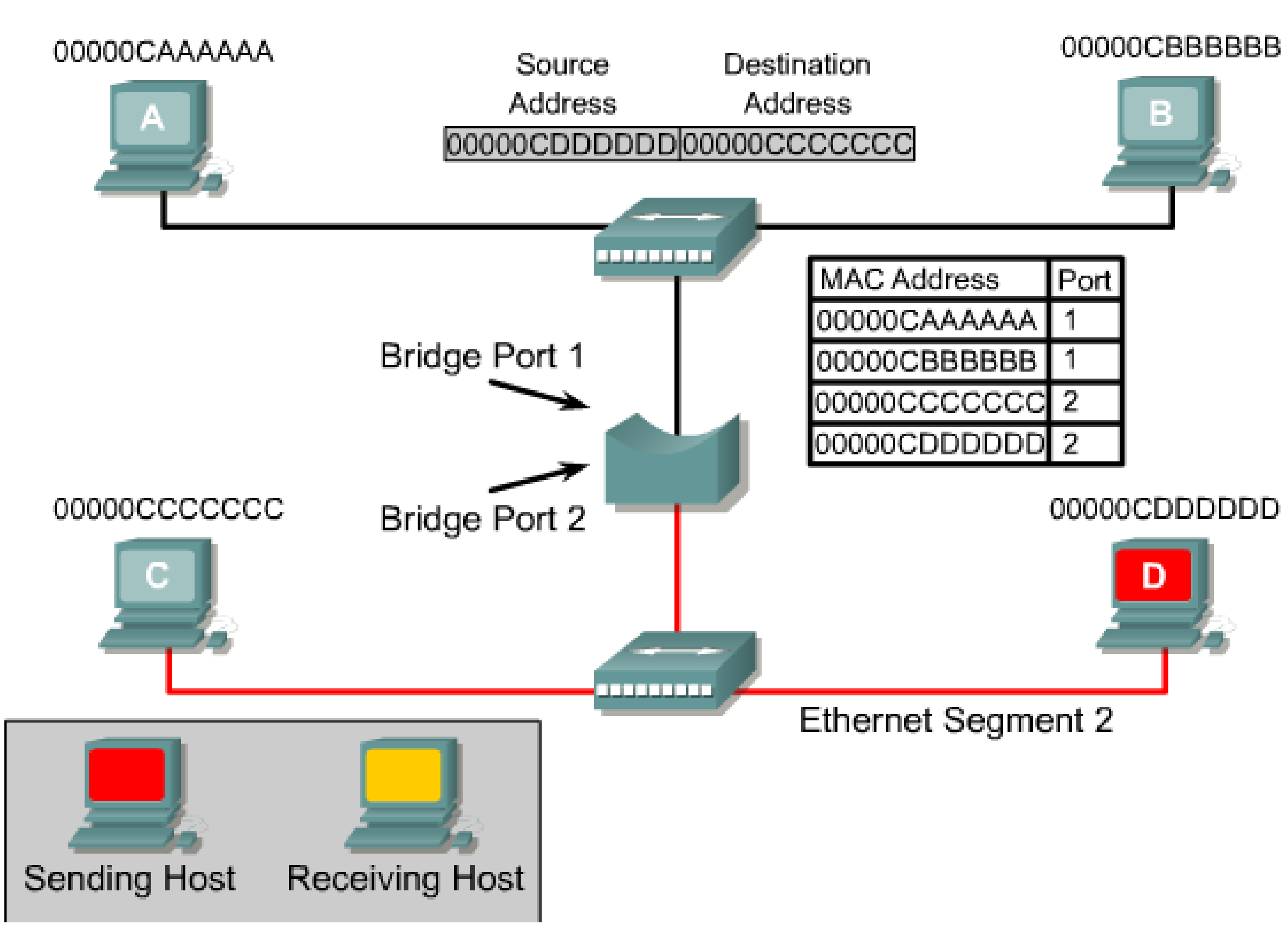


Source:
Cisco Systems,
CCNA1 Module 6

Ethernet Switching

- Original Ethernet:
  - Bus topology
  - All computers share access to link
  - If too many computers, performance drops significantly (due to collisions)
- Bridged Ethernet:
  - Separate segments (collisions domains) by a 'bridge'
  - Only send packets to other side of bridge if destination is there
- Switched Ethernet:
  - Similar to bridge, but more ports (e.g. one for each computer)
  - Only two hosts per collision domain (switch and computer)
    - But using twisted pair cable, can have full duplex
    - Switch and computer transmit at same time
    - No collisions!

Ethernet Bridging



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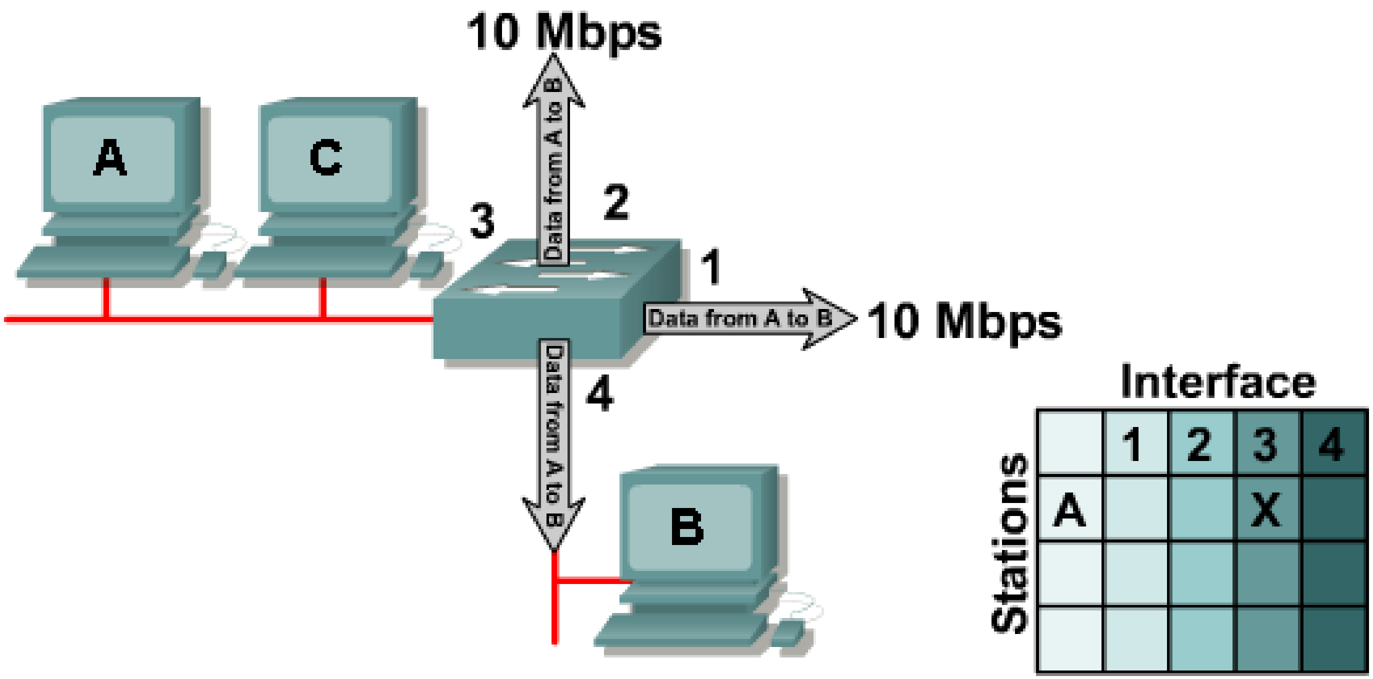
Ethernet Switching



- Forward packets based on MAC address in forwarding table
- Operates at OSI Layer 2
- Learns a station's location by examining source address

Source:
Cisco Systems,
CCNA1 Module 8

Gigabit Ethernet

- Standards: IEEE 802.3z, IEEE 802.3ab
- Use (Fast) Ethernet MAC over different Physical layers:
  - Optical fibre
  - Shielded Coaxial cable
  - UTP copper
- Trade-off between cost and distance
- Interoperate with existing Fast Ethernet networks
  - Preserve Ethernet frame format
- Applications:
  - LAN backbones
  - Server-switch links
  - Gigabit Ethernet workstations

Gigabit Ethernet Media

- Different physical layers are available:
  - Copper (UTP): maximum distance of 100m
    - suitable for Gigabit LANs
  - Coaxial cable: 25m, obsolete by UTP
  - Fibre optic: different wavelengths
    - Single-mode fibre: 2-3km
    - Multi-mode fibre: 300-500m
    - Suitable for backbones and links between devices

10 Gigabit Ethernet

- IEEE 802.3ae
- LAN *and WAN* physical interfaces
- Utilizes DWDM and Wide WDM
- Optionally can run on top of SONET/SDH
  - WAN interface places Ethernet frames into SONET/SDH frames, which are then transported over OC-192c (10Gb/s)
- Challenges:
  - Doesn’t include redundancy features of SDH/SONET
  - Doesn’t include in built QoS of ATM
- Media:
  - Optical fibre: 10’s of metres to 10’s of kilometres
  - Copper: 10-30 metres

10 Gigabit Ethernet Applications

- Enterprise
  - Storage Area Networking: interconnect servers and storage over a enterprise or campus
- Points of Presence (PoP)
  - Layer 2 switches interconnecting edge routers (to LANs) and corer routers (to WAN)
- Metropolitan Are Networks
  - Ring networks interconnecting campus' around a city
- Wide Area Networks
  - Optical DWDM WANs with 10GbE wavelengths

Residential Access

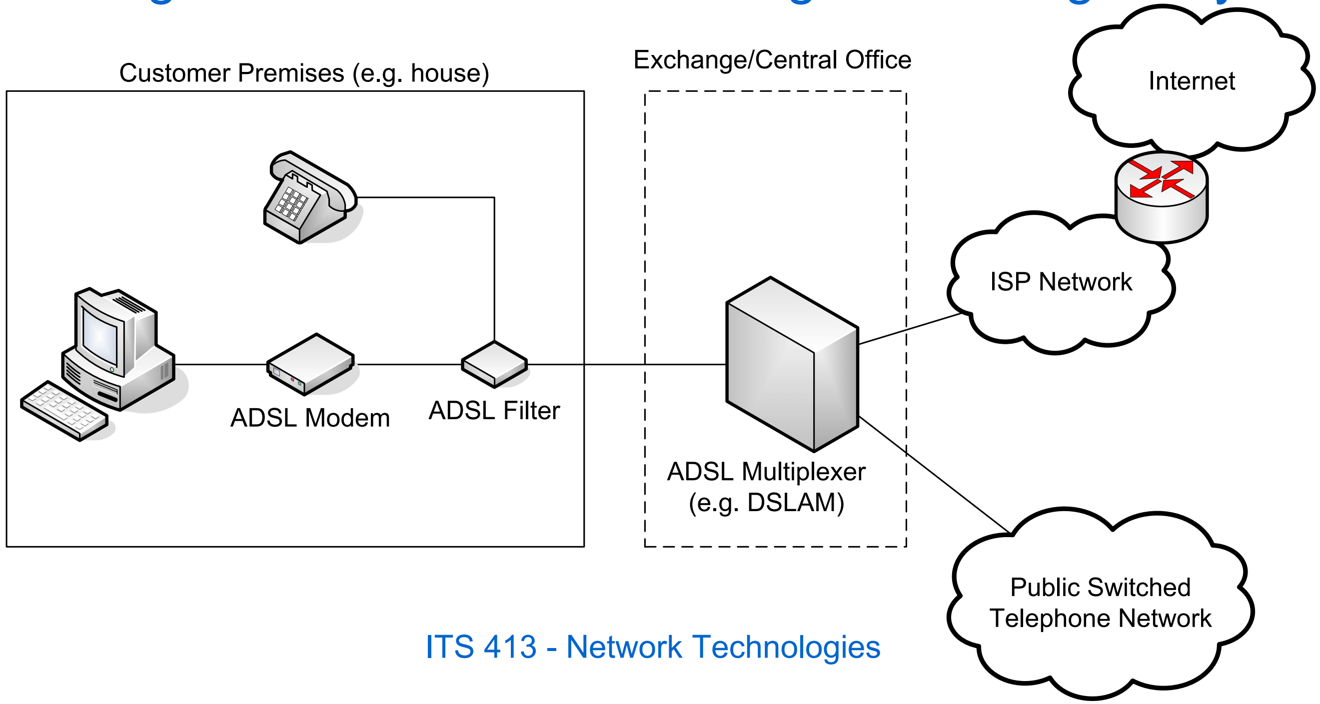
Network Technologies

Residential or Small Office Access

- Dialup Modem
  - Use modem to connect over Public Switched Telephone Network (PSTN)
  - Very low cost, can be used over almost any phone line
  - Data rates: 10-56kb/s (v.92)
    - Generally slow for today's web pages and multimedia content
- ISDN
  - Integrated Services Digital Network
  - Uses two copper lines to achieve 128kb/s
  - Line can also be used for voice calls and fax
  - Not very common – overtaken by ADSL
    - Except where ADSL is not available (e.g. rural areas)

ADSL

- Part of Digital Subscriber Line technologies
- Asymmetric (others include Symmetric, High data rate, Very high data rate, …): e.g. 128kb/s upload, 512kb/s download
- Typical distance up to 5 kms
- ADSL2/2+ offer download rates up to 24Mb/s (in practice 8-12Mb/s)
- Requires significant DSLAM in exchange – coverage may be limited



Other Technologies

- Cable Modem
  - Utilise existing cable technology for TV access
  - Downloads of 8-30Mb/s, but shared amongst neighbourhood
- Wireless Access
  - Satellite broadcast for download, dialup modem for upload
    - Performance problems when combine with dialup modem
  - VSAT, two-way access
    - Small satellite ground station at premises for upload and download via satellite
    - IPStar: up to 4Mb/s (often 512/1024kb/s) download
  - Point-to-point wireless LAN and Mesh Networks
    - Wireless Ethernet direct to premises (similar rates to ADSL)
    - Covered in later topics

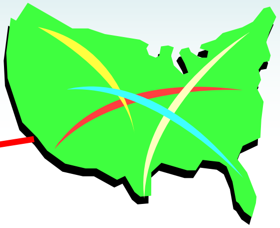
Core and Backbone Technologies

Network Technologies

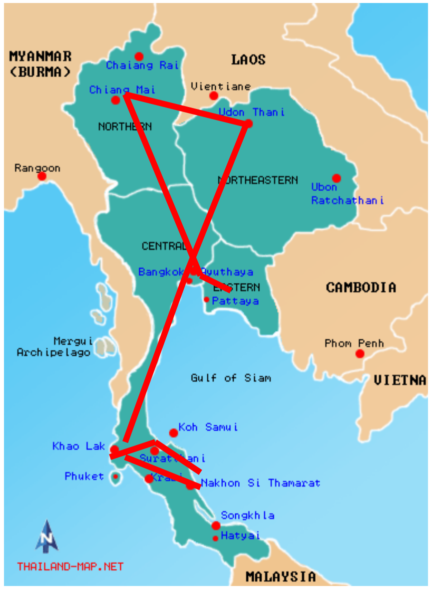
Overview

- We will use *Transport Networks* to refer to both core and backbone networks
  - Although size of core and backbone differ, technologies are same
- Gigabit and 10 Gigabit Ethernet can be used for transport networks
- We will look at some “old” and “new” technologies used in transport networks

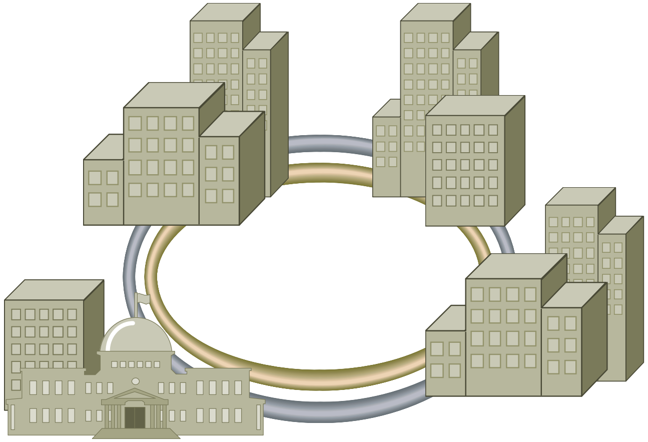
Interconnecting countries ….



… Interconnecting cities …



…. Interconnecting large networks.

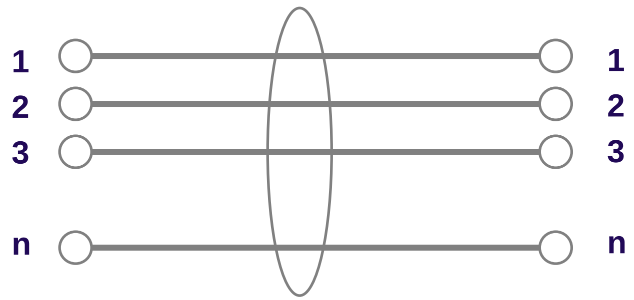


Transport Network Requirements

- Characteristics of transport networks:
  - High cost
    - Installing cables underground or undersea in cities, across countries is expensive
    - Renting premises for network equipment is expensive
  - Large and complex
  - Carry large amounts of traffic
    - Traffic of all users of an ISP; traffic between cities and countries
- Therefore important requirements of:
  - Flexibility
    - Can interconnect many different points
    - Interconnections can be changed; upgraded easily
  - Easy Management
    - Bandwidth can be assigned to any pair of connecting points
  - Resilience
    - Network can tolerate errors and failures
      - If a link fails, need (at least one) backup

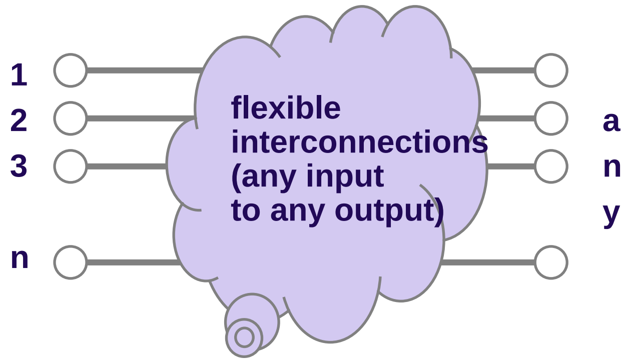
Old and New Transport Networks

- "Older" transport networks
  - Fixed point-to-point interconnections between connecting points



  - Multiplexers (MUX) used to multiplex many lines onto 1
  - E.g. Line 1 to 1, 2 to 2, …
  - Fixed connections
  - Original PDH (E1,T1)

- "New" transport networks
  - Flexible interconnections



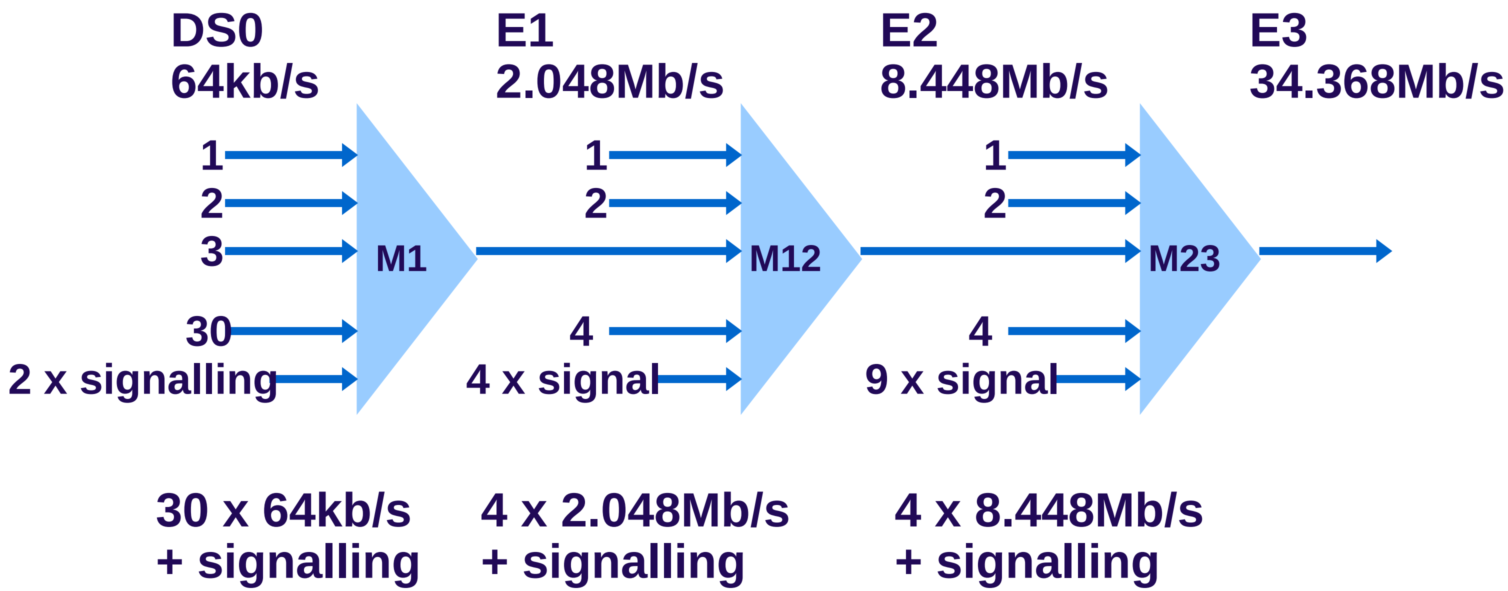
  - To achieve this network uses:
    - Add/Drop Multiplexers
    - Digital Cross connect switches
    - Hubs
    - Ring and bus topologies
  - SDH/SONET, ATM, MPLS

Legacy Transport Networks

- Based on traditional telecommunication circuits
  - Continuous transmission over copper
  - Time Division Multiplexing, using basic 64kb/s circuit
- Also called *leased digital circuits* or *leased line*
  - User pays monthly rate for connection between end-points
- Connection is long-term (months, years)
- Example use:
  - ISPs and Telecommunication providers interconnecting networks across cities, countries, the world
  - ISPs interconnecting exchanges within their network
  - Large organisations (company, university) interconnecting sites or connecting to ISP

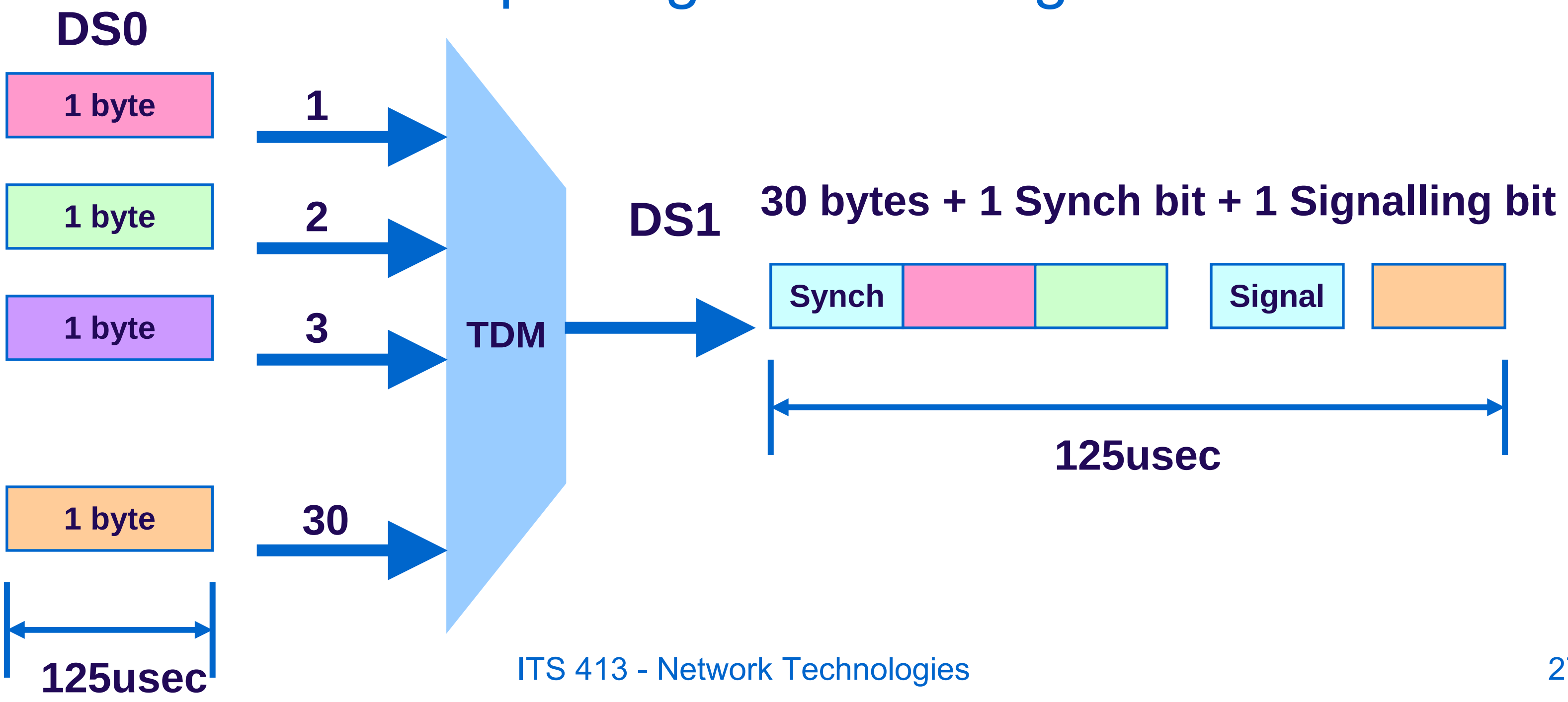
Plesiochronous Digital Hierarchy (PDH)

- Based on basic 64kb/s voice circuit using Time Division Multiplexing
  - Clocks may be free-running (imperfect alignment)
  - “bit stuffing” techniques used to re-align clocks
- European System
  - E1 takes 30 x 64kb/s input lines to create 2Mb/s output



Time Division Multiplexing

- 'Digitised voice networks' are based on multiples of 8kHz sampling rate, 64Kb/s channels and on 125usec time slots
- Digital Signal Level 0 (DS0): 64Kb/s
- Time division multiplexing to create higher rates



Hierarchical Multiplexing in PDH

North American PDH

electr/carrier	data rate
DS0 / T0	64 kbps
DS1 / T1	1.544 Mbps
DS2 / T2	6.312 Mbps
DS3 / T3	44.736 Mbps
DS4 / T4	274.176 Mbps

International PDH

carrier	data rate
DS0	64 kbps
E1	2.048 Mbps
E2	8.448 Mbps
E3	34.368 Mbps
E4	139.264 Mbps

Problems with PDH

- Multiplexing hierarchy
  - At each end-point to obtain data from E1 (2Mb/s), must de-multiplex down to that level, for example: E3 → 4xE2 → 16xE1
  - Complex to implement, meaning slow equipment
- Use of copper wiring limits the speeds
  - (Overcome with later standards to allow optical fibre)
- Inflexible management features

Synchronous Hierarchies

- Replacement for PDH
  - All clocks referenced to the same high precision source
    - “byte-stuffing” used to align payload entities with the synchronous frame
  - Transmission medium is optical fibre (not copper wire)
    - Higher reliability
    - Lower BER
    - Higher bandwidth per fibre
    - Longer transmission distances
  - International: Synchronous Digital Hierarchy (SDH)
  - US: Synchronous Optical Network (SONET)
    - SDH used in Thailand

SDH/SONET Transmission Rates

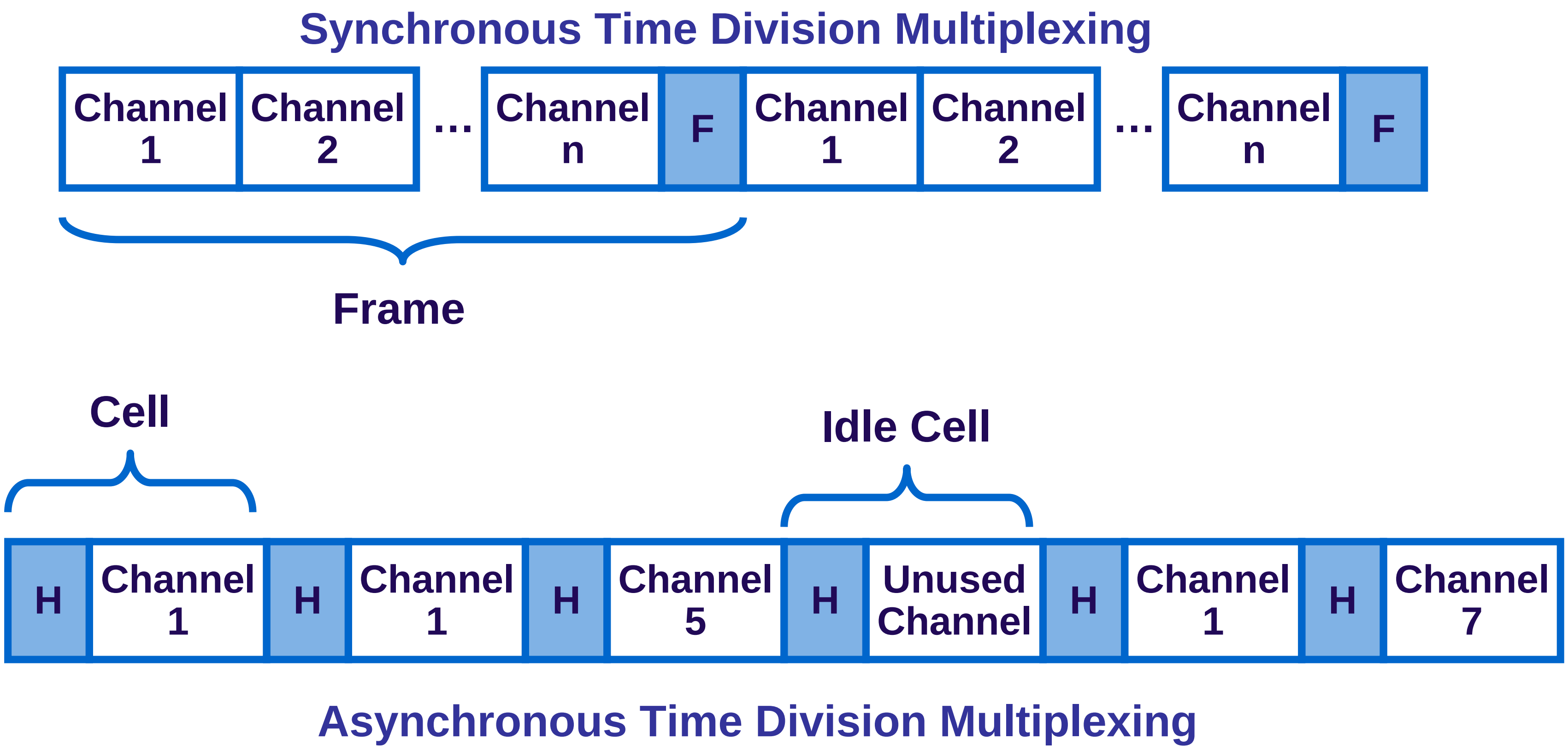
SONET	SDH	Optical	Rate (Mb/s)
STS-1	STM-0	OC-1	51.84
STS-3	STM-1	OC-3	155.52
STS-12	STM-4	OC-12	622.08
STS-48	STM-16	OC-48	2,488.32
STS-192	STM-64	OC-192	9,953.28
STS-768	STM-256	OC-768	39,813.12

- Electrical:
  - STS-N: Synchronous Transport Signal level N
  - STM-N: Synchronous Transport Module level N
- Optical:
  - OC-N: Optical Carrier level N

Benefits of SDH/SONET

- Efficient multiplexing from low-order to high-order
  - Can also carry many different types of traffic: E/T hierarchy, ATM, IP, …
- Resilience
  - Ring and bus topologies cope with failures
    - Ring topology: 2 lines, one in each direction; if one fails, the other can be used
- Network Management: built in features
  - Automatic Protection Switching: when a link fails, can automatically switch to another link (in milliseconds or seconds)
  - Connection monitoring and parity checking in frames
  - Voice/Data channels for technicians via the SDH signal
  - Alarms for error reporting

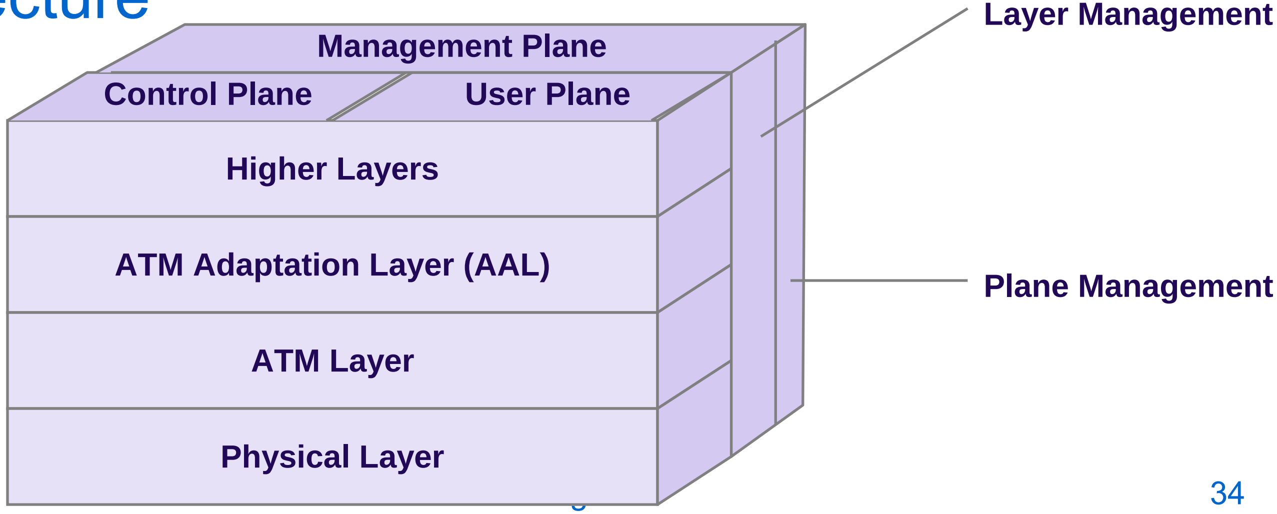
Synchronous Vs Asynchronous Multiplexing



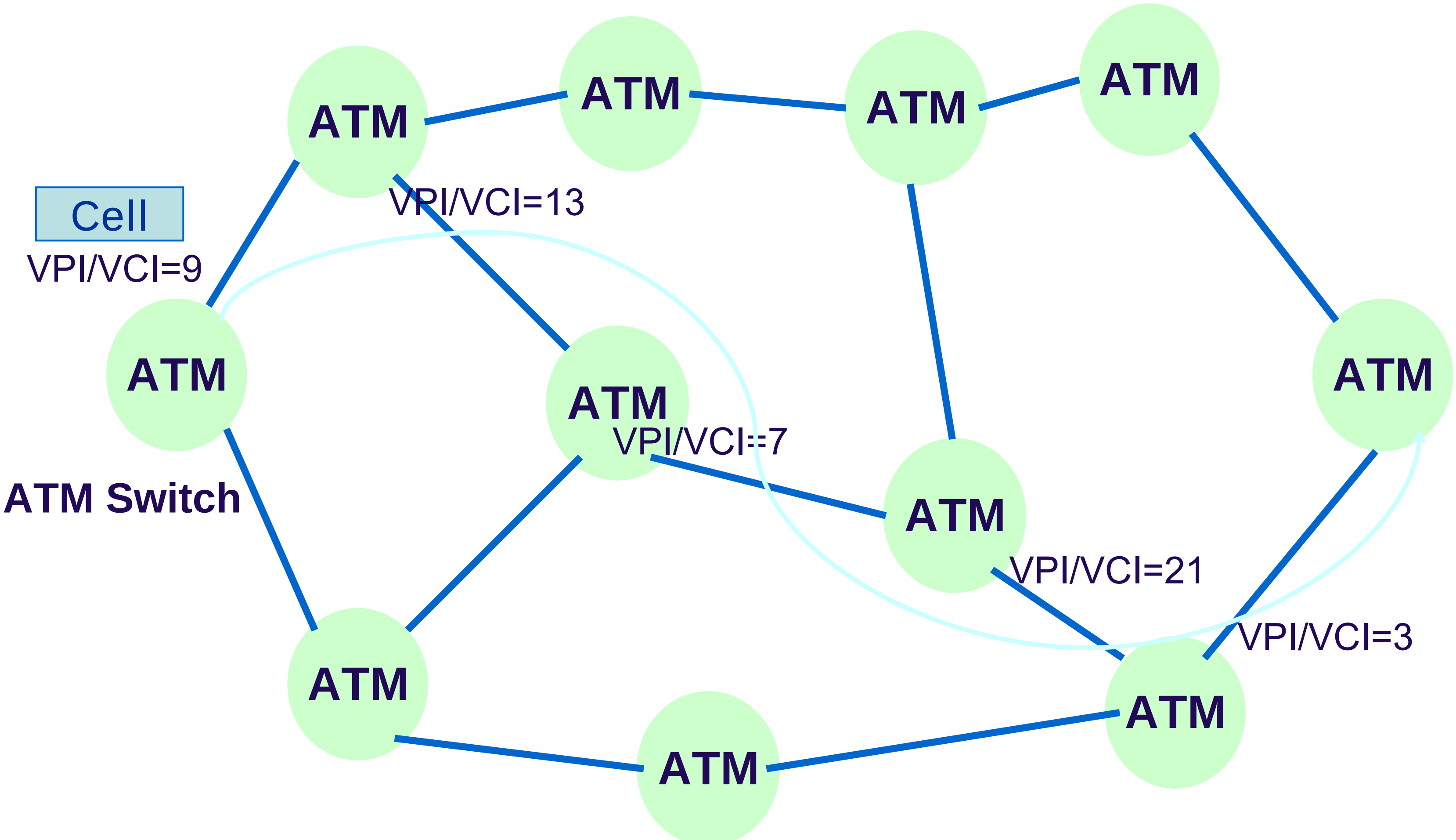
Time slots (or cells) are available to any user ready to transmit

ATM

- ATM (Asynchronous Transfer Mode) is a fast packet switching transfer mode
  - small, fixed size/format (53 octets) packets (cells)
  - high speed optical fibre transmission systems
  - fast packet switching - it is not necessary to buffer the entire cell in order to perform cell switching
  - Connection-oriented service
- Protocol Architecture



Cell Switching/Label Swapping



Require signalling to establish VPI/VCI (label) swapping tables at switches

ATM

- ATM aims and features:
  - Support all types of services: voice, data, video
  - Explicit quality of service control
    - Setup a connection – if not enough resources for session, then connection setup fails
  - Support different higher layer protocols
  - Segmentation and re-assembly to carry different types of frames in 53-byte cell
  - LAN and WAN solution
  - SONET/SDH can encapsulate ATM cells

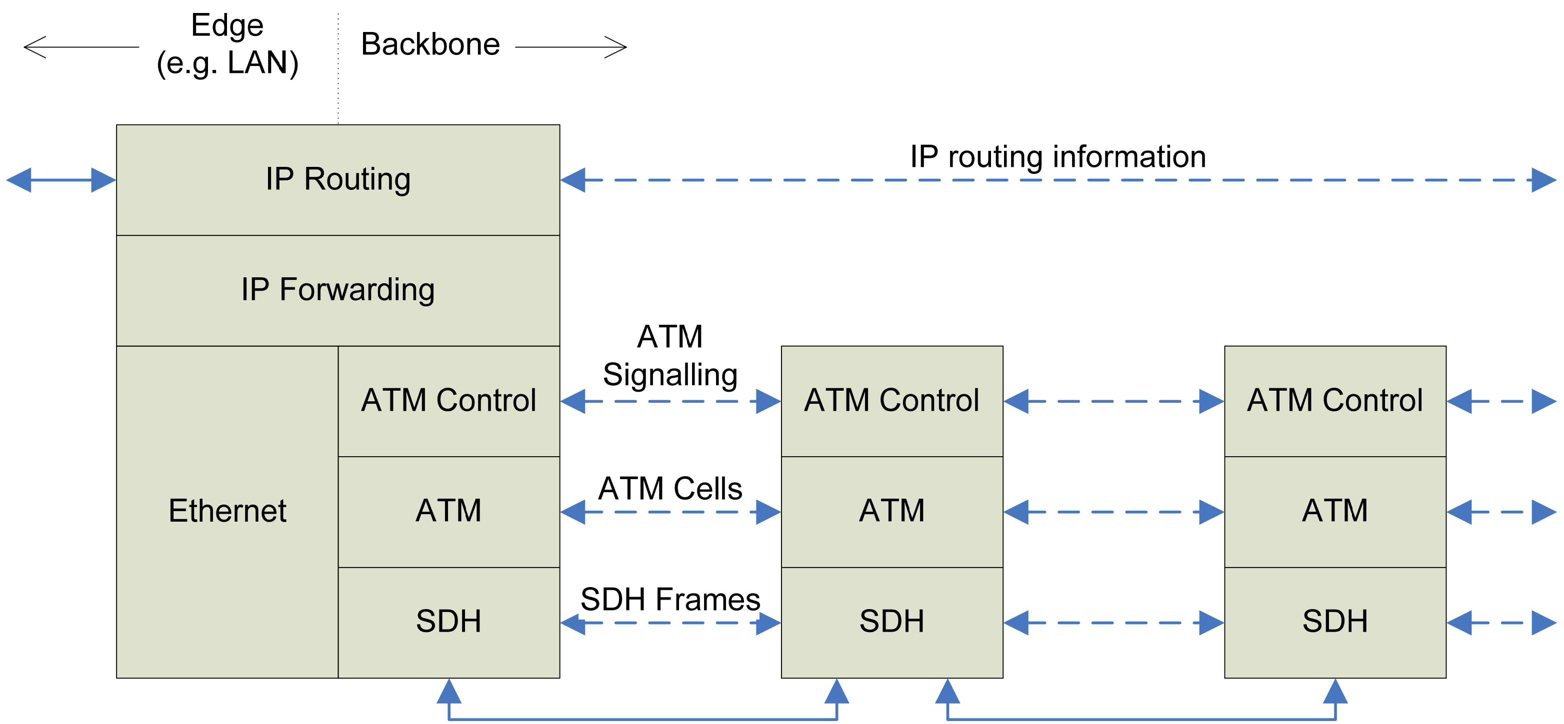
Problems with ATM

- Lengthy and complex standardisation process
  - Other protocols/technologies became popular before ATM
  - Complex standards to implement
- LAN component is very expensive (compared to Ethernet)
- Segmentation and Re-assembly complex and expensive to implement (SAR is needed to support different traffic such as Ethernet over ATM)
- ATM ‘cell tax’: inefficiencies of using 53-byte cell

Classical IP over ATM

Past

- Use ATM forwarding and signalling over backbone
  - Complex ATM switches
  - Scalability issues

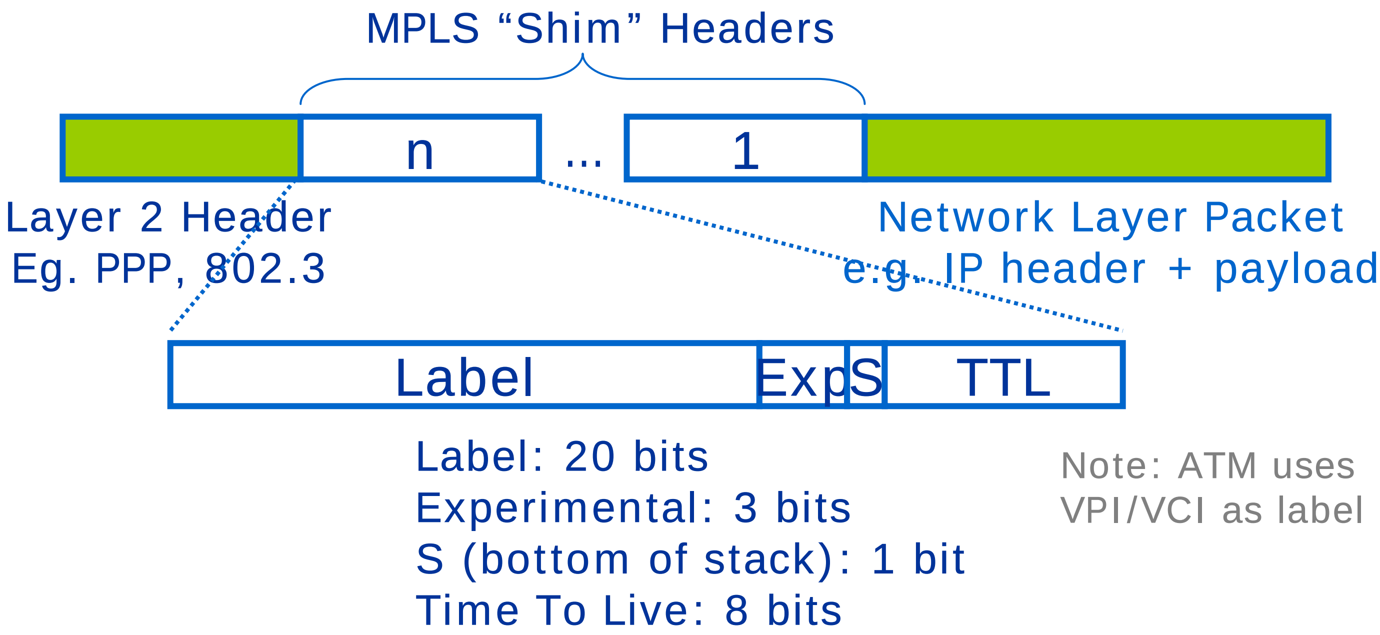


MPLS

- Multi Protocol Labelled Switching
- Motivation:
  - IP routing had performance problems when using all software routing
    - Very large routing tables (slow to search)
    - Packet forward was relatively slow
  - Classical IP over ATM
    - ATM provides fast (hardware) packet switching, so use ATM in the backbone network and IP at edge
    - Can utilise SDH/SONET and ATM QoS Features
  - But Classical IP over ATM …
    - Complex ATM switches and signalling protocols
    - Does not scale very well with many switches/routers
- Hence, IETF developed MPLS (RFC 3031)

MPLS

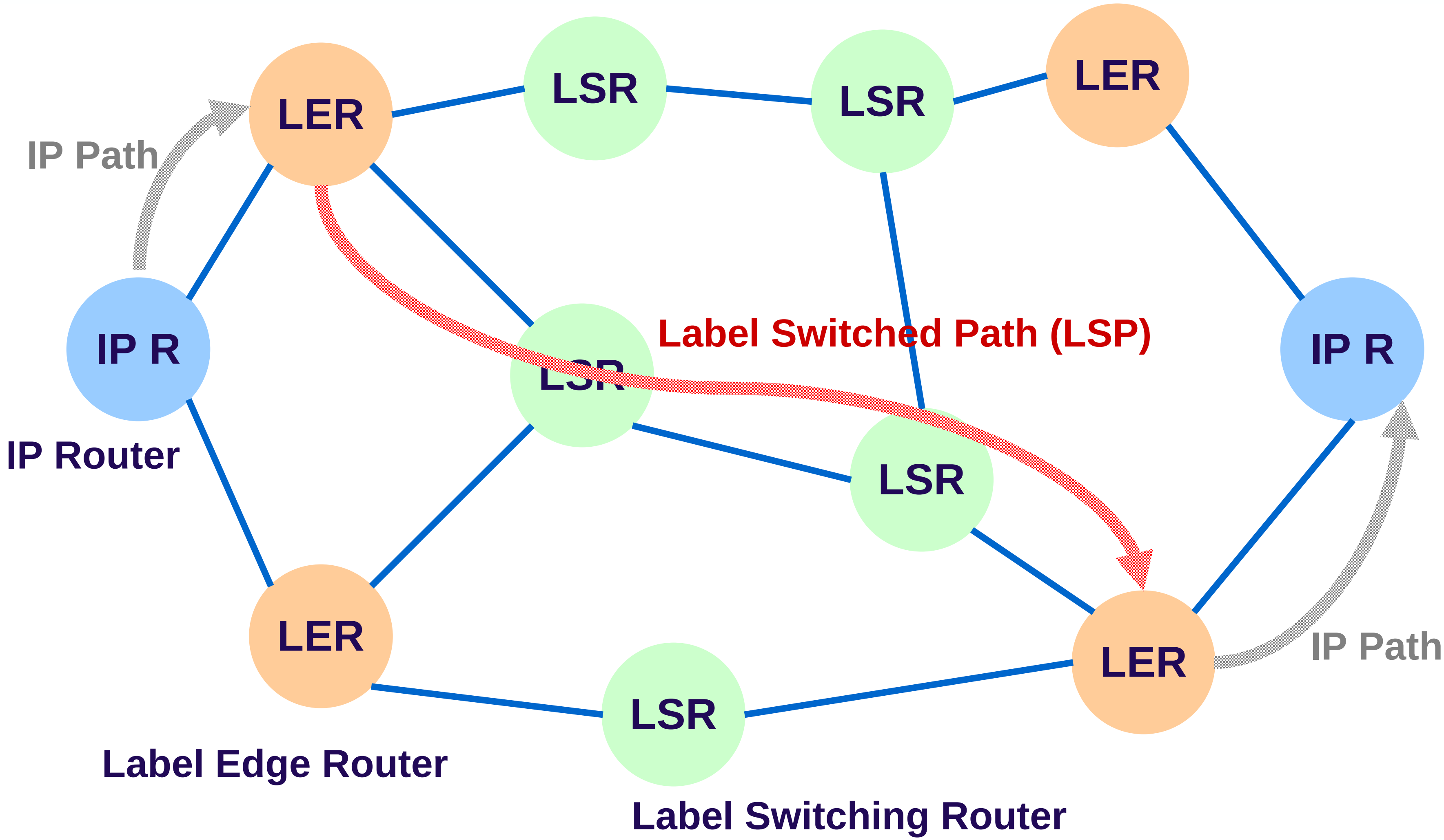
- Combines Layer 2 switching with Layer 3 routing
- Uses cell switching/label swapping like ATM
  - Introduces new label into packet
  - (if ATM is used as Layer 2, then ATM cell header is MPLS label)
- Two types of routers: Label Edge and Label Switch
- Requires protocols for distributed labels (similar to routing protocols)



MPLS Routers

- Label Switched Router (LSR)
  - Operates in the core MPLS network
  - Participates in MPLS signalling, eg. for label distribution
  - High speed forwarding based on a Label Forwarding Information Base (LFIB)
- Label Edge Router (LER)
  - Operates on the edge of the MPLS network
  - Connects external networks (e.g. Ethernet, Frame Relay) to MPLS network
  - Assigns packets to Forward Equivalence Classes
  - Initiates set-up of Label Switched Paths

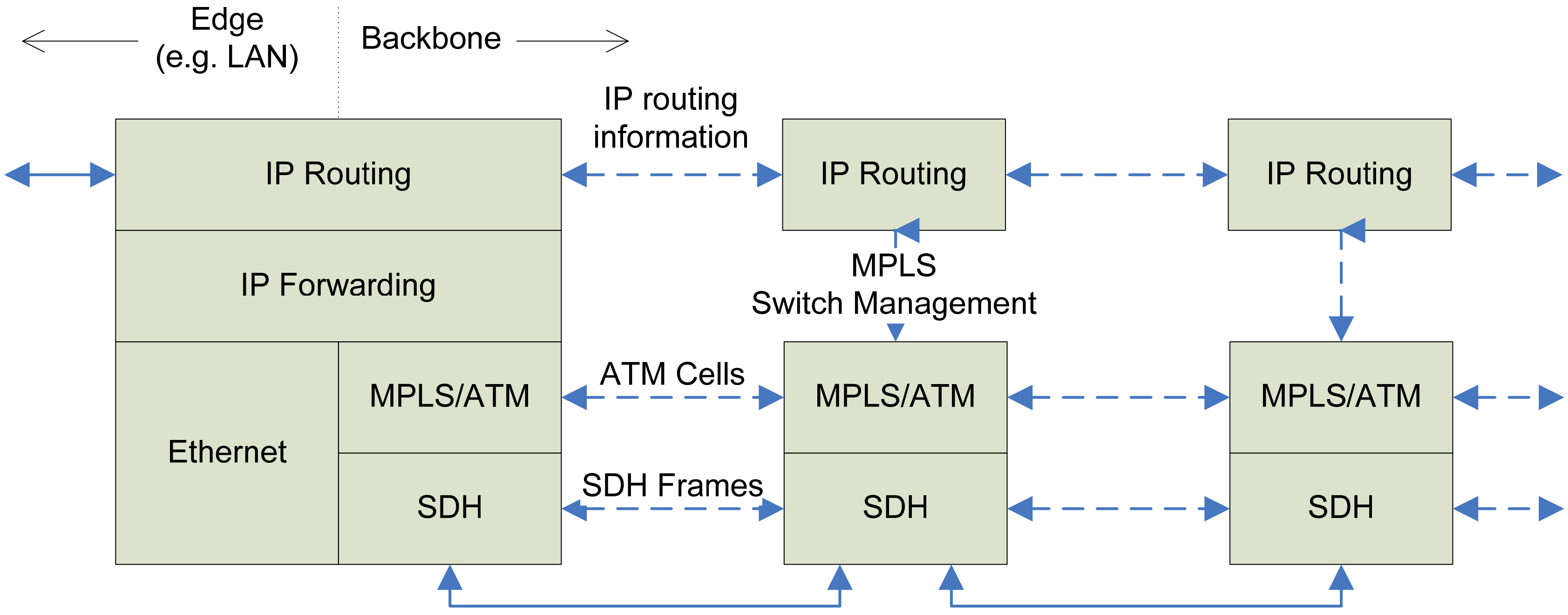
Example: IP over MPLS



MPLS and ATM

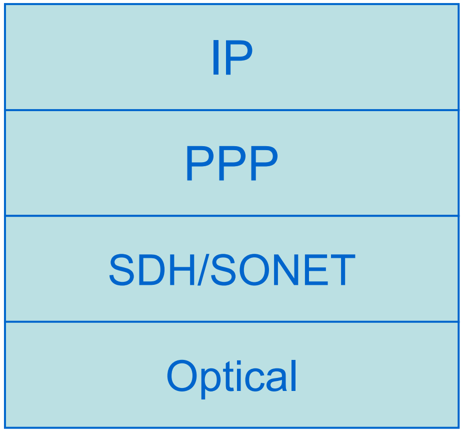
Present

- Use IP routing tables to control ATM switches
  - Removes the complex ATM signalling and scalability problems



Packet over SDH/SONET

- RFC 2615 defines how to transport IP packets over SONET/SDH networks
  - No need for ATM, MPLS
  - Use PPP to frame IP datagrams



- Advantages
  - Much simpler than ATM and MPLS
  - Reduces overheads of ATM
  - Can use existing infrastructure of SDH/SONET networks, including management networks
- Disadvantages
  - No built-in QoS features of ATM
  - May require costly SDH/SONET on edge of network (rather than just in core of network)

Point-to-Point Protocol

- Layer 2 (data link) protocol defined in RFC 1661
- Commonly used for connecting two nodes, that is a point-to-point link
- Includes
  - Method for encapsulating datagrams (e.g. IP) in PPP frame
  - Link Control Protocol (LCP) for establishing the connection between end-points and testing the link
  - Network Control Protocols for managing the network layer protocols, e.g. addressing in IP

PPP Examples

PPP
TCP/UDP
IP
PPP
SDH, Satellite, X.25, …

over ATM or Ethernet	
TCP/UDP	
IP	
PPP	
PPPoE	PPPoA
Ethernet	ATM

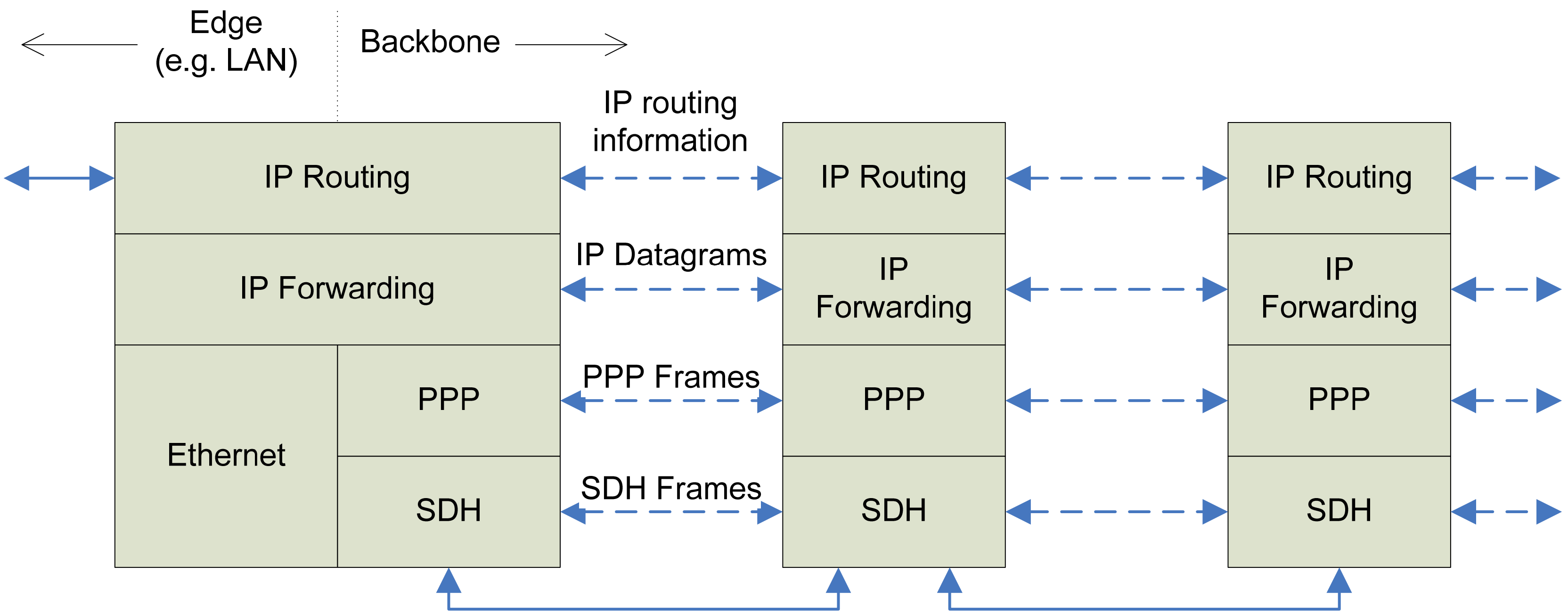
Tunnelled PPP
TCP/UDP
IP
PPP
GRE
PPP or IP or …

- Commonly used in residential Internet access for dial-up connections and some ADSL/cable modem connections
- Used for Packet over SONET/SDH

Packet over SDH/SONET

Future?

- Essentially IP routers that use optical links (SDH/SONET)
  - No overheads of ATM (PoS: 3%; ATM: 15%)
  - Very efficient way to transmit IP over existing SDH/SONET links

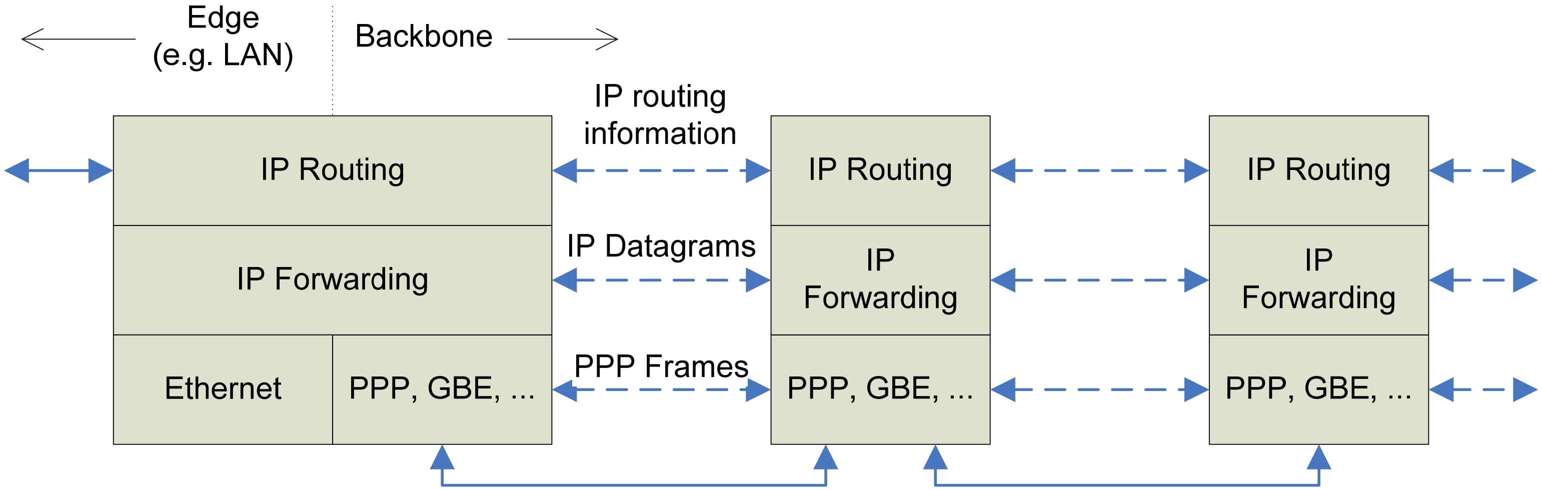


Wavelength Division Multiplexing

- TDM (using SDH/SONET) provides bandwidths in the range of 10Gb/s and more recently 40Gb/s
  - The equipment is becoming increasingly complex
  - Tied to the fixed TDM structure: circuit vs cell vs packet
- How do we increase the capacity?
  - Increase bit rate – difficult, SDH/SONET are limited
  - Lay more fibre – very expensive
  - Wave division multiplexing
- Wave Division Multiplexing (WDM)
  - Assign incoming optical signals to wavelengths
  - Multiplex the wavelengths (lambdas) on to fibre
    - Ranging from 40 to 160 wavelengths per fibre
    - 100's Gb/s to terabits per second
  - Technology of optical amplifiers provides the gain
    - Boost signal of all wavelengths at once; don't have to regenerate individual signals
  - Dense WDM: wavelengths ~ 1550nm

IP over WDM

- Creating a path through a network:
  - ATM switches and MPLS routers switch based on labels/cell headers
  - Optical Cross Connects (OXCs) “switch” wavelengths
- IP over WDM
  - IP datagram is framed (e.g. using PPP or Gigabit Ethernet) and converted to optical signal for transmission
  - Control of OXCs (e.g. what path should the data take) can be done via IP routing or other specific signalling protocols



Summary of IP over Optical Networks

- IP over ATM over SONET/SDH (IPoA)
  - – Used in many networks today
  - ✓ Easy to support non-IP traffic
  - ✓ Use built-in QoS features of ATM
  - ✗ Complex, inefficient, not scalable
- IP over SONET/SDH (PoS)
  - ✓ More efficient than IPoA (no ATM cell-tax)
  - ✓ Make use of existing SDH/SONET management features and deployments
  - ✗ PPP and SDH/SONET do not have flexibility/QoS of ATM
- IP over WDM (IPoW)
  - – Still in development/standardisation
  - – How to frame IP packets? PPP, Gigabit Ethernet, …
  - ✓ Much simpler architecture than IPoA and PoS
  - ✓ Few operations in electrical domain (which is slower than optical)
  - ✗ Hard to connect to existing networks (need complex optical devices)
  - ✗ Lack built-in management of SDH/SONET and QoS of ATM

Example and Future Networks

Network Technologies

Internet Backbone

- Originally a single network which connected all network sites in Internet: ARPANET
- Today, ISPs have their own backbone networks
- Peering:
  - ISPs have arrangements between each other for transit traffic
  - Must have physical connections between ISPs
    - For example, leased line or SDH between routers
  - Must exchange routing information
    - For example, using Border Gateway Protocol (BGP)
- Hierarchy of peering
  - Tier 1 – ISP that peers with or sells to all other networks (only about 10 in world)
  - Tier 2 – ISP that peers with some networks, and pays for some transit traffic
  - Tier 3 – ISP that pays for all traffic to reach Internet

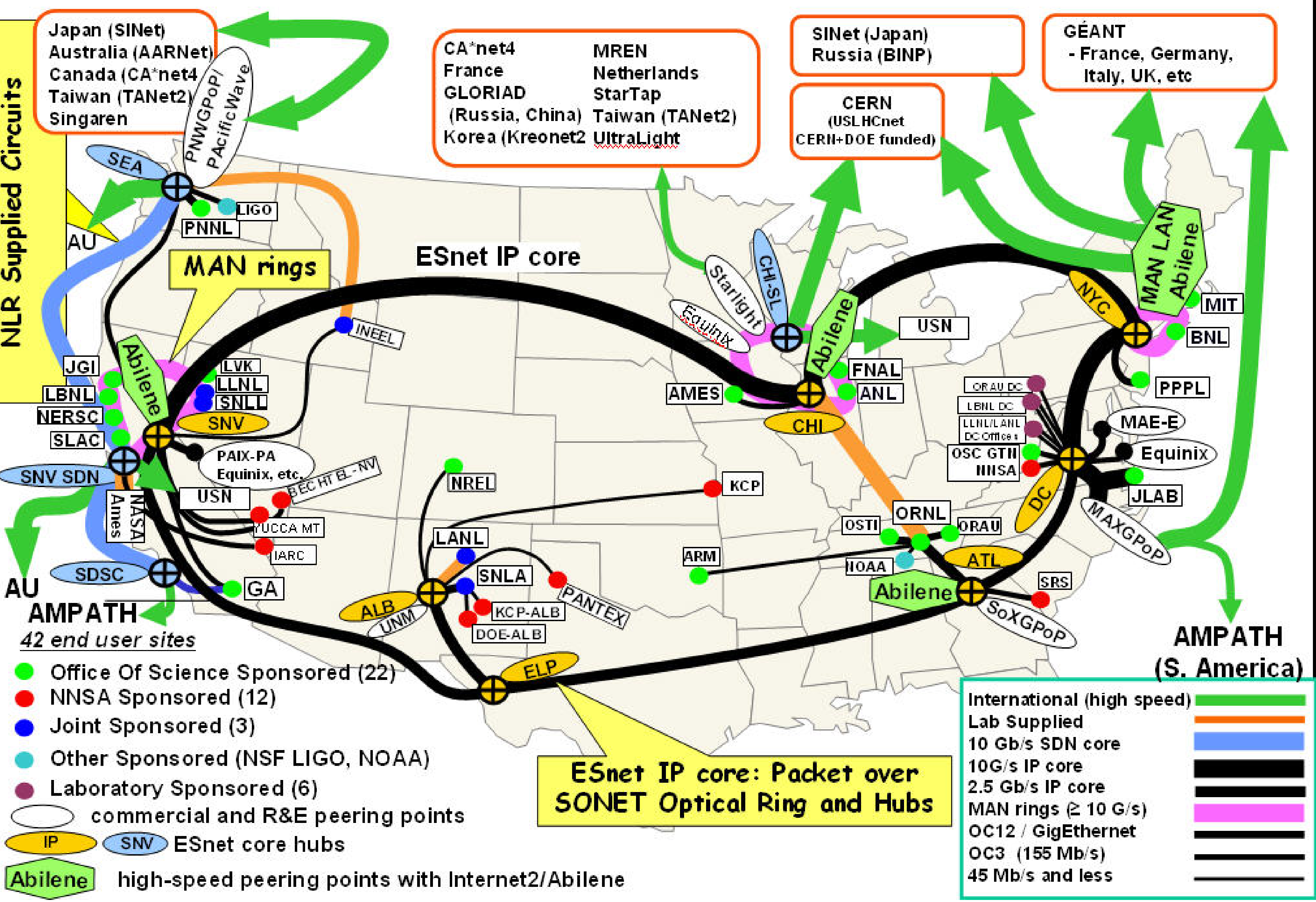
Abilene

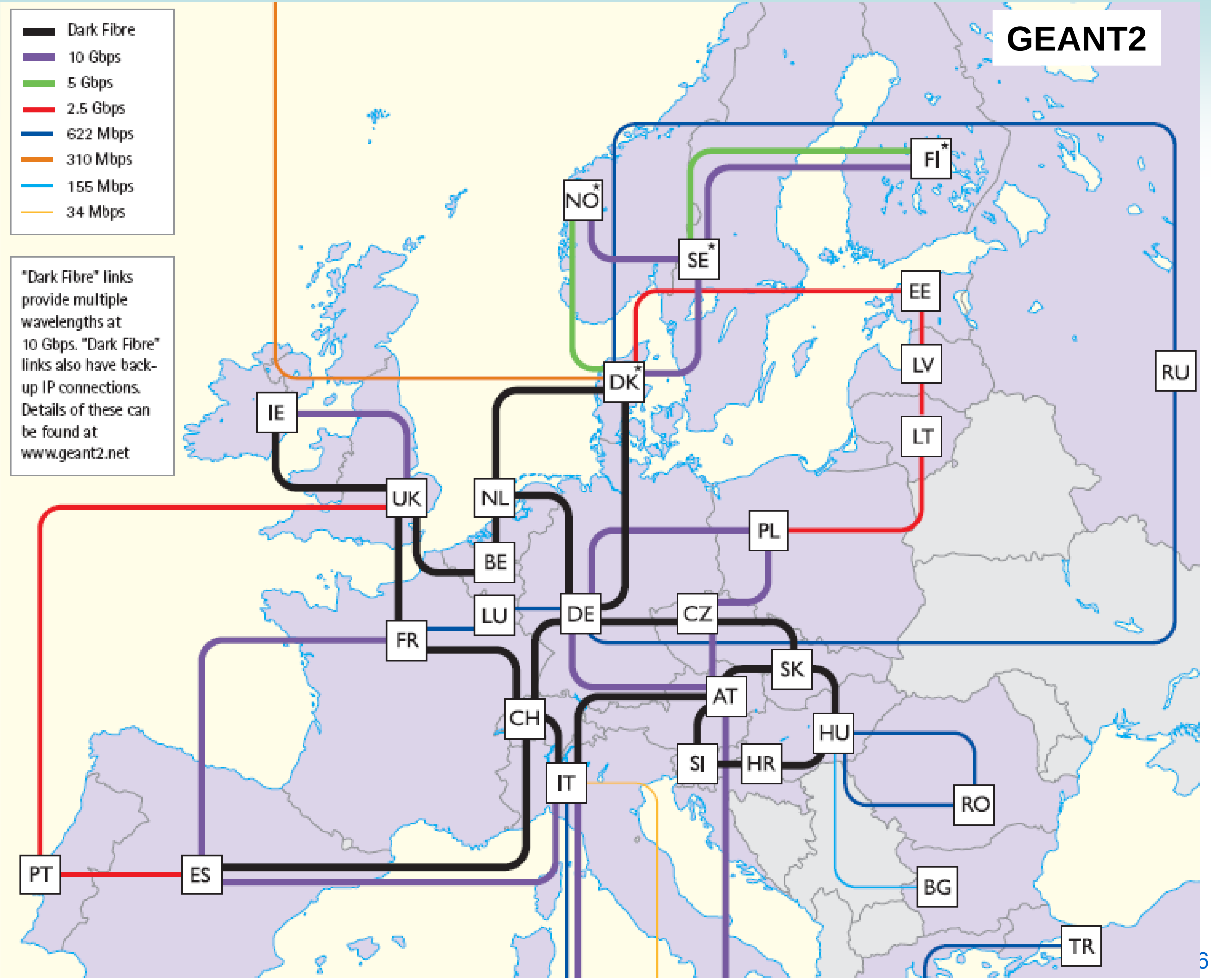
- High performance backbone network between universities and research labs in USA
  - Project within Internet 2 organisation
- Support development and testing of new Internet applications
  - Virtual labs, distance education, tele-medicine, …
- 10Gb/s OC-192c SONET and 10Gb/s Ethernet

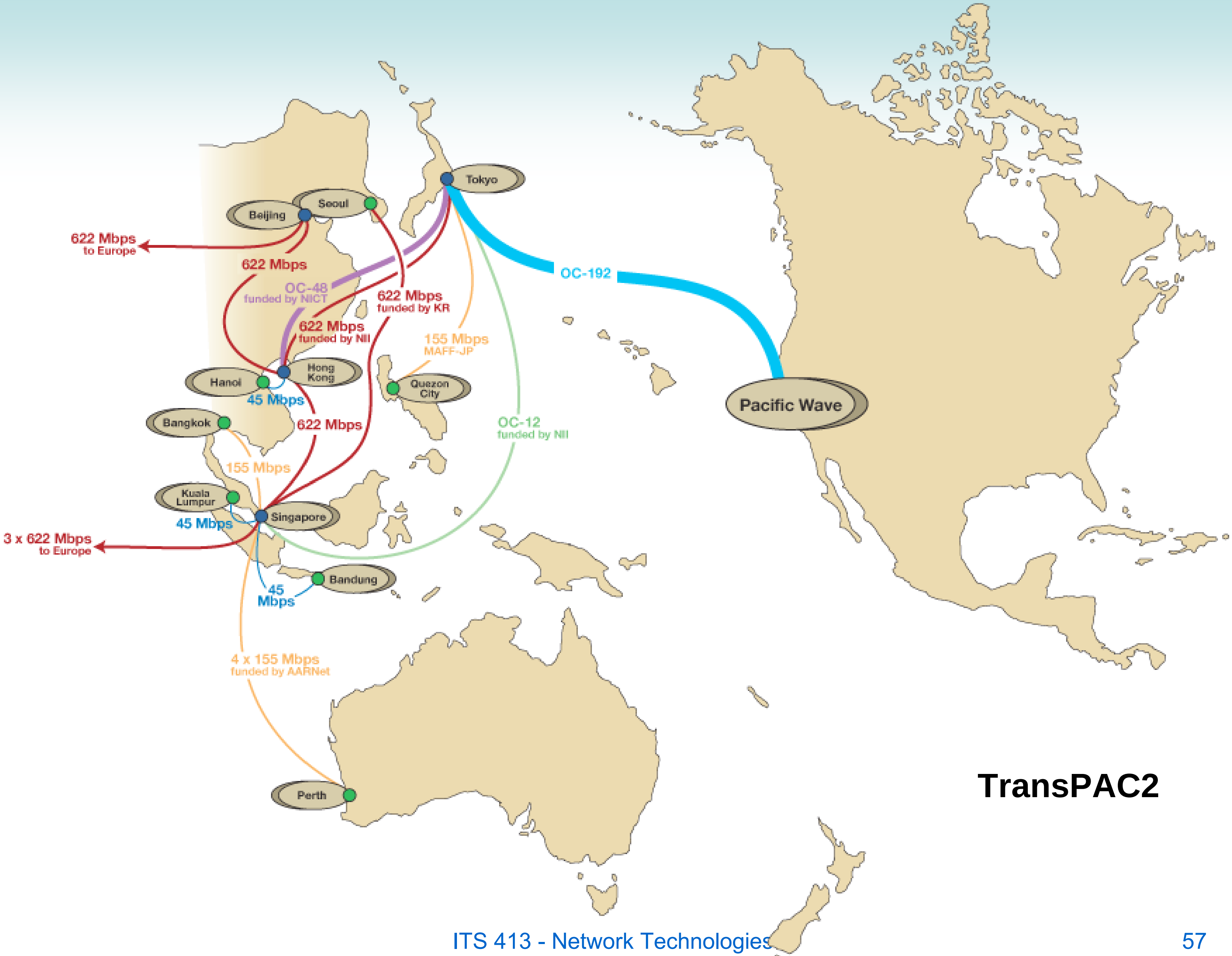
Other Networks and Projects

- 6Bone
  - IPv6 test bed started in 1996 and finished in June 2006
  - Used native and tunnelled IPv6 links between collaborating sites across world
  - Mainly for testing IPv6 protocols, transition issues and some applications
- ESnet
  - US energy science network
    - Dept of Energy labs and other research labs
- GEANT2
  - Latest European research network
- TEIN2
  - Connect European networks with Asia Pacific
- TransPAC and TransPAC2
  - North America to Asia links

➢ESnet's Physical Connectivity (Spring 2006)




GEANT2
Dark Fibre
10 Gbps
5 Gbps
2.5 Gbps
622 Mbps
310 Mbps
155 Mbps
34 Mbps
"Dark Fibre" links provide multiple wavelengths at 10 Gbps. "Dark Fibre" links also have back-up IP connections. Details of these can be found at www.geant2.net
NO*
SE*
FI*
EE
LV
LT
RU
DK*
IE
UK
NL
BE
LU
DE
PL
CZ
FR
SK
AT
CH
HU
SI
HR
IT
RO
BG
TR
PT
ES


Tokyo
Seoul
Beijing
622 Mbps
to Europe
622 Mbps
OC-48
funded by NICT
622 Mbps
funded by KR
622 Mbps
funded by NII
OC-192
155 Mbps
MAFF-JP
Hong
Kong
Hanoi
45 Mbps
Quezon
City
Pacific Wave
Bangkok
622 Mbps
OC-12
funded by NII
155 Mbps
Kuala
Lumpur
Singapore
45 Mbps
3 x 622 Mbps
to Europe
Bandung
45
Mbps
4 x 155 Mbps
funded by AARNet
Perth

TransPAC2

Internet in Thailand

- 2 International Internet Gateways
  - CAT: > 20 links to international providers
    - Upto 1Gb/s links to US and Hong Kong
  - TOT: 2 links to international providers (USA, Japan)
  - Total of 10Gb/s capacity to/from Thailand
- 3 national Internet exchanges: CAT, TOT and NECTEC
- > 20 commercial providers, some with international links
- Several research/education networks

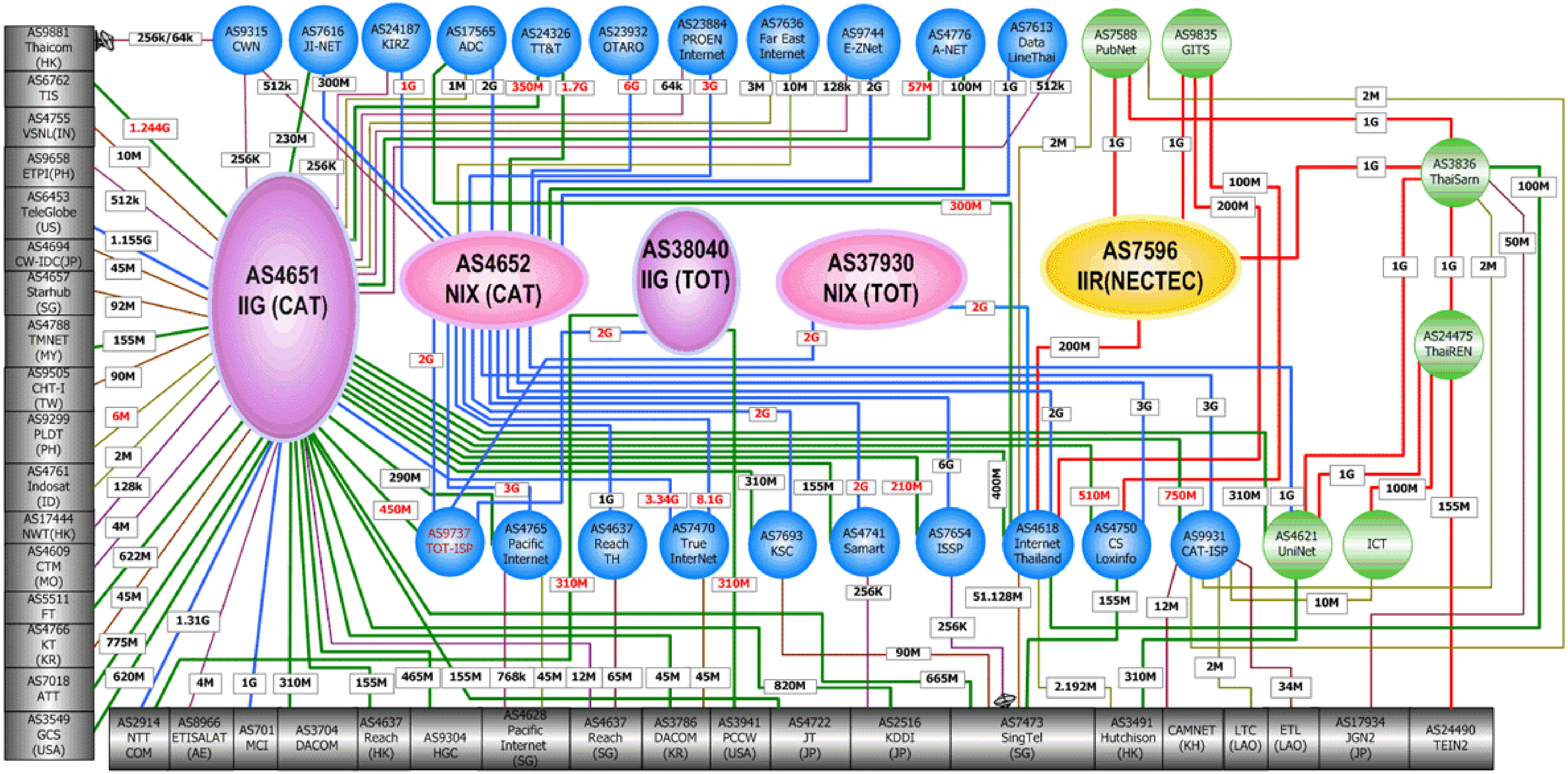
Total International Bandwidth
9902.176 Mbps (Into Thailand)
9902.176 Mbps (Out from Thailand)

Internet Connectivity in Thailand (October 2006)

http://iir.ngi.nectec.or.th/

Internet Map V2.0
Powered by NTL

ThaiSarn3 NECTEC



Academic/Research/Goverment
Commercial
Commercial domestic Exchange
Government/Research/ Academic domestic Exchange
International Gateway
International Provider
Government/Research/Academic Link
Link (< 1Mbps)
Link (1Mbps -10Mbps)
Link (>10M and <100Mbps)
Link (>=100Mbps and < 1Gbps)
Link (>=1Gbps)

Chart date
06-10-2006