Network technology
Introduction

CSCI E 45a: The Cyber World – part A

Introduction: learning goals

- Understand the technology and basic operation of various types of networks
- Including the types of networks used in today's enterprises and homes and, for history's sake, traditional telephone networks

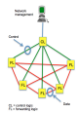
Introduction: this module

- This module deals with technology

Topics

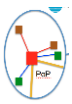
- Layers – R
  - What are layers
  - OSI & Internet models
- Legacy telco networks – O
  - The technology used in the legacy telephone network
- New telco networks – R
  - The technology that is, or could be, used in new telephone networks

Topics, contd.



- Enterprise Layer 2 networks – R
  - E.g., Local area networks
- Enterprise Layer 3 networks – R
  - Routed IP networks
- Software defined networks – R
  - Networks whose logical topology is determined by software

Topics, contd.



- Internet service provider networks – R
  - Architectures used in internet service provider networks
- MPLS overview – R
  - Multiprotocol Label Switching in the enterprise and within ISPs
- Cellular networks – R
  - Networks that underlie cellular telephone systems

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5	Ethernet card - https://en.wikipedia.org/wiki/Network_interface_controller

Network technology
Layers

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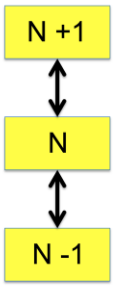
Layers



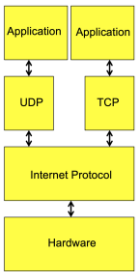
- Network protocols are conceptualized in "layers"
  - Each layer has standard interfaces "up" and "down"
- A layer deals with a particular local or end-to end path
  - E.g., a particular type of addressing (link vs. network vs. session) or function (presentation, application)
- May or may not relate to implementation

Layers

7 - Application
6 - Presentation
5 - Session
4 - Transport
3 - Network
2 - Data-link
1 - Physical

- Each layer provides services only to the layer above it
- Each layer depends only on the layer below it
- Each layer isolates the layers above it from the differences in the layer below it
- Beware of "layer violations"
- OSI 7-layer model
- Internet 4-layer model

Internet 4-layer model



OSI 5-7 (application, presentation, session)

OSI 4 (transport)

OSI 3 (network)

OSI 1-2 (data ink, physical)

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Network technology
Legacy telco network technology

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Legacy telco: carriers

- *"carrier" "a company that provides facilities for conveying telecommunications messages"*

  http://oxforddictionaries.com

Structure: regulated monopoly

- By mid 1900s most countries had a single dominant telephone service provider operating as a regulated monopoly
  - In the US that was AT&T
  - E.g., "The Telephone Company"

Telephone company reliability

99.999%

- Telephone service seen as a life safety requirement
  - Regulators demanded very high reliability
    - And allowed carriers to charge enough to ensure reliability
- "Five nines" seen as the requirement
  - Maximum of 5.26 minutes of (unplanned) outage per year
  - Disconnect when it came to cell phones

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Telephone company reliability, contd.

- But reachability reliability on land line phones quite poor anyway

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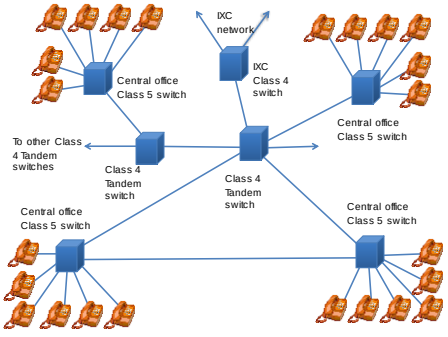
Legacy telephone network architecture



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Telephone network features

- Connections between local carriers via inter exchange carriers (IXCs)
  - "long distance"
    - Some "local carriers" are now national in scope
- Telephone offices are self sufficient for power
  - Batteries & generators

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Telephone network features, contd.

5ESS telephone switch

- Central office switch can serve 100s of thousands of customers
  - Mostly using direct "home runs"
- Therefore switch must be extremely reliable

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Telephone network: call flow

- Caller dials number
- Switch looks up dialed number in database (SCP)
- Returns actual # to be called
  - Translated number or dialed number
- Set up circuit to destination
  - Reserved bandwidth
- Call proceeds
- Circuit torn down when call complete

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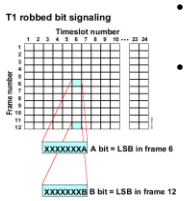
Telephone carrier OAM



- Operations, administration and management
- Provides for in-band monitoring of customer experience
  - See the service from the customer point of view

Telephone residential customer circuits

- Analog
  - Twisted-pair of copper wire between CO and phone
  - Traditional residential phone service
  - Power supplied by CO
    - works when local power fails
  - Supports a single phone call
  - Being replaced by fiber in many places
    - Requires local battery if reliability still needed

Legacy telco line technology: point-to-point

- Time-division multiplexing (TDM)
  - Common speeds:
    - DS0 – 64Kbps – one phone call
    - T1 (a.k.a., DS1) – 1.544 Mbps – 24 phone calls
    - T3 – 44.736 Mbps – 672 phone calls
  - Internal telephone company links
    - Also used for enterprise voice/data circuit
- Microwave links
  - TDM over microwave radio
  - Largely replaced with fiber

Legacy telco, multipoint, X.25

- Reliable packet switched data service
- Once seen as a TCP/IP "competitor"
- Mostly 64 Kbps
- Supports virtual circuits
  - Service is multipoint
  - Connections are p2p
- Various charging models
  - Flat rate
  - Per packet

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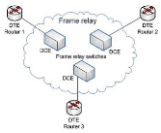
Legacy telco, multipoint, frame relay



- Packet switched data service
  - No reliability function
- Configurable Committed Information Rate (CIR)
  - Many carriers offered CIR 0 service
- Mostly DS0 to T1 speeds
- Supports virtual circuits
  - Service is multipoint
  - Connections are p2p

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Legacy telco, multipoint, SONET

- Synchronous Optical Networking (SONET)
- Dual ring-based, multiplexed data service
  - Provides multiple fixed rate p2p circuits
- Dual ring for L2 reliability
- Mostly replaced with L3 redundancy

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Legacy telco, multipoint, ATM

- Asynchronous Transfer Mode (ATM)
- Once assumed to be only data network in future
- Assumed there is an absolute QoS requirement
- Small fixed-length frames called cells
  - 53-byte cell with 5-byte header & 48-byte payload

ATM, contd.

- Virtual circuit-based
- Permanent virtual circuit (PVC)
  - Manually set up
- Switched virtual circuit (SVC)
  - Set up on demand
  - Very rare, even in ATM's heyday

ATM, services

The Lighthouse at the End of the World
Jules Verne

- Constant bit rate (CBR)
  - Fixed rate wire replacement
- Variable bit rate (VBR)
  - Not fixed rate but guaranteed up to configured rate
- Available bit rate (ABR)
  - Network admission control
- Unspecified bit rate (UBR)
  - Uses residual capacity

ATM, reasons for failure

- Far too much hype
- Required a new physical network
- Required significant management
- "New technology"
- Far more expensive than alternatives
- Fixated on QoS

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Network technology
New telco technology

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NGN: New telco – ITU Vision

- Next Generation Network (NGN)
- Replacement telephone carrier network
- Assumes absolute QoS requirement

NGN: New telco – ITU Vision, contd.

- Assumes continued support for telco business and service model
  - Can also support best-effort Internet service
- Mixture of ITU-T, 3GPP & IETF technologies
  - IETF: MPLS, SIP, enum, …
  - 3GPP: IMS

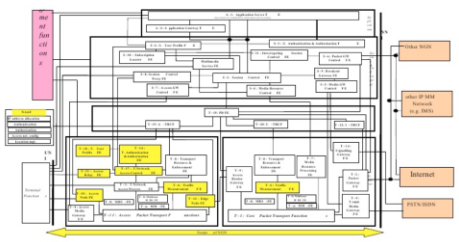
ITU-T NGN, feature list

- Packet-based transfer
- Separation of control functions among bearer capabilities, call/session, and application/service
- Decoupling of service provision from transport, and provision of open interfaces
- Support for a wide range of services, applications and mechanisms based on service building blocks (including real time/streaming/non-real time services and multi-media)
- Broadband capabilities with end-to-end QoS and transparency
- Interworking with legacy networks via open interfaces
- Generalised mobility
- Unfettered access by users to different service providers
- A variety of identification schemes which can be resolved to IP addresses for the purposes of routing in IP networks

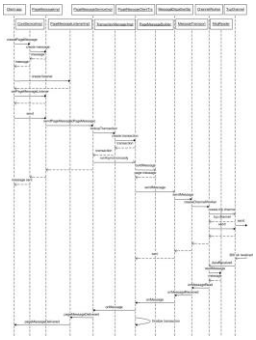
ITU-T NGN, feature list

- Unified service characteristics for the same service as perceived by the user
- Converged services between Fixed and Mobile networks
- Independence of service-related functions from underlying transport technologies
- Support of multiple last mile technologies
- Compliant with all Regulatory requirements, for example concerning emergency communications and security/privacy, etc.

ITU-T NGN, diagram



NGN IMS call flow



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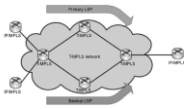
New telco, MPLS-Transport Profile

- History



ITU-T felt that MPLS could provide useful NGN functions

To transport legacy telco services (e.g. TDM)

Wanted a non-IP version so did their own (T-MPLS)

After significant turf battle with IETF agreement was reached:

IETF would develop based on ITU-T requirements and with ITU-T help

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New telco, MPLS-Transport Profile, contd.

- Architectural requirement:

Mimic existing telephone systems

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New IP

- Replace current Internet to enable guaranteed services
- Top-down approach
  - Driven by Chinese government, Huawei & telcos, in ITU-T
- End system must have "contract" with network to send anything
  - Contract specifies needed network services & identifies user
- Gateways enforce contract requirement between nets

New IP, contd.

- Assumes carriers run networks
- Puts carriers in control of services, i.e. not end-to-end
- Surveillance enabler
  - Contract requirement means all communications tied to individuals (not just IP addresses)
- Governments & carriers like it
  - Could be legally mandated in some countries

New telco – alternative approach

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	IETF logo –
4 & 5	NGN presentation - *www.itu.int/ITU-T/worksem/ngn/200610/presentations/ts2-p2.pdf*
6	NGN diagram - http://image.slidesharecdn.com/0067200602aktkinterconnectandenumrstastnyv1ppt225/95/0067200602aktkinterconnectandenumrstastnyv1ppt-13-728.jpg?cb=1273137389
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Network technology
Enterprise layer 2 networks

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L2 Networks, Concepts

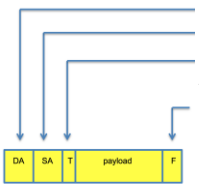
- A single local area network (LAN) is the "world"
- Use media access control (MAC) address for forwarding decisions
  - 48-bit globally unique address assigned to device during manufacturing process
    - All bits on = broadcast
    - Group bit on = multicast
- L2 wired network: "Ethernet"
- L2 wireless network: "WiFi"

Ethernet

- Little in common between today's Ethernet and the Ethernet Bob Metcalfe invented
  - Other than frame size and format

Ethernet, contd.

- Frame characteristics
  - 64 to 1518 bytes long
  - 14 byte header
    - Destination MAC address
    - Source MAC address
    - Field to indicate payload type in header
  - Trailing checksum (frame check sequence)



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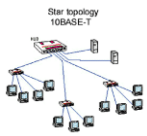
Ethernet host interface operation

- The interface receives all frames on the LAN segment
- Interface checks destination MAC address
  - Passes frame to host if the MAC address is same as interface's preconfigured MAC address
  - Passes frame to host if the MAC address is the broadcast address
  - Passes frame to host if the MAC address is in a list of configured multicast MAC addresses
  - Otherwise discards frame

5

Ethernet networks



- Ethernet was a multi-drop & CSMA/CD network when developed
  - Carrier Sense, Multiple Access/Collision Detect
- Ethernet is now always a cascaded star network
  - Direct connections from end nodes to switches
  - Not CSMA/CD anymore
  - Switches can be interconnected

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Ethernet switch operation

- Learning
  - look at source addresses in all frames
  - Add addresses to database, listing what port seen on
    - Update database entry if already in database

MAC	Port	time
XX:XX…XX	1	1234
XX:XX…XX	1	2345
XX:XX…XX	3	0234

7

Ethernet switch operation, contd.

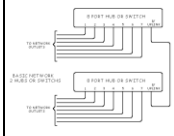
- Forwarding frames
  - Look at destination addresses in all frames
    - Flood frames if broadcast or multicast destination address
      - Some switches handle multicast specially
    - Flood frames if destination address not in database
    - Send frames to at most to one port If destination address in database
- Management
  - Timeout old database entries

MAC	Port	time
XX:XX…XX	1	1234
XX:XX…XX	1	2345
XX:XX…XX	3	0234

8

Ethernet switch features

- Transparent operation
  - Automatically self configures
- Frame only goes where it needs to go
  - Unless destination node has never sent anything
  - Reduces load on LAN segment to what is required
  - Security advantage
    - But can be spoofed by node sending forged source address
- Frame not modified during forwarding



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Ethernet, virtual LAN (VLAN)

4-byte VLAN tag

- Creates multiple virtual LANs on same physical LAN
- Add VLAN tag to frame
  - Devices & switch configured to only pay attention to frames with specific VLAN tag(s)
  - 4-byte VLAN tag
    - 2-byte tag type (8100x)
    - 3-bit priority
    - 1-bit format identifier (0 for Ethernet)
    - 12-bit VID (VLAN ID) – 4,096 possible VLANs

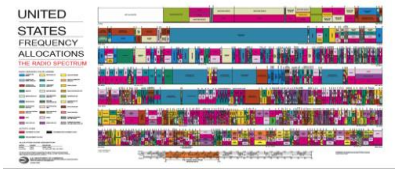
Pseudowires

Frame Relay
IP

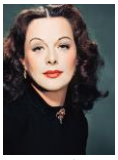
- Emulate Layer 2 networks over IP or MPLS
- First done by MCI in the early 1990s
  - Frame relay encapsulated in IP
- Support for many Layer 2 technologies defined
  - Ethernet, TDM, HDLC, Frame Relay, ATM, SONET, …

WLANs, WiFi (IEEE 802.11)

- Wireless LAN
  - "Looks like" a wireless Ethernet
- Non-licensed spectrum
  - Uses industrial, scientific and medical (ISM) radio bands



Spread spectrum



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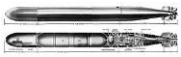

- Used by 802.11
- Three types
  - Frequency Hopping Spread Spectrum (FHSS)
  - Direct Sequence Spread Spectrum (DSSS)
  - Orthogonal frequency-division multiplexing (OFDM)
- Allows sharing of single channel

WiFi types & speeds

IEEE

- 802.11b: 11 M, 2.4 GHz (1999)
- 802.11a: 54 M, 5 GHz (1999)
- 802.11g: 54 M, 2.4 GHz (2003)
- 802.11n: 450 M, 2.5 & 5 GHz (2009)
- 802.11ac: 1 G, 5 GHz (2014)
- 802.11ad: 7 GHz, 2.5, 5 & 60 GH (2013)
- 802.11af: 27 M, White Space (2014)
  - 802.11n, 802.11ac & 802.11ad use MIMO

Multi Input Multi Output (MIMO)

- Concept: send on multi channels where there are simultaneous multiple paths
  - Needs multiple paths
- Mathematically separate at receiver
- Increased data throughput with same spectrum

WiFi - architecture

- Hosts connect to local "access points"
  - Radio transceivers, connected to wired network
  - Networks named with SSID (service set identifier)
    - Inserted in frame header
- Range: 100-300'
  - Much longer point-to-point with special antennas
  - Blocked by water (e.g. people) & some other materials

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CSMA/CA

- WiFi uses CSMA/CA
  - Carrier Sense Multiple Access with Collision Avoidance
  - Original Ethernet scheme with tweaks for wireless

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CSMA/CA

- No synchronizer required
  - 1/ Listen for idle network (listen for carrier)
    - If carrier heard, delay, then go to 1
  - 2/ Send frame
  - 3/ Wait for ACK
    - Timeout means retransmission required
    - Done if ACK received
  - 4/ If retransmission required, use exponential back-off algorithm to determine wait time, then go to 1

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WiFi - issues

- Easily monitored
  - Supports link-level encryption
    - WEP is not better than nothing
    - 802.11i (WPA) better but is only local - not e2e
  - Can require password for WLAN access
- Easily disrupted
- Easily spoofed
- 802.1x mitigates many of these issues
- Disruption is hard (impossible?) to mitigate against

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Network technology
Enterprise Layer 3 networks

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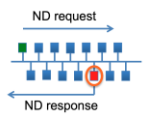
Layer 3 Networks, Concepts

- Operates at network layer
- Frame includes internetwork (L3) addresses
- Use L3 addresses in forwarding decisions
  - 32- or 128-bit addresses
- Need to map L3 address to L2 address, because packets are delivered on the L2 network to the L2 address

Source: xxx

Mapping L3 addresses to L2 addresses



- IPv4 – Address Resolution Protocol (ARP)
  - Send LAN broadcast packet asking "are you IP address a.b.c.d"
    - response includes MAC address of that node
- IPv6 – Neighbor Discovery
  - Send LAN multicast packet asking "are you IP address a:b:c:d:e:f:g:h:i"
    - sent to "selected node multicast" address
    - response includes MAC address of that node

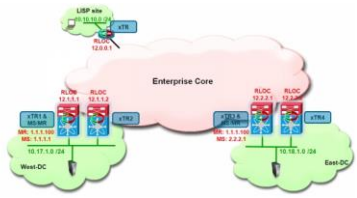
Layer 3 networks, concepts

AppleTalk,
Banyan Vines,
ChaosNet,
DECNet,
IPX,
OSI,
SNA,
XNS

- Internet protocol (IP) is the only meaningful L3
  - There once were many
- The scope is the world
- Use IP addresses for forwarding decisions
  - Node address is administratively assigned when device configured
  - Or automatically assigned on device startup (DHCP)

Layer 3 networks, concepts, contd.

- Network divided into "subnets"
  - Range of IP addresses assigned to a single L2 network



L3 frame delivery on LAN

- L3 address used to forward frame between LANs
- L2 address required for LAN delivery
- Host or router must encapsulate L3 packet in a L2 packet with the MAC address of the L2 destination

Routers

- L3 forwarding devices
- Exchange reachability information with other routers to maintain a routing table

Prefix	Metric	Next hop	timers
128.103/16	123	140.248.5.16	493
173.166.5/26	38593	140.248.5.1	82765
0.0.0.0	100	140.248.5.2	0

Routing protocol lecture later

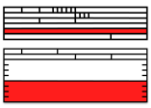
Used in enterprises and ISPs

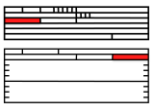
Enterprises assumed to be in same trust domain

ISPs assume to interconnect across trust domains

7

Router operation





- Process frames sent to router's MAC address
  - Strip off L2 header & FCS
- Look at IP destination address in L3 frame
  - Send frame to router's CPU if address is the router's
- Decrement TTL & recalculate checksum
  - Send error message & discard frame if TTL = 0
  - Checksum calculation on IPv4 (no header checksum in IPv6)

8

Router operation, contd.

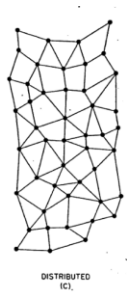
Table:
128.103.1.36/32
128.103.1/24
128.103/16

Address:
128.103.8.36

- Find best match address range in routing table
  - If not found:
    - If default address defined, use that
    - If no default address defined, send error message & discard frame
- Build new L2 frame around L3 frame

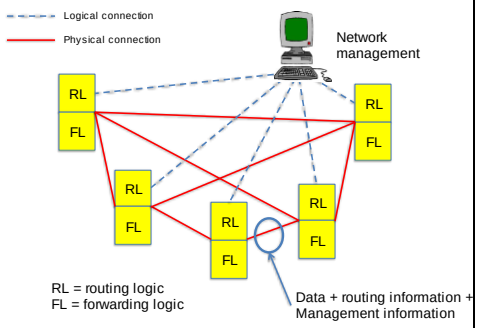
9

Router operation, contd.



- Send frame on LAN to next hop on path to destination
  - Must be "adjacent" node (on the same LAN, or on point-to-point link)
  - Could be the destination itself
- Frame modified during forwarding
  - TTL/HC & checksum (IPv4)
- Routing information is generally in-band

Router-based networks



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10	P Baran - 1962

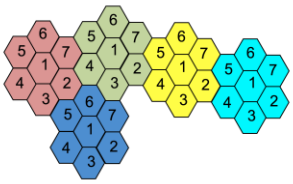
Network technology
Cellular networks

CSCI E 45a: The Cyber World – part A

1

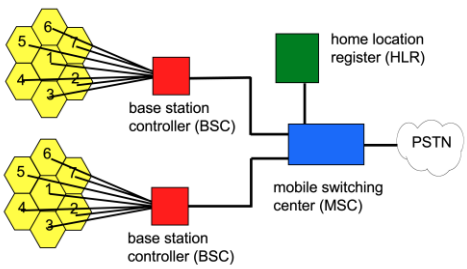
Cellular wireless

- Infrastructure:
  - Local transmission towers
  - Cover small "cell"
    - Can be directional antennas at cell intersections
  - Adjacent cells must use different channels



2

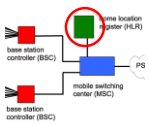
Cellular wireless, system



3

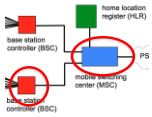
Cellular Wireless: Process

- Phone contains a replaceable Subscriber Identity Card (SIM)
- Turn power on:
  - Phone scans control channels for strongest signal
    - Rescan if signal gets too weak
- Logging on:
  - Phone sends message to MSC
  - Includes electronic serial number (ESN) from SIM
  - If not in home service area, carrier retrieves billing info from home carrier's HLR (roaming)



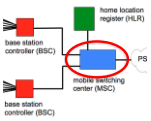
Cellular Wireless: Process, contd.

- Place call:
  - Phone sends ESN and called number to MSC
  - MSC validates request, connects to called party and tells BSC and phone what channels to use & tells phone what power to use
- Receive call:
  - MSC broadcasts phone # of mobile phone on all channels
  - Addressed phone responds
  - MSC tells BSC and phone what channels to use & tells phone what power to use



Cellular Wireless: Process, contd.

- Handoff:
  - While a call is in progress MSC adjusts the transmitted power of phone and changes channels of phone and base stations as phone moves
  - Control signaling applied to voice channels to let phone be controlled by BSC & MSC



The Gs

- Cellular transmission technology referred to as "generations"
  - 1G - 1979 – analog only
  - 2G – 1991 – 50 Kbps
  - 3G – 1998 – 200 Kbps
  - 4G – 2009 – 100 Mbps
    - a.k.a. Long-Term Evolution (LTE)
  - 5G – future – multi gigabit
- Specifications by ITU – technology by others
- Telco assumption since 3G has been LAN replacement

7

Technology Narcotics

- Every decade or so a technology captures the tech press attention
- Generates expectations way out of line with reality
- E.g., ATM, 5G
  - Huge sums spent for little return
  - e.g., Full deployment of 5G would be 100s of billions of dollars in the U.S. alone
    - e.g., cells only a few hundred feet across

8

5G

I tried 5G. It will change your life — if you can find it
CNN – 8/9/2019

- Huge hype about 5G
  - High speed, low latency, high capacity, everything connected, replace WiFi, remote surgery, billions of devices, …
- Reality is very different
  - Smart net with all its issues
  - Requires closely spaced base stations
  - Pay-per device model
  - Download caps

9

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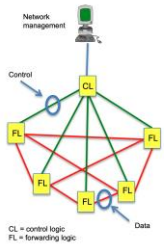
	https://sedac.ciesin.columbia.edu/gpw-v1/globldem.doc.html

Network technology
Software defined networks

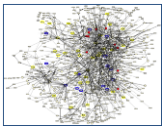
CSCI E 45a: The Cyber World – part A

Software Defined Networks (SDN)



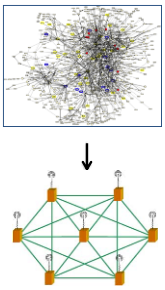
- Decouple control and forwarding functions in a network
  - Traditionally unified in routers and switches
- Control functions centrally programmable
  - E.g., by business logic or network management

SDN, contd.



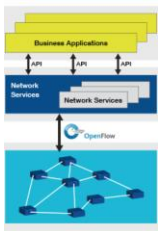
- Produces an overlay network that is not limited to physical connectivity
- Logical network architecture can be modified dynamically
  - e.g., subnets in a data center
- Used in data centers & WANs

SDN, contd.



- SDN is essentially centralized VLAN management
- Central server pushes configuration to forwarding devices
- Single source for configuration means that network is more likely to be consistent
  - e.g. end-to-end consistency in ACLs
- Also rapid reconfiguration

Control technologies



- "Standard" for control to forwarding logic communication
  - E.g., OpenFlow
- Supported by multiple switch & router vendors

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4	http://blogs.cisco.com/news/software-defined-networking-for-service-providers-data-center-fabric-analogies-breakdown-in-the-wan
	http://forum.mikrotik.com/viewtopic.php?t=48906
5	https://www.opennetworking.org/sdn-resources/openflow

Network technology
Internet service providers (ISPs)

CSCI E 45a: The Cyber World – part A

1

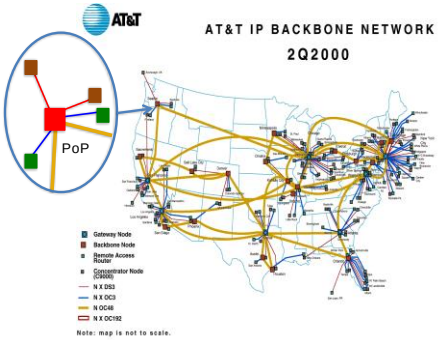
Internet Service Providers (ISPs)

PsiNet UUNET verizon comcast TIME WARNER CABLE

- Initially, companies whose basic business was providing Internet service
- Currently residential ISPs mostly telephone or cable TV carriers
- Network architecture similar for similar-sized enterprises and ISPs
  - Except that ISPs have more "tail circuits"
    - Connections to customer locations

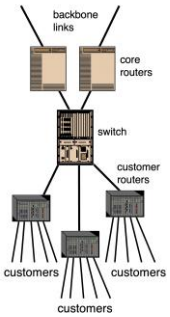
2

Example ISP network



3

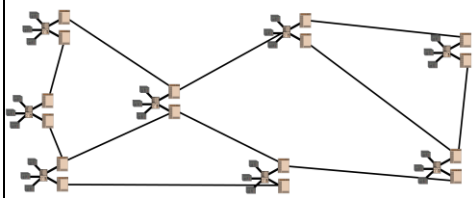
ISP PoP



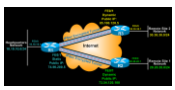
- Point of presence (POP) e.g., in a city
- Parts
  - core routers
  - customer routers
  - DSLAMs etc

ISP network

- multiple POPs
- interconnected with backbone links
  - not full mesh



ISP Service: Virtual Private Networks (VPN)



- ISP offered service
- Provides a virtual network to an enterprise
  - Can look like a collection of point to point lines or a isolated network
- Reasons
  - Address & traffic isolation for virtual enterprise network
  - Could include service guarantees
- Technically not required
  - Enterprise could build their own VPN using tunnels over Internet service

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4	http://www.firewall.cx/cisco-technical-knowledgebase/cisco-routers/936-cisco-router-vpn-dynamic-endpoint.html

Network technology
Multi Protocol Label Switching (MPLS)

CSCI E 45a: The Cyber World – part A

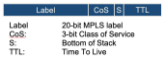
MPLS, History & Purpose

- Evolved by IETF from Cisco Tag Switching
  - Tag Switching – 1997
  - MPLS – 2001
- Purpose
  - Original: Improve price/performance of networks
    - Switching faster and cheaper than routing – or so people thought
  - Later: traffic isolation & traffic engineering
- Underlying concept
  - ATM-like forwarding for IP

MPLS features

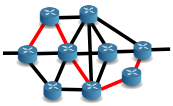
- Explicit path for (TE) traffic engineering
  - Direct packets in a way that routing would not have
- Enable packet forwarding decisions based on things other than destination IP address
- Aggregate traffic with some common characteristics
- Support VPN services

MPLS, operation



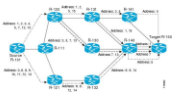
- Insert header in frame below IP
  - "layer 2.5"
- Header includes a 20-bit "label" & other info
  - Label is locally significant
    - i.e., it changes at each hop
- Labels used to select LSP

Label-Switched Path (LSP)

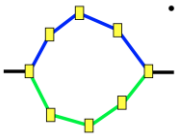


- LSP is a specific path through an MPLS network
  - i.e., a sequence of label switch routers to traverse
- LSPs are unidirectional

MPLS "circuits" (label switched paths)

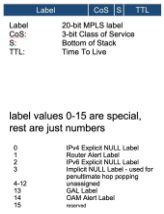


- Much MPLS use does not involve circuits as traditionally understood
  - Specific path not setup in advance
  - Path changes as the underlying routing changes



- TE MPLS & MPLS-TP do use pre established paths
  - Some as trunks - not individual sessions
  - Generally not end-to-end - LANs at edges

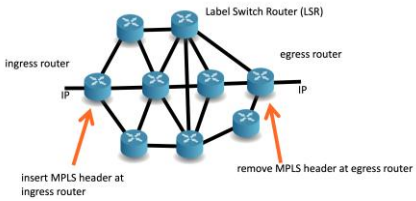
MPLS operation



- Header inserted at ingress removed at egress
  - Header includes a label
- Forwarding decisions based on label
  - Look incoming label up in LFIB
    - Includes label manipulation instructions, output label & next hop
- Most common manipulation
  - Replace input label with output label & forward frame

MPLS, operation, contd.

- Can have multiple labelsin a stack
  - Push & pop label functions supported
  - Used for trunks



Loading Label Forwarding Information Base

iTag	OTa g	Prefix	Int	Next hop
43	95	1.1.1.2/32	3	10.1.1.2
74	pop	2.2.2.3/32	1	10.3.4.5
39	43	3.2.1.0/32	3	10.1.1.2

- LFIB can be loaded by Label Distribution Protocol (LDP)
  - LDP uses IP-level routing to determine paths though the network
- LFIB can be loaded manually or by traffic engineering application
  - Define fixed paths through the network for specific traffic

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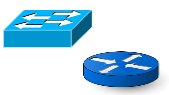
3	http://www.packetizer.com/ipmc/h323/forum/logos2.html
5	http://www.cisco.com/c/en/us/td/docs/switches/datacenter/sw/5_x/nx-os/mpls/configuration/guide/mpls_cg/mp_mpls_multipath_tree.html

Network technology
Conclusion

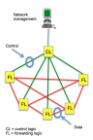
CSCI E 45a: The Cyber World – part A

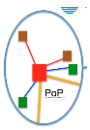
Network technology



- Conceptual layer model
- Old telephone technology fading
  - Being replaced by Internet protocol networks
  - But trying to preserve old operating models
- Enterprise networks are comprised of LANs (subnets) and internets

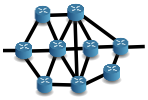
Network technology, contd.





- Software defined networks decouple logical and physical networks
- ISP networks use PoPs to aggregate customer connections and dual backbone connections for reliability

Network technology, contd.



- MPLS provides for address isolation and, sometimes, direct traffic where routing would not have
- Cellular networks support mobility and roaming

4

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5