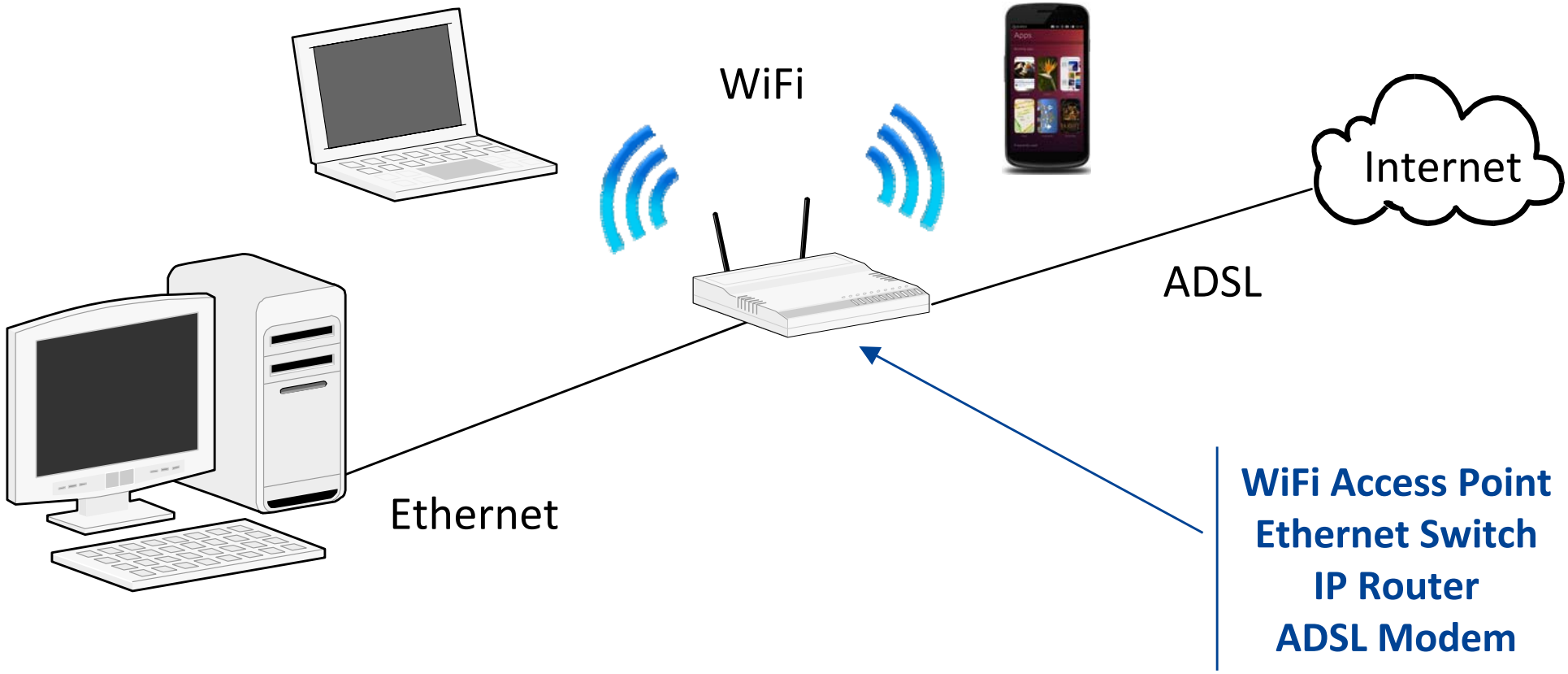
Access Networking

Connecting the User to the World

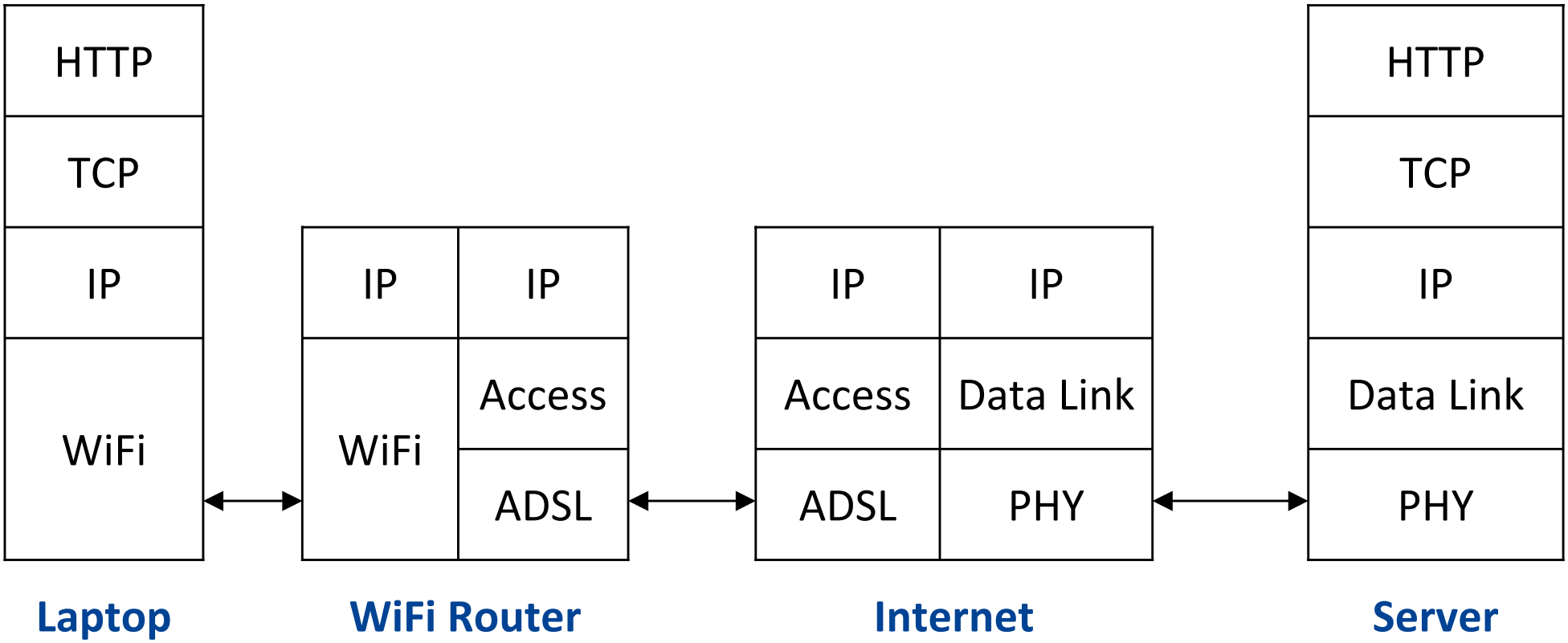
Small Office / Home Office (SOHO)

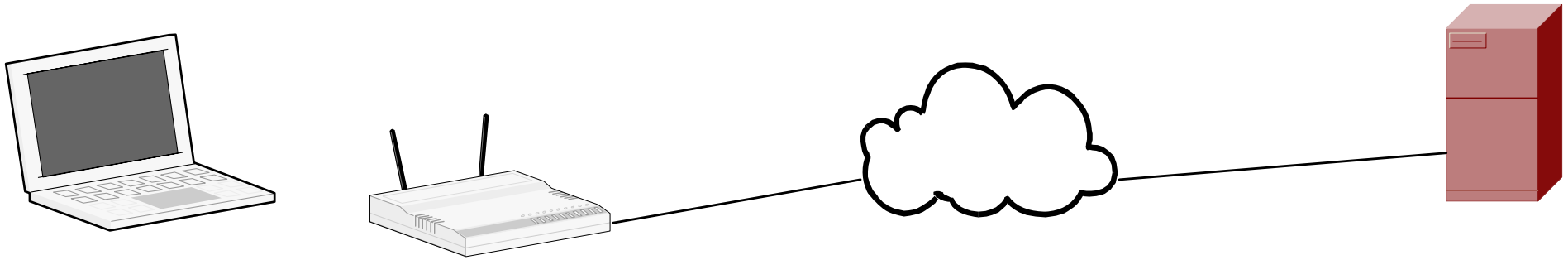
LAN (Local Area Network) to WAN (Wide Area Network)



Ethernet	802.3	Cable-based **LAN** protocol defined at **DATA LINK** and **PHY** layers
WiFi	802.11	Wireless **LAN** protocol defined at **DATA LINK** and **PHY** layers
ADSL	G.992.5	Cable-based transmission protocol defined at **PHY** layer

Laptop Browser to Web Server — Simplified View

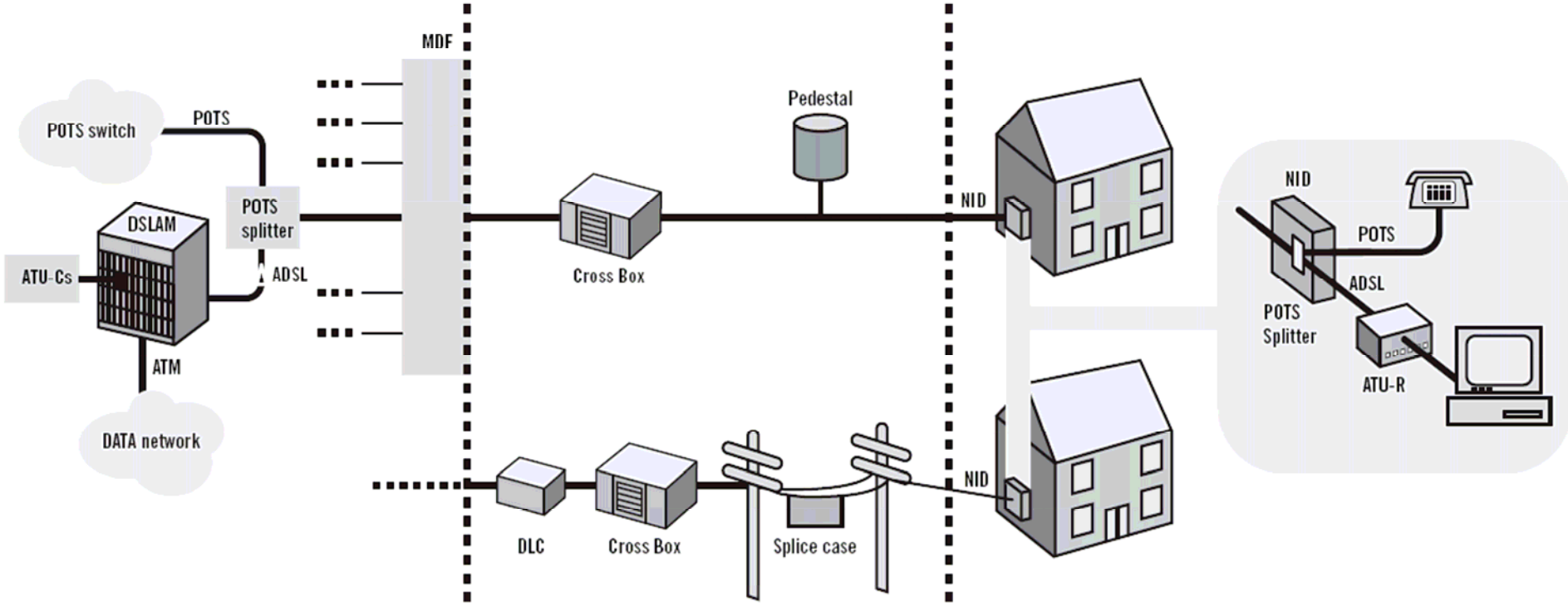




ADSL — Asymmetric Digital Subscriber Line

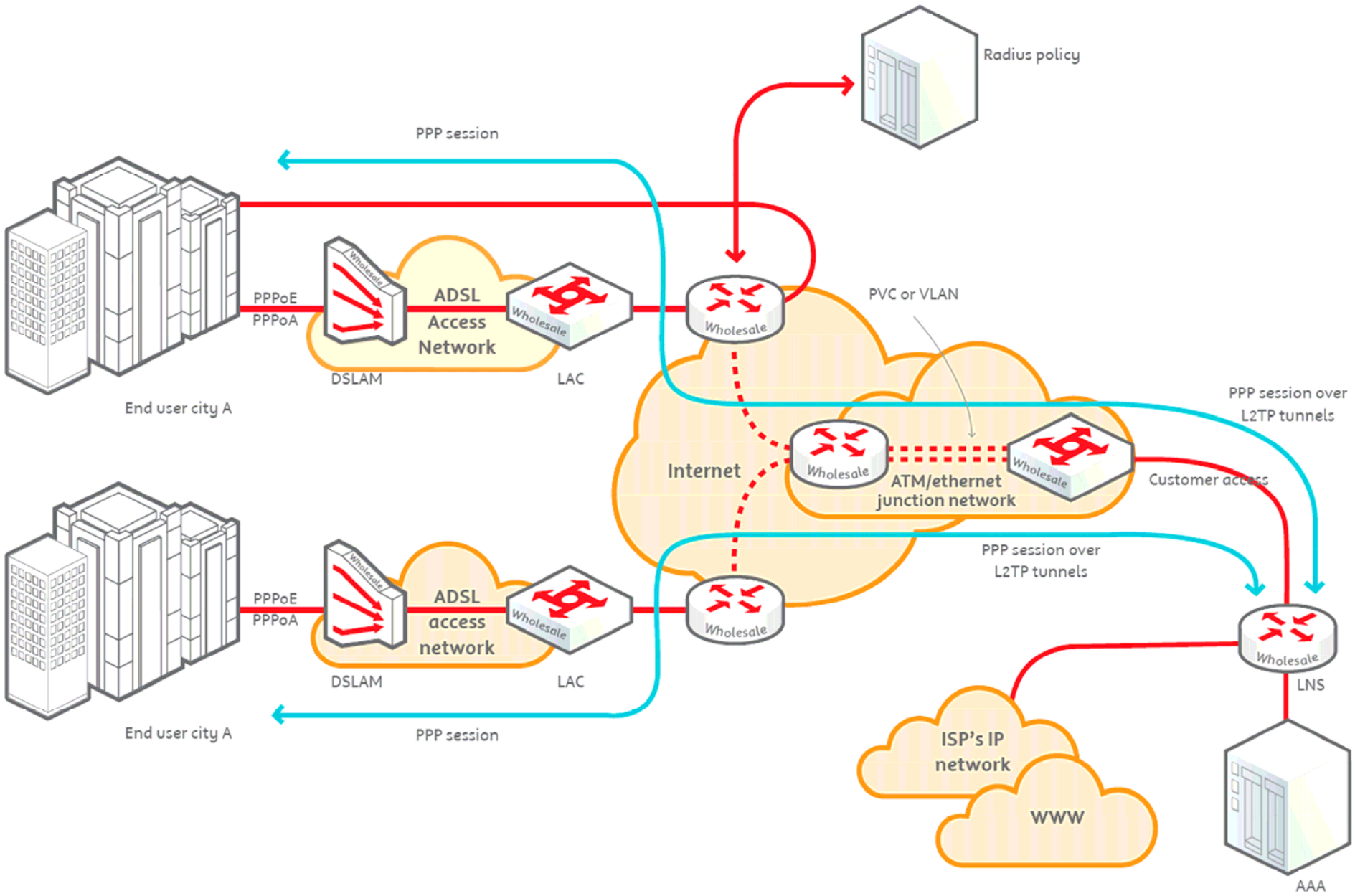
High speed transmission on standard voice line

- POTS — plain old telephone service
- 24 Mbps downstream
- 3.3 Mbps upstream



Ref: JDSU, **ADSL Technology**, JDS Uniphase Corporation, 2005

ADSL Access Network



Ref: Vodaphone, **Wholesale Layer2 DSL (W-DSL-L2I)**, VTCW011 - I 03/13

Typical Bezeq ATU-R

בזק. הכי טוב בבית

מדריך התקנה
מודם נתב אלחוטי
D-Link N 2760U



802.11
WiFi

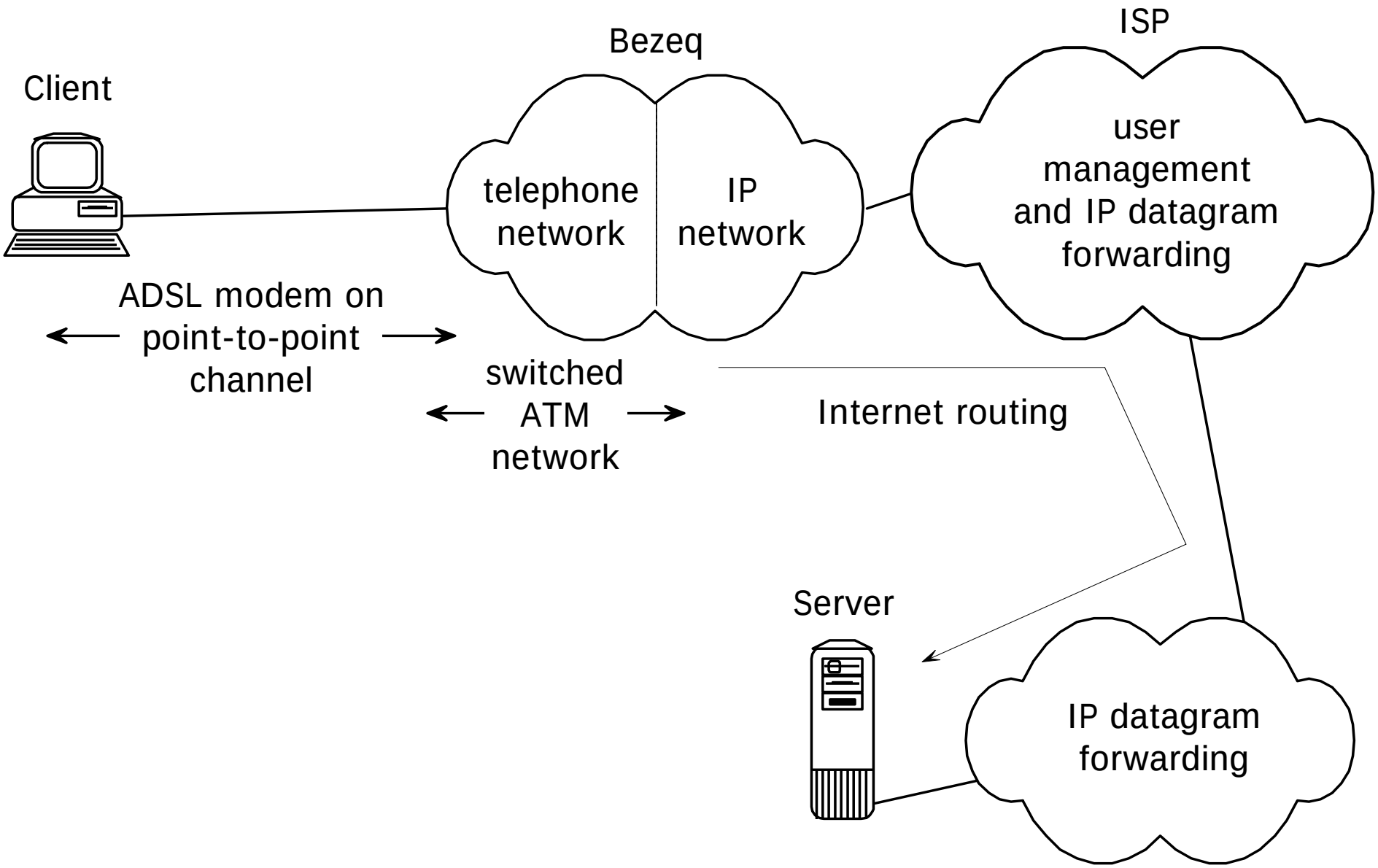
802.3
Ethernet

IP
Routing

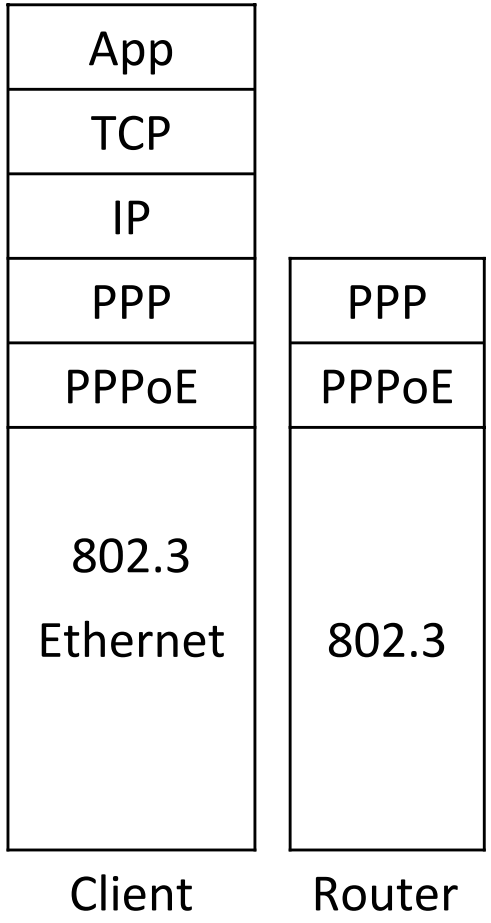
ADSL
33 Mbps



Bezeq Fast Internet Access



Fast Internet Protocols — Envisioned Campus Case



PPP

Point to Point Protocol

Logon + connection management

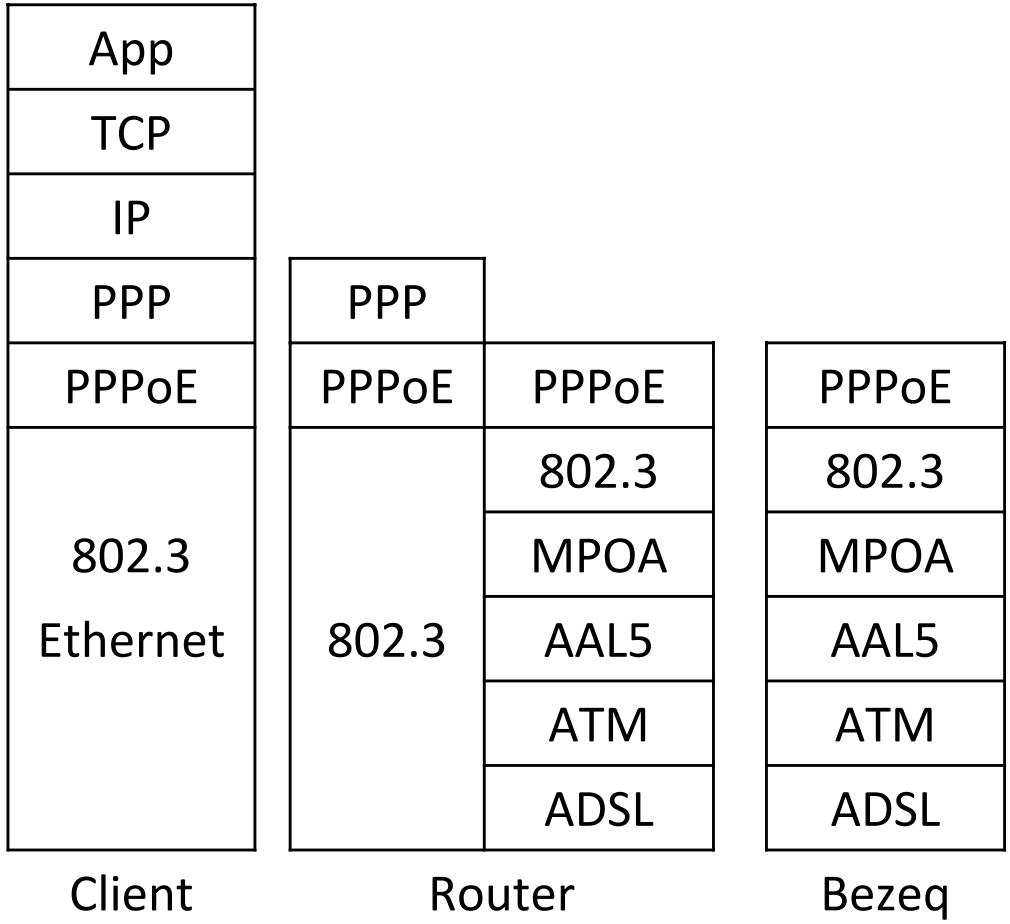
PPPoE

PPP over Ethernet

Virtual point-to-point connection over shared LAN

Client opens private session with ISP

Fast Internet Protocols — Envisioned Campus Case



ATM

Asynchronous Transfer Mode

Data Link protocol for broadband telephone services

Permits real time QoS

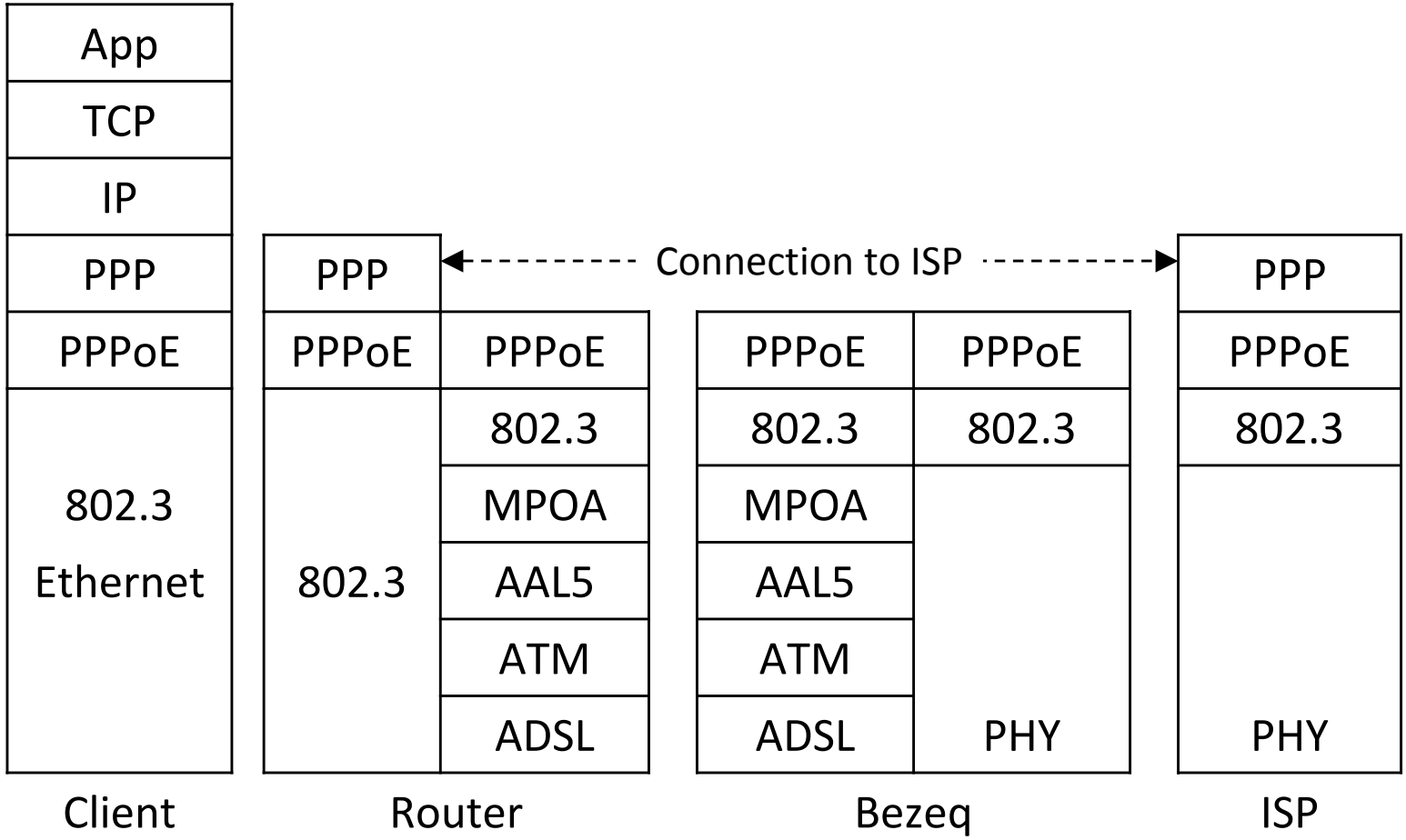
MPOA + AAL5

Adaptation protocols for ATM

ADSL

Physical bit transmission

Fast Internet Protocols — Envisioned Campus Case



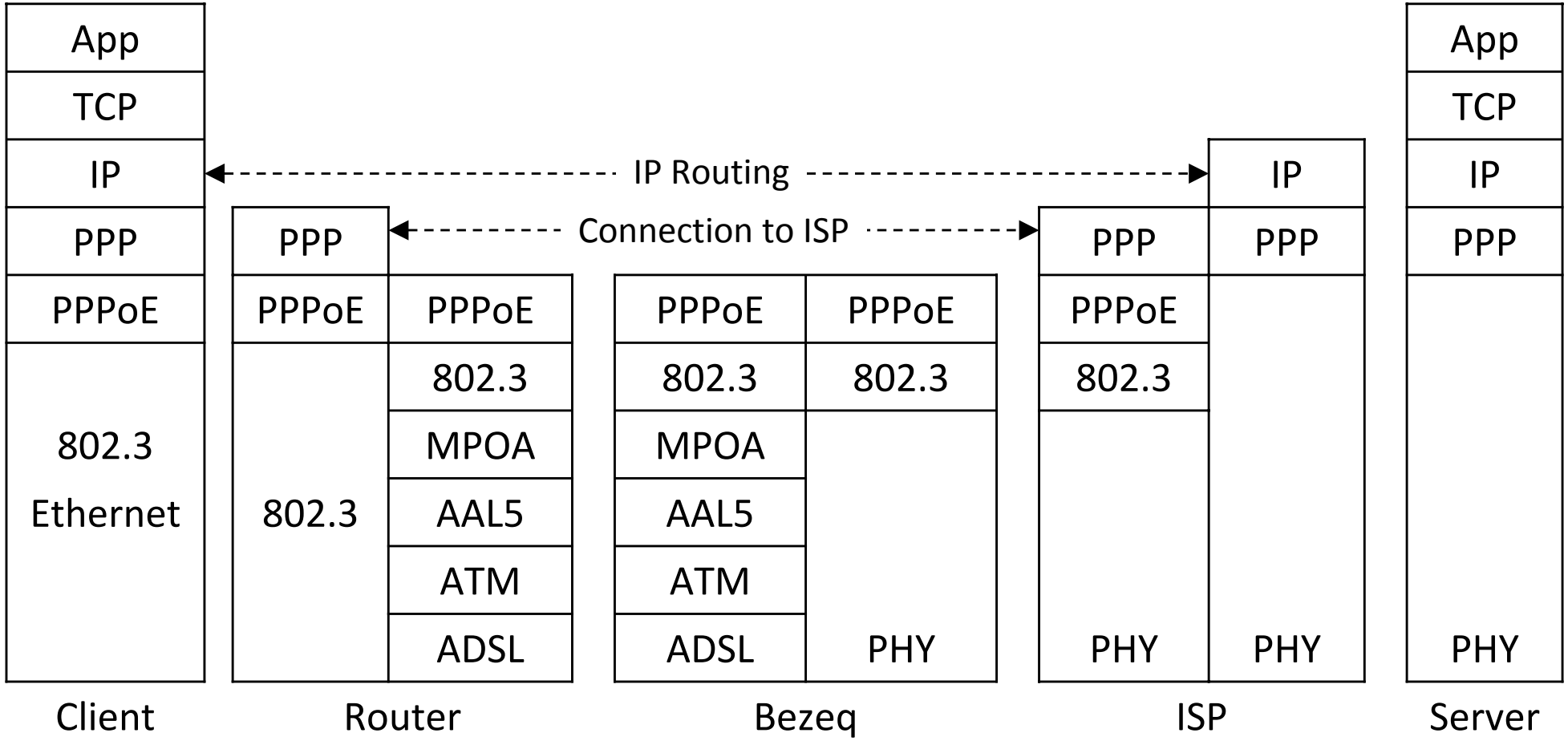
Connection to ISP

Client runs Network Control Protocol (NCP) over PPP

CHAP (challenge handshake authentication protocol) — User Name + Password

ISP authorizes user and engages IP forwarding

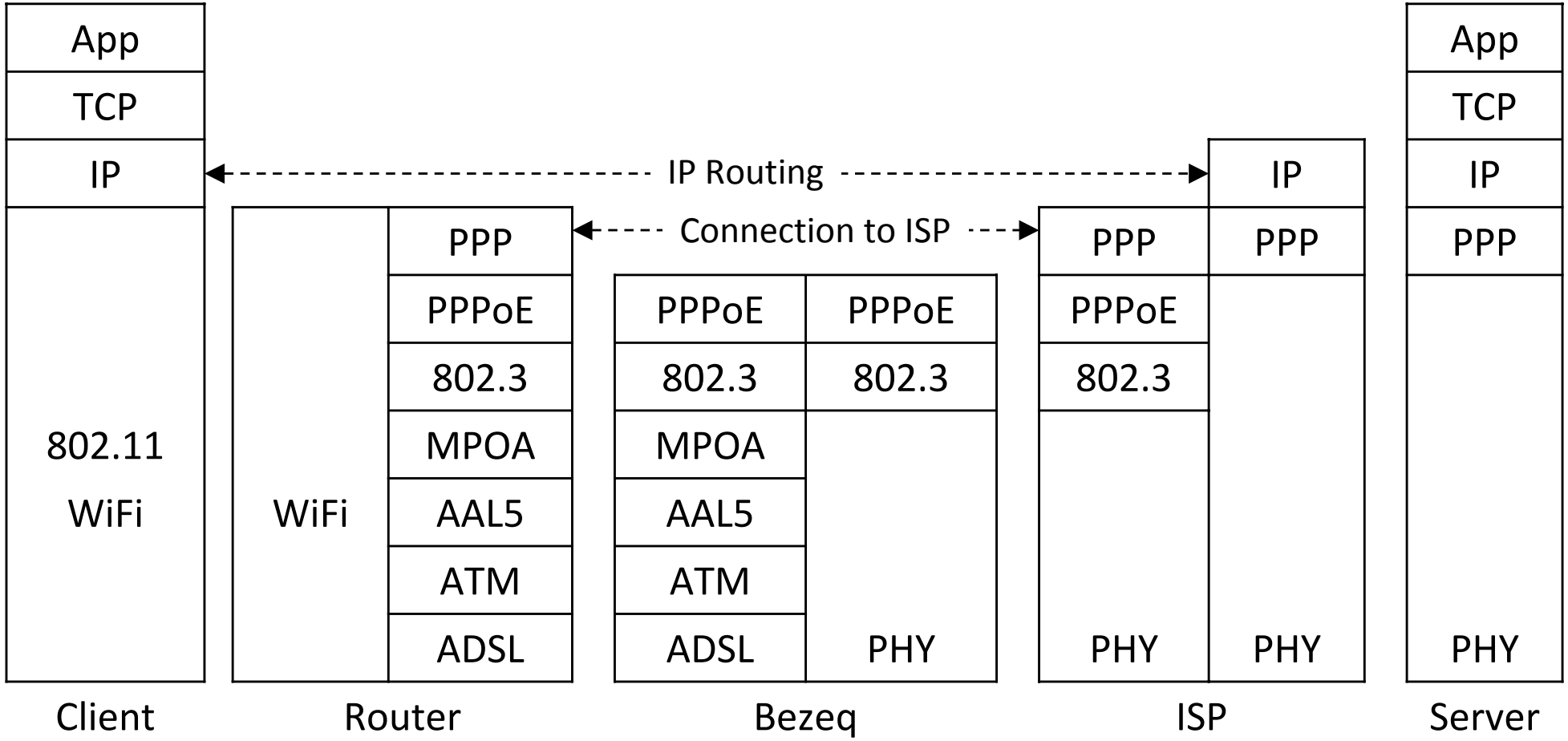
Fast Internet Protocols — Envisioned Campus Case



IP forwarding

ISP forwards IP datagrams to server via Internet backbone

Fast Internet Protocols — Typical SOHO Case



Router/modem initiates connection to ISP

Runs NCP over PPP over PPPoE over Ethernet

Router provides always-on Internet access over WiFi + Ethernet

Public Switched Telephone Network (PSTN)

Local loop (last mile) wired service

Analog voice + data

Voice → 64 kbps (DS0)

PDH / SDH digital hierarchy

DS0 streams combined to hierarchy of data rates

1.544 Mbps (T1) to 40 Gbps (STM-256)

ESS7

Hierarchical tree of central office switches for DS0 streams

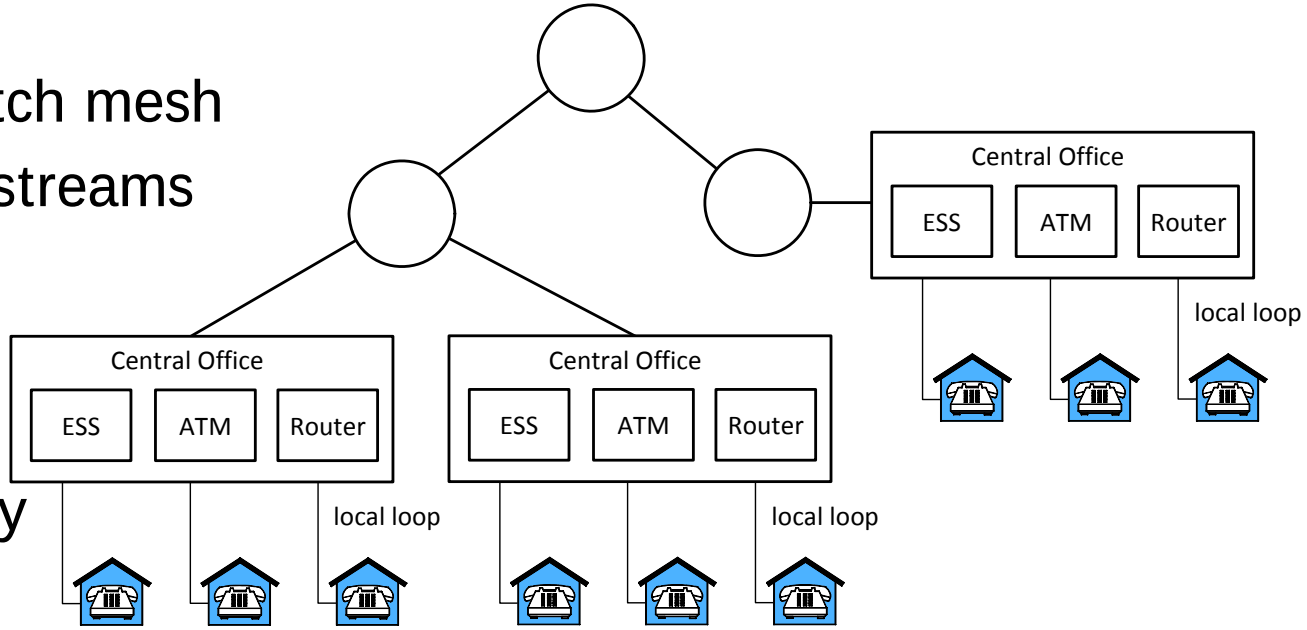
ATM

General packet switch mesh

Switches 2.5 Gbps streams (STM-16)

Telco

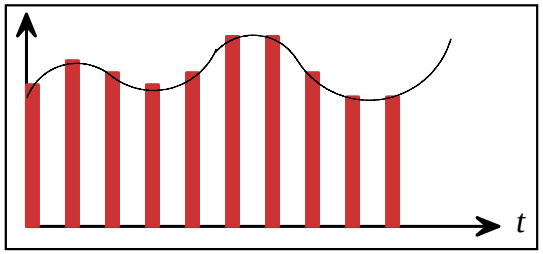
Telephone Company

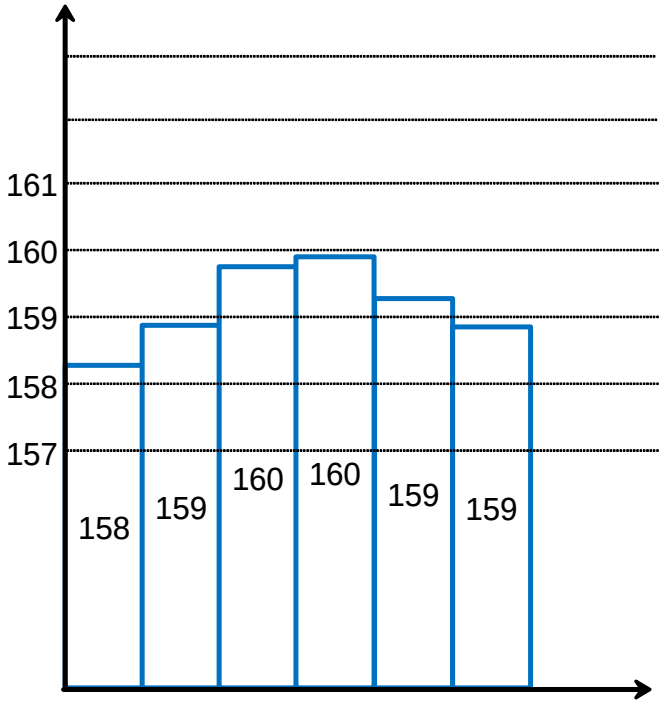


Digital Voice on Telco Telephone

Sample analog voice signal every 0.125 ms

0.125 ms per voice sample ⇒ 8000 voice samples / second





Round-off sample to 8-bit data

Data ∈ {0, 1, 2, … , 255}

Sample = {158.276, 158.879, 159.724, 159.821, 159.312, 158.791}

Data = {158, 159, 160, 160, 159, 159}

DS-0 stream

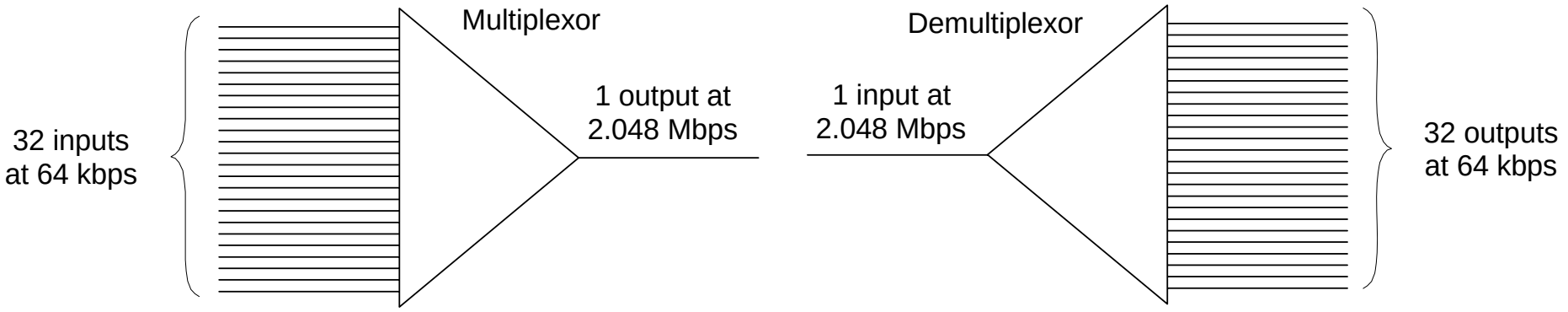
(8000 samples / second) × (8 bits / sample) = 64 kbps

64 kbps digitized voice (no compression)

Data Concentration

Multiplexing

Combine multiple nodes onto one link

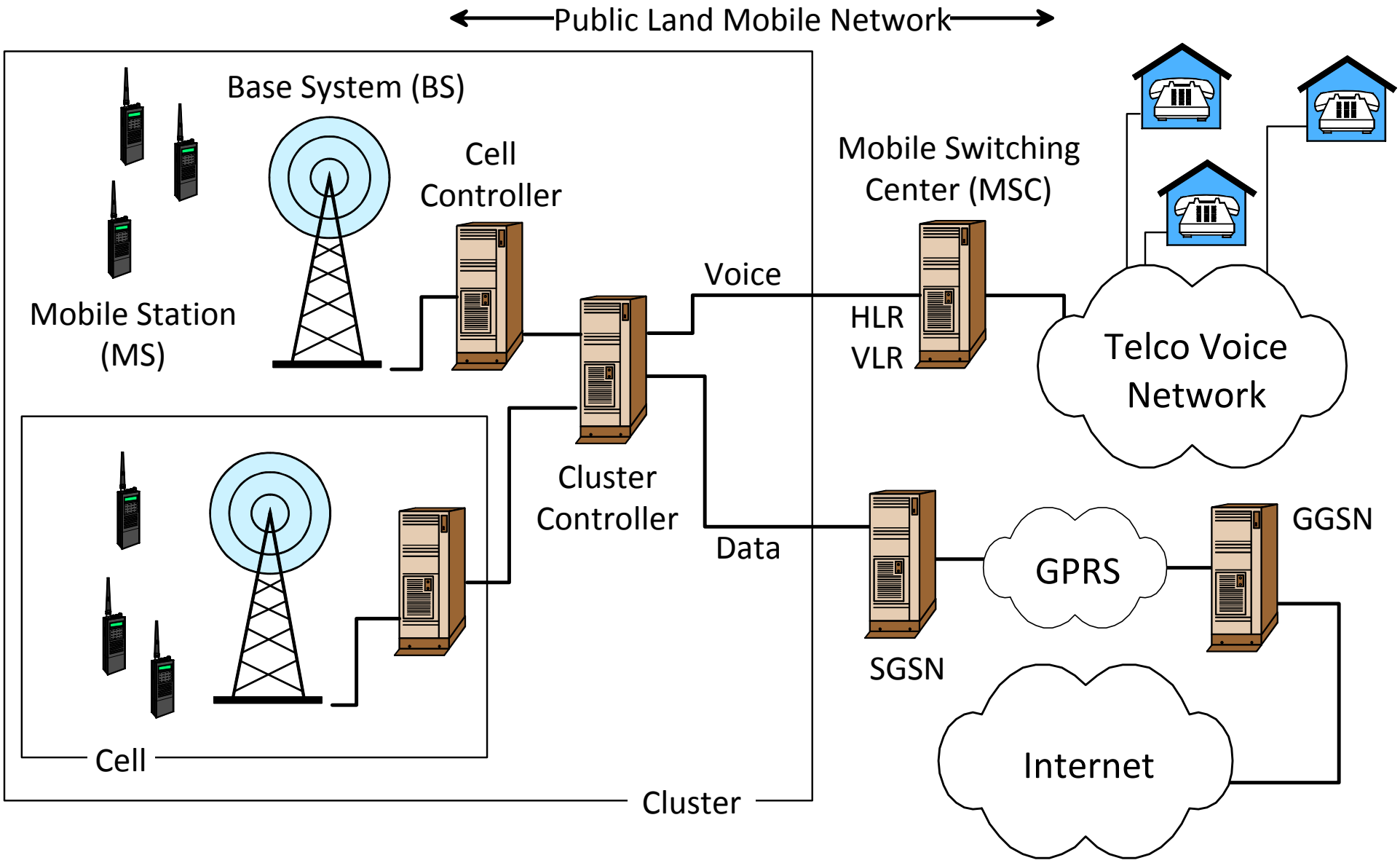


PDH		
E1	32 x DS0	2.048 Mbps
E2	4 x E1	8.448 Mbps
E3	4 x E2	34.368 Mbps
E4	4 x E3	139.264 Mbps

SDH		
STM-0	21 x E1	51.84 Mbps
STM-1	E4	155.52 Mbps
STM-4	4 x E4	622.08 Mbps
STM-16	16 x E4	2.48832 Gbps
STM-64	64 x E4	9.95328 Gbps
STM-256	256 x E4	39.81312 Gbps

Cellular Network in 2G

Wireless to base station — uses Telco network for voice service

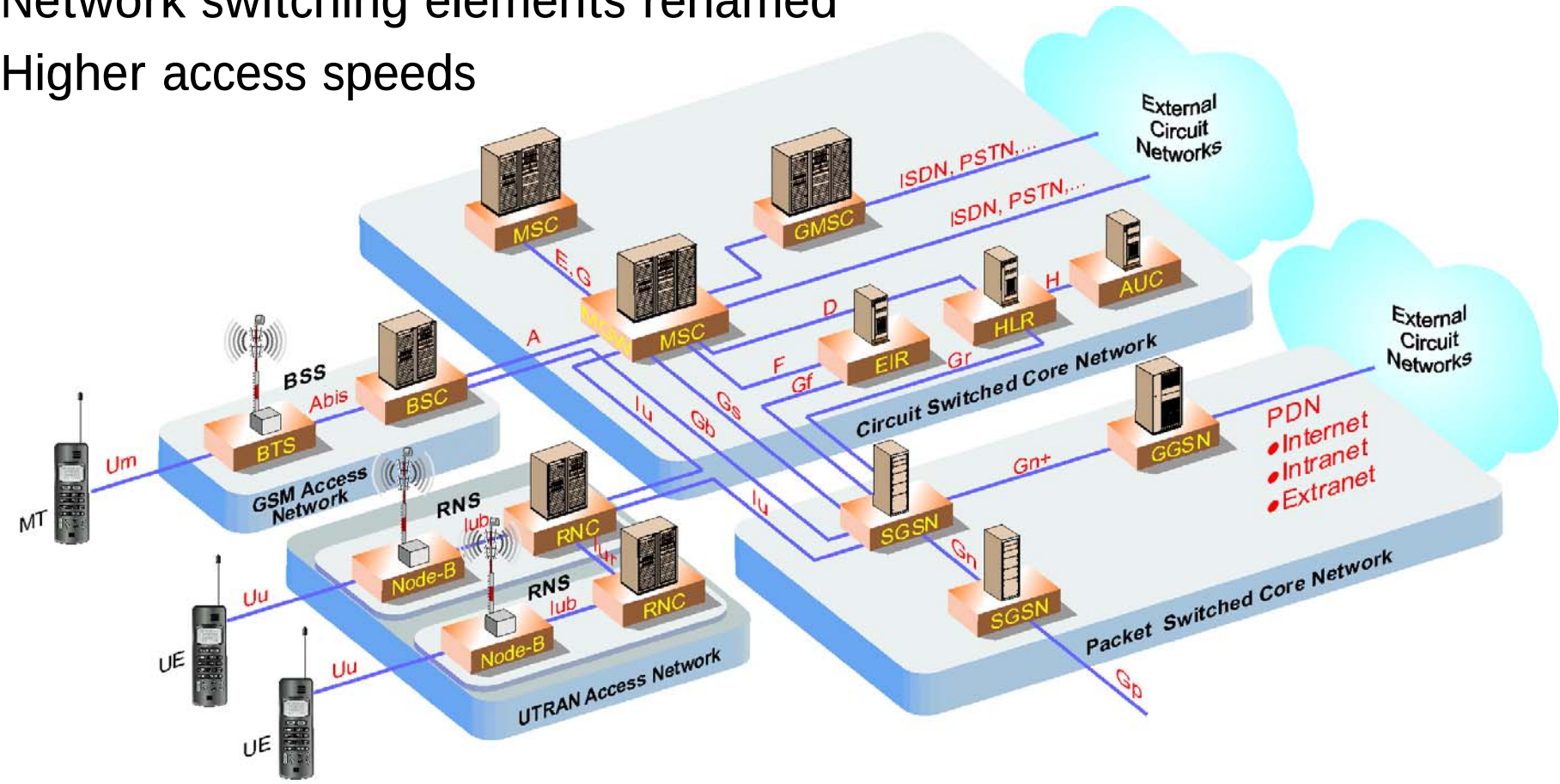


3G / 4G / 5G Cellular Networks

3G — evolution / improvement of 2G

Network switching elements renamed

Higher access speeds



4G / 5G — packet switched core network only

Eliminate circuit switched core network for voice

Voice calls carried as Voice over IP (VoIP)

Network Infrastructure

Economic perspective

Enormous investment in existing equipment

- Global network of hardware nodes + transmission lines
  - Developed to provide many services
  - Internet (IP-based unreliable connectionless) just one service
- Most developed before Internet
  - Telegraph — 1794
  - Telephone — 1876
  - Teletype modem — 1943
  - Digital telephone — 1962
  - Internet opened to public — 1992

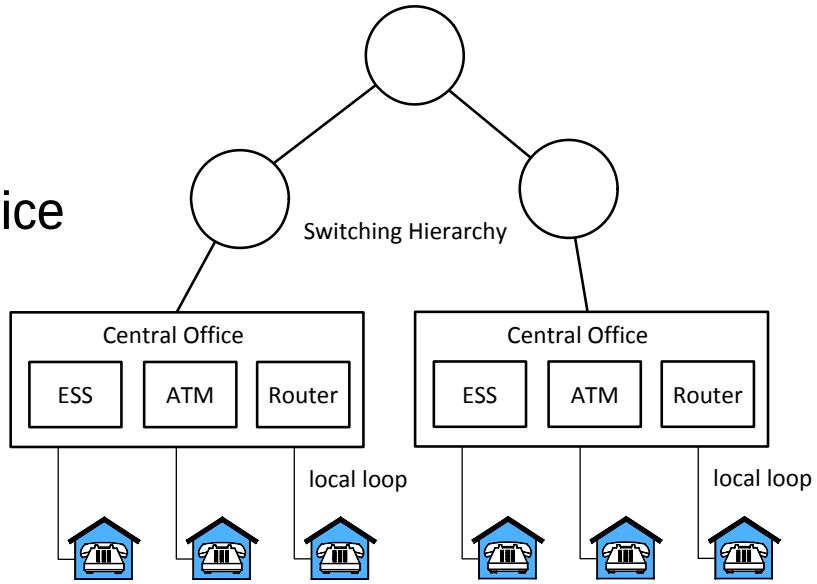
Hardware updates

- Replacement of manufactured hardware
- Slower than software updates
- More expensive than software updates

Changes in Telephone Business: 2000 — 2008

Enterprise networking needs

- Business revolves around data center
  - Access + storage + processing + service
- But employees still talk on phone
  - Mobility = standard
  - Voice calls cost money
  - Video calls growing



Network infrastructure providers (Telcos)

- Existing infrastructure designed for voice calls — not profitable
- Profit in leasing lines for data networks
  - Internet + private WAN + mobile backhaul (connections between cells)
- Strategy
  - Eliminate PSTN
  - Sell central office real estate to raise cash
  - Build data-oriented mesh network
  - Support voice as media streaming

Next Generation Networks (NGN)

ITU model for network planning in 21st century

ITU-T Recommendation Y.2001 (12/2004)

All-IP network

Every service operates over IP

IP operates over every infrastructure

Universal gateway point

Eliminate traditional service boundaries

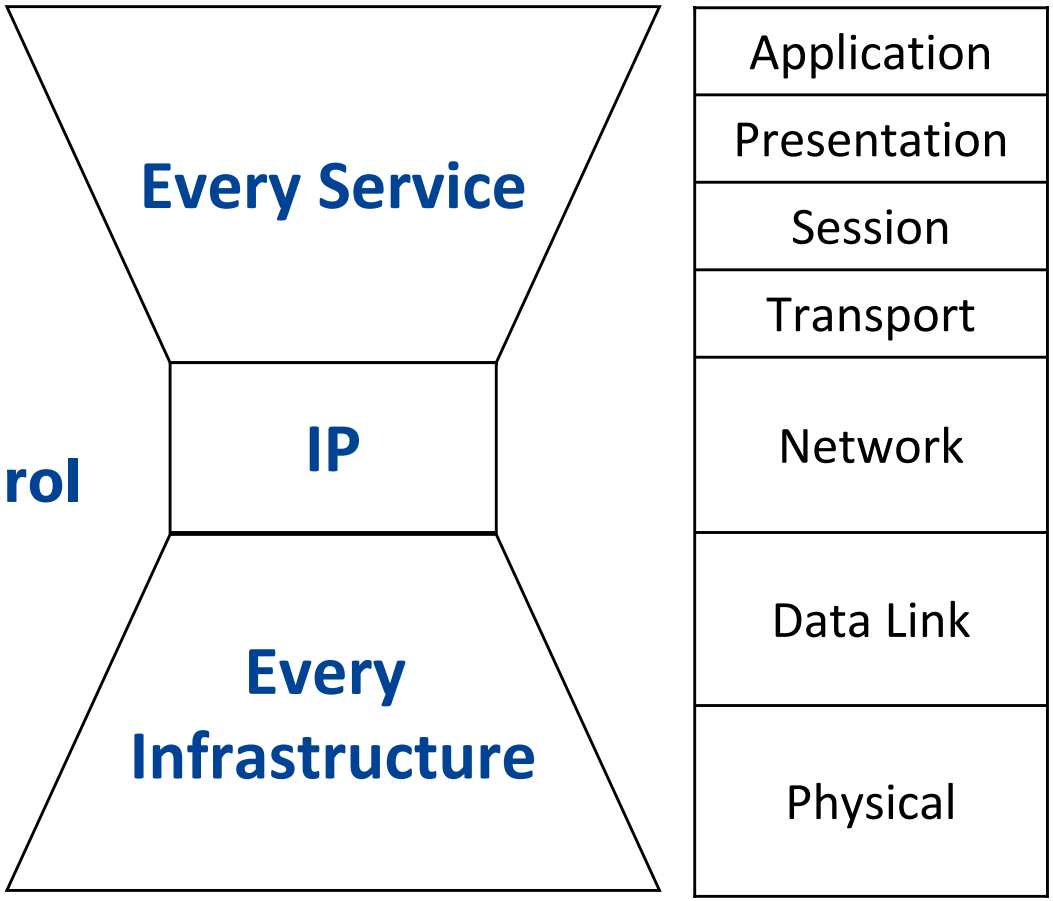
Universal mobility

Every service to every user

Quality of Service (QoS) control

Protocols with QoS fields

- IPv6
- MPLS
- SIP



Virtualization in Networking

Dedicated system

- Hardware constructed to perform one specific task
- Examples
  - WiFi access point
  - Internet router

Virtual system

- Implemented in software on programmable generic hardware
- Examples
  - Router implemented software
  - Java code running on Java VM over Linux

Transparency

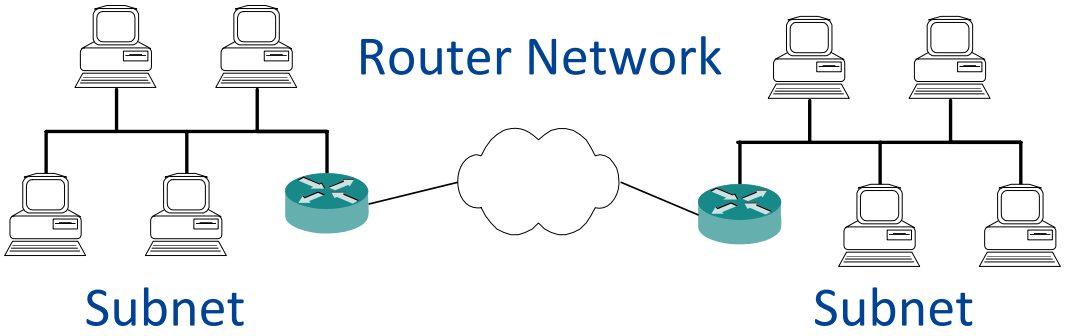
- Virtual system must look like dedicated system
  - To service requesters
  - To service providers

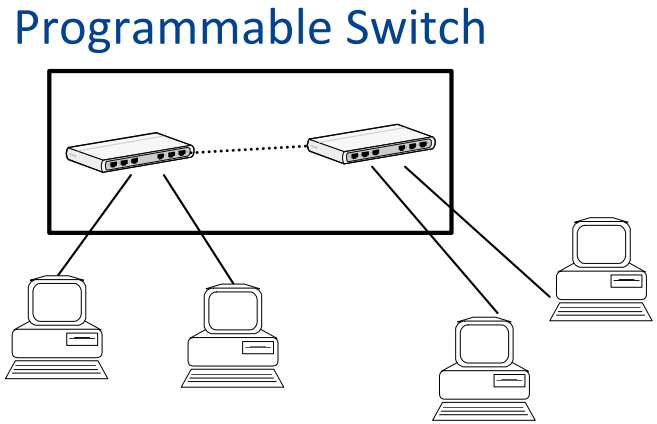
Standard Virtual Networks

Virtual LAN (vLAN)

LAN switch configured to partition nodes into subnets

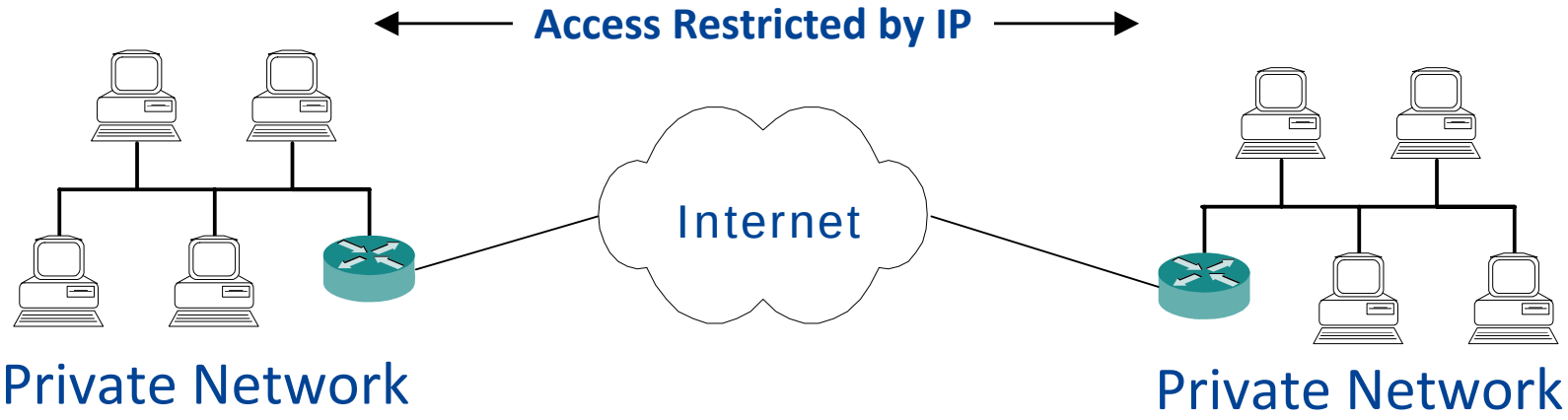
No router needed for subnet partitions





Virtual Private Network (VPN)

Private network implemented on public infrastructure



Traditional Networking Functions

Forwarding function

- Data transfer
- Implement network protocols
- High performance in specially designed dedicated hardware
  - Switches
  - Cable connections
  - Programming at console interface

Control function

- Configuration of network topology and policies
- Management of forwarding function
  - Supervision
  - Measurement
  - Maintenance

Software Defined Networking (SDN)

Virtual network

- Generic programmable hardware
  - Fast implementation of networking protocols
  - High capacity I/O
  - Standardized control interface for configuration
- Configured in software to implement networking functions
  - Modes, connections, protocols, policies

Data plane (user plane)

- Forwarding of user data

Control plane

- Network configuration data
- Security, maintenance, management

Fabric

- Hardware configured to implement SDN

Logical device

- Networking function implemented in SDN

Software Defined Networking (SDN)

SDN Application

Communicates network requirements to SDN Controller

Receive abstracted view of network

SDN Controller

Translates requirements from SDN application into SDN Datapaths

Provides SDN applications with view of network

SDN Datapath

Logical network device controls data forwarding hardware

Provides configured data forwarding capabilities

Programmable network

Regard network definition as problem in software engineering

Cloud Computing Business Model

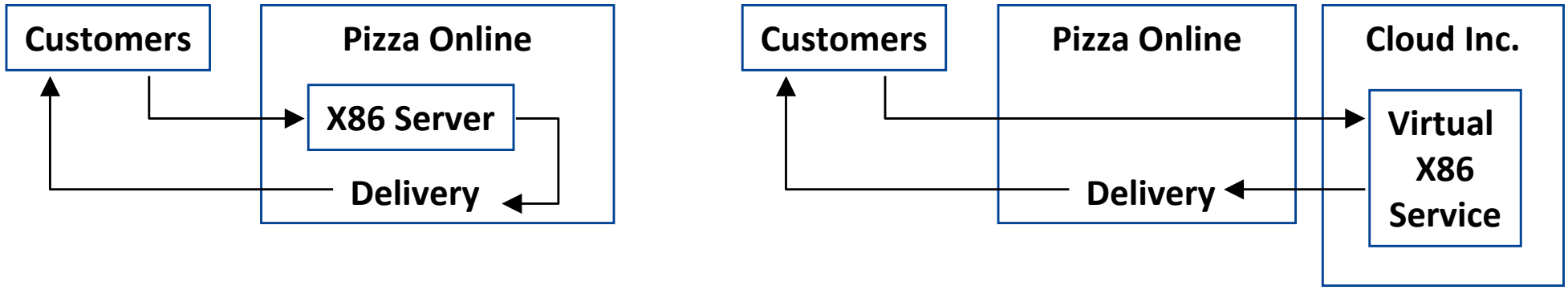
Outsourcing service model

Replace user hardware/software with "computing as service“

Implement virtual networks

Service Level Agreement (SLA)

- Defines service provided to user
- Guarantees performance and quality of service
- Provider handles operations+administration+maintenance (OAM)



Business advantages

Economies of scale to large provider → lower cost to user

User cuts labor/capital costs from balance sheet → happy investors

Cloud Computing Architecture

Cloud service organized from conventional resources

- Provider installs computing / networking hardware
  - Usually large servers or mainframes
- Provider offers menu
  - Mix of hardware + software + network types
- User chooses Service Level Agreement (SLA) from menu
- SLA implemented with dedicated or virtual system

Unique technological issues

- Service reliability
  - Provider financially committed to SLA
- Provider-side
  - Seeks minimum configuration cost for SLA
- User-side
  - Seeks minimum contract cost for requirements

Service Hierarchy in Cloud Computing

Infrastructure as a service (IaaS)

User sees virtual hardware environment

Real hardware or hypervisor / system virtual machine

User installs OS → installs software → runs jobs

Platform as a service (PaaS)

User sees virtual OS environment

OS on single hardware platform or virtual OS

User installs software → runs jobs

Software as a service (SaaS)

User sees virtual application software environment

Applications running on private OS or "sandboxed" on shared OS

Sandbox — private execution environment per application instance

User runs jobs

Storage as a service (STaaS)

User sees virtual mounted storage device

Considerations in Cloud Computing

Cost

- Provider issues
  - Economies of scale $\Rightarrow$ lower cost per compute job
- User issues
  - Capital + OAM costs $\rightarrow$ operating costs
  - Lower start-up costs $\Rightarrow$ operating debt

Reliability

- Provider issues
  - Redundant infrastructure $\rightarrow$ continuity + disaster recovery
  - Centralized management of OAM, security, performance
  - Virtualization $\rightarrow$ serve multiple users on physical server
  - Multitenancy $\rightarrow$ provide multiple sandboxed application instances on OS
- User sees guaranteed service

Agility

- User / provider reconfigure service / infrastructure as needed
- Growth, load balancing, time-zone serving

Cloud Ownership

Public cloud

- Service provider as public utility — sells / rents computing service
  - Initial providers leverage large existing infrastructure
  - Amazon, Microsoft, Google, IBM
- Menu of services at fixed prices

Private cloud

- Cloud infrastructure for private organization
- Managed internally or outsourced
- Isolates service developers from implementation issues
  - Standard development platform
- Requirements for economic justification
  - Large organization
  - Technology-based services
  - Frequent new service
  - Example — internet content provider

What's Different in Cloud Networking

End user

Not much

Accesses service "somewhere" on network

Business service provider

Define business service

Outsource implementation

OAM limited to SLA-level virtual environment



Cloud service provider

Manage vast real environment mapped to virtual environments

OAM requires effective picture of real system from SLA POV

Centralize → Decentralize → Centralize → ?

1950s — 60s

Centralized mainframe computer + multiple OS instances over hypervisor

Timesharing OS serves multiple users

User sees OS environment via dumb terminal (thin client)

1970s

User applications offloaded to minicomputers + timesharing services

User sees timeshared OS environment via dumb terminal

1980s

User applications offloaded to personal workstations (PC)

User sees single-user OS environment running locally

1990s

Network single user workstations

User sees single-user OS environment running locally

2000s

Centralized control of local OS environment by IT departments

2010s

Cloud + netbook / tablet / smart phone — dumb terminal with high-res GUI

Enterprise Networks

Enterprise

The word (ref: http://www.etymonline.com)

- Past participle of entreprendre — "undertake, take in hand"
- From Old French — entre "between" + prendre "to take"

The pose



Enterprise network

Larger + more complex + more expensive + more awesome than SOHO

Integrated LAN + WAN technologies

- Traditionally implemented in specifically-designed hardware systems
- Increasingly implemented as Software Defined Networks (SDN)

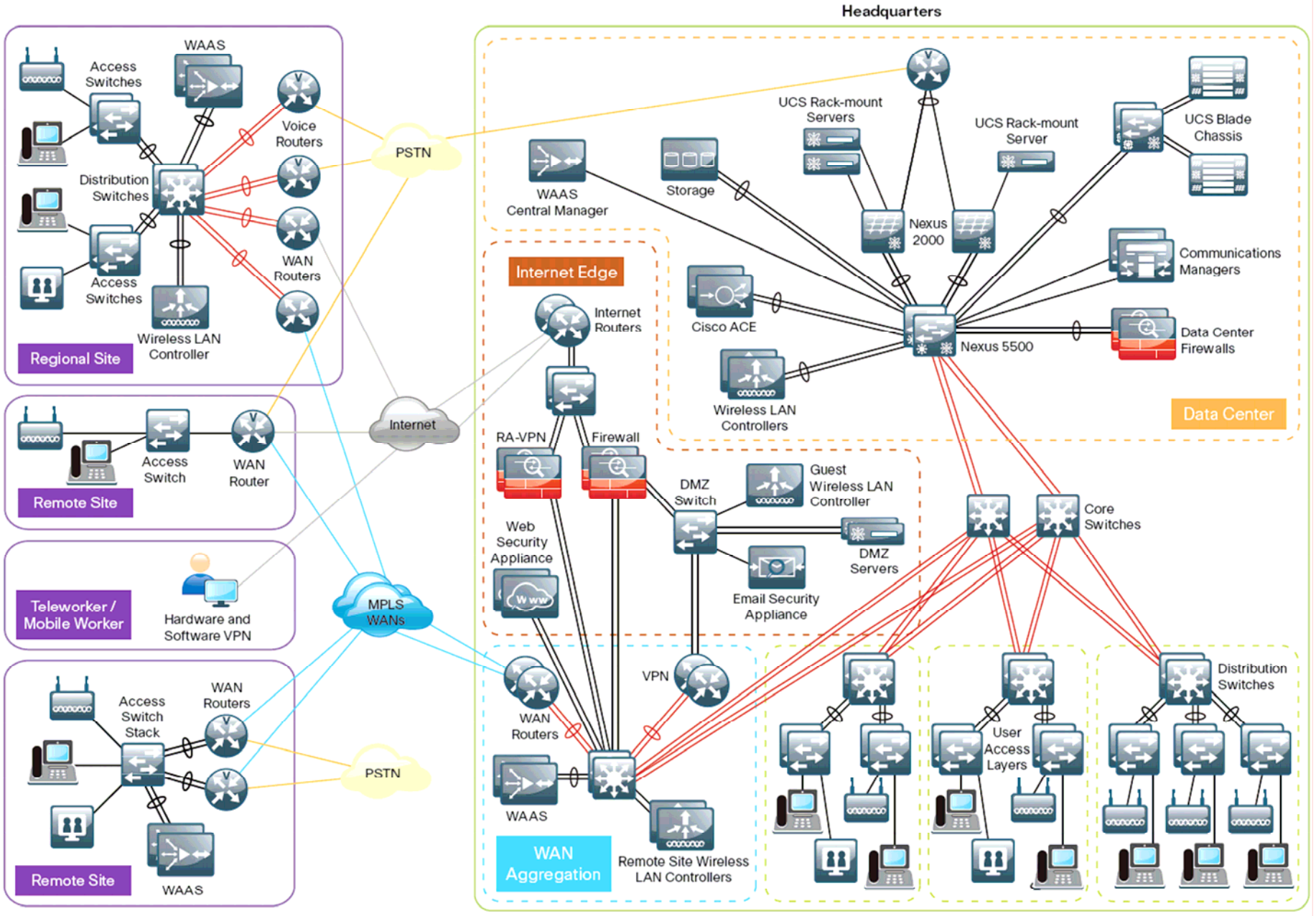
Security

High overall traffic volume

Traditional Network Infrastructure

Cisco Smart Business Architecture (SBA)

Ref: WAN Design Overview, Cisco 2013



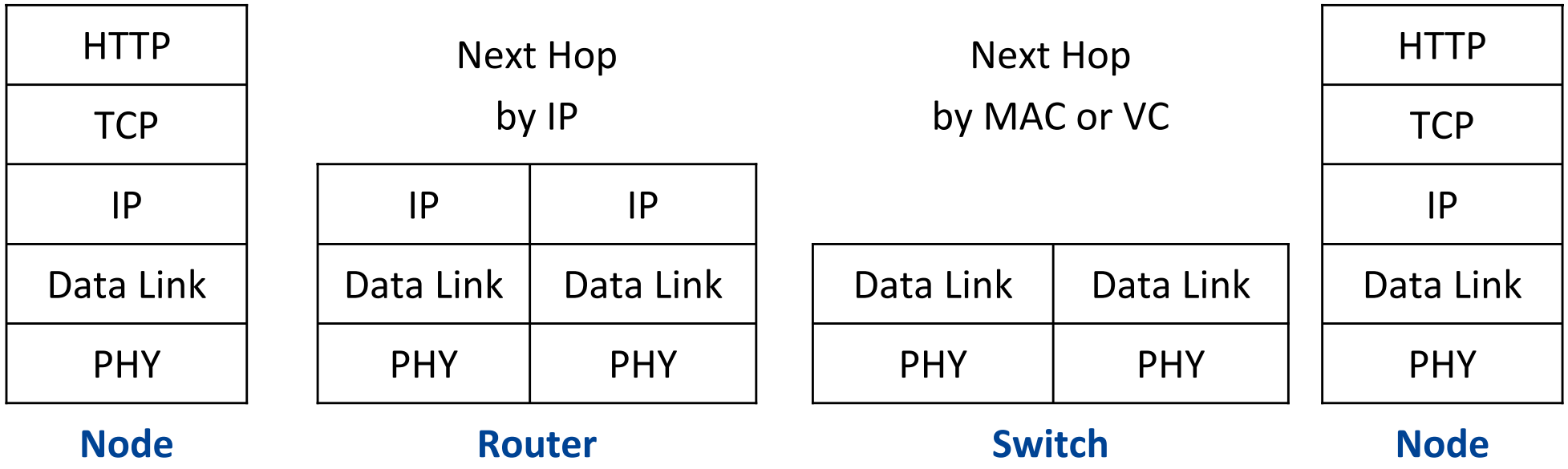
Technologies in the Cisco SBA

Conventional Layer 3 routing

- Permits universal access to any host / node
- Next-hop IP datagram forwarding

Conventional Layer 2 switching — N x N non-blocking switching

- Permits access to nodes on same physical network
- Ethernet MAC physical port-to-port switching
- ESS7 64 kbps voice telephone switch
- ATM cell switching for switched and permanent virtual circuits
- Frame Relay switching for permanent virtual circuits



Technologies in the Cisco SBA

Multiprotocol Label Switching (MPLS)

Label header added to IP datagram

Label identifies end-to-end route

Implements end-to-end virtual circuit

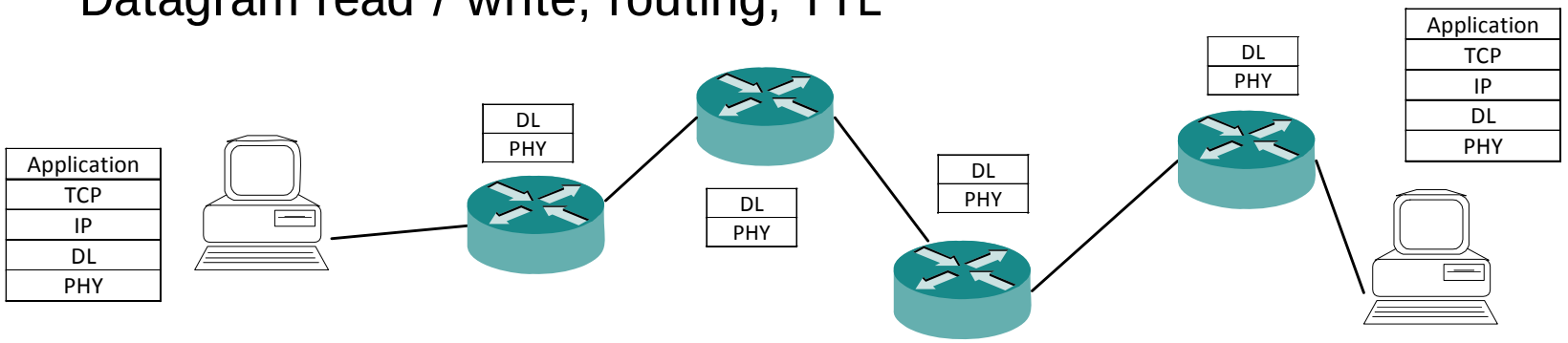
MPLS enabled router

Next hop by MPLS label

Faster than next hop IP routing

Saves time of layer 3 processing

Datagram read / write, routing, TTL



Switch / Router Interaction

Permits vLAN and VPN definition

Optimizes multimedia streaming

Technologies in the Cisco SBA

Nexus 7000 Switch



- 100 Gbps Ethernet switch
- Copper or fiber access ports
- QoS control
  - Cut-through architecture (forward data without buffering)
  - Low latency + jitter
- Extensible through fabric extenders (FEX)
  - Scalable to 15.76 Tbps (15,760 Gbps)
- Supports virtual networking through MPLS

Nexus 2000

- Fabric extender (FEX)
- Add remote ports to Nexus 7000



Ref: http://www.cisco.com

Technologies in the Cisco SBA

Cisco XR 12000 Router

For large enterprises and service providers

1280 Gbps capacity

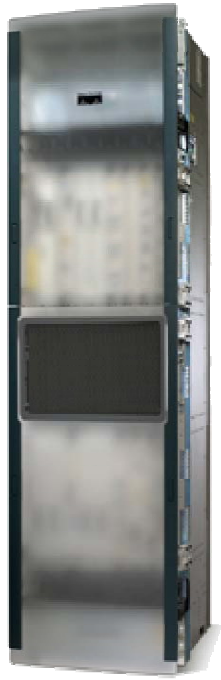
Internet protocols

IPv4/v6, MPLS

BGPv4/v6, IS-IS, OSPFv2.0, RIPv2, IGMP, DVMRP, PIM DX/SX

Infrastructure protocols

SONET/SDH, Ethernet, ATM, copper (DS-3/E3)



Cisco 7600 Router

WAN router

240 Gbps capacity

Infrastructure — Telco leased lines DS0 to OC-192



Cisco 3900 Router

For branch office

4 Gigabit Ethernet ports



Cisco Software-Defined Access Design

Underlay network

Physical dedicated hardware

Overlay network

Virtual network implemented in SDN

Management

Identity Services Engine (ISE)

- Account database

DNA Center

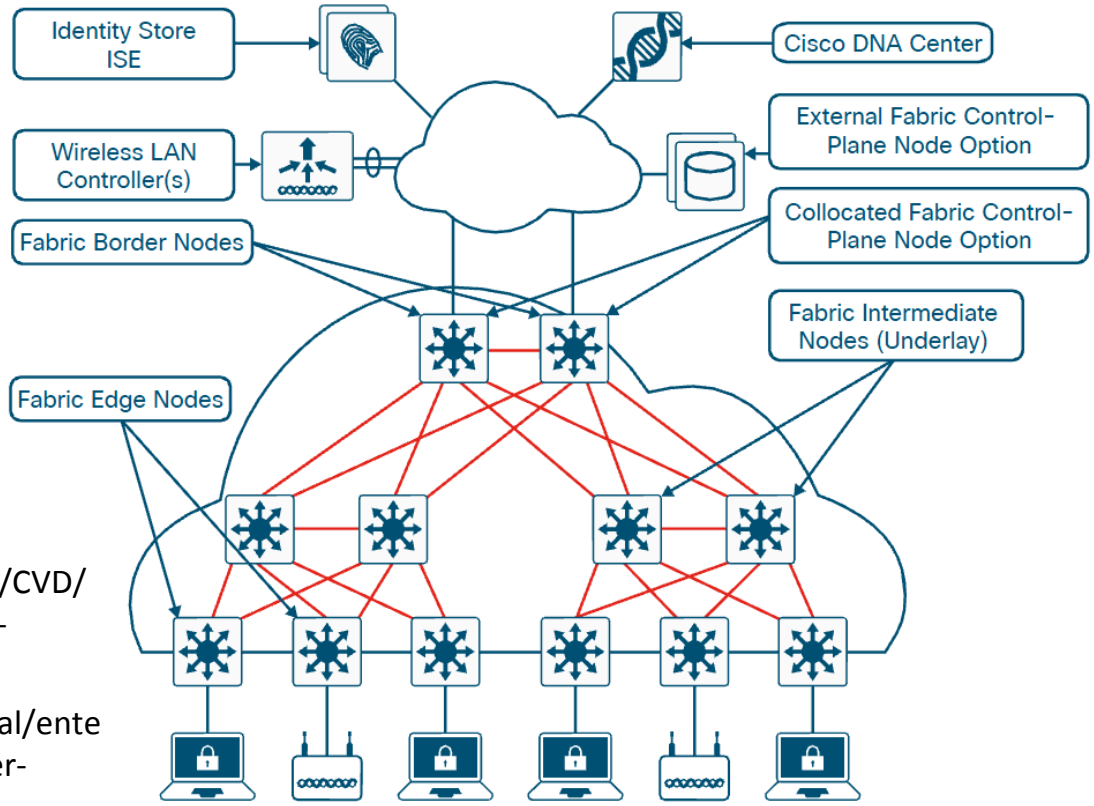
- Hardware database

Border node

- Connects fabric to WAN

Edge node

- Connects fabric to user



References:
https://www.cisco.com/c/dam/en/us/td/docs/solutions/CVD/Campus/CVD-Software-Defined-Access-Design-Sol1dot2-2018DEC.pdf

https://www.cisco.com/c/dam/en/us/solutions/collateral/enterprise-networks/enterprise-network-security/data-center-design-playbook.pdf

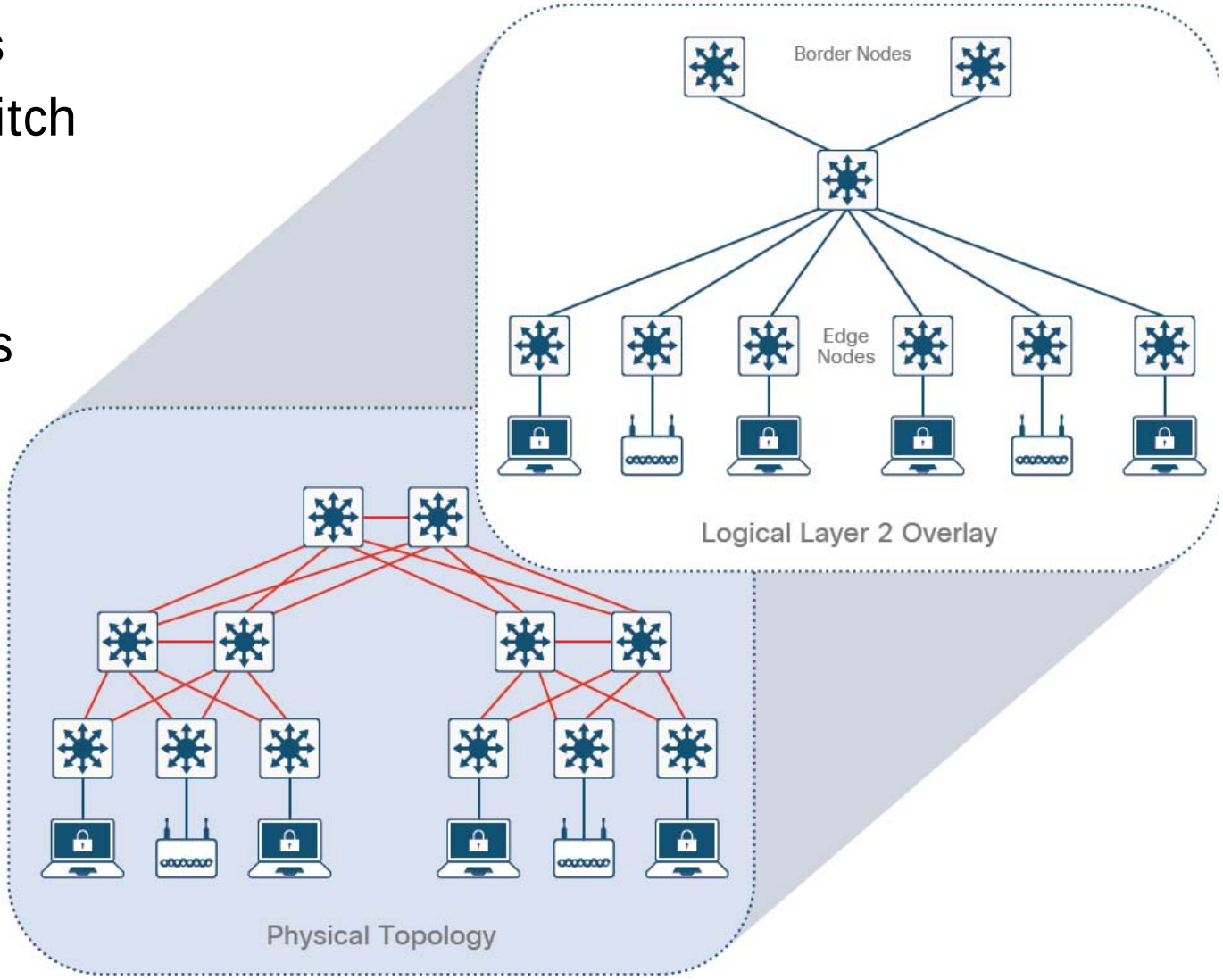
Layer 2 Overlay

Layer 2 (Data Link) Logical network

- Edge switches
  - Ethernet, etc
  - Connect users
- Intermediate switch
- Border switches

Physical network

- Physical switches
- Cables



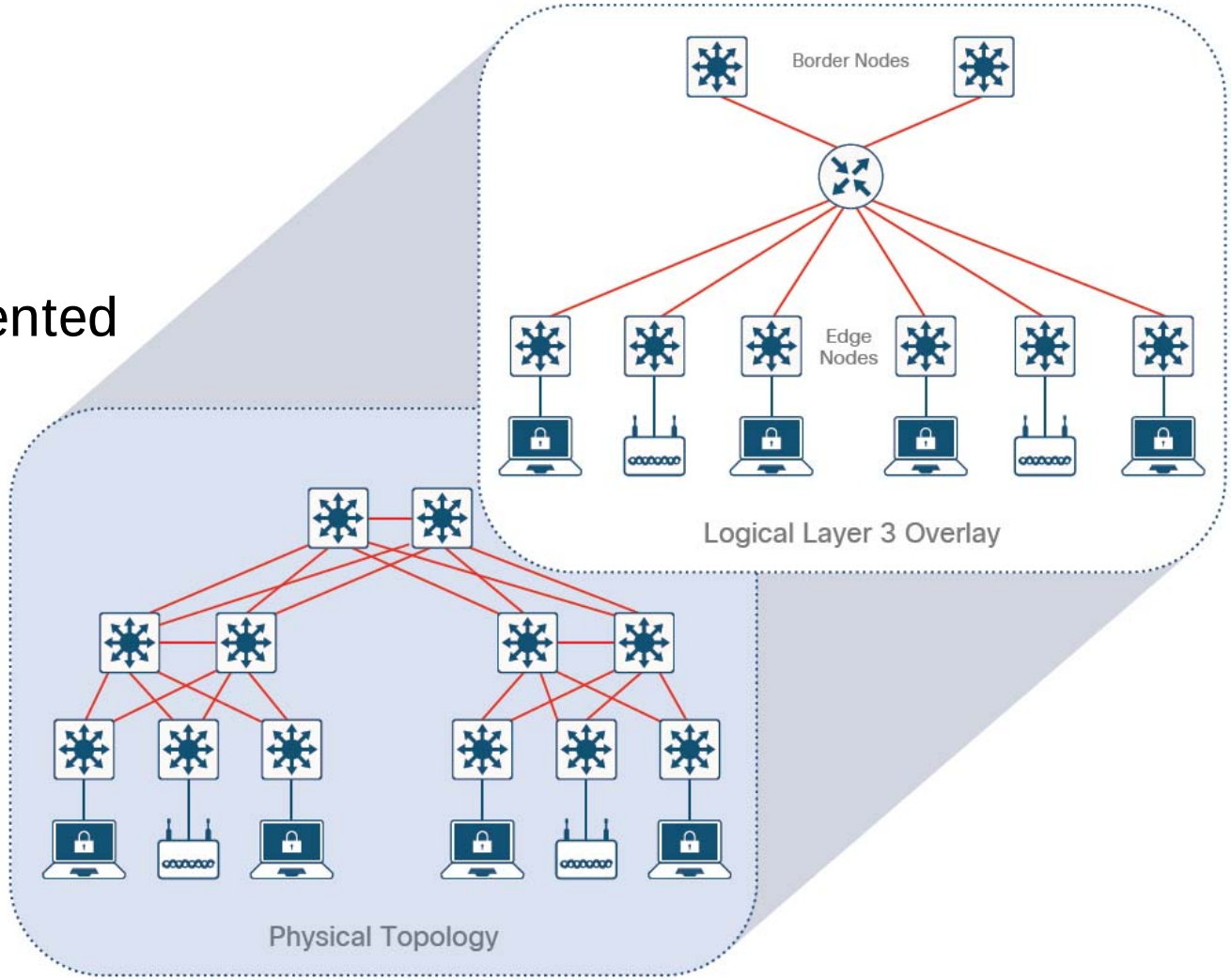
Layer 3 Overlay

Logical IP + switched network

- Edge and border switches
- Intermediate IP router

Physical network

- Same as Layer 2
- Physical switches
- Cables
- IP routing implemented in software



What Network Access Providers Do



RAD

Your Network's Edge®

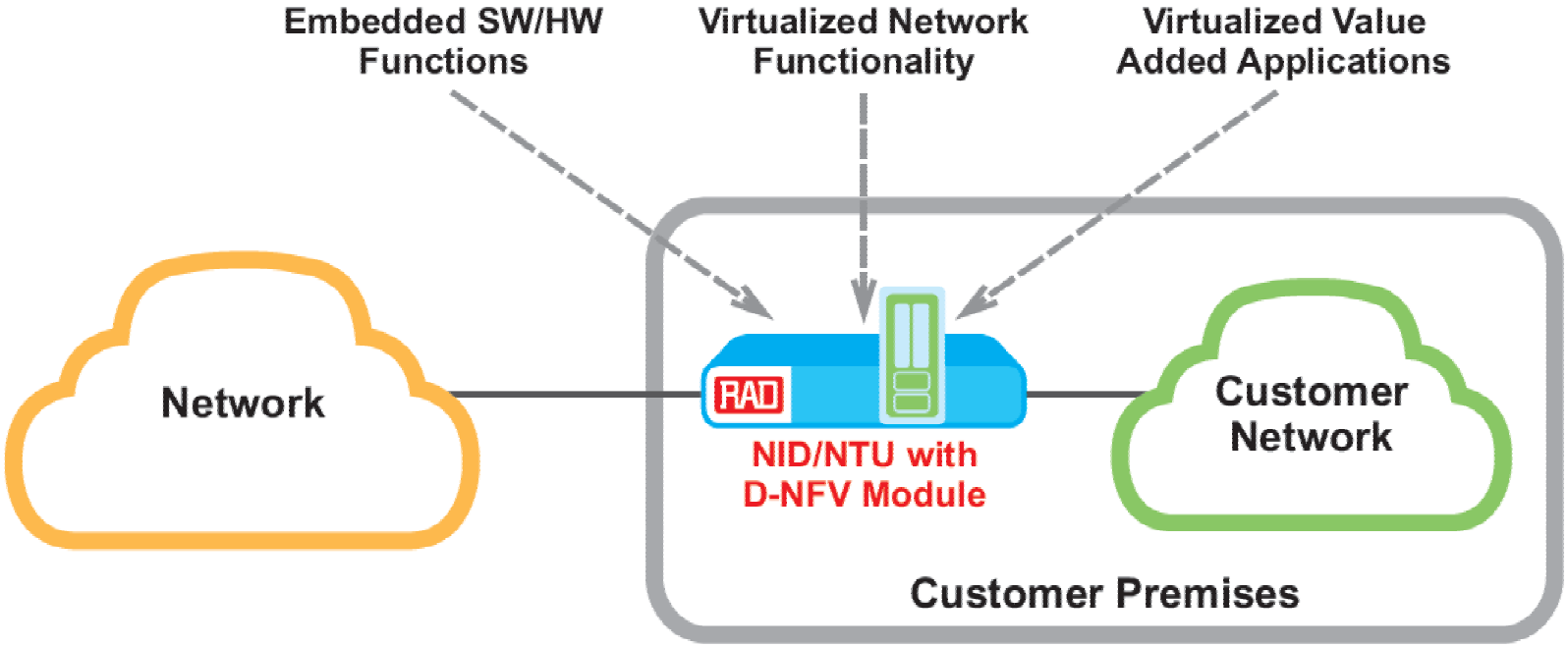
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https://www.rad.com/system/files/Media/rad-catalog-2019.pdf
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Distributed Network Functions Virtualization (D-NFV)



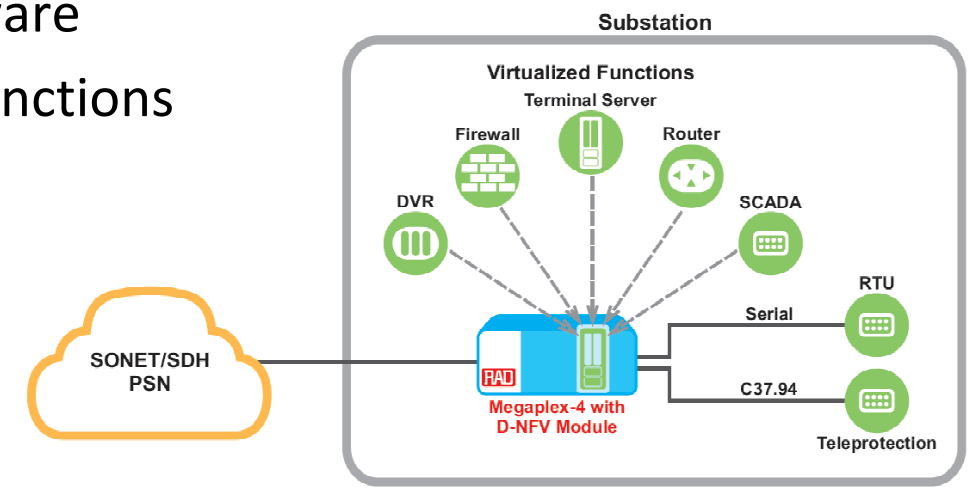
Virtualization

Highly configurable network hardware

Software defined network (SDN) functions

NID — Network Interface Device

NTU — Network Termination Unit for Carrier Ethernet



Carrier Ethernet

Ethernet

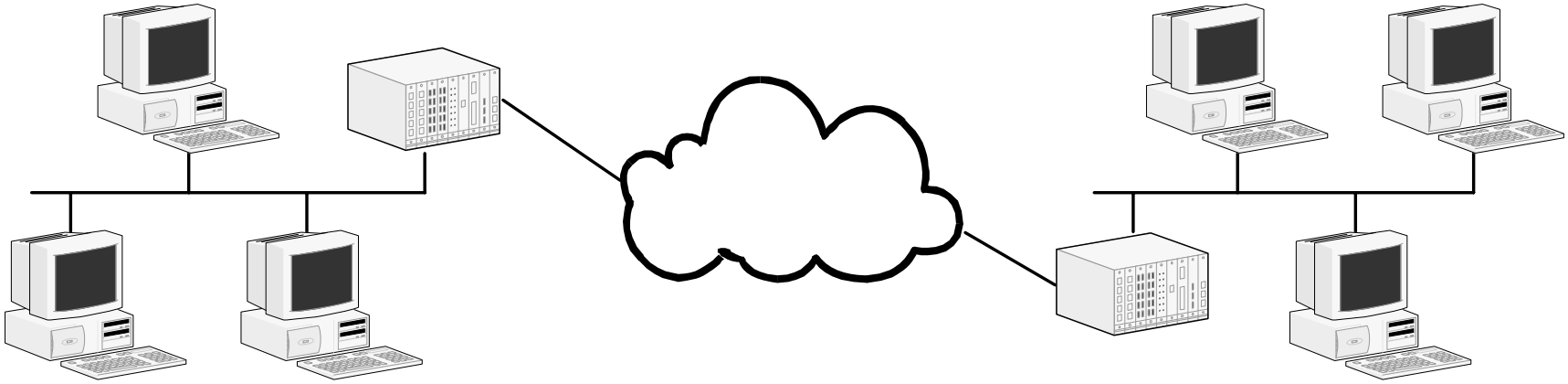
802.3 CSMA/CD shared medium local area (~ 100 m) network

Data rates — 10 Mbps to 100 Gbps on copper or optical fiber

Carrier Ethernet

Bridge Ethernet LAN segments over WAN

Operates as single Ethernet broadcast domain

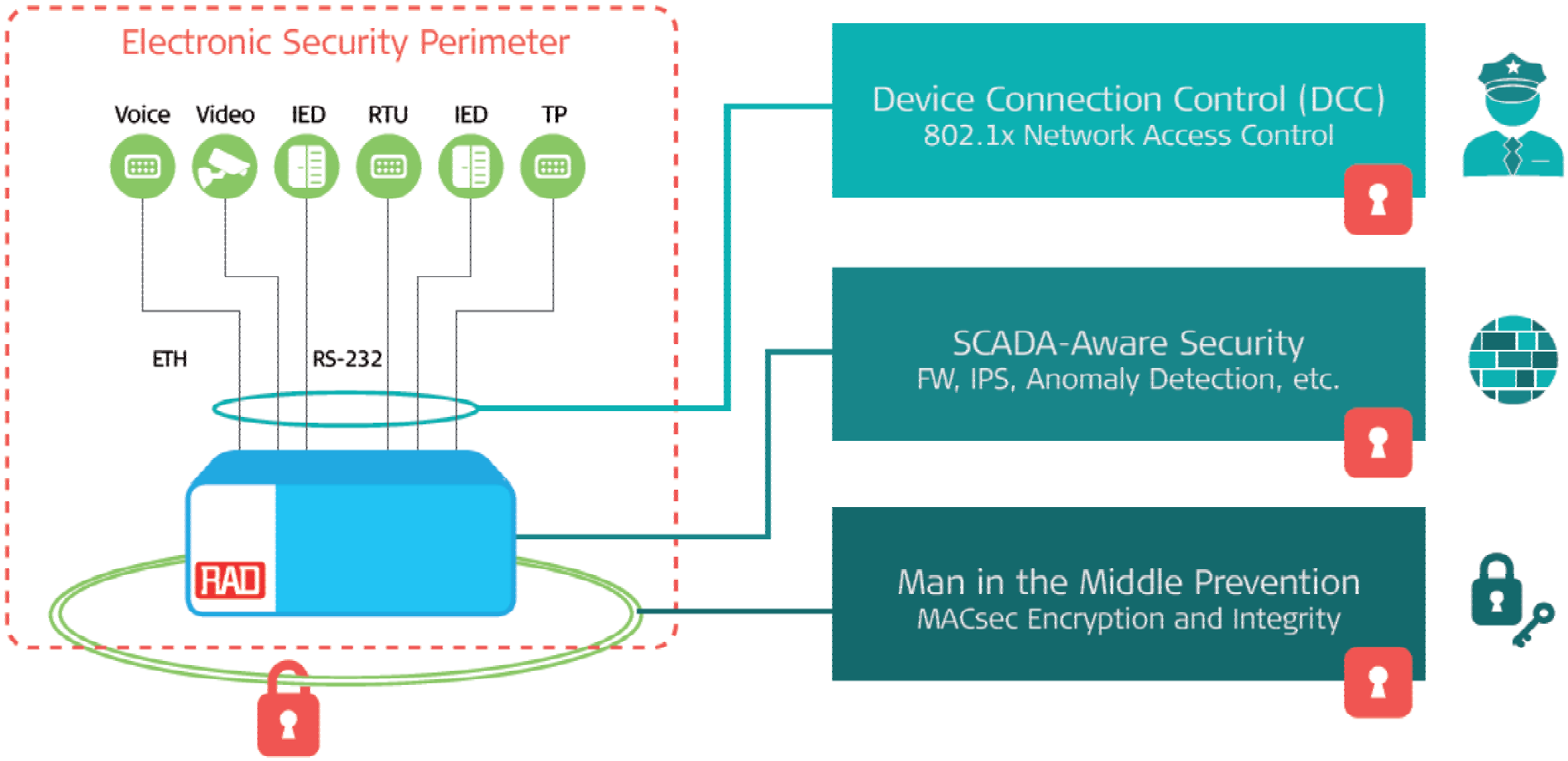


E-Line — point-to-point connection

E-LAN — general mesh

E-Tree — hierarchical tree

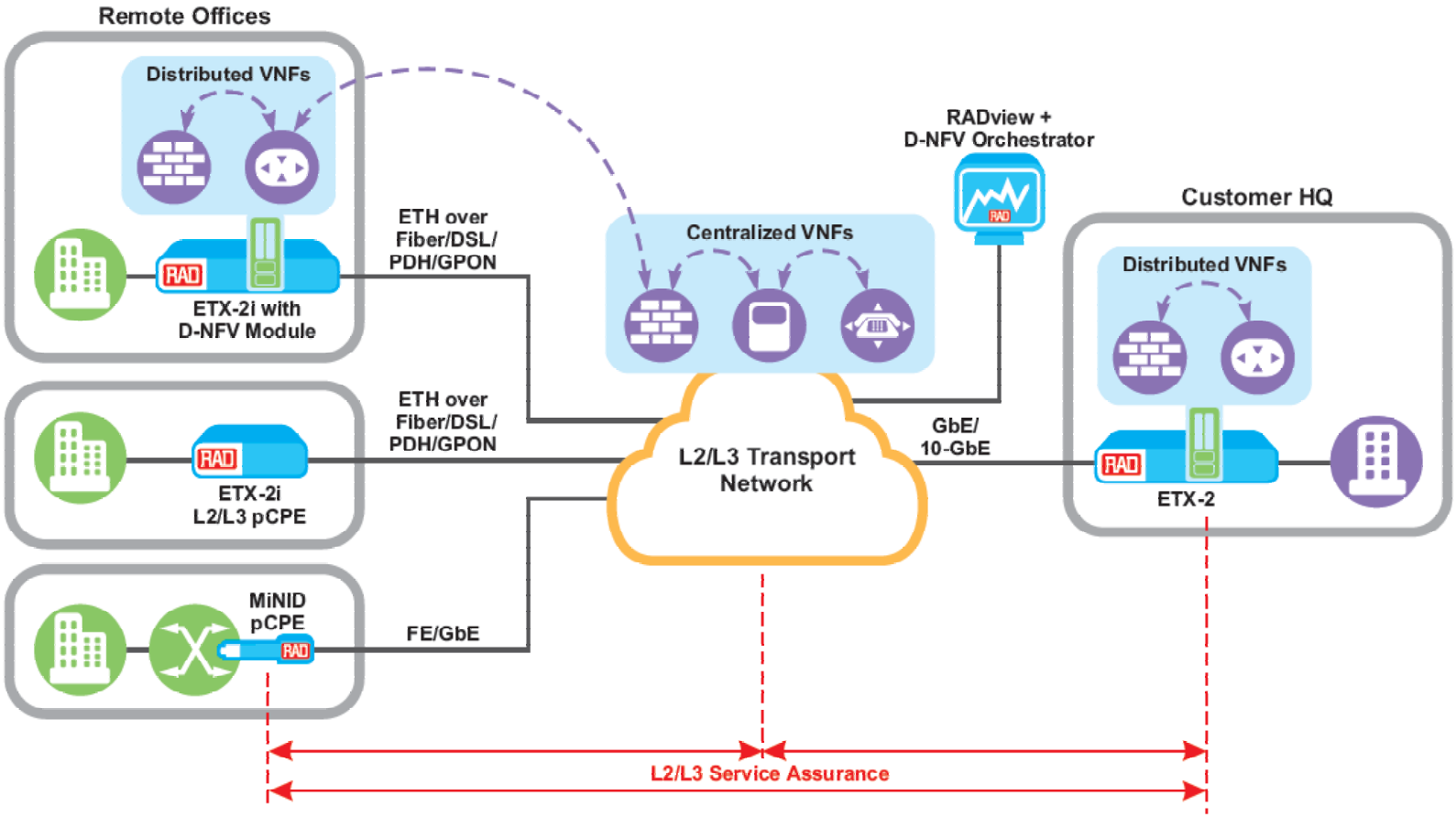
Cyber Security



DCC	Data Communications Channel Port Based Network Access Control (802.1X)
SCADA	Supervisory Control and Data Acquisition Remote Monitoring and Control
MACsec	MAC layer security standard (802.1AE)

IED	Intelligent Electronic Devices
RTU	Remote Terminal Unit
TP	Terminal Protocol (?)
ETH	Ethernet

vCPE (virtual customer premises equipment)



VNF — Virtualized Network Function

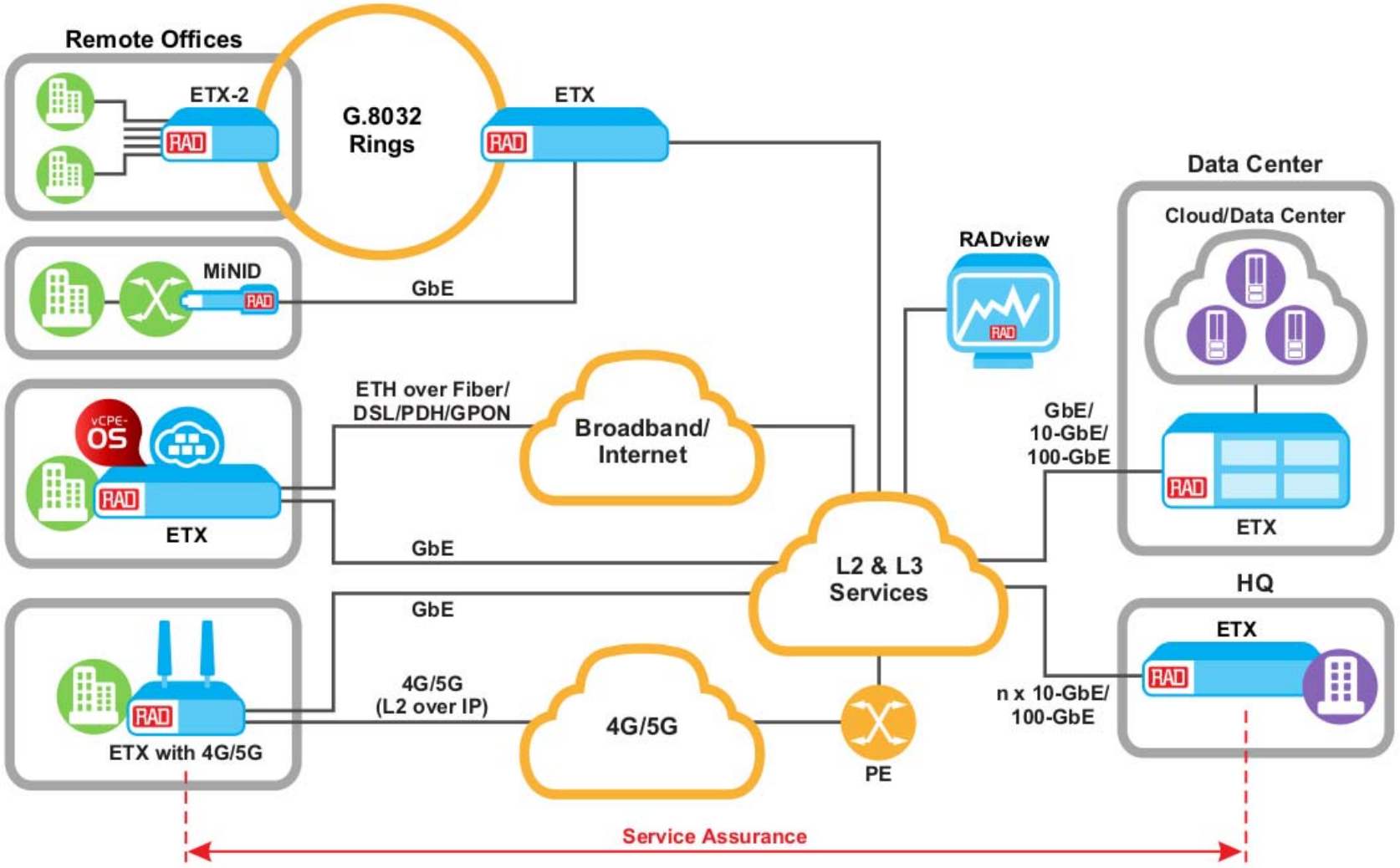
GPON — Gigabit Passive Optical Network

PDH — Plesiochronous Digital Hierarchy (standard telco multiplex hierarchy)

GbE — Gigabit Ethernet

L2/L3 — layer 2 (data link) switching + layer 3 (IP) routing

Carrier Ethernet



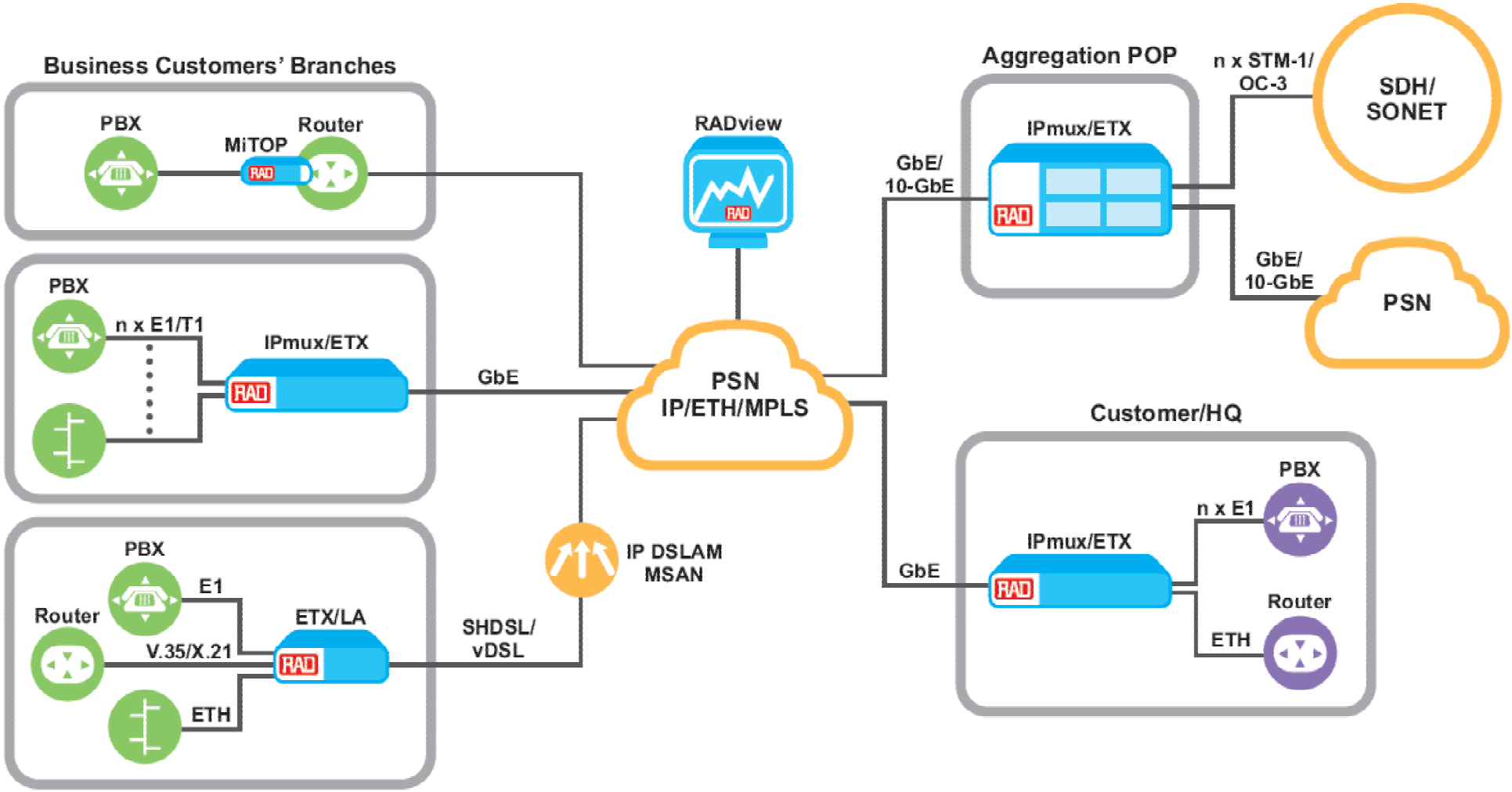
ETX

Carrier Ethernet demarcation and aggregation

MinID

login system

TDM Over Packet Mode Networks



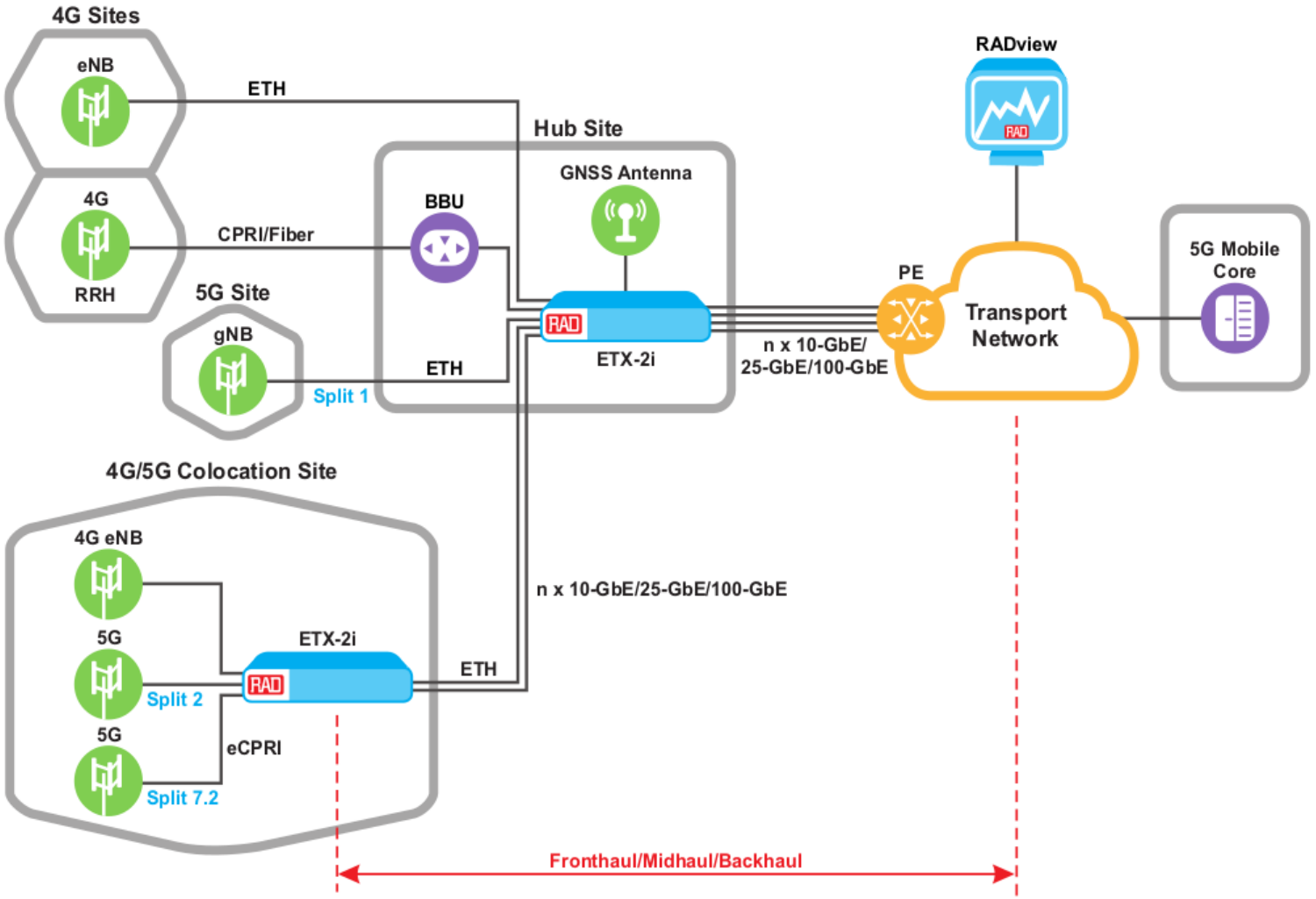
PSN

Packet Switched Network

PBX

Private Branch Exchange — telephone switchboard

Cellular Backhaul



Cell site

2G BTS or 3G/4G Node B (NB/eNB) connects mobile device to cellular network

Backhaul

Carry digital voice from mobile cell site to telephone central office