Columbia Networking Group Seminar
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Next Generation Networks
The New Public Network

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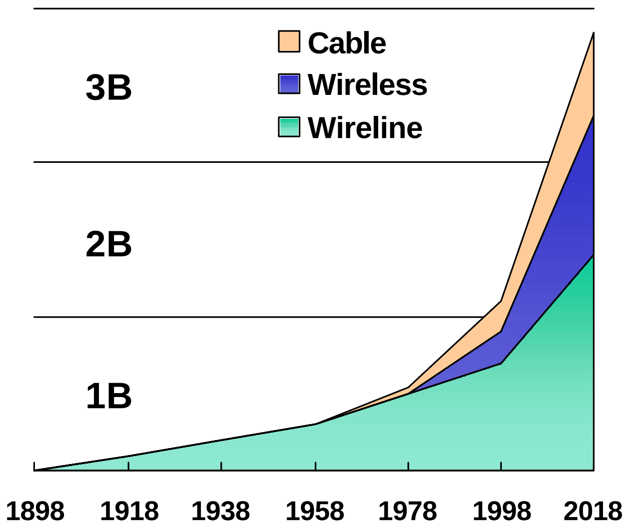
Next Generation Networks

The New Public Network

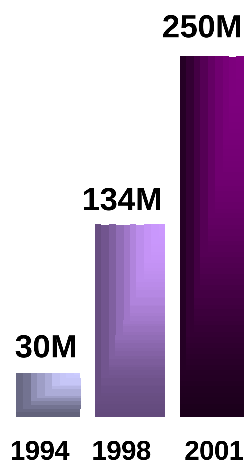
- The Network Revolution/Evolution
  - Disruptive market and technology trends
  - Network paradigm shifts
  - Emerging applications, services, and requirements
- Technology Issues and Proposed Solutions
  - Core Network Infrastructure: Optical Switching
  - Quality of Service
  - Security
  - Network Management
  - High Reliability
  - Intelligent Networking/Service Creation
- Example: Voice on the next-generation network
- What to expect in next generation networks

The Networking R/Evolution Is Fueled By Unparalleled Customer Demand (and by telecom deregulation and the Internet)

Worldwide Access Lines



Global Internet Users



Changing Traffic Patterns

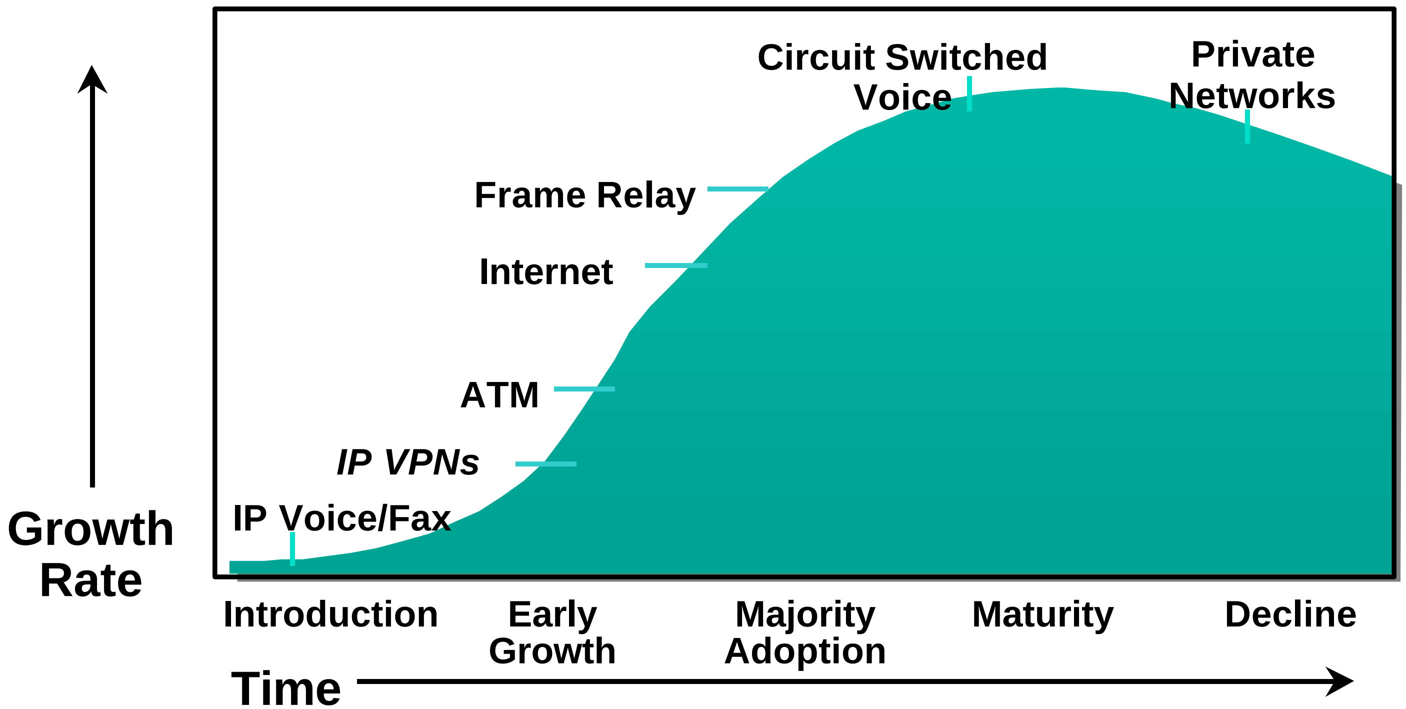
Internet Session
20 - 30 minutes

Voice Call
3 minutes

Average Holding Times

- **It took about a century to install the world's first 700 million phone lines; an additional 700 million lines will be deployed over the next 15-20 years**
- **There are more than 200 million wireless subscribers in the world today; an additional 700 million more will be added over the next 15-20 years**
- **There are more than 200 million Cable TV subscribers in the world today; an additional 300 million more will be added over the next 15-20 years**
- **More than 100 million additional Internet users will come online by 2001 ---the Net is experiencing a 1000% per year growth! If this trend continues, by 2004 more than 95% of the world's bandwidth will be Net traffic ---including computer-to-computer communication!**

Networking Industry Trends
Leading to the New Public Network



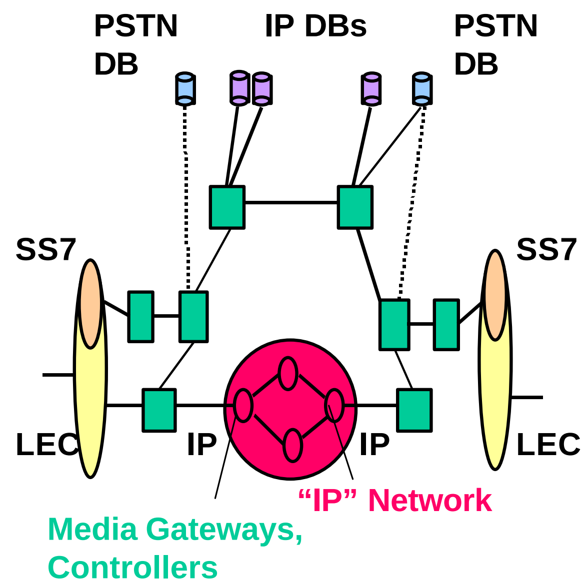
•**No longer any debate that a *converged* [voice/data/multimedia], *packet* network will emerge as a compelling alternative to the PSTN**

•**Migration strategies, quality of service [QoS], rapid service creation, and reliability are the major concerns of the service providers ---as well as the almost $1 trillion invested in the PSTN**

Next Generation Networks (The New Public Network)

- **Some principles for the new network**
  - **give customers access choices (ISDN, cable, DSL, wireless)**
  - **optimize IP switching (DiffServ, MPLS, RSVP) and QoS support**
  - **separate service intelligence from network transport -- open interfaces between intelligent call control features and packet gear**
  - **provide support for third-party applications providers [eg, IP-based billing and network management]**

- **The converged public network will**
  - **utilize the complementary strengths of the PSTN, the Internet, and SS7**
  - **be optimized for IP-based applications and be QoS aware**
  - **be the innovation platform for voice and data *service creation***
  - **be a simpler [“flatter”, standardized, open] network that will reduce *costs* of equipment, staff, and operations**
  - **support applications that communicate, interoperate, and configure the network to meet changing customer needs**
  - **support and drive service discontinuities [eg, *application service providers, ASPs,* who run applications on centralized servers]**



The Next-Generation Public Network

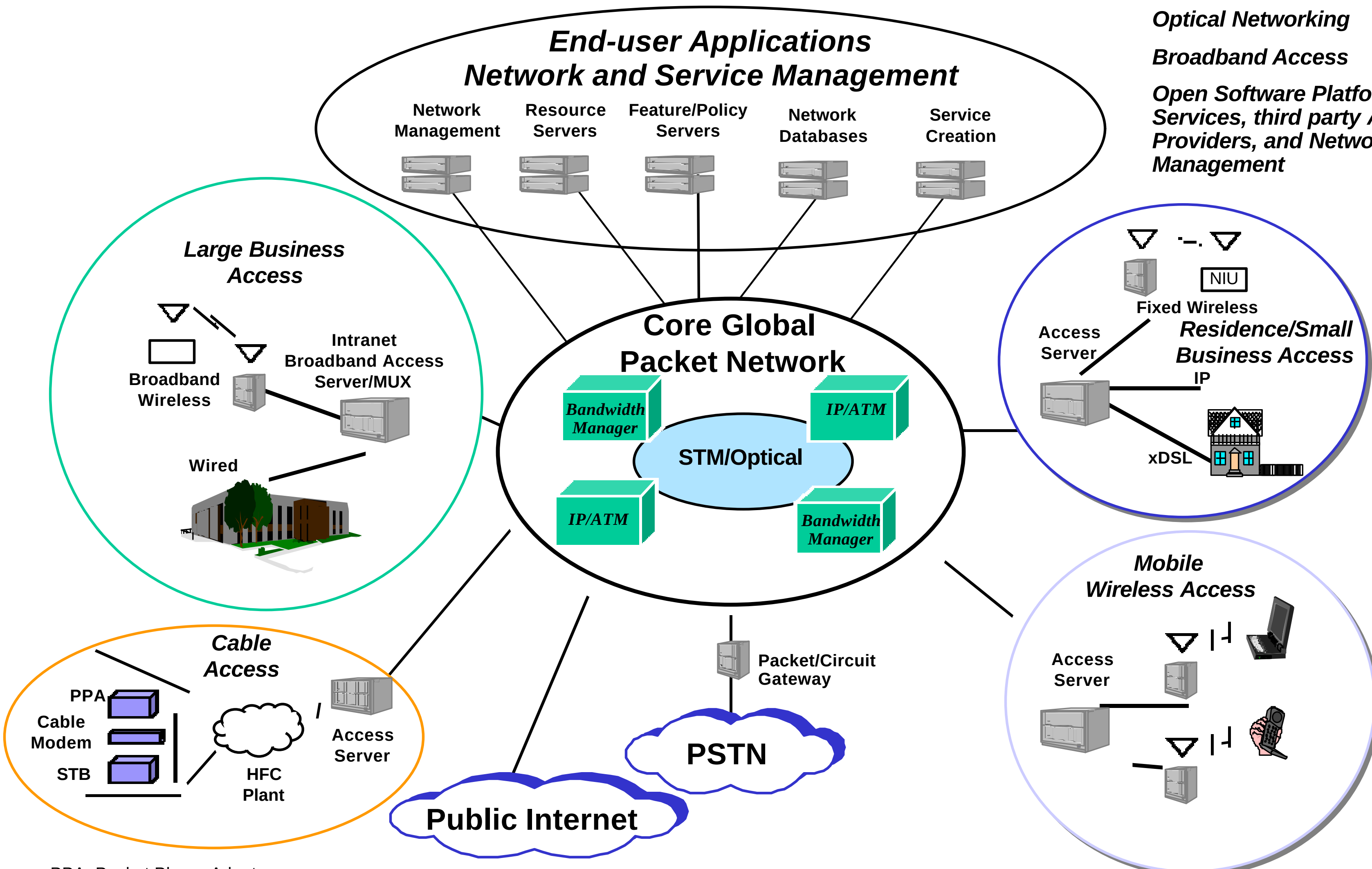
- *Enabling Technologies*

  Internetworking: IP/ATM /PSTN

  Optical Networking

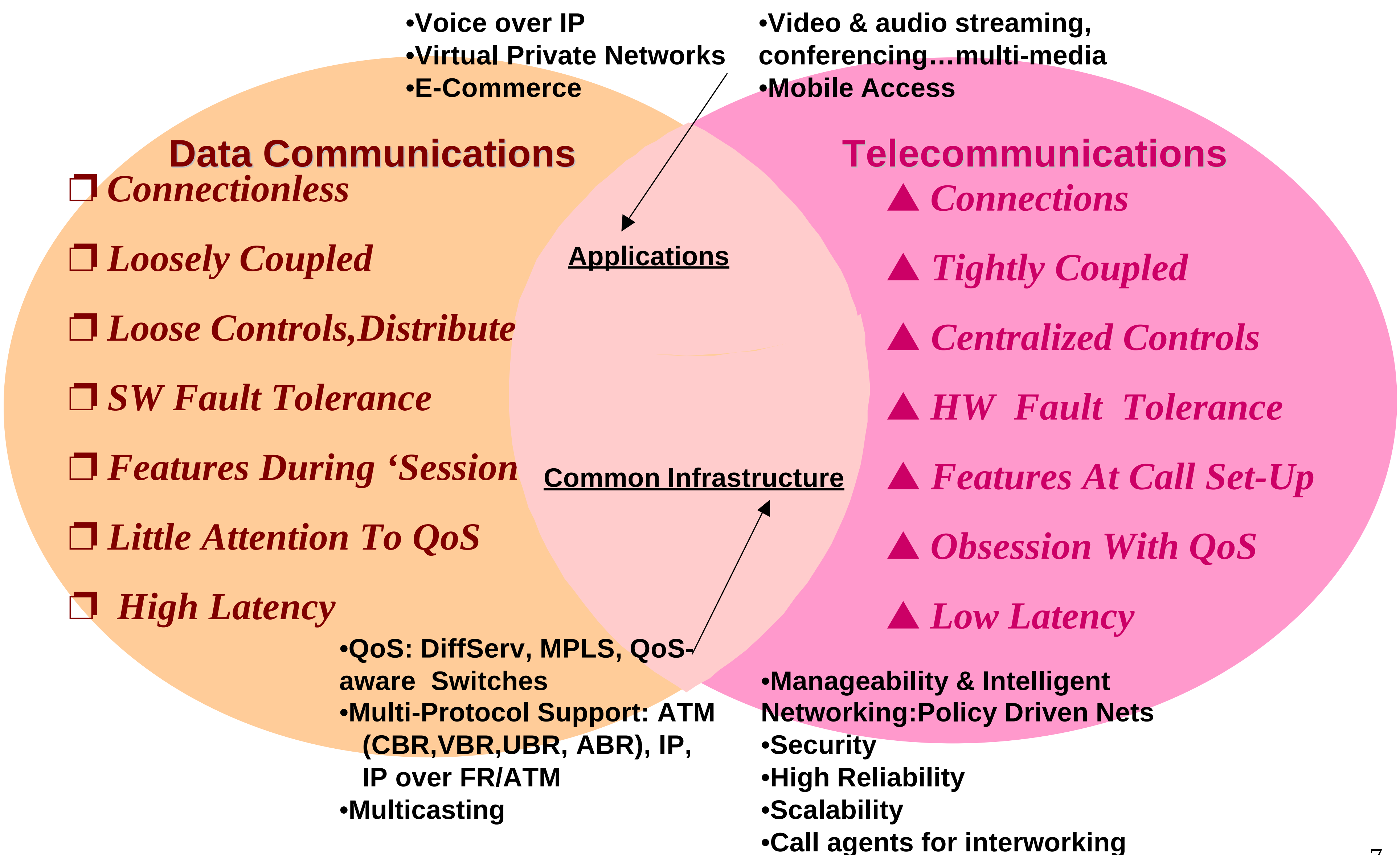
  Broadband Access

  Open Software Platforms for New Services, third party Application Providers, and Network Management

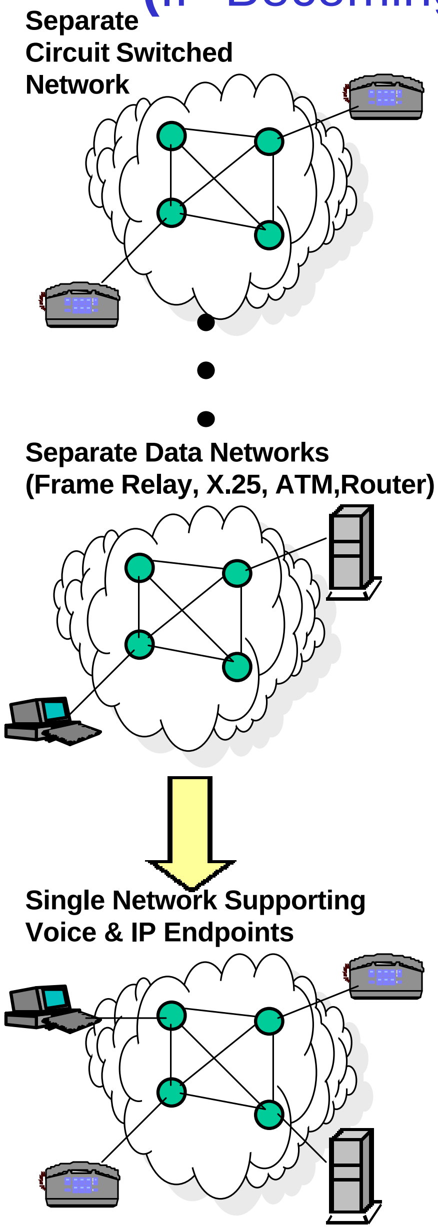


PPA: Packet Phone Adapter
STB: Set-Top Box

Convergence of Communications Paradigms Leads to New Services and Requires New Technologies



Networking Paradigm Shifts are Occurring
(IP Becoming the Dominant WAN and LAN Protocol)



- Route once, switch often” Þ route at wire speed
- Dial Þ “always on” capability
- WAN throughput bottleneck Þ optical networking [IP ->ë]
- “80/20” Enterprise/WAN data traffic split Þ “20/80”
- Networks Þ Network of networks

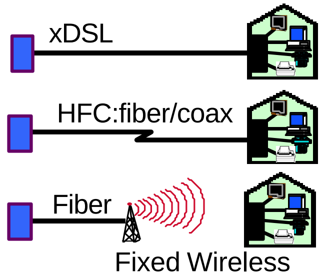
- Metcalfe’s Law: the value of a network grows exponentially with number of users and connected sources and this implies that a “network of networks” will become the organizing principle for most communications

The Incredible Pace of Technology Is Driving Revolutionary Network Changes

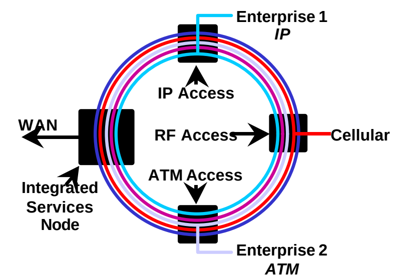
Technology	Trend
Silicon Chips	X2 in density/speed every 18-24 months
Optics	X2 in transmission capacity every year
Data/Web	X2 Internet subscribers every 2-3 years X2 Internet hosts/servers every 18 months X2 Internet traffic every 100 days
Wireless	X1000 in capacity in 5 years
Power	X2 MIPs/MW every 2 years (DSPs)
Software	From closed to open, distributed environment for creating network services
Compression	X2 in information density every 5 years

Disruptive Technologies and their Impact on Networking

- **<u>Access</u>: – Mbps (home) and Gbps (office) will substantially increase data traffic via xDSL, cable modems, wireless, and optics**



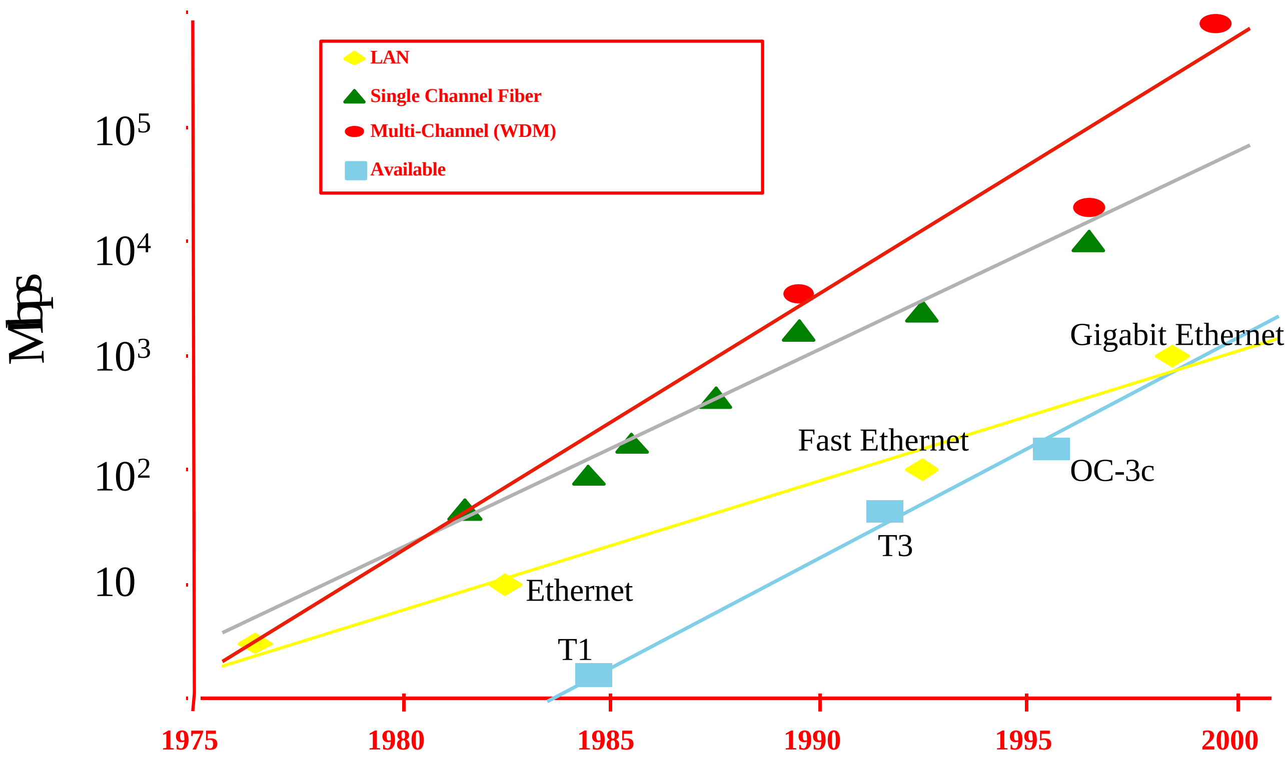
- **<u>Semiconductors</u>: Atomic-scale transistors will mean**
  - **- 64 Gb DRAM, 10 GHz processor clocks and giga-instructions/sec (GIPs)**
  - **- heterogeneous and multi-protocol functions on a chip reduce power/cost**
  - **- wire speed processing in data networks**
- **<u>Optical networking</u>: WDM-fueled bandwidth explosion will**
  - **- trade bandwidth for network complexity**
  - **- lower risk with new networking solutions (e.g., IP Þ WDM)**



- **<u>Communications Software</u>: Will drive and support**
  - **- high performance databases/directories supporting advanced network features (e.g., policy servers)**
  - **- speech recognition, media conversion (e.g., text-to-speech), and network agents to realize value-added intelligent networks**
  - **- call agents that mediate between the PSTN, the Internet, and SS7 to support IP telephony and other advanced applications**

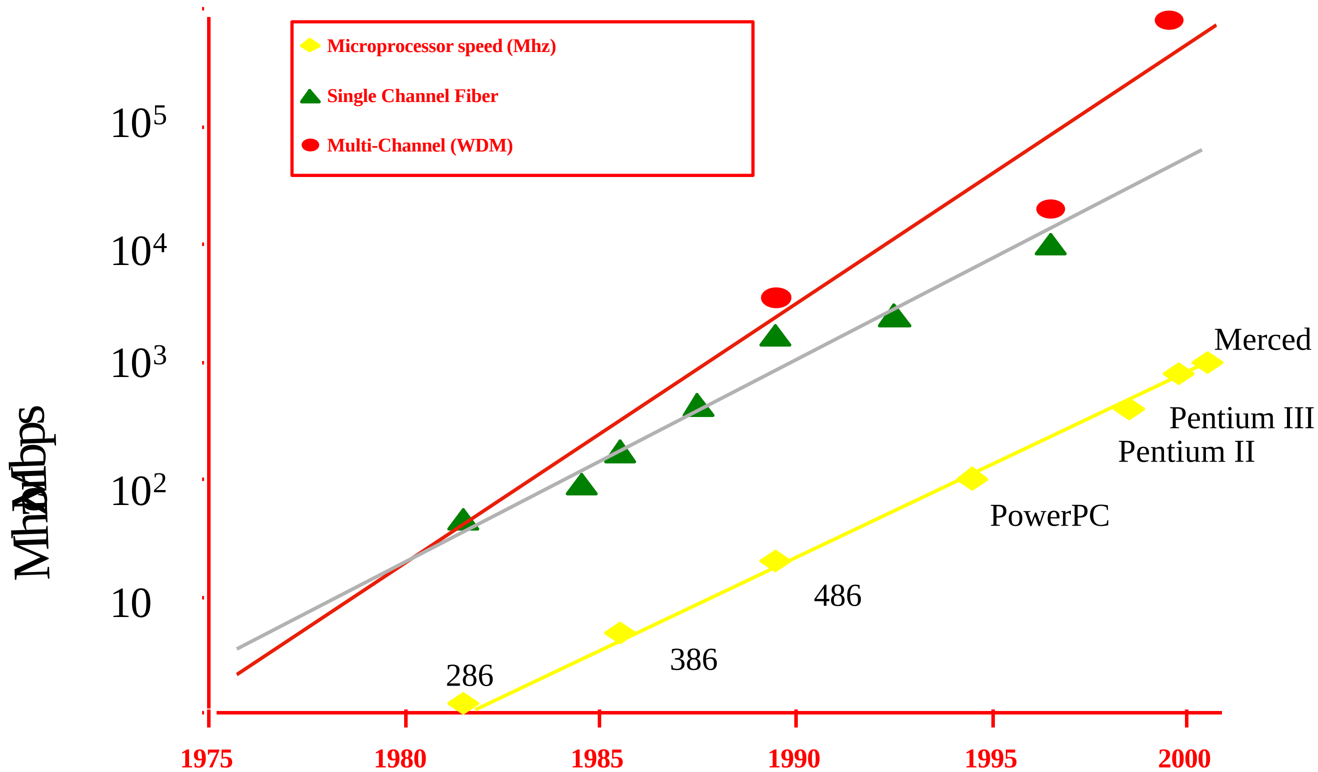
Impact of Transmission Speeds on Networking

- **Available WAN bandwidth has been less than LAN bandwidth --- this situation is expected to change at the millennium---> *WANs will no longer be a bottleneck for leading edge customers***
  - **Fiber optic transmission speeds have increased by 50% per year since 1980 (x100 in 10 years)**
  - **LAN bandwidth has increased at 25% per year and WAN bandwidth has remained expensive (shared)**
  - **"Available" curve purchased by leading-edge users (e.g., OC-3c); about 1% of WAN BW**



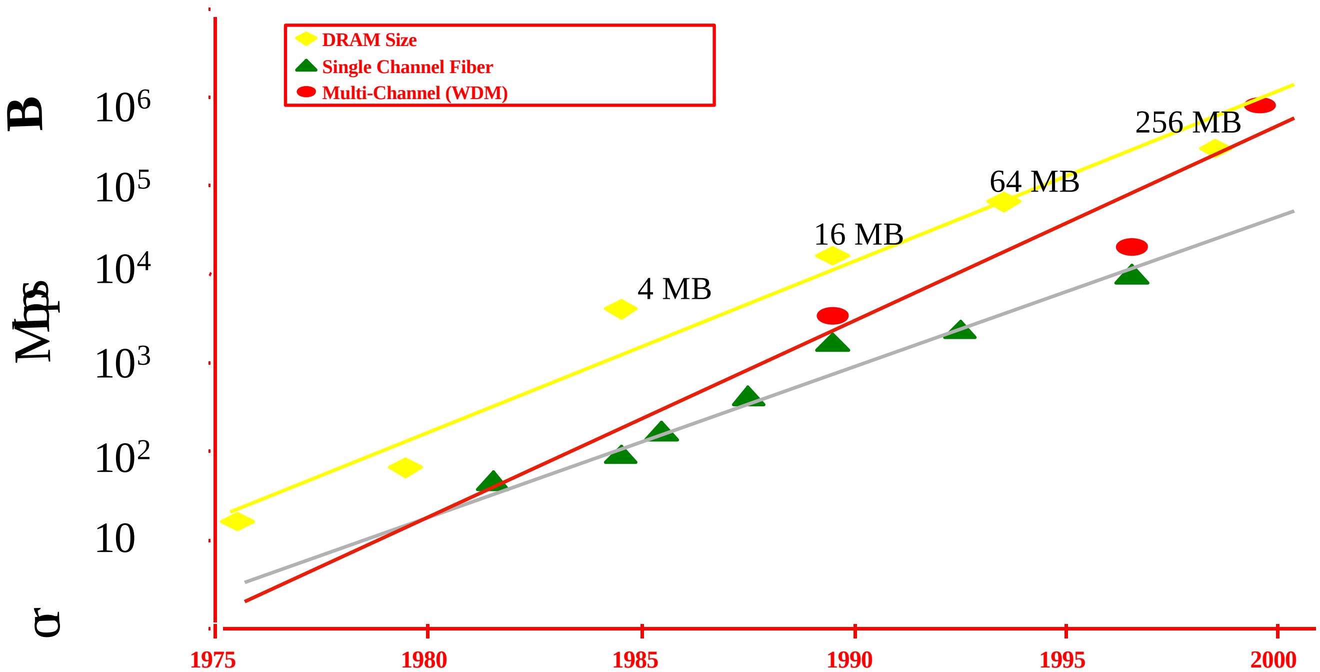
Impact of Speeds of Fiber Transmission and Microprocessors on Networking

- **Speed gains for microprocessors have kept pace with fiber transmission speeds**
- **The number of instructions available to process an optically transported packet, using the “hottest” micro has remained constant**
- **Network processing will not be a bottleneck to network throughput**



Impact of DRAM Memory Size and Transmission Speeds on Networking

- **With increasing transmission speeds, more packets are "in flight" for a given round trip propagation time; common error recovery protocols require that one round trip worth of data be stored**
- **e.g., NY-LA-NY round trip propagation time of 50 ms results in 1 MB for a 155 Mbps link**
- **Size of DRAM increasing 58% per year**
  - **Effective BW of memory is increasing at about 40%**
- **Storage capacity and transmission speeds are increasing at the same rate, thus number of chips to hold one "window" of data has remained constant**



Fundamental Core Network Elements

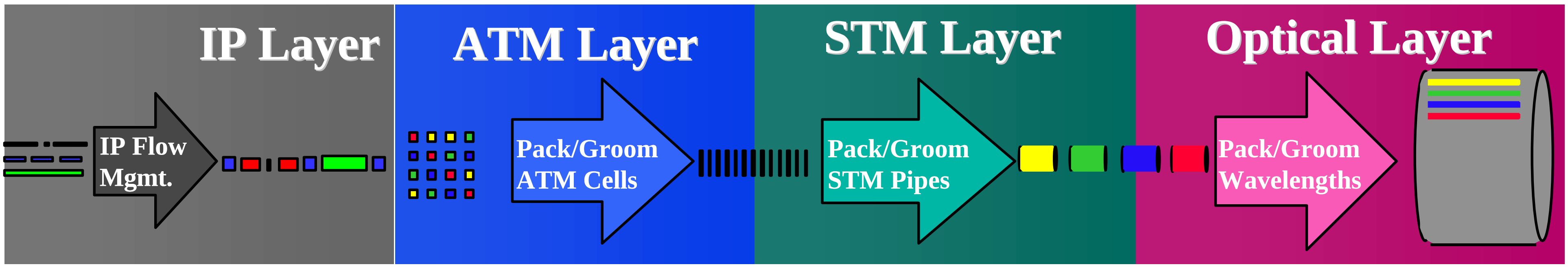
Low Cost, Low Delay Bits

- **Multiprotocol Switching**
  - Edge
  - Backbone
- **Multi-protocol Optical Backbone**
  - Access Multiplexor
  - Bandwidth Management
  - Transport
- **Multi-protocol Broadband Access**
  - Customer Premises
  - Remote
  - Central Office

High Value Services

- **Open Services Platforms**
  - Telecommunications
  - Internet
- **Servers**
  - Telecommunications
  - Internet
- **Multi-protocol Interworking**
  - Gateways
  - Gatekeepers
- **Network Management**
  - Business Management
  - Service Management
  - Network Management
- **Customer Provided Equipment**

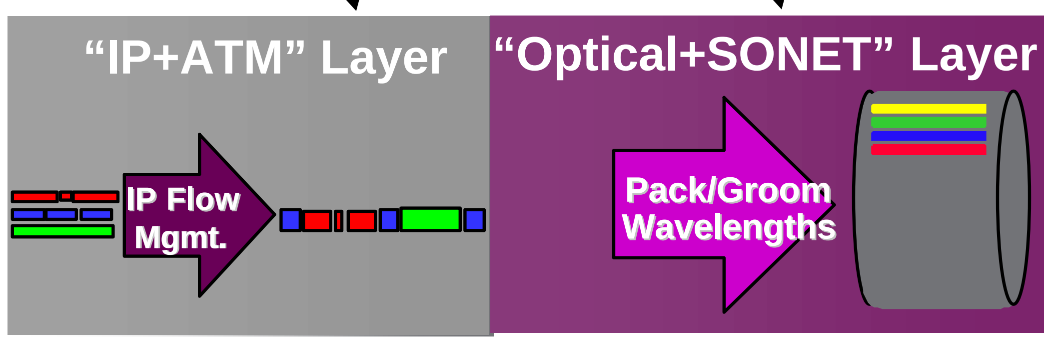
WAN Core Networking Layers - Today : IP Packets, ATM Cells, SDH/SONET Circuits and Optical Wavelengths Provide High-Speed, Reliable, Lower Cost, Ubiquitous Connectivity



- **IP networking provides:**
  - **Interoperability**
  - **Management of IP Flow QoS**
  - **Security/VPN Support**
- **ATM networking provides:**
  - Single network for all services
  - Intelligent, distributed provisioning and restoration of services
- **SONET and SDH networking provide:**
  - High-reliability circuits
  - Distributed high-speed facility restoration
- **Optical networking provides:**
  - High capacity transport
  - Independence of bit rate and format

WAN Core Networking Layers - Vision

- Email
- Multimedia
- Video
- Private Line
- Voice Services
- VPN



ATM Attributes {

Today's IP Networking
+
Grades of QOS
+
Service Maintenance
+
Restoration of Services

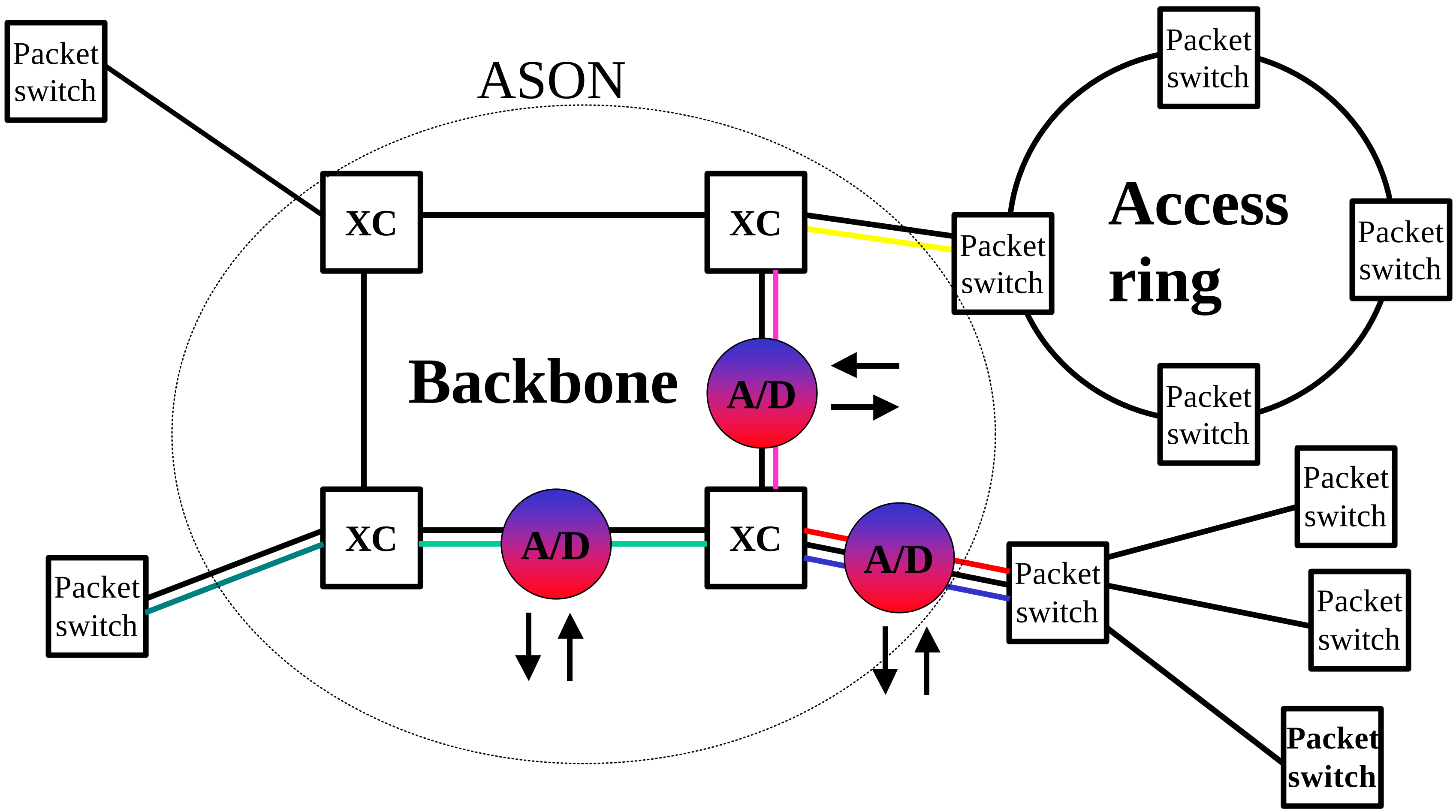
= "IP+ATM"

Today's Optical Networking
+
High Reliability Transport
+
High Speed Restoration
+
BW Management

} **SONET/SDH Attributes**

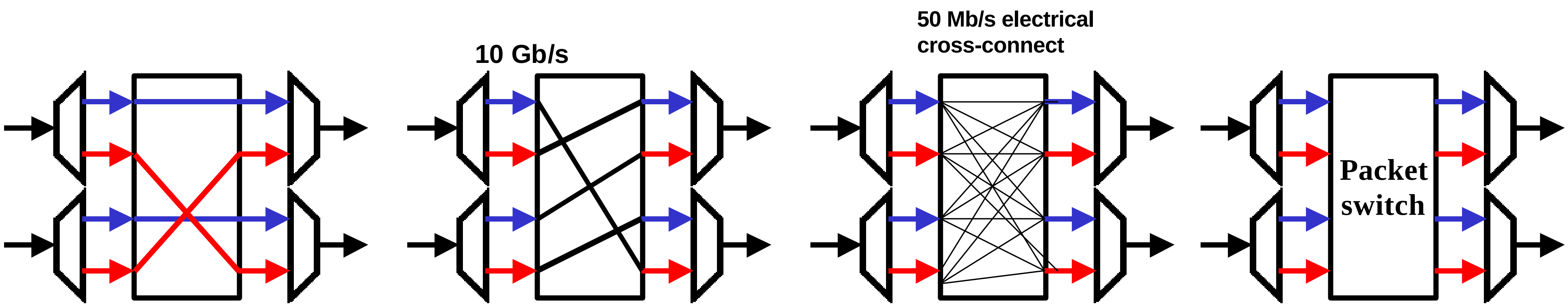
= "Optical+SONET/SDH"

Backbone Networks Will Have Packet Switches at the Edge and Wavelength [Circuit] Switches in Core



ASON = Automatically Switched Optical Network
XC = Cross Connect [Circuit/Wavelength]

Four Basic Types of Switching Nodes [switching granularity decreases left to right]



Wavelength Selective Cross-connect [WSC]

- transparent routing
- low-cost: little or no electronics
- very attractive when most traffic is through traffic
- wavelength blocking

Wavelength Interchanging Cross-connect [WIC]

- generally non-blocking center stage [E or O]
- Tellium: Electronic: 512x512@2.5 Gb/s --> 1Tb/s
- Lucent: Optical Lambda Router: MEMS technology: 256X256@10 Gb/s -->2.5 Tb/s
  Agilent: micro bubble technology

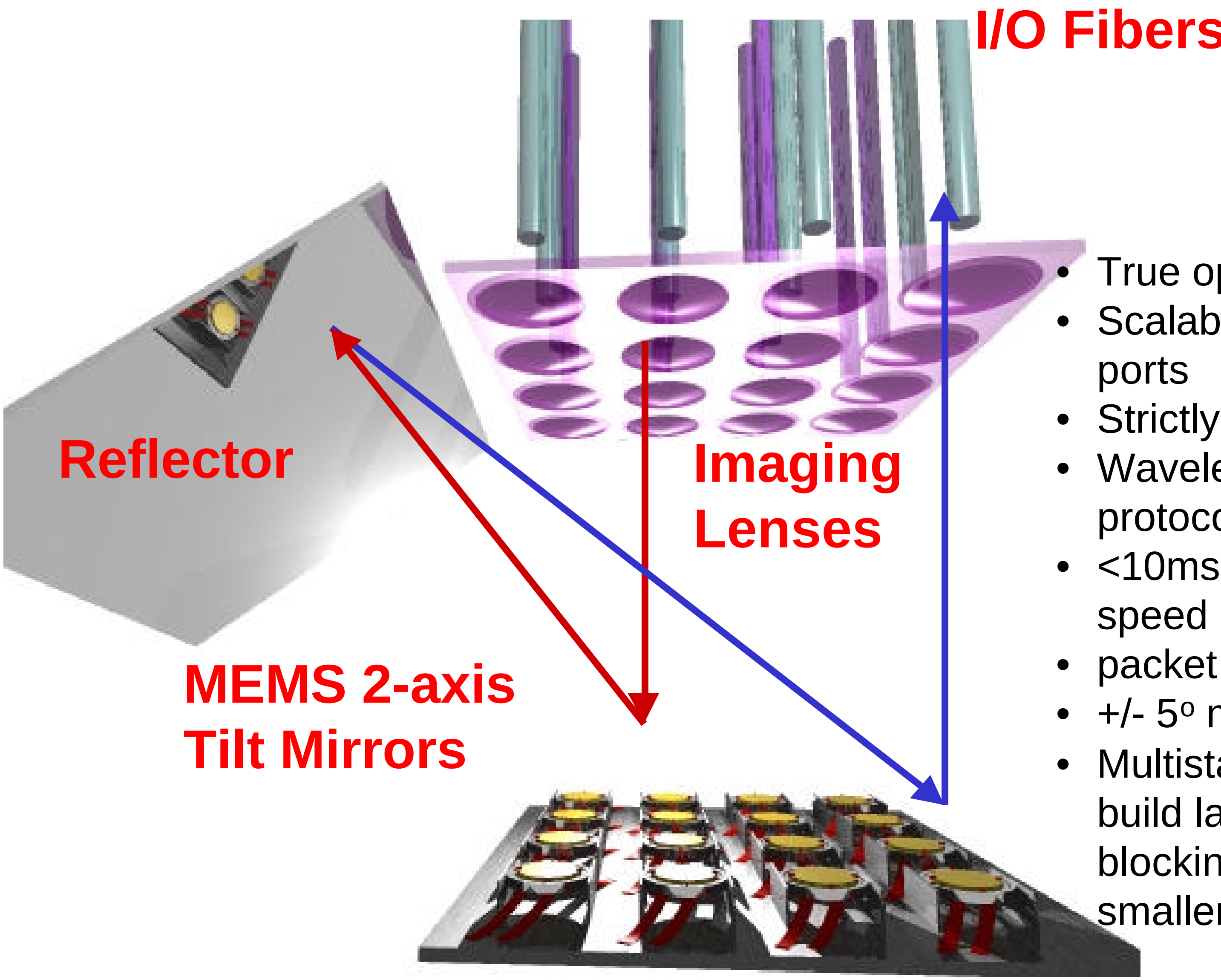
SONET type Cross-connect

Packet-Switch

- current routers use electronic fabrics
- fast tunable lasers, and smart schedulers can realize >10 Tb/s routers.

For equal throughput WIC 10x cheaper than Packet switch

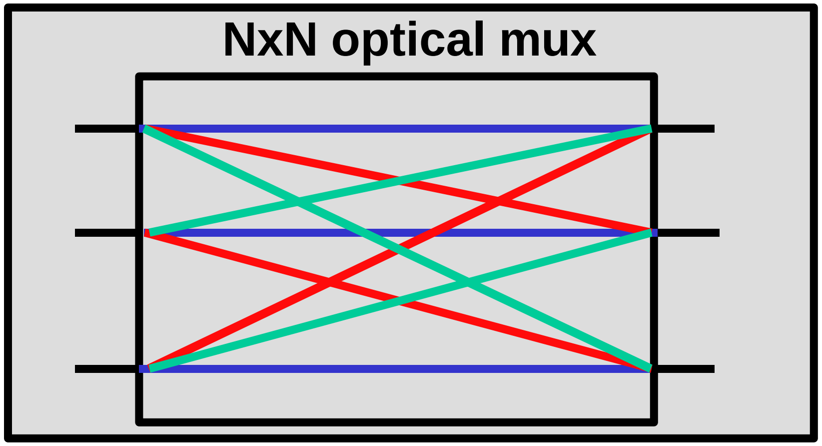
WaveStar™ Lambda Router: Lucent



- True optical switch fabric
- Scalable to >1000 x 1000 ports
- Strictly non-blocking
- Wavelength, data-rate, and protocol independent
- <10ms mirror switching speed [not fast enough for
- packet switching]
- +/- 5° motion on each axis
- Multistage Clos Network to build large strictly non-blocking fabrics out of smaller ones

Packet Switching can be achieved in Wavelength Domain using Tunable Lasers

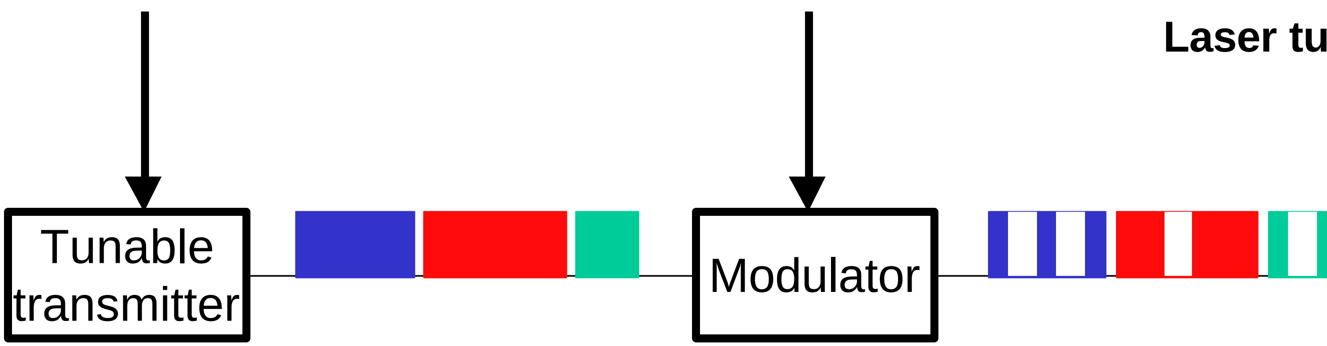
Passive ë-routing device [used in WDM transmission systems]



Destination

Packet data transmitter

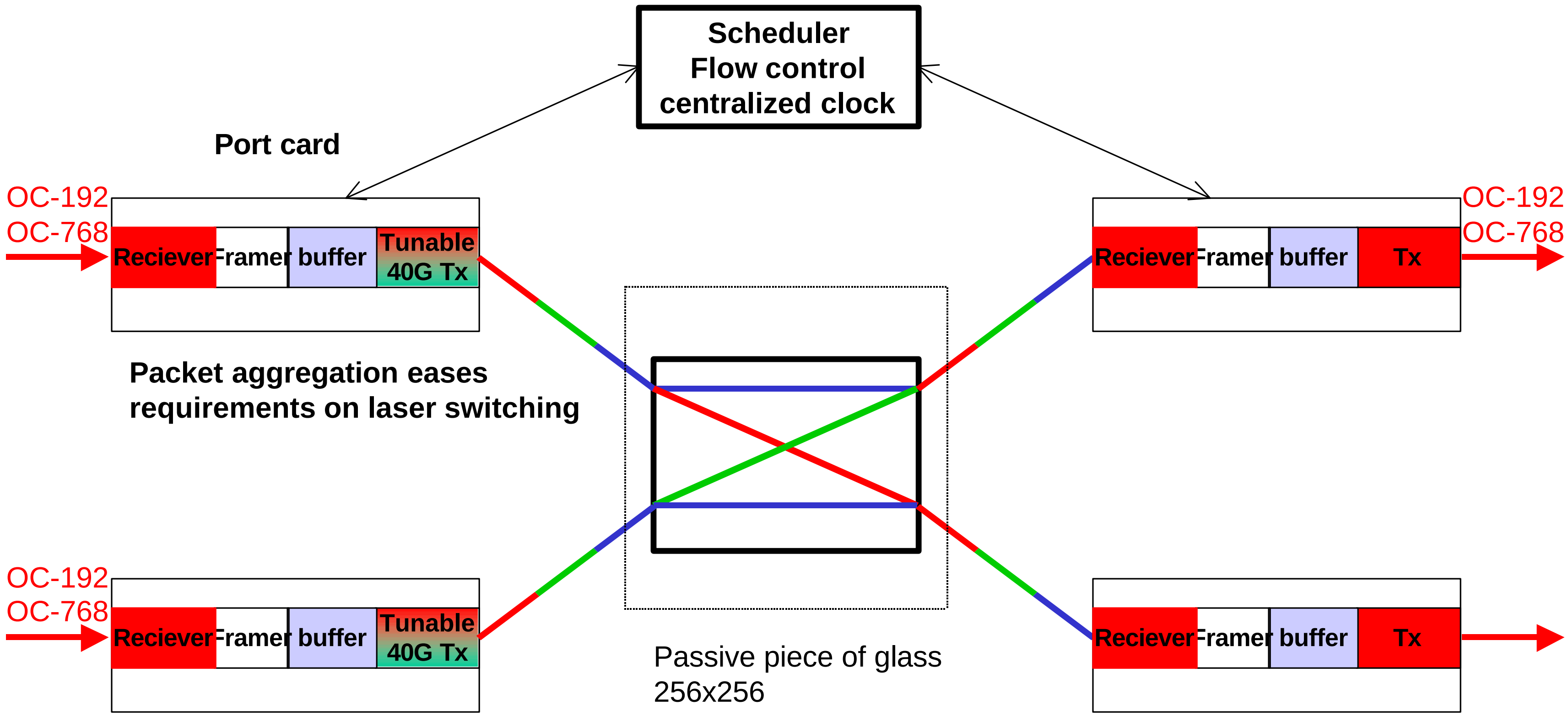
Laser tuning speed: ns



Input to ë-routing device

Transmitted wavelength determined by packet scheduler

10 Tb/s Packet Router Architecture based on 256x256 Optical Switching Fabric, Fast Tunable Lasers, and @40 Gb/s per port Speeds



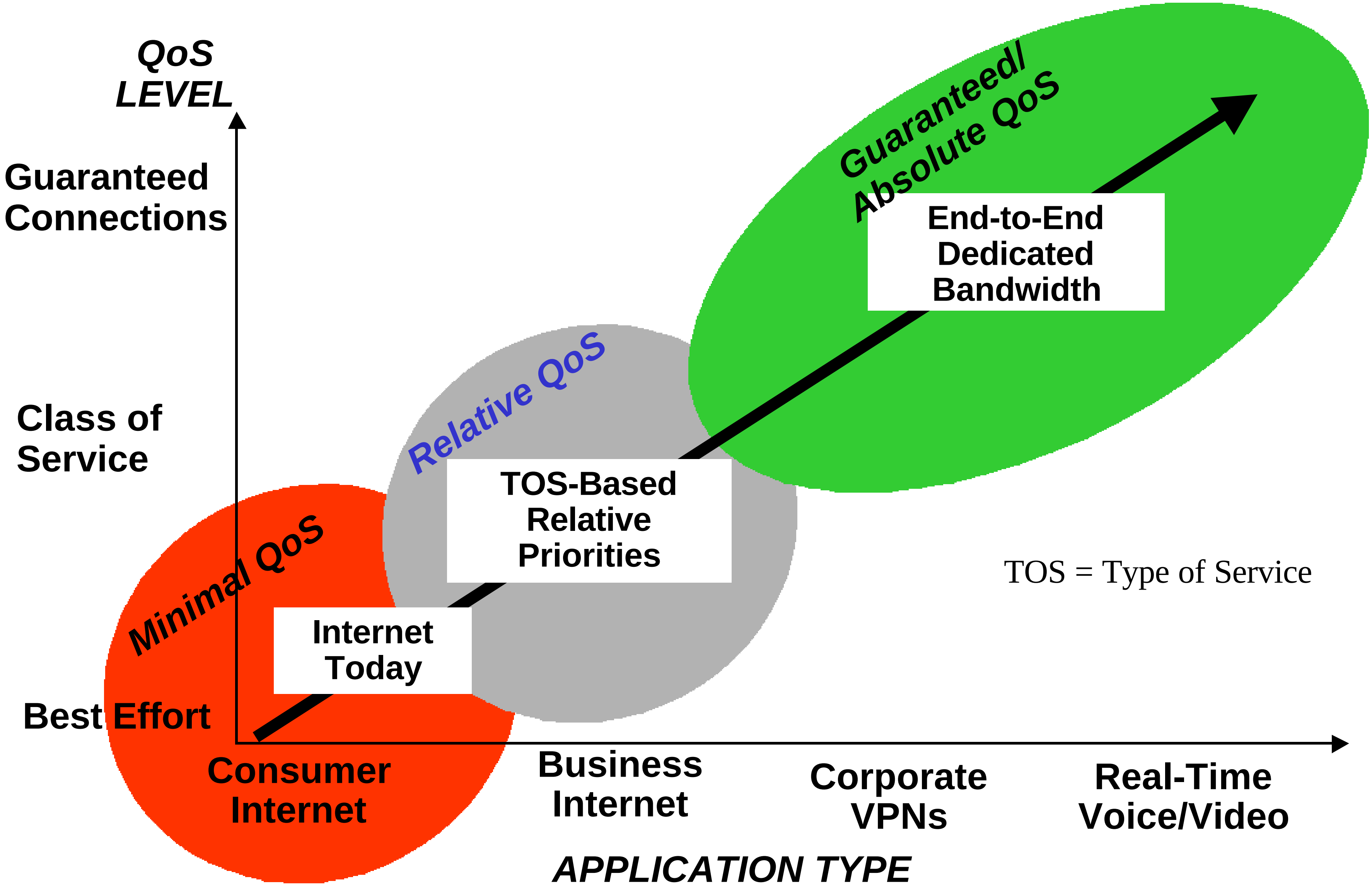
Key components for optical fabric:

- **Tunable laser with ns tuning speed**
- **High speed modulator**
- **256x256 optical mux**
- **Scheduling algorithm with packet aggregation**
- **clock distribution and fast, phase recovering receiver**

Requirements for Next-Generation Network Applications

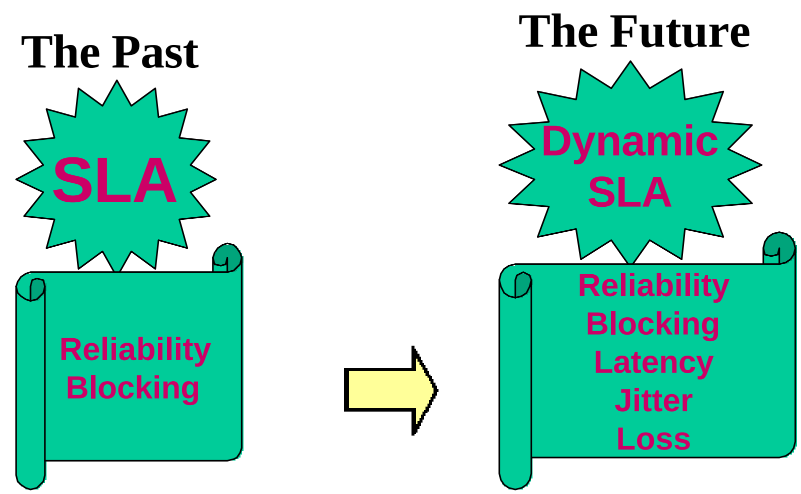
	QoS	High Reliability	Network Management	Security	Intelligent Networking
VoIP	✓	✓	✓	✓	✓
E-Commerce	✓	✓	✓	✓	✓
Multi-Media	✓	✓	✓		
Multi-casting	✓	✓	✓		
Mobile Access	✓				✓
Value Added Services	✓	✓	✓	✓	✓
VPN	✓	✓	✓	✓	✓

Quality of Service [QoS] Evolution



How Will IP Networks Approach the QoS Performance of Voice Networks [without over provisioning]?

- QoS Issues
  - Guarantees beyond availability
    - maximum delay and jitter
    - minimum effective bandwidth
    - packet loss
  - Service Level Agreements [SLAs] by
    - class of service [application]
    - customer or groups of customers [VPNs]
    - flow or connection

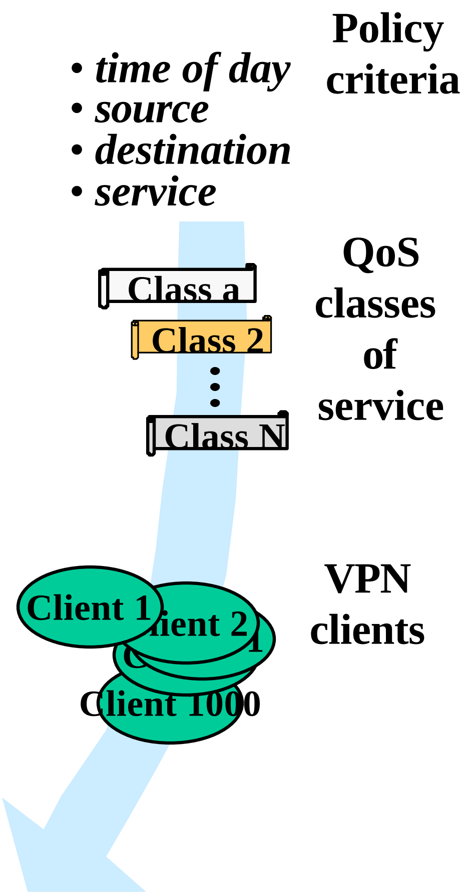


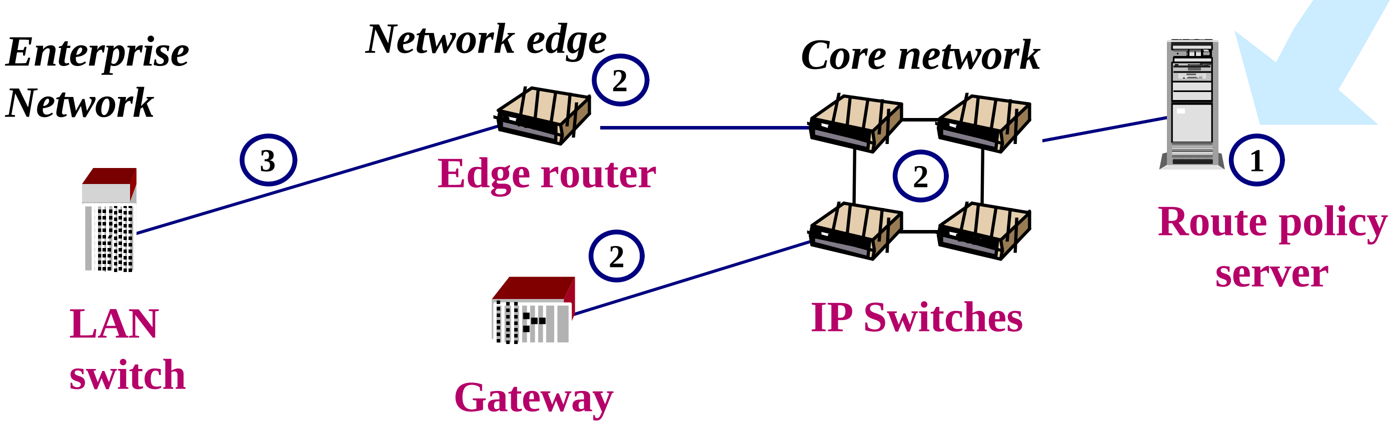
- Intelligent Switching
  - wire-speed switches [classify, queue, and schedule]
  - ASICS for congestion control directly on flows
- Network Design
  - traffic engineering and network design tools for efficient paths
  - executing congestion control within core instead of /in addition to at edge
  - decreasing effect of IP packet variability and header size at higher speeds
- Network and Policy Management
  - per flow queuing
  - make IP connection oriented via MPLS
  - support of multiple levels of QoS [DiffServ/ToS]

The Implementation of QoS

To implement QoS, IP networks will have

1. centralized route policy servers
2. policy enabled network elements
3. policy aware interfaces





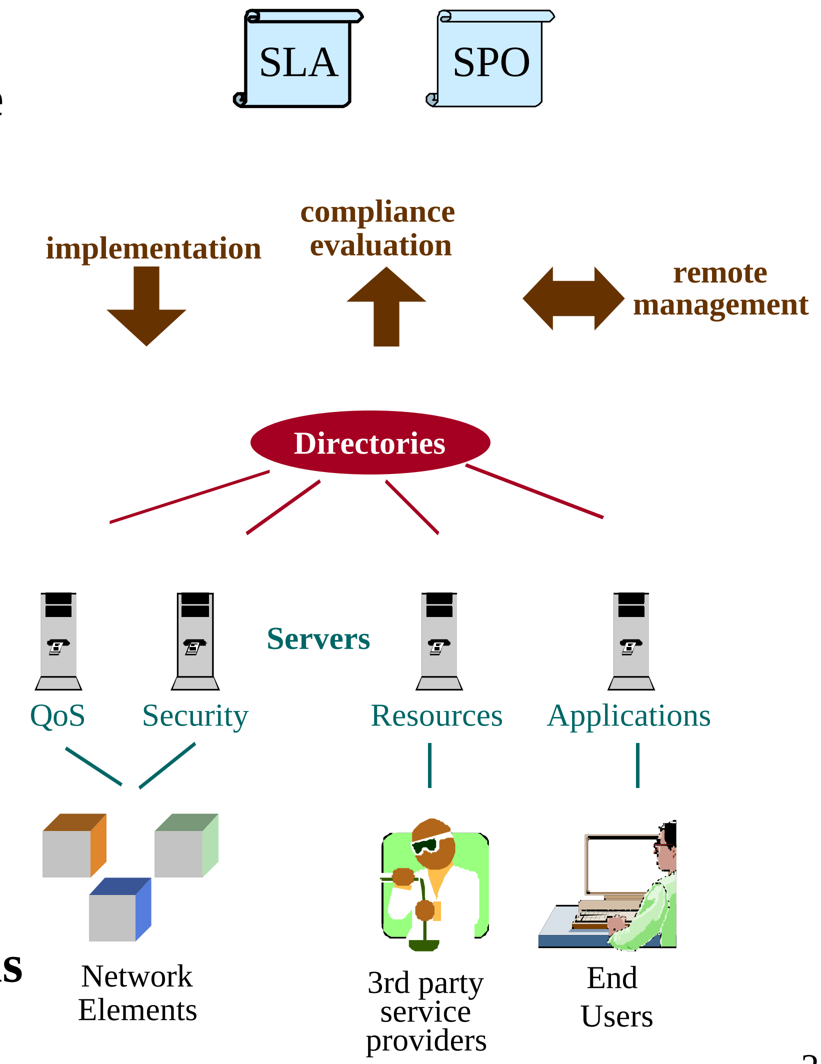
Service Level Administration

Service Criteria:
- **Private network (VPN) SLAs**
- **Public network Service Performance Objectives (SPO)**

Policy administration:
- **implementation**
- **compliance evaluation**
- **remote management by users**

Policy coherence:
- **common directories**

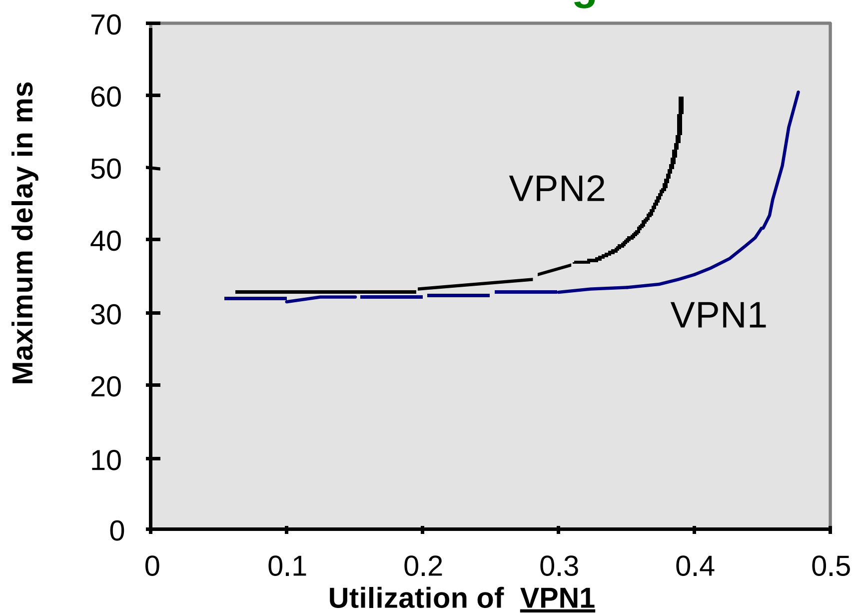
Policies:
- **QoS**
- **Security**
- **Allocation of network resources**
- **Access to network based applications**



Congestion Control of "Bad Behavers": Value of Isolating Flows in QoS Management

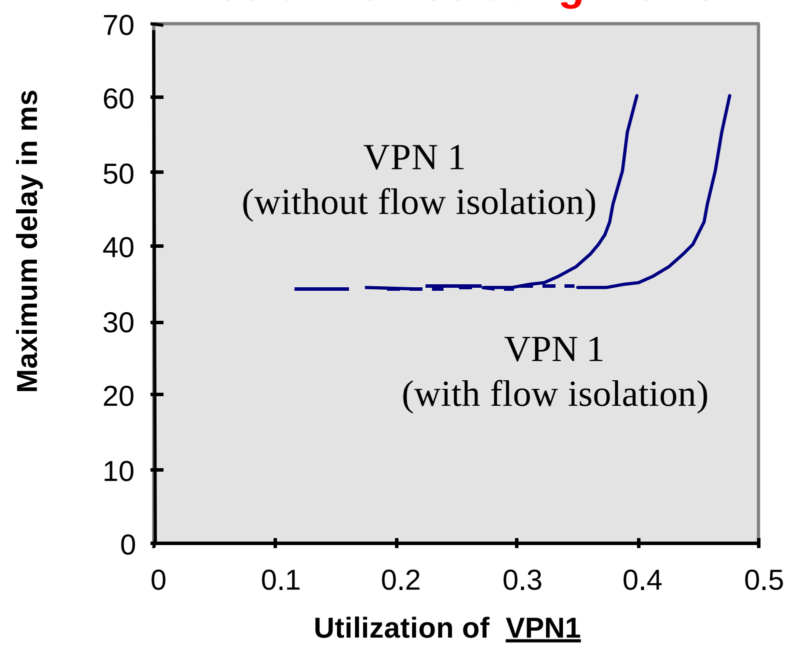
VPN1 And VPN2 Have The Same Contract (0.4 of the DS1 capacity)
VPN2 uses 0.52 of the capacity (i.e., 30% more than contract)

Benefit of Isolating Flows



Both at same priority with routers using flow isolation (by VPN) and equal weights for the two VPNs

Price of Not Isolating Flows



Both at same priority with no discrimination

- **Without flow isolation, all VPNs get unacceptable delay when one creates congestion**
- **With flow isolation, all well behaving VPNs get acceptable delay**
- **With flow isolation, misbehaving VPNs can get acceptable delay only when other VPNs well below contracted load**

Reducing Latency With Multicasting

Current Situation

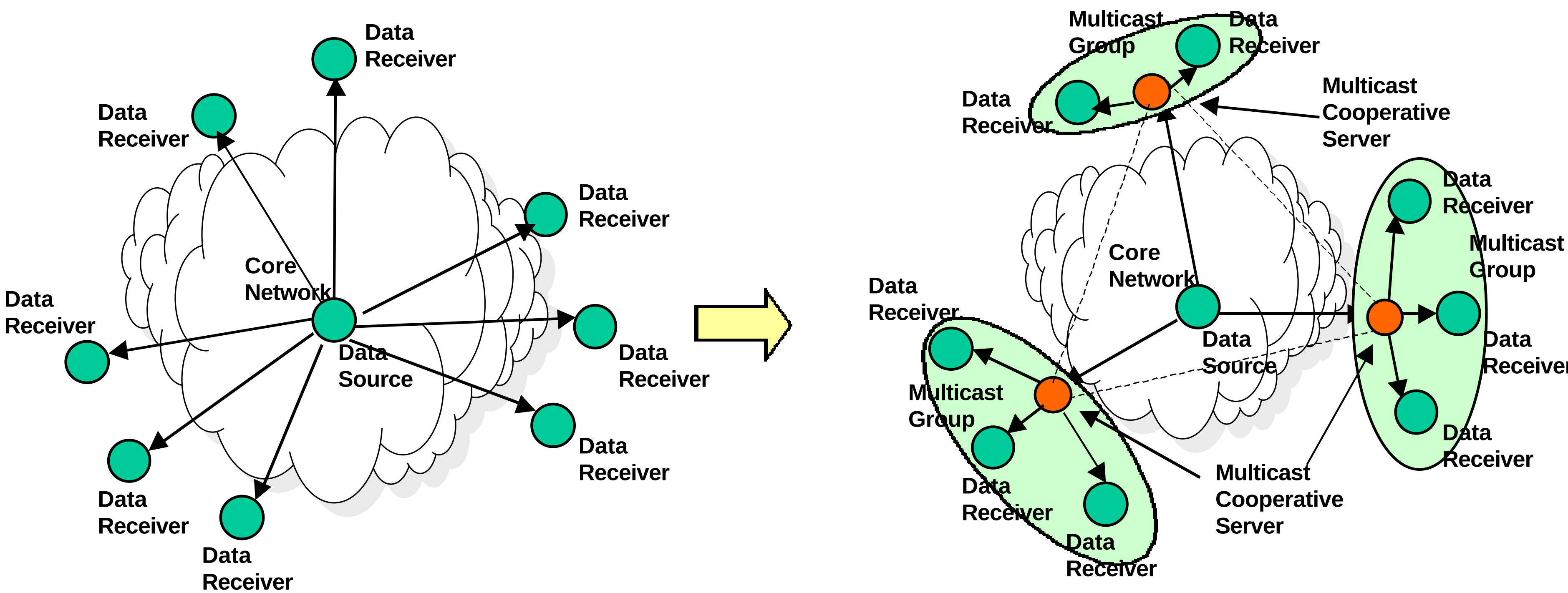
- Redundant traffic causing needless loading of network and servers
- Results in unacceptable latency

Solution: Reduced latency via

- Reduced traffic on core network
- Reduced load at data source server
- Data closer to receivers
- Combination with caching and replication

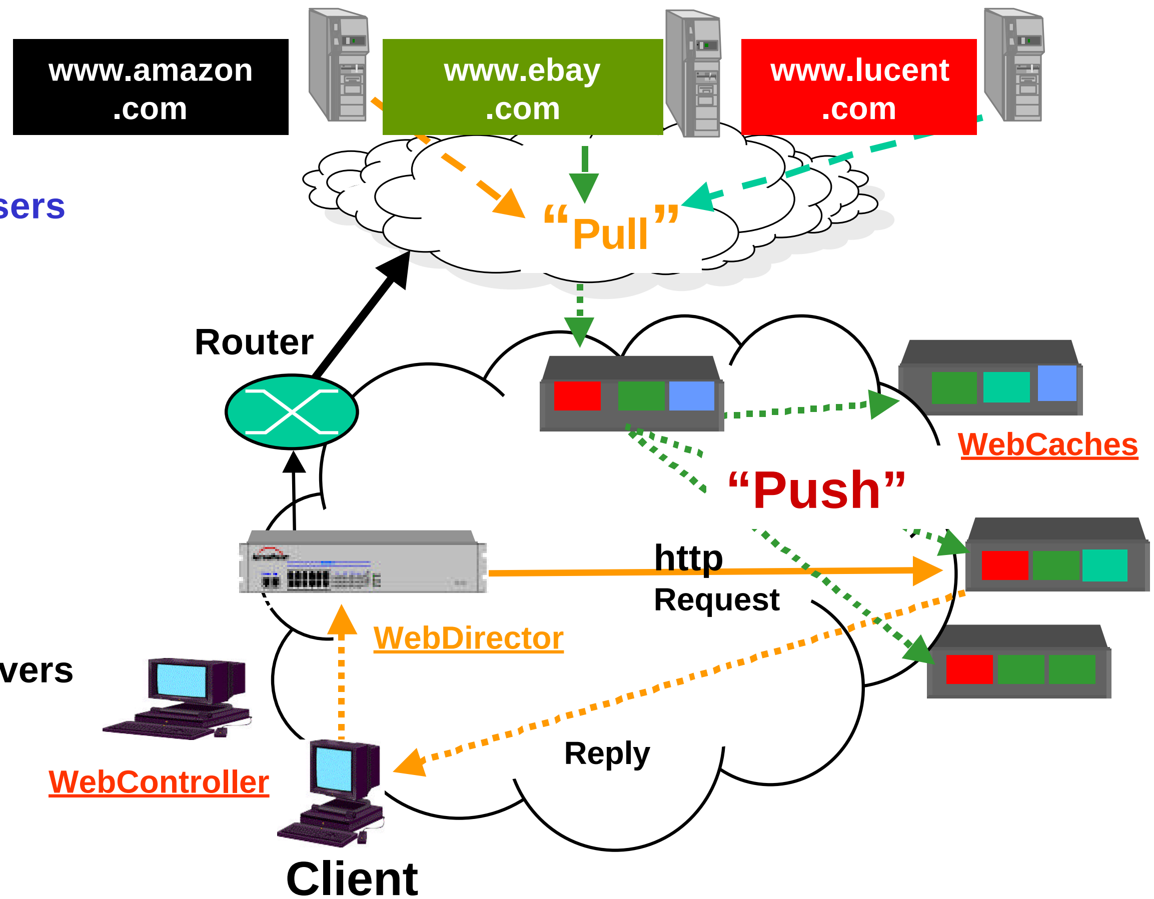
Obstacles to Overcome

- Lack of unique set of protocols
- Data synchronization
- Reliability, recovery from lost data
- Current implementations too static



Dynamic Web Caching Reduces Load on the Internet and Improves Response Time

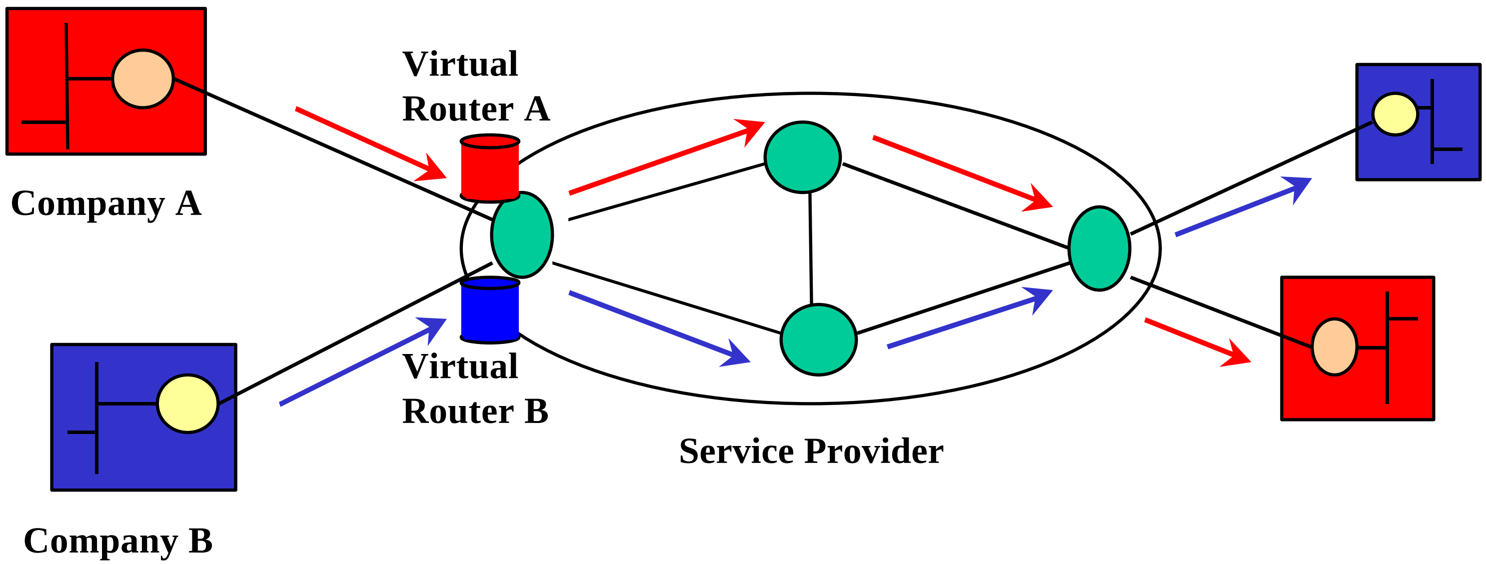
- Current Situation
  - High end-to-end latency
  - High network load
  - High server load
- Approach: move content closer to users
  - much lower web access latency
  - reduced network congestion
  - higher content availability
- Benefits
  - Reduces network load of ISP by as much as 50%
  - Reduces congestion and balances load among many servers
  - Guaranteed "freshness" of hot information in each cache
  - Scalable to large networks



Security for Next Generation Networks

- **Security is the technology that will enable a wave of new applications**
  - **IP paved the way for client/server, the Web, and converged networks**
  - **security technologies are the *key* for ubiquitous e-commerce**
- **Principal security functions**
  - **Confidentiality: protect internal systems and data**
    - **Authentication**
    - **Access control**
    - **Audit**
    - **Integrity: ensure information cannot be modified**
  - **Enable secure communications across untrusted networks**
- **Security Technologies**
  - **Firewalls**
  - **Virtual Private Networks [VPNs]**
  - **Public Key Infrastructure [PKI]**
  - **tunneling: IPsec, L2TP, PPTP**
  - **network address translation [NAT]**
  - **anti-virus software**
  - **vulnerability monitoring and intrusion detection**

Solving Private Address Issues With Virtual Routers

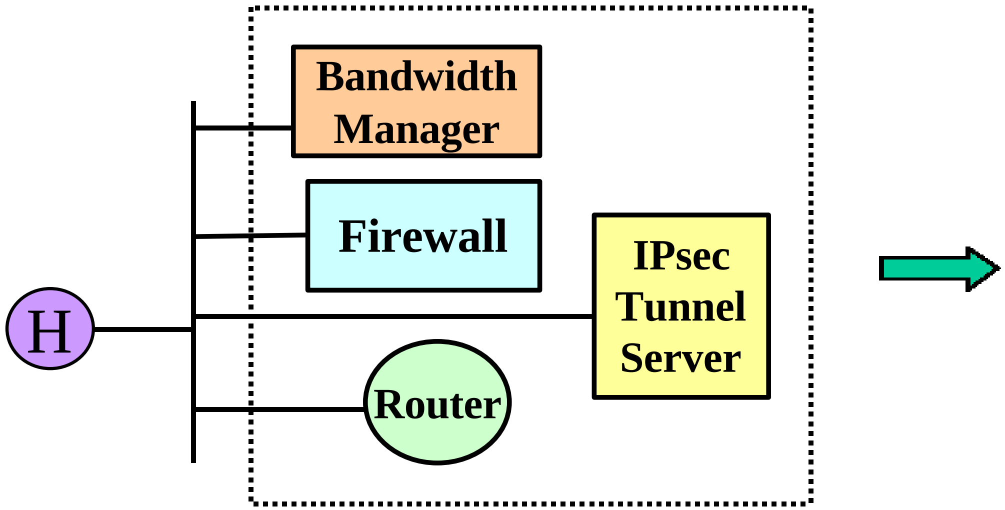


Problem

•Limited IP address space and large number of IP addressable endpoints cause enterprises to create their own private addressing plans
•These addresses are not understood by service provider network routers

Solution: Establish virtual routing capability in edge switch/router
•allows handling of customers' private addressing plans
•creates an instance of routing protocol (e.g. OSPF) per customer

Security Emerging Capabilities: More Powerful and Efficient Firewalls



VPN Gateway: Integrated Firewall

- **Hardware implementations are emerging**
- **Integration of several functions (firewall, IPsec server, router, bandwidth manager...) into one device improves performance and cost**

Evolving to a Next Generation Network Management/Policy Paradigm

Current Situation

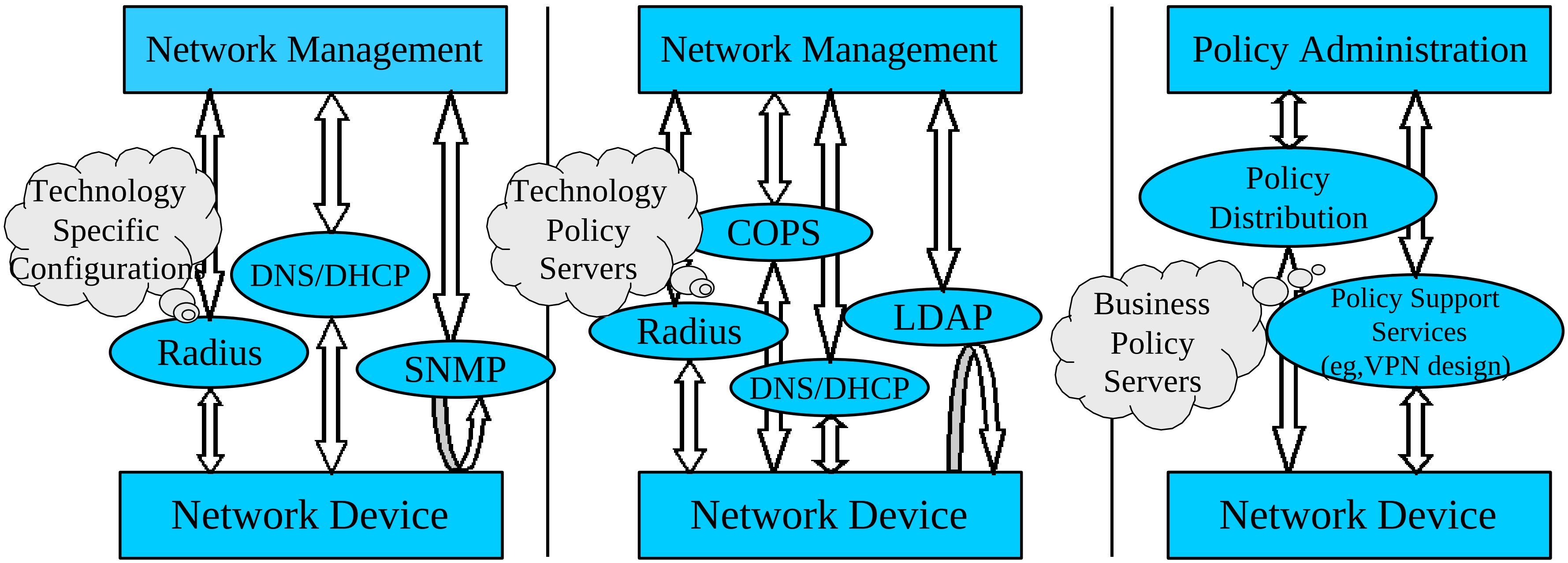
- Independent device and independent services management
- Table-driven device functions
- Client(NM)-Server(Device) architecture

Near Term

- Directories drive data unification
- Central policy management on service basis [policy agents]
- Dynamic device functions

The Future

- Distributed policy management
- Integrated services through policies
- Reactive agents added
- Complex & reactive policy capabilities



Configuration, fault management, billing, performance and security

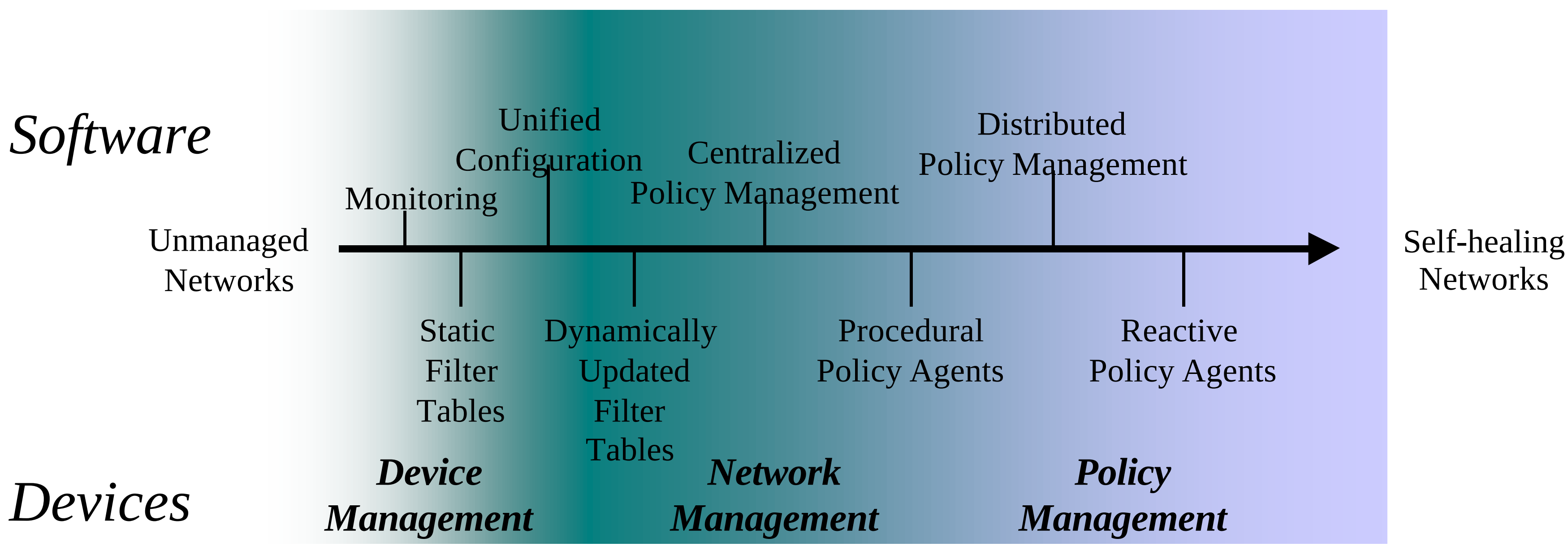
Complex Networks and New Dynamic Services Drive Changes to Policy Management and Infrastructure

Issues

- Management is device configuration:needs to be offer & service related
- Associated data is per device per vendor and largely in tables; needs to be integrated for the offer or service
- Data inconsistency and synchronization problems since data repeated for devices
- Management rules need to respond to changes in network conditions

Solutions

- Technology Policy Þ Service Policy
- Protocol Based Management Tables Þ Common Information Model
- Configuration Þ Policy Management
- Provisioned Þ Dynamic Þ Reactive Policy

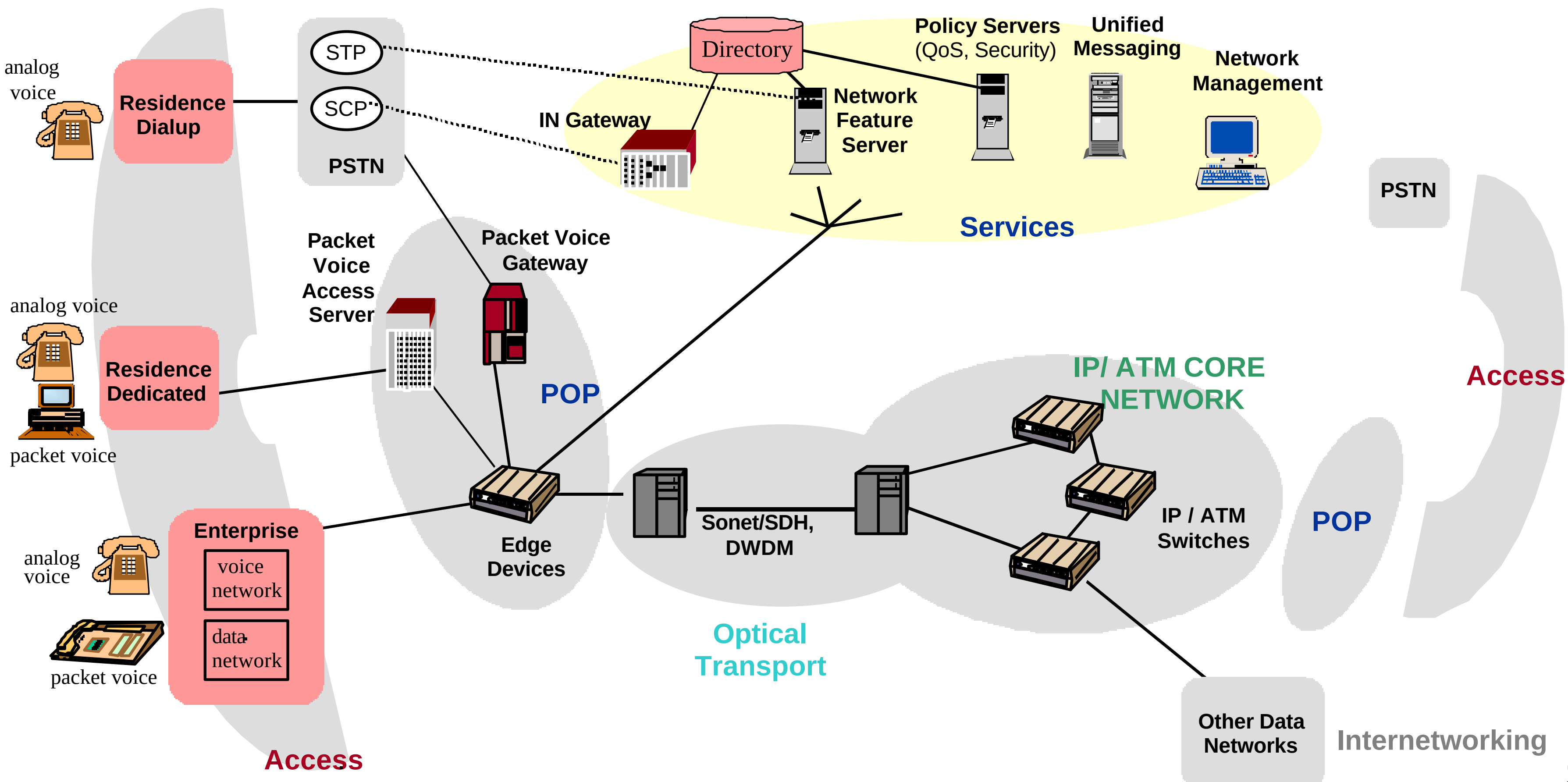


Voice over IP (VoIP) Applications and Issues

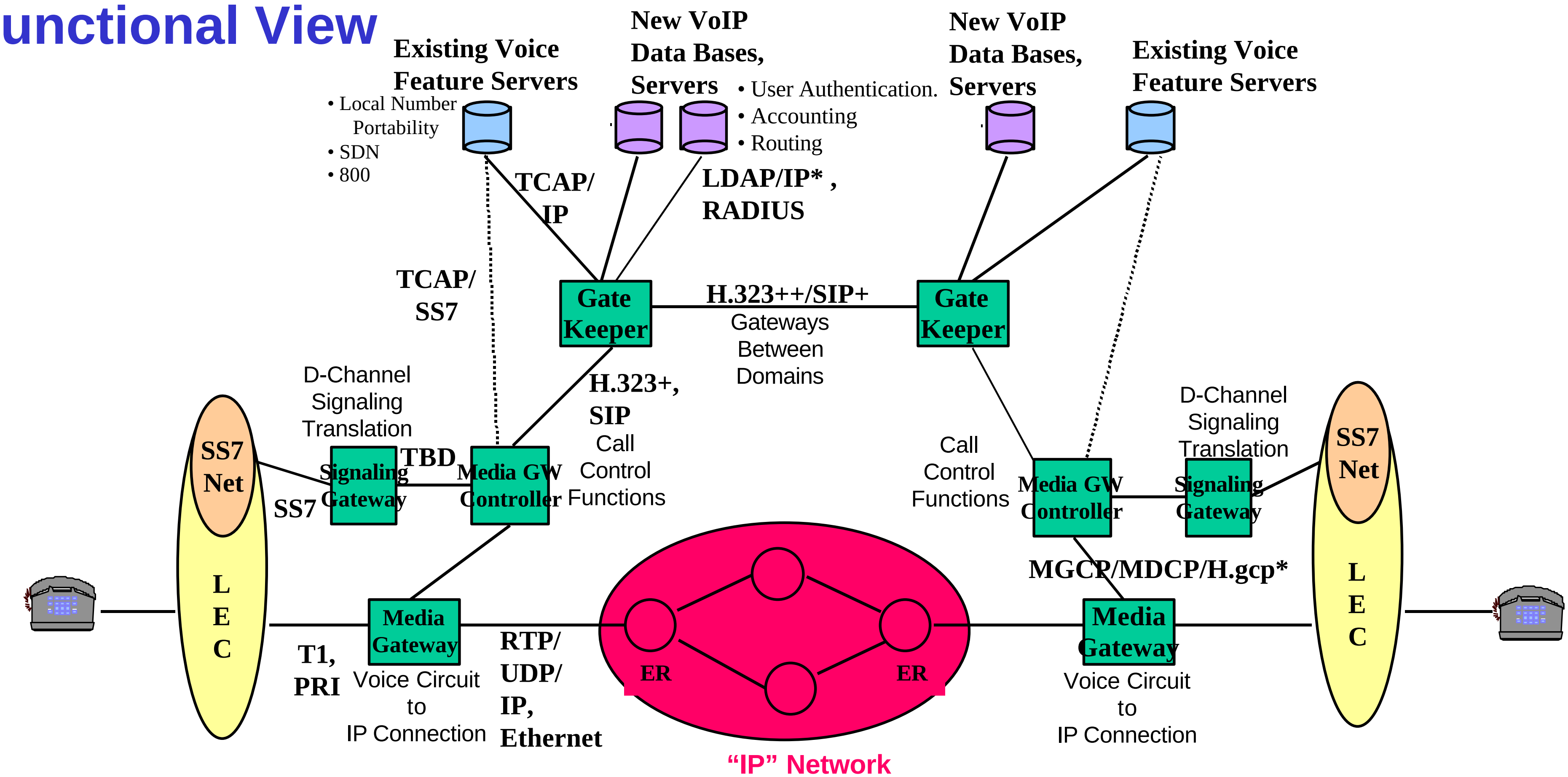
- **Applications**
  - **IP transport: lower cost alternative to circuit transport [access or IXC bypass]**
    - **compression**
    - **routing vs circuit switching costs**
  - **IP services to end users**
    - **evolving from basic and enhanced PSTN-like to integrated multimedia services**
    - **addition of voice to existing data networks [eg, data/voice LAN]**
- **Issues**
  - **Many of today's products do not scale well ---need to separate signaling from media transport and control for large, scalable networks**
    - **Media Gateways ~ 1000's**
    - **Media Gateway Controllers/Gate Keepers ~ 10's,**
    - **Signaling Gateways < 10**
  - **Today's solutions do not cleanly interface with value-added feature data bases or Signaling Control Points (SCPs).**
  - **Voice feature support requires interaction with existing and future SCPs such as Local Number Portability (LNP), 800, SDN, …**
- **Commercial Success of VoIP (including VPNs) will require QoS for**
  - **Call admission**
  - **Media transport**

Packet Voice Networks Services Architecture

- **Network Feature Server** *coordinates with voice gateways to provide enhanced voice/data services*
- **IN gateway** *brings telephony IN features to packet networks*
- **Unified Messaging** *provides integrated voice/data messaging*
- **Policy Servers** *enable voice grade Quality of Service*
- **Directories** *allow efficient management of information*



Near-Term Evolution of VoIP Architecture: Functional View



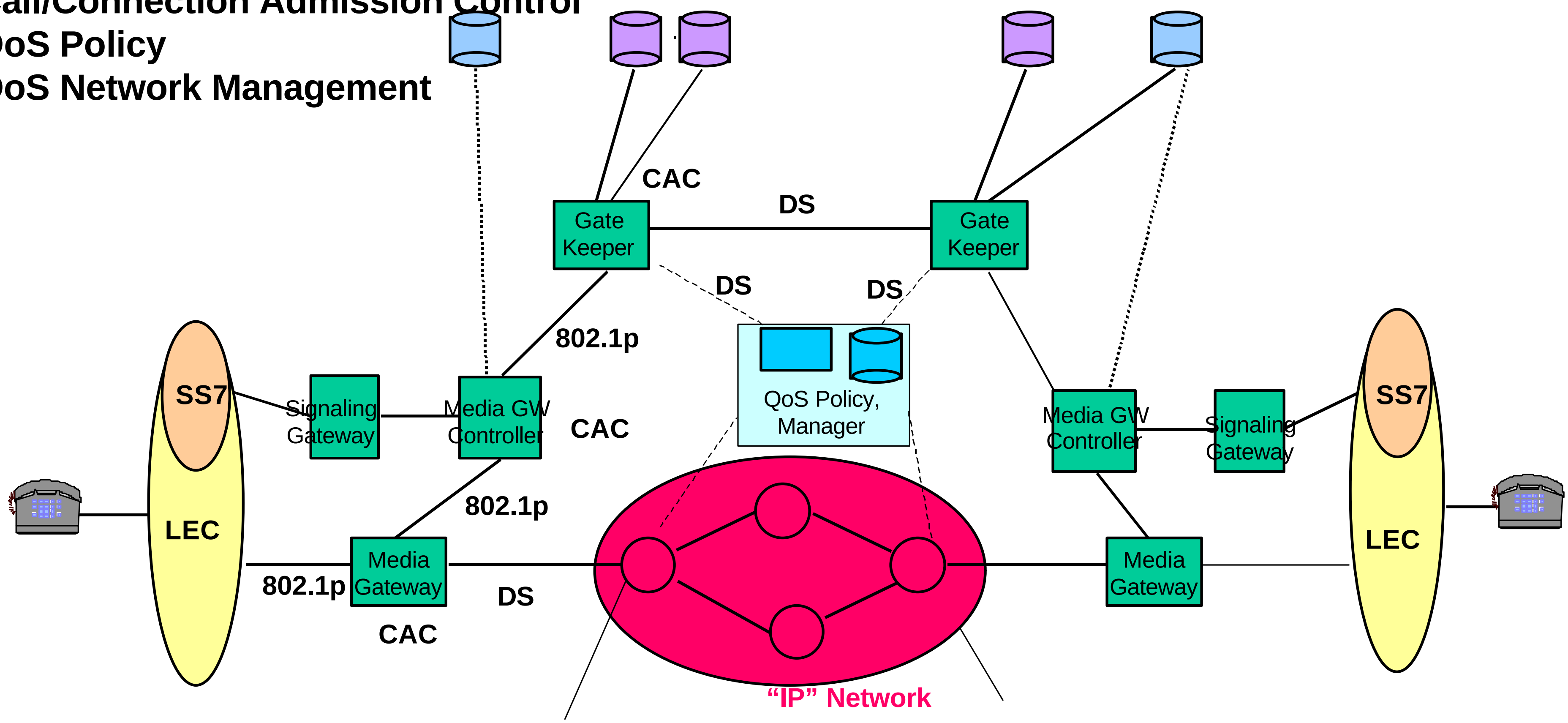
Challenges (Mainly Due to Number of Devices and Protocol Conversions)

- •Call Set Up Time
- •Reliability
- •Voice Quality
- •QoS Guarantees
- •Network Management
- •Cost/Minute

* Proposed Protocol
H.323+ = H.225+ & H.245
H.323++ = H.225+, H.245 & Annex G

Requirements for Future QoS VoIP Architecture

- •QoS Aware Network Elements
- •QoS Protocols
  - •MPLS, RSVP, LDP in IP Network
  - •802.1p on Ethernet LANs
  - •DiffServ on IP
- •Call/Connection Admission Control
- •QoS Policy
- •QoS Network Management



CAC=Call/Connection Admission Control
DS=DiffServ Byte in IP Header

Summary: What to Expect in Next Generation Network [of Networks]

- Enormous innovation
  - a shared packet-based, optical core network using DWDM with optical add/drop and possibly elementary routing
  - a variety of broadband access systems
  - access to traditional and new advanced services by internetworking with the PSTN and to new open applications platforms
  - a new style of network management based on active directories and policy managers
- Value generated by a converged network with
  - the reliability and security of the PSTN
  - simplified network management due to standard interfaces and intelligence incorporated in products
  - support for a broad range of network servers that enable high value applications and services
  - the ability to allow customers to provide service differentiation
  - support for heterogeneous, multi-vendor environments