Quality of Service in Data Networks: Trends, Solutions, and Issues

Future

All I want you to tell me is what will be the networking technology in the year 2000.

The Ohio State University Raj Jain

2

Raj Jain

New Address: Raj Jain, Washington University in Saint Louis, jain@cse.wustl.edu, http://www.cse.wustl.edu/~jain

Future

White House Astrologer

Joan Quigly

All I want you to tell me is what will be the networking technology in the year 2000.

- 10 Trends in Networking
- QoS Approaches:
  - ATM
  - IEEE 802.1D
  - Integrated Services
  - Differentiated Services
  - MPLS
- Design Philosophies of each and problems

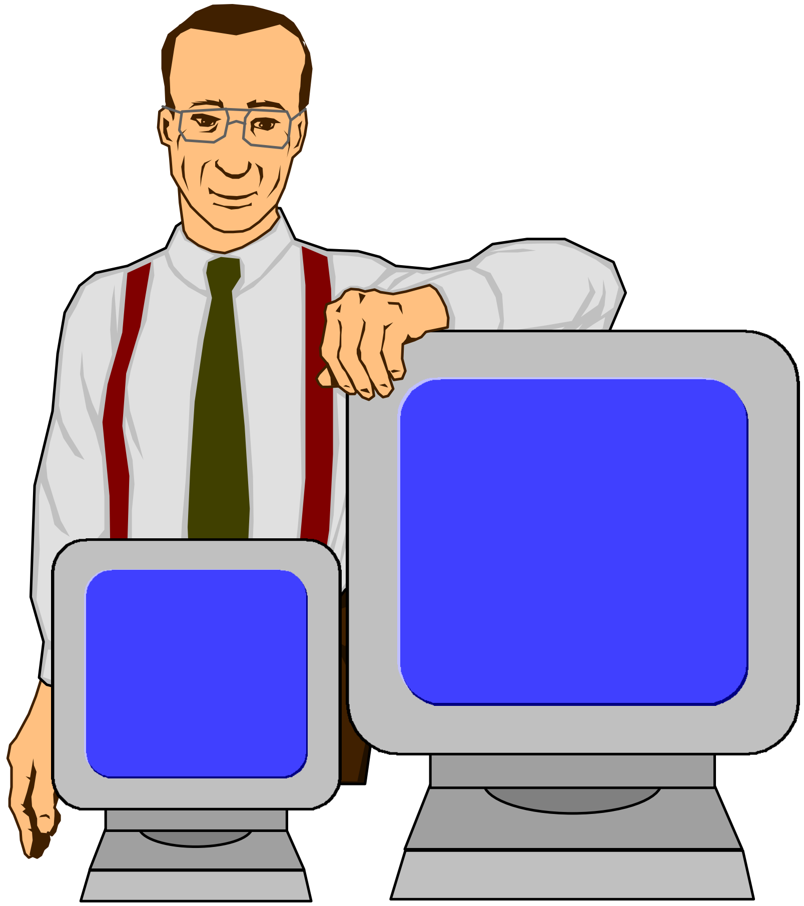
These slides are available at

http://www.cis.ohio-state.edu/~jain/talks/icon99.htm

Ten Networking Trends

1. Faster Media
2. More Traffic
3. Traffic > Capacity
4. Data > Voice
5. ATM in Backbone
6. Everything over IP
7. Differentiation Not Integration
8. Back to Routing From Switching
9. Traffic Engineering
10. Other Trends

Dime Sale

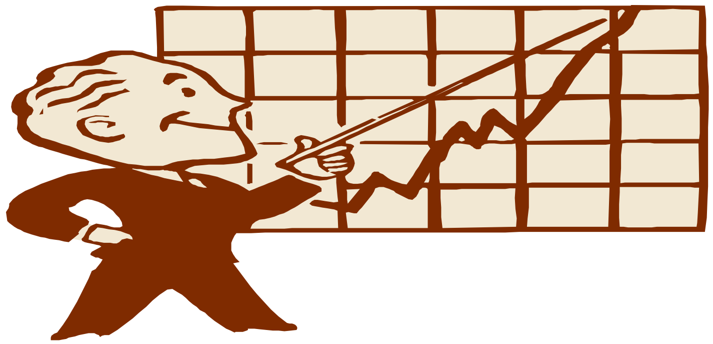


One Megabit memory, One Megabyte disk,
One Mbps link, One MIP processor, 10 cents each.....

Trend 1: Faster Media

- One Gbps over 4-pair UTP-5 up to 100 m
  10G being discussed.
  Was 1 Mbps (1Base-5) in 1984.
- Dense Wavelength Division Multiplexing (DWDM)
  64×OC-192 = 0.6 Tbps
  OC-768 = 40 Gpbs over a 1λ to 65 km [Alcatel98]
  400 Gbps using 80λ products.
  Was 100 Mbps (FDDI) in 1993.
- 11 Mbps in-building wireless networks
  Was 1 Mbps (IEEE 802.11) in 1998.
  2.5 Gbps to 5km using light in open air

Trend 2: More Traffic

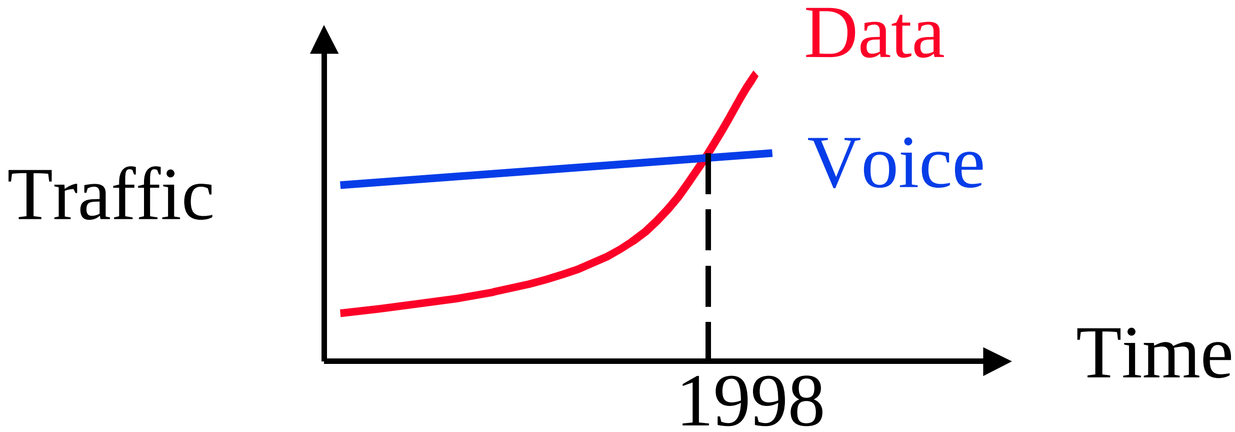


- Number of Internet hosts is growing super-exponentially.
- Traffic per host is increasing:
  - Cable modems allow 1 to 10 Mbps access from home
  - 6-27 Mbps over phone lines using ADSL/VDSL
- Bandwidth requirements are doubling every 4 months

Trend 3: Traffic > Capacity

Expensive Bandwidth	Cheap Bandwidth
❑ Sharing	❑ No sharing
❑ Multicast	❑ Unicast
❑ Virtual Private Networks	❑ Private Networks
❑ Need QoS	❑ QoS less of an issue
❑ Likely in WANs	❑ Possible in LANs

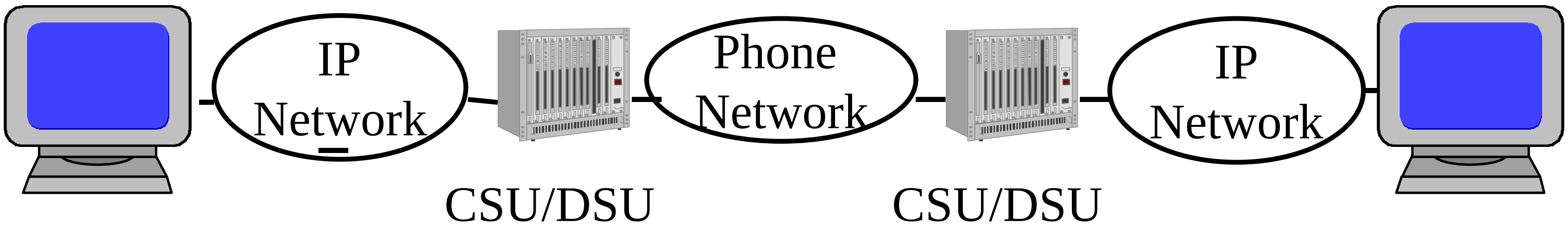
Trend 4: Data > Voice



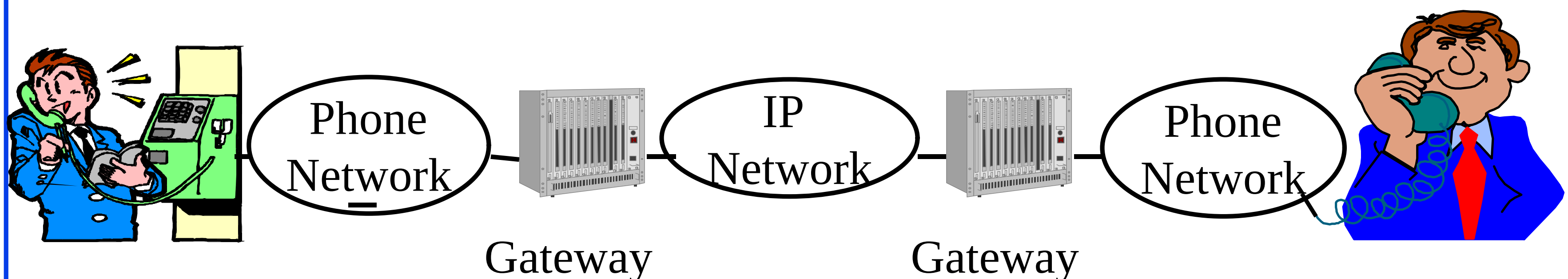
- Voice traffic is growing linearly
  Data traffic is growing exponentially
- In 1998-99, data traffic on carrier networks exceeded the voice traffic.
- Everyone is trying to get into the data business:
  - Phone Networks ⇒ High-speed frame relay
  - Video Networks ⇒ Cable Modems

Data > Voice (Cont)

- Past: Data over Voice



- Future: Voice over Data

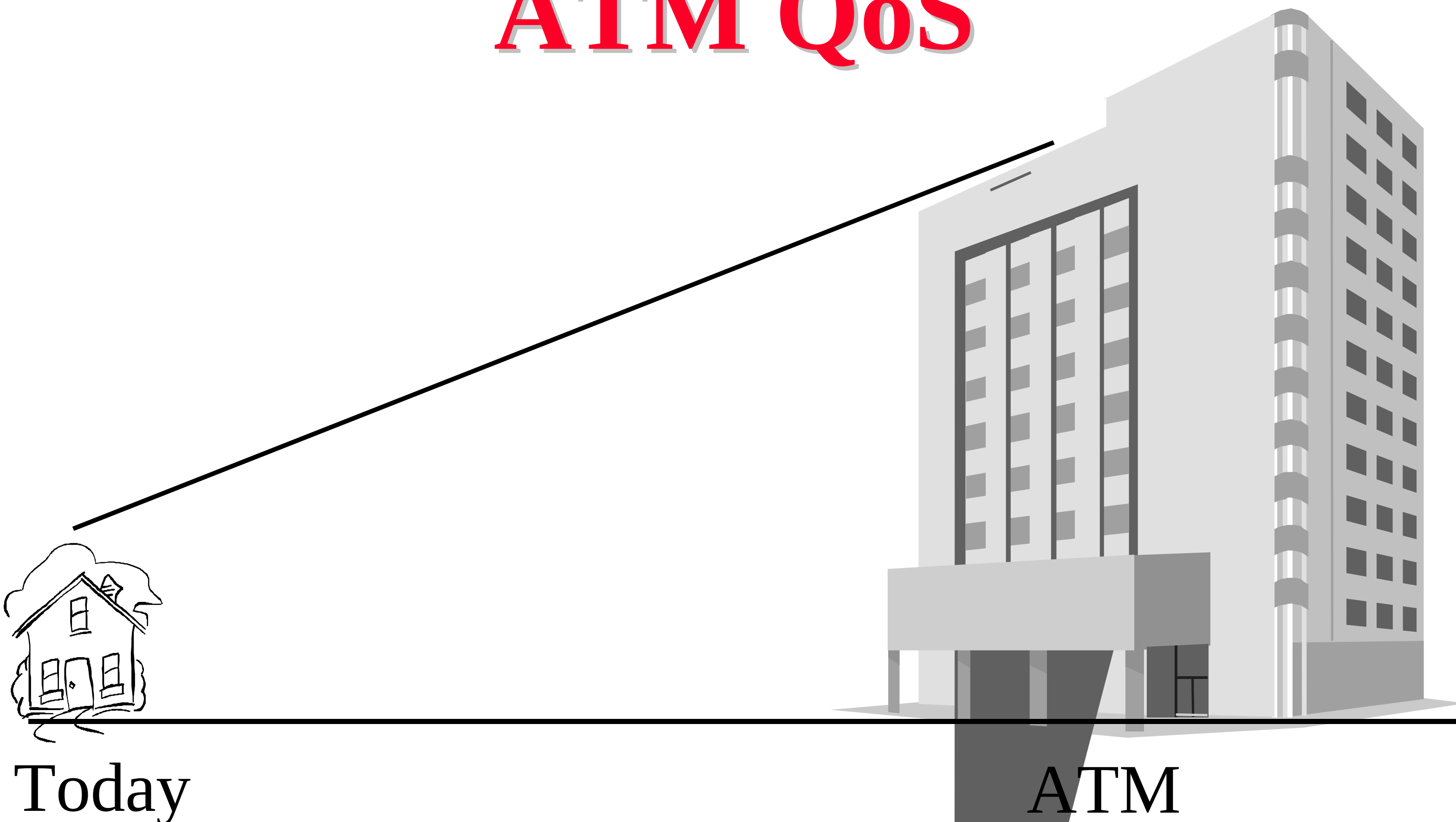


- Convergence: Data+Voice+Video
  AT&T + TCI, Lucent+Ascend, Nortel+Baynetworks
- Voice over DSL: 16 lines + Data over 1 UTP by CLECs

Trend 5: ATM in Backbone

- Most carriers including AT&T, MCI, Sprint, UUNET, have ATM backbone
- Over 80% of the internet traffic goes over ATM
- ATM provides:
  - Traffic management
  - Voice + Data Integration: CBR, VBR, ABR, UBR
  - Signaling
  - Quality of service routing: PNNI
- ATM can't reach desktop: Designed by carriers. Complexity in the end systems. Design favors voice.

ATM QoS



Too much too soo

IEEE 802.1D Model

- Massive bandwidth. Simple priorities will do.
- **Up to eight priorities**: Strict.

  1 Background

  2 Spare

  0 Best Effort

  3 Excellent Effort

  4 Control load

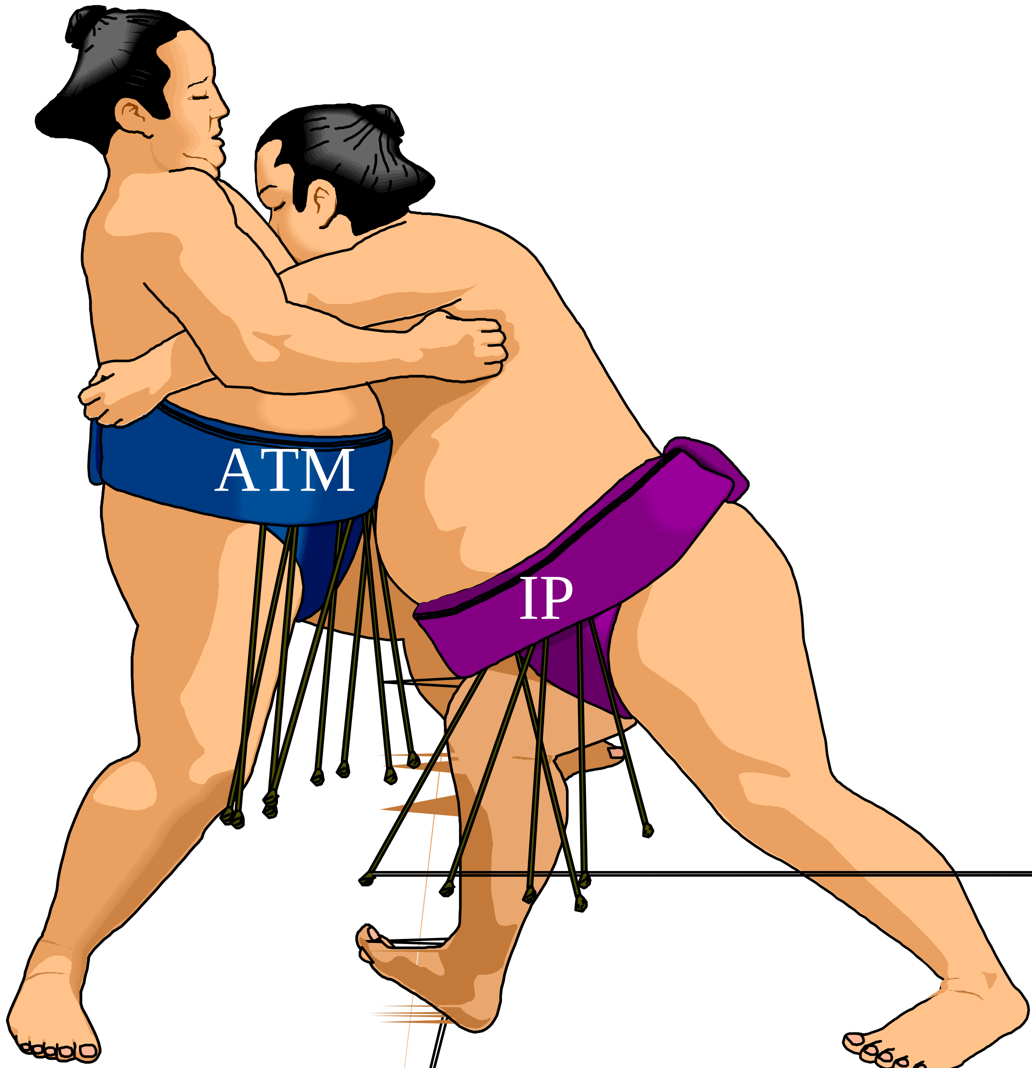
  5 Video (Less than 100 ms latency and jitter)

  6 Voice (Less than 10 ms latency and jitter)

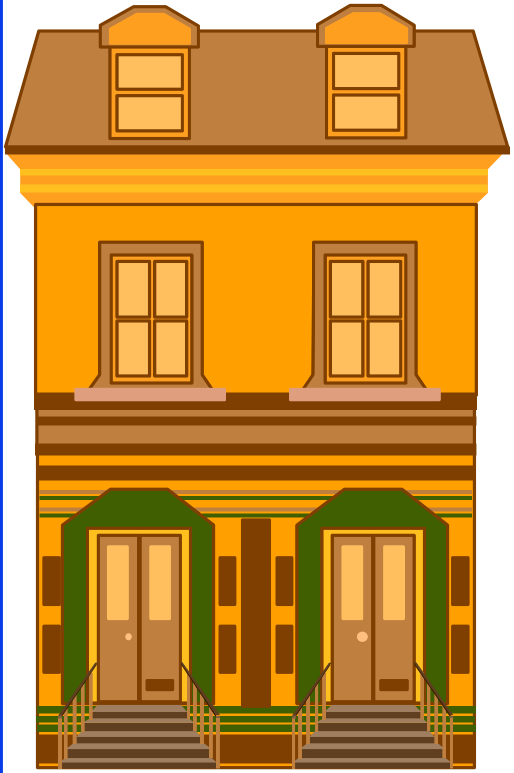
  7 Network Control

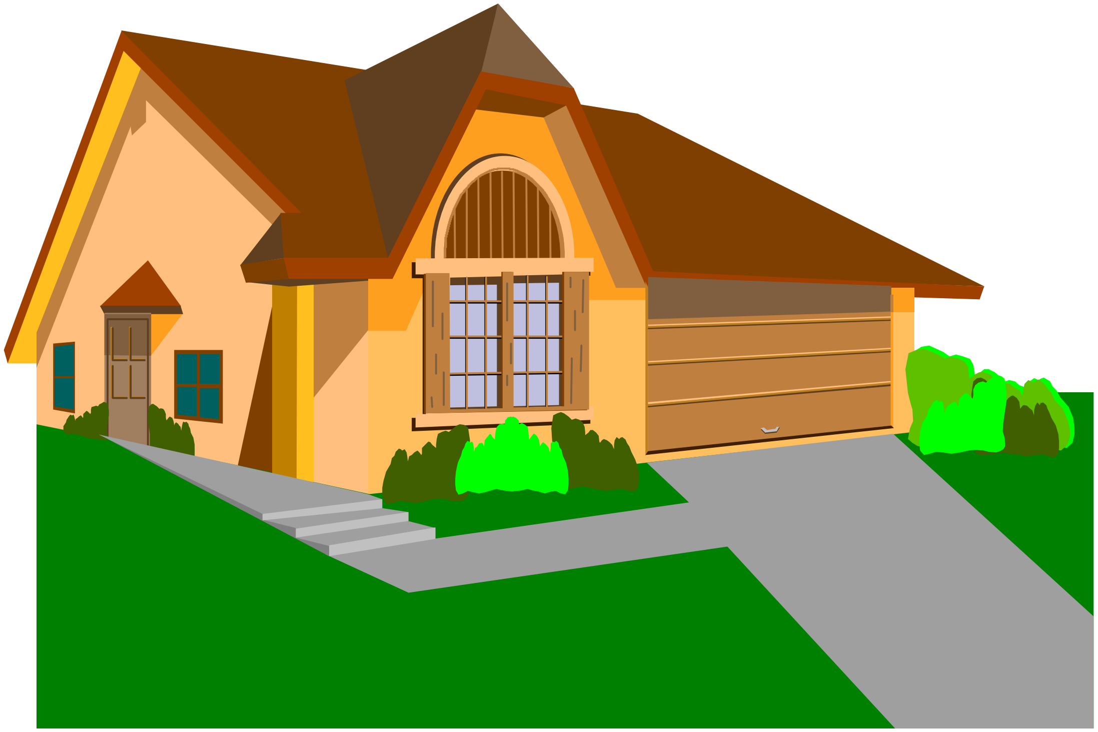
IP vs ATM

1995-98



Old House vs New House





- New needs:
  Solution 1: Fix the old house (cheaper initially)
  Solution 2: Buy a new house (pays off over a long run)

Trend 6: Everything over IP

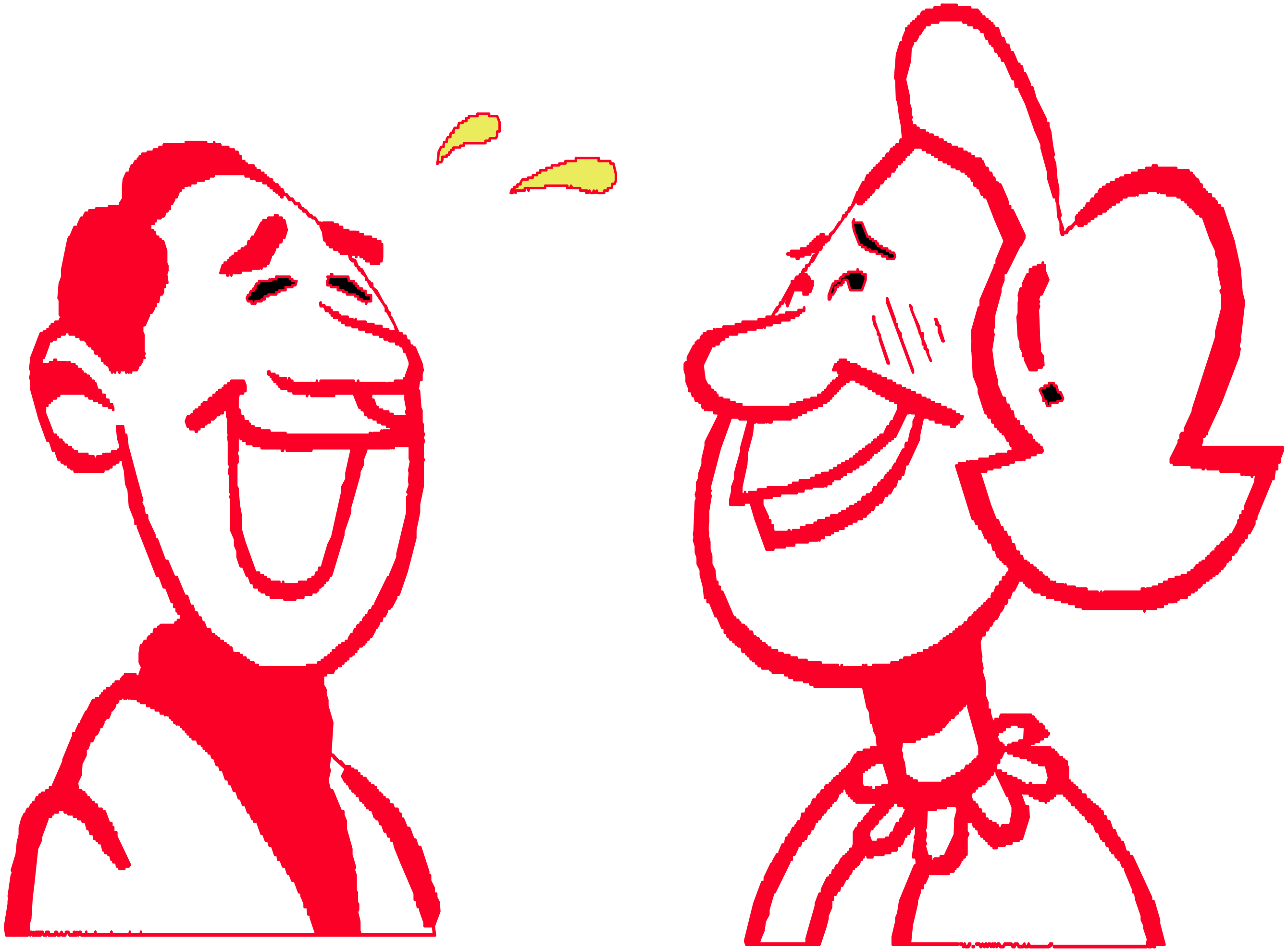
- Data over IP $\Rightarrow$ IP needs Traffic engineering
- Voice over IP $\Rightarrow$ Quality of Service and Signaling
- Internet Engineering Task Force (IETF) is the center of action.
  Attendance at ATM Forum and ITU is down.

Integrated Services

1. **Best Effort Service**: Like UBR.
2. **Controlled-Load Service**: Performance as good as in an unloaded datagram network. No quantitative assurances. Like nrt-VBR or UBR w MCR
3. **Guaranteed Service**: rt-VBR
   - Firm bound on data throughput and delay.
   - Like CBR or rt-VBR

- Need a signaling protocol: RSVP
- Design philosophy similar to ATM
  - Per-flow
  - End-to-end
  - Signaling

Before Marriage

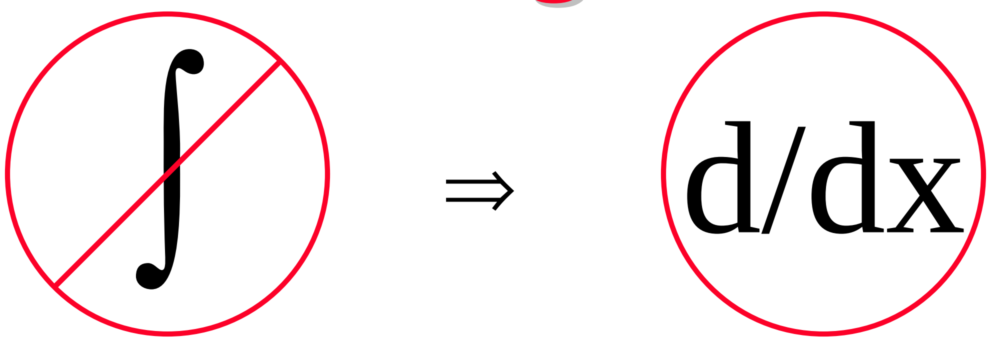


After Marriage

Problems with IntServ+RSVP

- Complexity in routers: classification, scheduling
- Not scalable with # of flows
  ⇒ Not suitable for backbone.
- Need a concept of "Virtual Paths" or aggregated flow groups for the backbone.
- Need policy controls: Who can make reservations?
  ⇒ RSVP admission policy (rap) working group.
- Receiver Based:
  Need sender control/notifications in some cases.
- Soft State: Need route/path pinning (stability).
- No negotiation and backtracking
- Note: RSVP is being revived for MPLS and DiffServ

Trend 7: Differentiation Not Integration



- DiffServ to standardize IPv4 ToS byte's first six bits
- Packets gets marked at network ingress
  Marking ⇒ treatment (behavior) in rest of the net
  Six bits ⇒ 64 different per-hop behaviors (PHB)

Ver	Hdr Len	Type of Service (ToS)	Tot Len
4b	4b	8b	16b

DiffServ (Cont)

- Per-hop behavior = % of link bandwidth, Priority
- Services: End-to-end. Voice, Video, ...
  - Transport: Delivery, Express Delivery,...
    Best effort, controlled load, guaranteed service
- DS group will not develop services
  They will standardize "Per-Hop Behaviors"
- Marking based on static "Service Level Agreements" (SLAs). Avoid signaling.

Problems with DiffServ

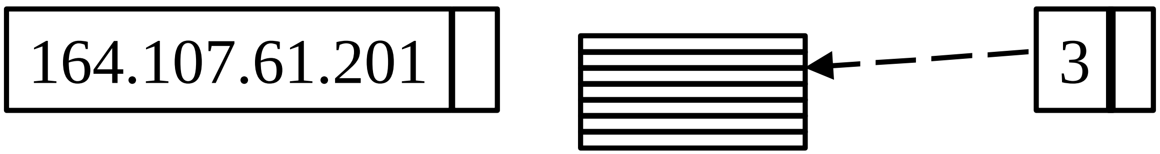
- End-to-end ≠ Σ per-Hop
  Designing end-to-end services with weighted guarantees at individual hops is difficult.
  Only Expedited Forwarding will work.
- Designed for static Service Level Agreements (SLAs)
  Both the network topology and traffic are highly dynamic.
- How to ensure resource availability inside the network?
- DiffServ is unidirectional ⇒ No receiver control

DiffServ Problems (Cont)

- QoS is for the aggregate not micro-flows.
  Not intended/useful for end users. Only ISPs.
    - Large number of short flows are better handled by aggregates.
    - Long flows (voice and video sessions) need per-flow guarantees.
    - High-bandwidth flows (1 Mbps video) need per-flow guarantees.

⇒ DiffServ alone is not sufficient for backbone.
Signaling via RSVP will be required.

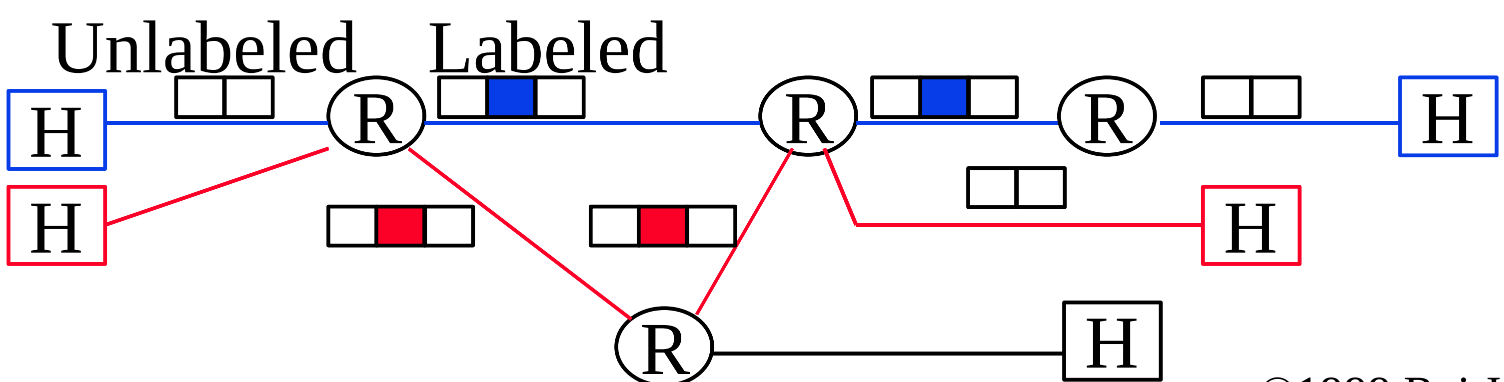
Trend 8: Back to Routing From Switching



- Routing: Based on address lookup. Max prefix match.
  ⇒ Search Operation
  ⇒ Complexity ≈ $O(\log_2 n)$
- Switching: Based on circuit numbers
  ⇒ Indexing operation
  ⇒ Complexity O(1)
  ⇒ Fast and Scalable for large networks and large address spaces
- 128 Gbps IP forwarding [Neo Networks 99]

Multiprotocol Label Switching

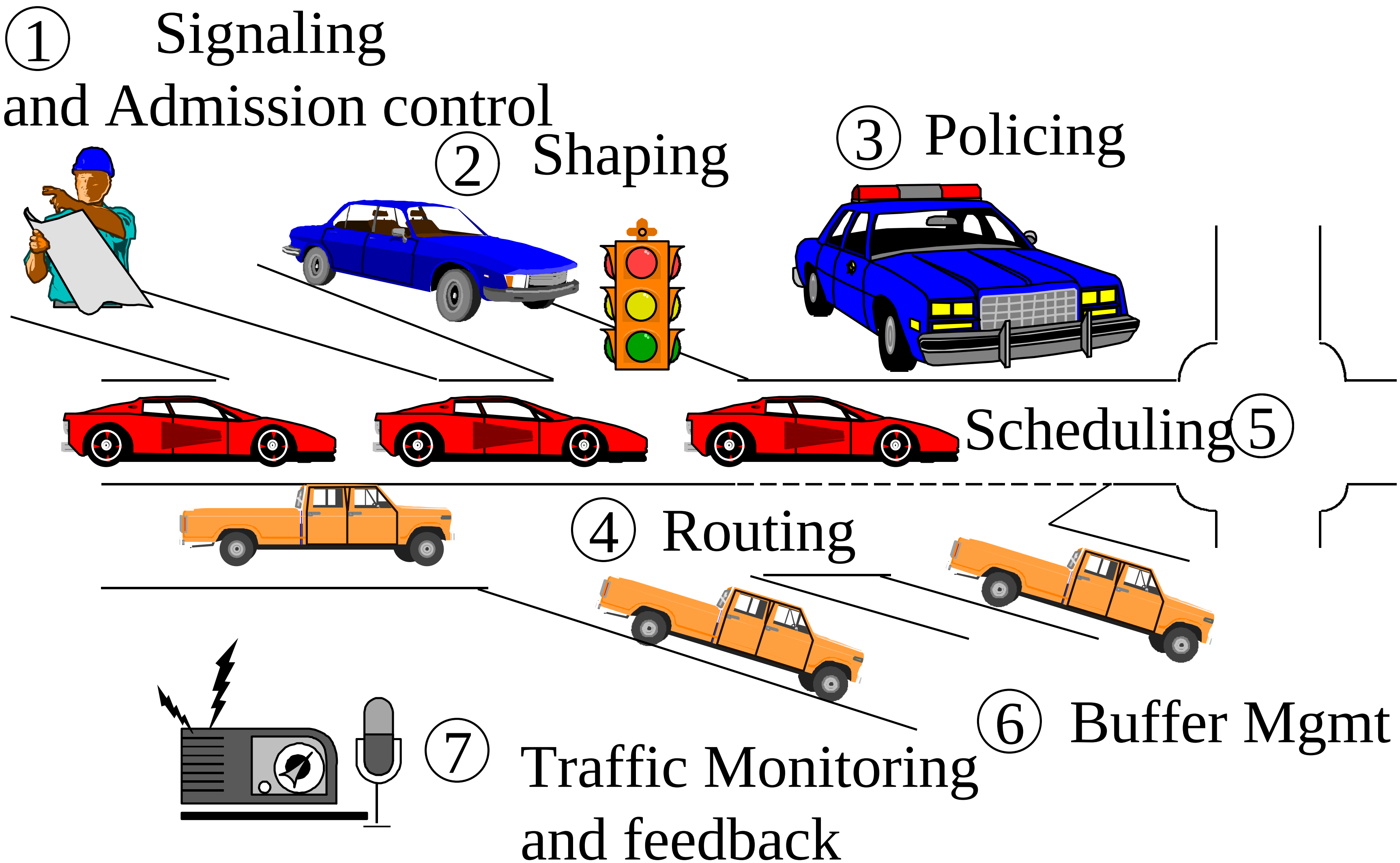
- Label = Circuit number = VC Id
- Ingress router/host puts a label.
  Exit router strips it off.
- Switches switch packets based on labels.
  Do not need to look inside ⇒ Fast.
- OC-192 (10 Gbps) routers from Nexabit.
  ⇒ Switching for traffic engineering, not for speed.



Trend 9: Traffic Engineering

- User's Performance Optimization
  $\Rightarrow$ Maximum throughput, Min delay, min loss, min delay variation
- Efficient resource allocation for the provider
  $\Rightarrow$ Efficient Utilization of all links
  $\Rightarrow$ Load Balancing on parallel paths
  $\Rightarrow$ Minimize buffer utilization
  - Current routing protocols (e.g., RIP and OSPF) find the shortest path (may be over-utilized).
- QoS Guarantee: Selecting paths that can meet QoS
- Enforce Service Level agreements
- Enforce policies: Constraint based routing $\supseteq$ QoSR

Traffic Engineering Components



MPLS Mechanisms for TE

- Signaling, Admission Control, Routing
- Explicit routing of Label Switched Paths (LSPs)
- Constrained based routing of LSPs
  Allows both Traffic constraints and Resource Constraints (Resource Attributes)
- Hierarchical division of the problem (Label Stacks)
- Danger: Too much too soon…again

QoS Design Approaches

- Massive Bandwidth vs Managed Bandwidth
- Per-Flow vs Aggregate
- Source-Controlled vs Receiver Controlled
- Soft State vs Hard State
- Path based vs Access based
- Quantitative vs Qualitative
- Absolute vs Relative
- End-to-end vs Per-hop
- Static vs Feedback-based
- Homogeneous multicast vs heterogeneous multicast
- 1-to-n multicast vs n-to-1 multicast

Comparison of QoS Approaches

Issue	ATM	IntServ	DiffServ	MPLS	IEEE 802.3D
Massive Bandwidth vs Managed Bandwidth	Managed	Managed	Massive	Managed	Massive
Per-Flow vs Aggregate	Both	Per-flow	Aggregate	Both	Aggregate
Source-Controlled vs Receiver Controlled	Unicast Source, Multicast both	Receiver	Ingress	Both	Source
Soft State vs Hard State	Hard	Soft	None	Hard	Hard
Path based vs Access based	Path	Path	Access	Path	Access
Quantitative vs Qualitative	Quantitative	Quantitative +Qualitative	Mostly qualitative	Both	Qualitative
Absolute vs Relative	Absolute	Absolute	Mostly Relative	Absolute + relative	Relative

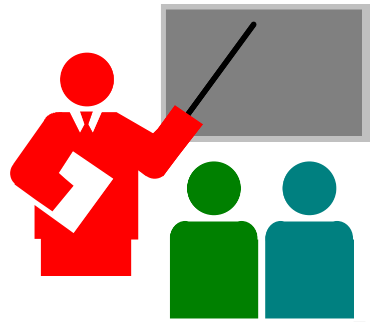
Comparison (Cont)

Issue	ATM	IntServ	DiffServ	MPLS	IEEE 802.3D
End-to-end vs Per-hop	end-end	end-end	Per-hop	end-end	Per-hop
Static vs Feedback-based	Both	Static	Static	Static	Static
Homogeneous multicast vs heterogeneous multicast	Homo-geneous	Hetero-geneous	N/A	Homo-geneous	N/A
1-to-n vs n-to-1 multicast	1-to-n	1-to-n	N/A	Both	Both

10. Other Trends

- LAN+MAN convergence: EtherLoop
- Packet over ATM vs SONET vs DWDM
- Network Economy:
  In 1999, revenues by Internet-based Corporations exceed that of Internet equipment vendors
- Networking is the key to a Corporation's (country's/individual's) success
- Information Glut $\Rightarrow$ Intelligent agents for searching, digesting, summarizing information
- Mobility, Security

Summary



- Super-exponential increase in data traffic and voice over IP ⇒ Traffic Engineering and QoS over IP
- ATM and Integrated Services are based on per-flow end-to-end guarantees using signaling.
- DiffServ provide aggregate per-hop treatment. Meaningful services yet to be designed.
- MPLS combines the best of ATM and IP. Must avoid becoming too complex too soon.

References

- References on MPOA, MPLS, and IP Switching, http://www.cis.ohio-state.edu/~jain/refs/ipsw_ref.htm
- Quality of Service using Traffic Engineering over MPLS: An Analysis, http://www.cis.ohio-state.edu/~jain/papers/mpls-te-anal.htm
- IP Switching, http://www.cis.ohio-state.edu/~jain/cis788-97/ip_switching/index.htm
- References on QoS over IP, http://www.cis.ohio-state.edu/~jain/refs/ipqs_ref.htm
- IP Switching: Issues and Alternatives, http://www.cis.ohio-state.edu/~jain/talks/ipsw.htm

References (Cont)

- Quality of Service in IP Networks, http://www.cis.ohio-state.edu/~jain/talks/ipqos.htm
- Requirements for Traffic Engineering over MPLS, draft-ietf-mpls-traffic-eng-01.txt
- Constraint-based LSP Setup using LDP, draft-ietf-mpls-cr-ldp-01.txt

Acronyms

ATM	Asynchronous Transfer Mode
CBR	Constant Bit Rate
CDV	Cell Delay Variation
DS	Differentiated Services
DVD	Digital Video Disks
DWDM	Dense Wavelength Division Multiplexing
FDDI	Fiber Distributed Data Interface
IEEE	Inst. of Elect. and Electronic Engineers
IETF	Internet Engineering Task Force
IP	Internet Protocol
ISP	Internet Service Provider

Acronyms (Cont)

LAN	Local Area Network
LSP	Label Switched Path
MCR	Minimum Cell Rate
MIPS	Millions of Instructions Per Second
MPLS	Multiprotocol Label Switching
MPOA	Multiprotocol over ATM
OC	Optical Carrier
PHB	Per-hop Behavior
PNNI	Private Network-Node Interface
QoS	Quality of Service
QoSR	Quality of Service Routing

Acronyms (Cont)

RIP	Routing Information Protocol
RSVP	Resource Reservation Protocol
SLA	Service Level Agreement
ToS	Type of Service
UBR	Unspecified Bit Rate
UTP	Unshielded Twisted Pair
VBR	Variable Bit Rate
VC	Virtual Circuit
VP	Virtual Path

Thank You!