Lecture 8
Virtual Circuits, ATM, MPLS

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Outline

- Exam discussion
- Layering review (bridges, routers, etc.)
  - » Exam section C.
- Circuit switching refresher
- Virtual Circuits - general
  - » Why virtual circuits?
  - » How virtual circuits? -- tag switching!
- Two modern implementations
  - » ATM - teleco-style virtual circuits
  - » MPLS - IP-style virtual circuits

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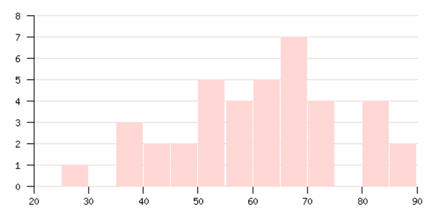
Exam stats

Max/avg/min: 90 / 63 / 20

A	B	C	D
19.6	17.9	12.8	11.0
57.6%	74.8%	58.3%	68.6%



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Common Exam Problems

- **Routing: No one big problem; many small misunderstandings. Please check your scores.**
- **Short answer: Many incorrect round-trip times vs. one-way times.**
- **DNS**
  - » Always sends the full query! (e.g. "ra1.streaming.npr.org", not just "npr.org")
  - » Clients don't recurse; the local recursive DNS server does. Could run on clients, but usually doesn't.
- **Routing and bridging and addressing…**

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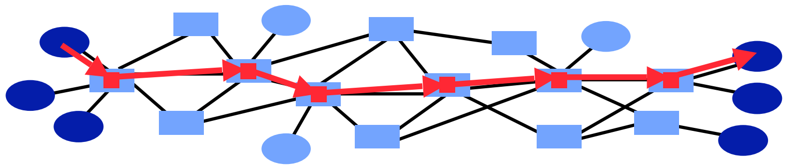
Packet Switching

- Source sends information as self-contained packets that have an address.
  - » Source may have to break up single message in multiple
- Each packet travels independently to the destination host.
  - » Routers and switches use the address in the packet to determine how to forward the packets
- Destination recreates the message.
- Analogy: a letter in surface mail.



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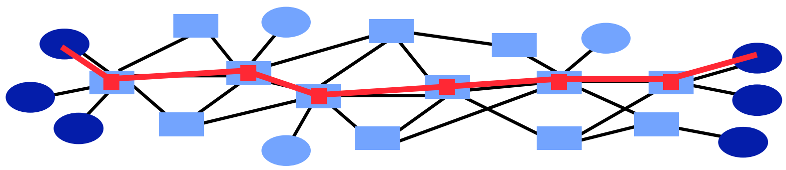
Circuit Switching

- Source first establishes a connection (circuit) to the destination.
  - » Each router or switch along the way may reserve some bandwidth for the data flow
- Source sends the data over the circuit.
  - » No need to include the destination address with the data since the routers know the path
- The connection is torn down.
- Example: telephone network.



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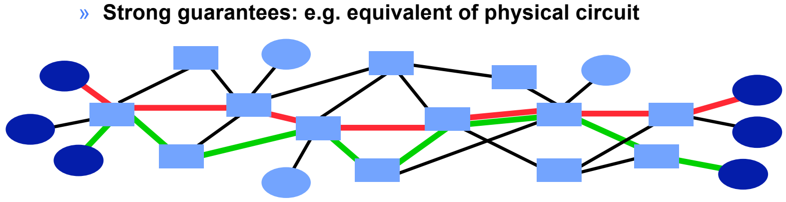
Circuit Switching Discussion

- **Traditional circuits: on each hop, the circuit has a dedicated wire or slice of bandwidth.**
  - » Physical connection - clearly no need to include addresses with the data
- **Advantages, relative to packet switching:**
  - » Implies guaranteed bandwidth, predictable performance
  - » Simple switch design: only remembers connection information, no longest-prefix destination address look up
- **Disadvantages:**
  - » Inefficient for bursty traffic (wastes bandwidth)
  - » Delay associated with establishing a circuit
- **Can we get the advantages without (all) the disadvantages?**

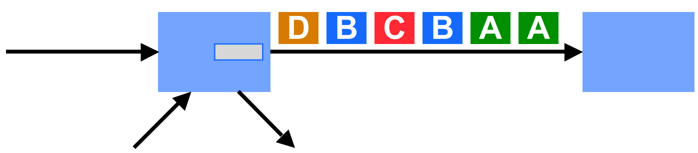
Virtual Circuits

- **Each wire carries many "virtual" circuits.**
  - » Forwarding based on virtual circuit (VC) identifier
    - – IP header: src, dst, etc.
    - – Virtual circuit header: just "VC"
  - » A path through the network is determined for each VC when the VC is established
  - » Use statistical multiplexing for efficiency
- **Can support wide range of quality of service.**
  - » No guarantees: best effort service
  - » Weak guarantees: delay < 300 msec, …
  - » Strong guarantees: e.g. equivalent of physical circuit



Packet Switching and Virtual Circuits: Similarities

- "Store and forward" communication based on an address.
  - » Address is either the destination address or a VC identifier
- Must have buffer space to temporarily store packets.
  - » E.g. multiple packets for some destination arrive simultaneously
- Multiplexing on a link is similar to time sharing.
  - » No reservations: multiplexing is statistical, i.e. packets are interleaved without a fixed pattern
  - » Reservations: some flows are guaranteed to get a certain number of "slots"



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Virtual Circuits Versus Packet Switching

- Circuit switching:
  - » Uses short connection identifiers to forward packets
  - » Switches know about the connections so they can more easily implement features such as quality of service
  - » Virtual circuits form basis for traffic engineering: VC identifies long-lived stream of data that can be scheduled
- Packet switching:
  - » Use full destination addresses for forwarding packets
  - » Can send data right away: no need to establish a connection first
  - » Switches are stateless: easier to recover from failures
  - » Adding QoS is hard
  - » Traffic engineering is hard: too many packets!

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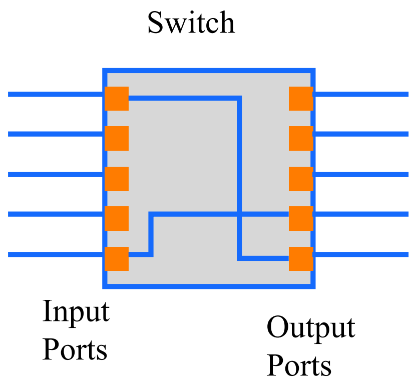
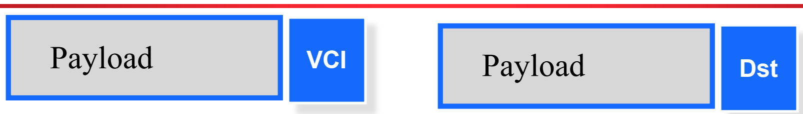
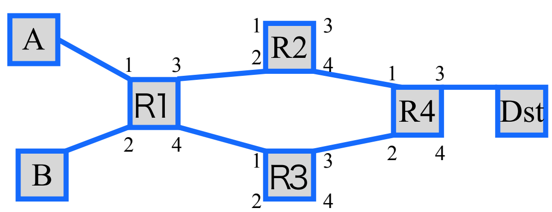
Circuit Switching



Connects (electrons or bits) ports to ports

Packet switched vs. VC





R1 packet forwarding table:

Dst R2

Different paths to same destination!

(useful for traffic engineering!)

R1 VC table:

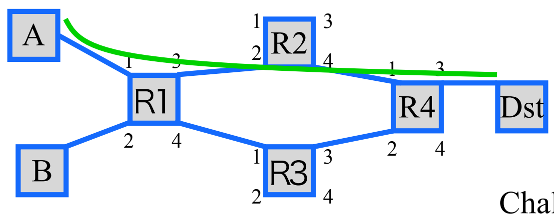
VC 1 R2

VC 2 R3

Virtual Circuit

Payload | VCI

Payload



Challenges:

- How to set up path?
- How to assign IDs??

R1 VC table:

VC 5 R2

R2 VC table:

VC 5 R4

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Connections and Signaling

- **Permanent vs. switched virtual connections (PVCs, SVCs)**
  - static vs. dynamic. PVCs last "a long time"
    - E.g., connect two bank locations with a PVC that looks like a circuit
    - SVCs are more like a phone call
  - PVCs administratively configured (but not "manually")
  - SVCs dynamically set up on a "per-call" basis
- **Topology**
  - point to point
  - point to multipoint
  - multipoint to multipoint
- **Challenges:**
  - How to configure these things?
    - What VCI to use?
    - Setting up the path

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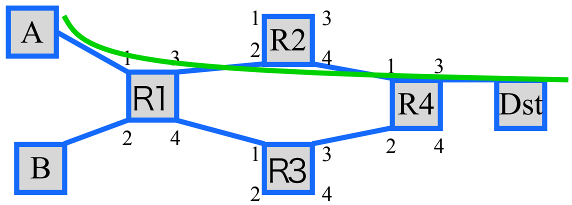
Virtual Circuit Switching: Label ("tag") Swapping



- Global VC ID allocation -- ICK! Solution: Per-link uniqueness. *Change VCI each hop.*

	Input Port	Input VCI	Output Port	Output VCI
R1:	1	5	3	9
R2:	2	9	4	2
R4:	1	2	3	5

Label ("tag") Swapping

- **Result: Signalling protocol must only find per-link unused VCIs.**
  - » "Link-local scope"
  - » Connection setup can proceed hop-by-hop.
    - – Good news for our setup protocols!

PVC connection setup

- Manual?
  - » Configure each switch by hand. Ugh.
- Dedicated signalling protocol
  - » E.g., what ATM uses
- Piggyback on routing protocols
  - » Used in MPLS. E.g., use BGP to set up

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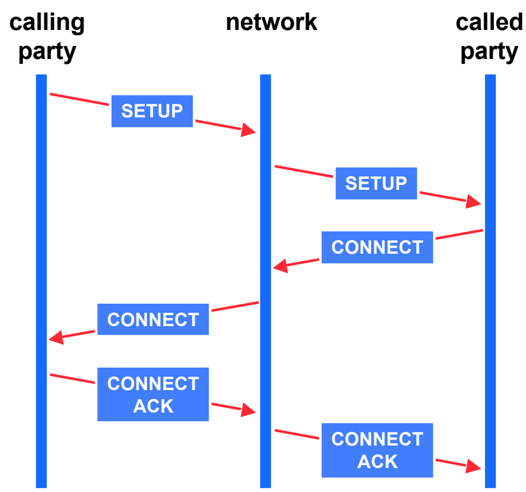
SVC Connection Setup



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Virtual Circuits In Practice

- ATM: Teleco approach
  - Kitchen sink. Based on voice, support file transfer, video, etc., etc.
  - Intended as IP replacement. That didn't happen. :)
  - Today: Underlying network protocol in many teleco networks. E.g., DSL speaks ATM. IP over ATM in some cases.
- MPLS: The "IP Heads" answer to ATM
  - Stole good ideas from ATM
  - Integrates well with IP
  - Today: Used inside some networks to provide VPN support, traffic engineering, simplify core.
- Other nets just run IP.
- Older tech: Frame Relay
  - Only provided PVCs. Used for quasi-dedicated 56k/T1 links between offices, etc. Slower, less flexible than ATM.

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Asynchronous Transfer Mode: ATM

- Connection-oriented, packet-switched
  - (e.g., virtual circuits).
- Teleco-driven. Goals:
  - Handle voice, data, multimedia
  - Support both PVCs and SVCs
  - Replace IP. (didn't happen…)
- Important feature: Cell switching

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Cell Switching

- Small, fixed-size cells
  [Fixed-length data][header]

- Why?
  - Efficiency: All packets the same
    - Easier hardware parallelism, implementation
  - Switching efficiency:
    - Lookups are easy -- table index.
  - Result: Very high cell switching rates.
  - Initial ATM was 155Mbit/s. Ethernet was 10Mbit/s at the same time. (!)
- How do you pick the cell size?

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ATM Features

- Fixed size cells (53 bytes).
  - Why 53?
- Virtual circuit technology using hierarchical virtual circuits (VP,VC).
- PHY (physical layer) processing delineates cells by frame structure, cell header error check.
- Support for multiple traffic classes by adaptation layer.
  - E.g. voice channels, data traffic
- Elaborate signaling stack.
  - Backwards compatible with respect to the telephone standards
- Standards defined by ATM Forum.
  - Organization of manufacturers, providers, users

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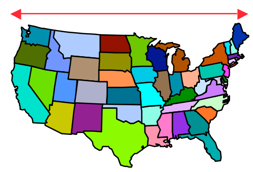
Why 53 Bytes?

- Small cells favored by voice applications
  - » delays of more than about 10 ms require echo cancellation
  - » each payload byte consumes 125 µs (8000 samples/sec)
- Large cells favored by data applications
  - » Five bytes of each cell are overhead
- France favored 32 bytes
  - » 32 bytes = 4 ms packetization delay.
  - » France is 3 ms wide.
  - » Wouldn't need echo cancellers!
- USA, Australia favored 64 bytes
  - » 64 bytes = 8 ms
  - » USA is 16 ms wide
  - » Needed echo cancellers anyway, wanted less overhead
- Compromise



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ATM Adaptation Layers

1	2	3	4	5
synchronous		asynchronous		
constant	variable bit rate			
connection-oriented			connectionless	

- AAL 1: audio, uncompressed video
- AAL 2: compressed video
- AAL 3: long term connections
- AAL 4/5: data traffic
  - AAL5 is most relevant to us…

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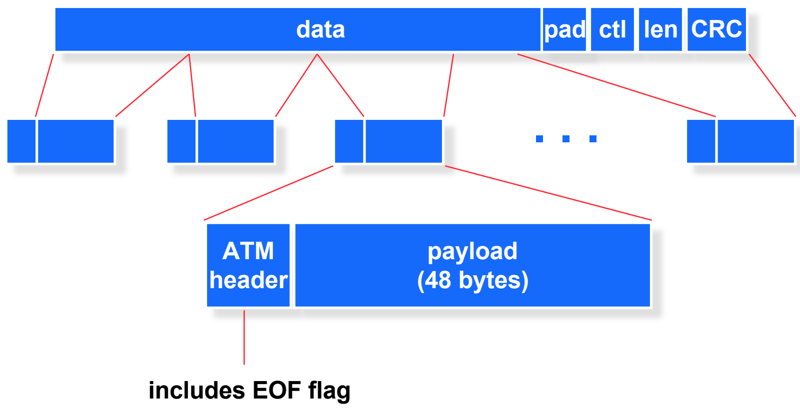
AAL5 Adaptation Layer



Pertinent part: Packets are spread across multiple ATM cells. Each packet is delimited by EOF flag in cell.

ATM Packet Shredder Effect

- **Cell loss results in packet loss.**
  - » Cell from middle of packet: lost packet
  - » EOF cell: lost two packets
  - » Just like consequence of IP fragmentation, but VERY small fragments!
- **Even low cell loss rate can result in high packet loss rate.**
  - » E.g. 0.2% cell loss -> 2 % packet loss
  - » Disaster for TCP
- **Solution: drop remainder of the packet, i.e. until EOF cell.**
  - » Helps a lot: dropping useless cells reduces bandwidth and lowers the chance of later cell drops
  - » Slight violation of layers
  - » Discovered after early deployment experience with IP over ATM.

IP over ATM

- When sending IP packets over an ATM network, set up a VC to destination.
  - » ATM network can be end to end, or just a partial path
  - » ATM is just another link layer
- Virtual connections can be cached.
  - » After a packet has been sent, the VC is maintained so that later packets can be forwarded immediately
  - » VCs eventually times out
- Properties.
  - – Overhead of setting up VCs (delay for first packet)
  - – Complexity of managing a pool of VCs
  - + Flexible bandwidth management
  - + Can use ATM QoS support for individual connections (with appropriate signaling support)

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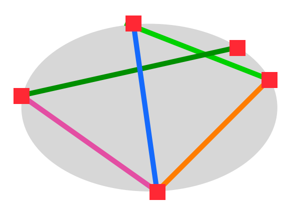
IP over ATM
Static VCs

- Establish a set of "ATM pipes" that defines connectivity between routers.
- Routers simply forward packets through the pipes.
  - » Each statically configured VC looks like a link
- Properties.
  - – Some ATM benefits are lost (per flow QoS)
  - + Flexible but static bandwidth management
  - + No set up overheads



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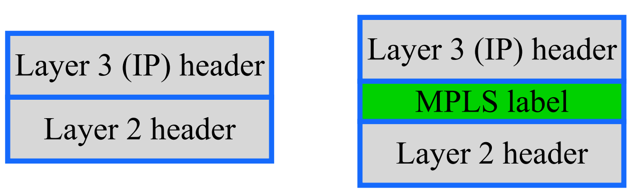
ATM Discussion

- At one point, ATM was viewed as a replacement for IP.
  - » Could carry both traditional telephone traffic (CBR circuits) and other traffic (data, VBR)
  - » Better than IP, since it supports QoS
- Complex technology.
  - » Switching core is fairly simple, but
  - » Support for different traffic classes
  - » Signaling software is very complex
  - » Technology did not match people's experience with IP
    - – deploying ATM in LAN is complex (e.g. broadcast)
    - – supporting connection-less service model on connection-based technology
  - » With IP over ATM, a lot of functionality is replicated
- Currently used as a datalink layer supporting IP.

Multi Protocol Label Switching - MPLS

- Selective combination of VCs + IP
  - » Today: MPLS useful for traffic engineering, reducing core complexity, and VPNs
- Core idea: Layer 2 carries VC label
  - » Could be ATM (which has its own tag)
  - » Could be a "shim" on top of Ethernet/etc.:
  - » Existing routers could act as MPLS switches just by examining that shim -- no radical re-design. Gets flexibility benefits, though not cell switching advantages



MPLS + IP

- Map packet onto Forward Equivalence Class (FEC)
  - Simple case: longest prefix match of destination address
  - More complex if QoS of policy routing is used
- In MPLS, a label is associated with the packet when it enters the network and forwarding is based on the label in the network core.
  - Label is swapped (as ATM VCIs)
- Potential advantages.
  - Packet forwarding can be faster
  - Routing can be based on ingress router and port
  - Can use more complex routing decisions
  - Can force packets to followed a pinned route

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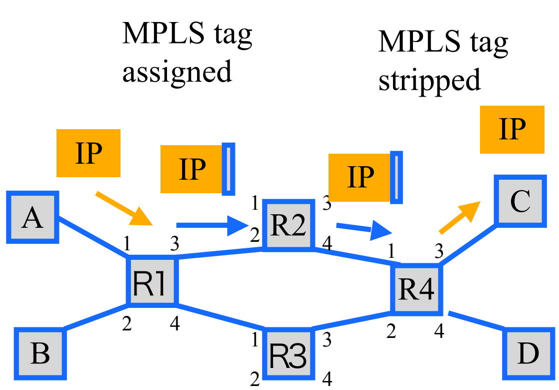
MPLS core, IP interface



MPLS forwarding in core

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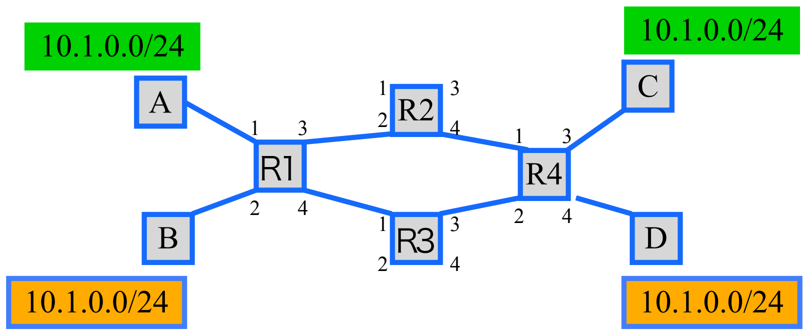
MPLS use case #1: VPNs

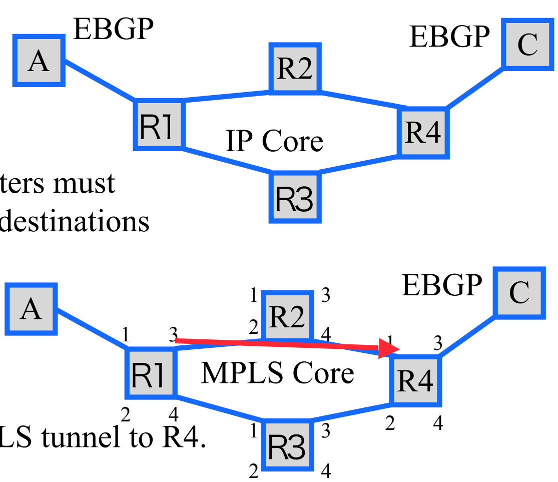


MPLS tags can differentiate green VPN from orange VPN.

MPLS use case #2: Reduced State Core

A-> C pkt

Internal routers must know all C destinations



R1 uses MPLS tunnel to R4.

R1 and R4 know routes, but R2 and R3 don't.

MPLS use case #3: Traffic Engineering

- As discussed earlier -- can pick routes based upon more than just destination
- Used in practice by many ISPs, though certainly not all.

MPLS Mechanisms

- MPLS packet forwarding: implementation of the label is technology specific.
  - » Could be ATM VCI or a short extra “MPLS” header
- Supports stacked labels.
  - » Operations can be “swap” (normal label swapping), “push” and “pop” labels.
    - – VERY flexible! Like creating tunnels, but much simpler -- only adds a small label.

Label	CoS	S	TTL
20	3	1	8

MPLS Discussion

- **Original motivation.**
  - » Fast packet forwarding:
    - Use of ATM hardware
    - Avoid complex "longest prefix" route lookup
    - Limitations of routing table sizes
  - » Quality of service
- **Currently mostly used for traffic engineering and network management.**
  - » LSPs can be thought of as "programmable links" that can be set up under software control
  - » on top of a simple, static hardware infrastructure

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Take Home Points

- **Costs/benefits/goals of virtual circuits**
- **Cell switching (ATM)**
  - » Fixed-size pkts: Fast hardware
  - » Packet size picked for low voice jitter. Understand trade-offs.
  - » Beware packet shredder effect (drop entire pkt)
- **Tag/label swapping**
  - » Basis for most VCs.
  - » Makes label assignment link-local. Understand mechanism.
- **MPLS - IP meets virtual circuits**
  - » MPLS tunnels used for VPNs, traffic engineering, reduced core routing table sizes

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--- Extra Slides ---

Extra information if you're curious.

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ATM Traffic Classes

- Constant Bit Rate (CBR) and Variable Bit Rate (VBR).
  - Guaranteed traffic classes for different traffic types.
- Unspecified Bit Rate (UBR).
  - Pure best effort with no help from the network
- Available Bit Rate (ABR).
  - Best effort, but network provides support for congestion control and fairness
  - Congestion control is based on explicit congestion notification
    - Binary or multi-valued feedback
  - Fairness is based on Max-Min Fair Sharing.

    (small demands are satisfied, unsatisfied demands share equally)

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LAN Emulation

- Motivation: making a non-broadcast technology work as a LAN.
  - » Focus on 802.x environments
- Approach: reuse the existing interfaces, but adapt implementation to ATM.
  - » MAC - ATM mapping
  - » multicast and broadcast
  - » bridging
  - » ARP
- Example: Address Resolution "Protocol" uses an ARP server instead of relying on broadcast.

Further reading - MPLS

- MPLS isn't in the book - sorry. Juniper has a few good presentations at NANOG (the North American Network Operators Group; a big collection of ISPs):
  - » http://www.nanog.org/mtg-0310/minei.html
  - » http://www.nanog.org/mtg-0402/minei.html
  - » Practical and realistic view of what people are doing _today_ with MPLS.

IP Switching

- How to use ATM hardware without the software.
  - » ATM switches are very fast data switches
  - » software adds overhead, cost
- The idea is to identify flows at the IP level and to create specific VCs to support these flows.
  - » flows are identified on the fly by monitoring traffic
  - » flow classification can use addresses, protocol types, ...
  - » can distinguish based on destination, protocol, QoS
- Once established, data belonging to the flow bypasses level 3 routing.
  - » never leaves the ATM switch
- Interoperates fine with “regular” IP routers.
  - » detects and collaborates with neighboring IP switches

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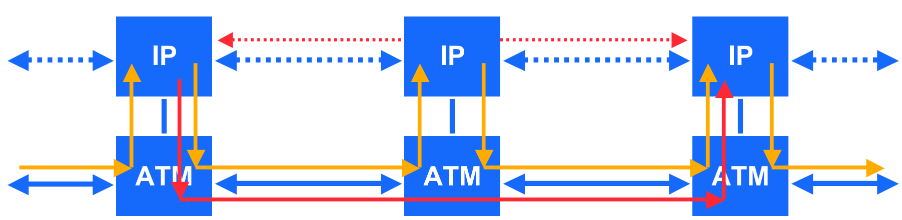
IP Switching Example



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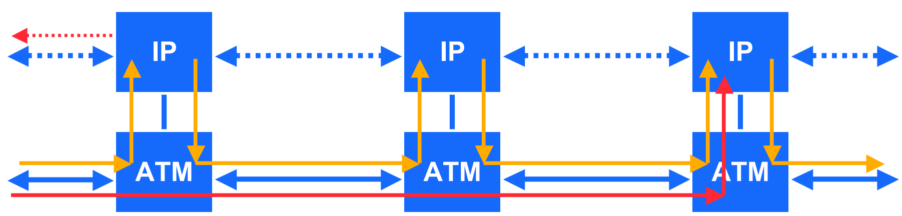
IP Switching Example



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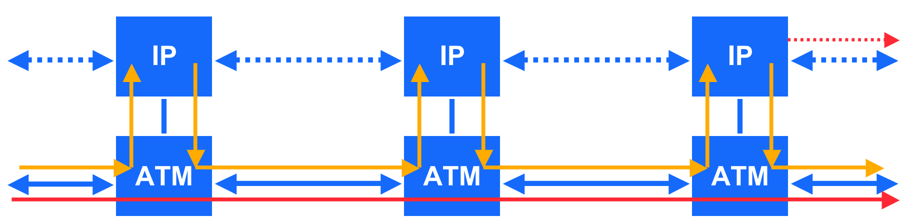
IP Switching Example



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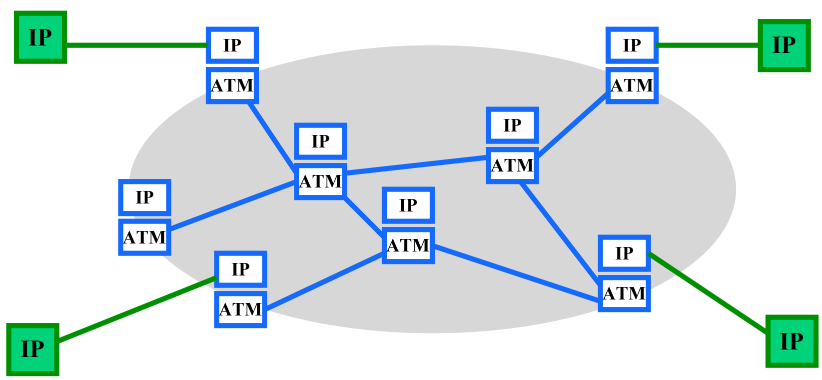
Another View



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IP Switching Discussion

- IP switching selectively optimizes the forwarding of specific flows.
  - » Offloads work from the IP router, so for a given size router, a less powerful forwarding engine can be used
  - » Can fall back on traditional IP forwarding if there are failures
- IP switching couples a router with an ATM switching using the GSMP protocol.
  - » General Switch Management Protocol
- IP switching can be used for flows with different granularity.
  - » Flows belonging to an application .. Organization
  - » Controlled by the classifier

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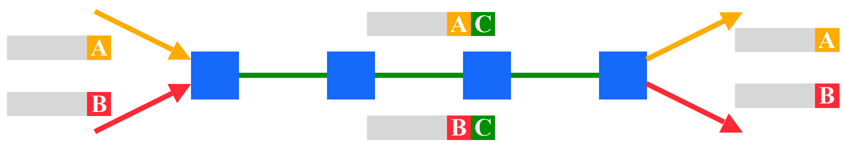
An Alternative
Tag Switching

- Instead of monitoring traffic to identify flows to optimize, use routing information to guide the creation of “switched” paths.
  - » Switched paths are set up as a side effect of filling in forwarding tables
- Generalize to other types of hardware.
- Also introduced stackable tags.
  - » Made it possible to temporarily merge flows and to demultiplex them without doing an IP route lookup
  - » Requires variable size field for tag

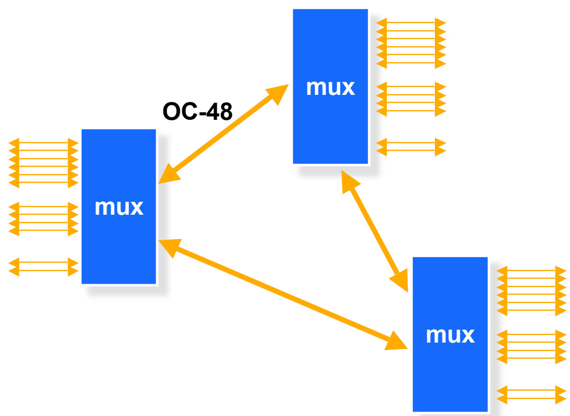


IP Switching
versus Tag Switching

- Flows versus routes.
  - » tags explicitly cover groups of routes
  - » tag bindings set up as part of route establishment
  - » flows in IP switching are driven by traffic and detected by “filters”
    - – Supports both fine grain application flows and coarser grain flow groups
- Stackable tags.
  - » provides more flexibility
- Generality
  - » IP switching focuses on ATM
  - » not clear that this is a fundamental difference

Packets over SONET

- Same as statically configured ATM pipes, but pipes are SONET channels.
- Properties.
  - – Bandwidth management is much less flexible
  - + Much lower transmission overhead (no ATM headers)



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