Last time...

- Taxonomy of application needs
- Network support for Quality of Service
  - IntServ (per-flow guarantees)
  - Traffic specification: Token bucket model
  - Reservation protocol: RSVP
  - Scheduling policy: Fair Queuing
- “Lectures are going at a good pace now”
- “Way too much covered in one day”

Questions from last time...

- Confused on RSVP
- Is QoS deployed? How is it used?
  - Not yet widely deployed (see RFC 2990)
- How do current multicast implementations work?
  - LAN: Using link layer broadcast
  - WAN: Some routers, but not all, support multicast.
    Read about the MBone on p. 344-5
- Start a final review sheet soon?

This time...

- Wrap up resource allocation
- Growth and Evolution
  - How do we cope as networks grow and evolve over time?
- Today
  - How can we make routing scale to the Internet?
IETF Differentiated Services

- A more coarse-grained approach to QOS
  - Packets are marked as belonging to a small set of services, e.g., premium or best-effort
- Marking is enforced at administrative boundaries
  - Your ISP marks 10Mbps (say) of your traffic as premium depending on your service level agreement (SLA)
  - SLA is a business contract that changes infrequently
- Core routers understand only the different service classes
  - Might separate classes with WFQ, but not separate flows

Two-Tiered Architecture

Mark at Edge routers
(per flow state, complex)

Core routers stay simple
(no per-flow state, few classes)

Growth and Evolution

- How do we cope as networks grow and evolve?
  - IP and heterogeneity
  - Routing, addressing, and naming
  - Overlay networks
  - Proxies, load balancing, and content distribution networks

Internet Growth
Routing Scalability

• What problems would we face if we used link state routing across the entire Internet today?

Routing Hierarchy

• Divide Internet into Autonomous Systems
  – Also known as administrative domains
  – Each has a globally unique AS number
• Route hierarchically
  – Within an autonomous system
  – Between autonomous systems

Inter-Domain Routing

• Border routers summarize and advertise internal routes to external neighbors and vice-versa
• Default route – just send to the nearest border router!

Exterior Gateway Protocol (EGP)

• First major inter-domain routing protocol (no longer in use)
• Constrained Internet to tree structure
Structure of the Internet Today

Border Gateway Protocol (BGP-4)

- Inter-domain routing protocol used in the Internet today

- Features:
  - Path vector routing
  - Application of policy
  - Operates over reliable transport (TCP)
  - Uses route aggregation (CIDR) (next time…)

Path Vector Routing

- Similar to distance vector, but send entire paths
  - e.g. 321 hears [7,12,44]
  - Stronger avoidance of loops
  - Explicit route withdrawal
  - Supports policy-based routing

- No link costs
- Prefer paths with fewer hops – modulo policy

An Ironic Twist on Convergence

- Recently, it was realized that BGP convergence can undergo a process analogous to count-to-infinity!

  - AS 4 uses path 4 1 X. A link fails and 1 withdraws 4 1 X.
  - So 4 uses 4 2 1 X, which is soon withdrawn, then 4 3 2 1 X, …
  - Many invalid paths can be explored before convergence
**Policies**

- Choice of routes depends on business relationships and economic considerations.
- Local policy dictates which routes will be chosen and which routes will be advertised.

**Transit Relationships**

- **Provider → Customer:** “You can reach the rest of the Internet through me.”
- **Customer → Provider:** “Here are paths to all of my IP address blocks.”
- **Provider → everyone else:** “Here are paths to reach my customers’ IP address blocks.”

**Multi-Homing**

- Connect to multiple providers for reliability.
- For each IP address block, choose best path announced by any provider:
  - Easy to control outgoing traffic, e.g., for load balancing.
- Advertise our address blocks to both providers:
  - Less control over what paths other parties will use to reach us.

**Peer Relationships**

- Peers exchange traffic for mutual benefit.
- Peers A and B announce paths to their customers’ IP address blocks to each other:
  - Lets A & B avoid paying transit provider for this traffic!
  - Do not propagate announcements further.
  - Peering is not transitive.
With whom should I peer?

- Backbone ISPs have no transit provider
  - Must peer to provide global reachability
- Economics
  - How much traffic is there between us?
  - Would we both save money on transit by peering?
  - Do we already have a peering point in common?
- Politics
  - Do we have an existing business relationship?
  - Do I trust you to be competent and responsive?

Impact of Policies – Example

- Early Exit / Hot Potato
  - If it’s not for me, get rid of it as soon as possible!
- Best local policies don’t always lead to best global routes
- Side-effect: route asymmetry

Operation over TCP

- Intradomain routing protocols operate directly over IP
- BGP uses TCP
  - TCP handles retransmission and reacts to congestion
  - Allows for incremental updates
- Issue: Data vs. Control plane
  - Shouldn’t routing messages be higher priority than data?

Key Concepts

- Differentiated Services provides coarse quality of service guarantees
- Internet is a collection of Autonomous Systems (ASes)
  - Structural hierarchy helps make routing scalable
  - Policy dominates routing at the AS level