Routing

- Finding a good path from source to destination
  - topology discovery
  - route selection
- Network as a graph...
  - links (point to point and L2 subnets) and routers
  - destinations are typically L2 subnets, not individual nodes
  - links may have “weights”

LINK COST

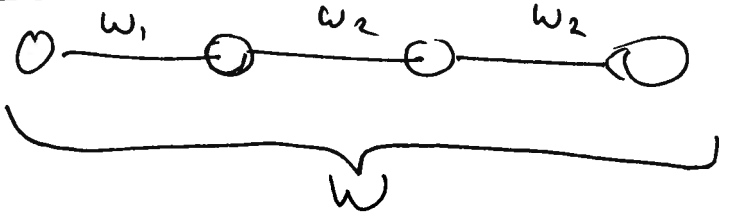
- LATENCY
- RATE
- DISTANCE
- ERROR RATE
- AVAILABILITY
- SECURITY
- COST
- ⋮

⟹ user assigned costs

- additive

PATH COST

Ex:



$w = w_1 + w_2 + w_2$

latency, cost, distance

$w = w_1 \cdot w_2 \cdot w_3$

Prob. of suc. trans

$w = \min/\max \{w_1, w_2, w_3\}$

security/rate

Hop-by-hop Forwarding

- **Approaches**:
  - First find a path from source to destination and then follow it...
  - Go to the first corner, ask for direction to the next corner that is on the way to the destination*. Repeat until you reach the destination...

* Routing tables give you that information

Routing Table Content

- Automatically populated with entries based in local L2 configuration
- Static entries - added by the network administrator
- Dynamic entries - added by dynamic routing protocols

Routing Protocols - Categories

- **Link State**
  - exact neighbor information flooded to everyone
  - topology of the entire networks is discovered in each node
  - shortest paths calculated and used to populate the routing tables
- **Distance Vector**
  - estimates of distances to all nodes in the network sent to all neighbors
  - estimates are improved based on information from neighbors
  - the process is repeated and routing tables are populated based on the estimates

Scalability of Routing

- Internet is large...
- Need to introduce hierarchy
  - ... into something that naturally does not have one
  - divide and conquer, abandoning hope for optimality
  - based on ownership - **Autonomous System** (AS)
- Different routing problems:
  - Intra AS routing - IGP interior gateway routing
  - Inter AS routing - EGP exterior gateway routing

Examples of Routing Protocols

	Distance Vector	*Link State*
IGP	RIP	OSPF
EGP	BGP-4*	

* BGP-4 extends the concept of Distance Vector routing to include the path information and is typically referred to as a *Path-Vector* routing protocol

Quality of Service - QoS

- **Measures**: throughput, latency, jitter, packet loss, ...
- **Issue**: Who pays the bill?
- **IP Approach**: TOS (Type of Service) field
  - priority (3 bits)
  - bits to request high throughput, low latency, low loss, and low monetary cost

a **FAIL**

Differentiated Services

- Domain-based solution
- Relative guarantees
- Few classes of service
- Framework rather than a complete and prescriptive solution
- Reuses TOS field (called DSCP - Differentiated Services Code Point)

Virtual Circuits

- Problems with *packet-switched* networks:
  - no connection between packets
  - difficult to provide QoS
  - difficult to provision resources
  - difficult to control routes the packets take
  - reactive fault-tolerance
- All these problems are addressed in *circuit-switched* networks

Virtual Circuit Switching

- Virtual Circuit (VC)
  - separation of routing and forwarding
- Circuit Switching Table
  - state-full forwarding
- Virtual Circuit Identifier (VC id)
  - global circuit vs locally significant circuit identifier

Circuits vs Virtual Circuits

- Virtual Circuit Switched Networks
  - an overlay on top of a *packet switched network* that provides a *circuit-based* service
  - "most of the benefits at a fraction of the cost"
  - trading *ability to control* for *loss of simplicity*
- Always the next big thing
  - OSI - Open System Interconnect (R.I.P.)
  - ATM - Asynchronous Transfer Mode (R.I.P.)
  - MPLS - MultiProtocol Label Switching (alive and well)

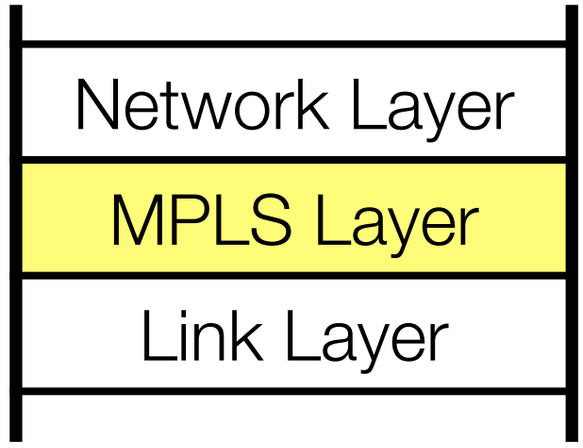
MPLS

- MultiProtocol Label Switching
  - a protocol providing *virtual circuit service*
  - designed to coexist and complement existing protocols, not to replace them
- One protocol, many uses:
  - simplification of forwarding
  - traffic engineering
  - protection and restoration
  - support for legacy services
  - VPNs, ...

MPLS Terminology

- Label Switched Path (LSP): a VC
- Label: VC id
- Label Switched Router (LSR): a switch

Typically:



- Forwarding Equivalence Class (FEC)

MPLS packet