Advanced Networking

Routing:
RIP, OSPF, Hierarchical routing, BGP

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Routing Algorithms: One or Many?

- Is there a single routing protocol in the Internet?
- How can different protocols and algorithms coexist
  - Homogeneous results
  - Risk of incosistent routing
- Complexity of routing algorithms/protocols
  - Can they scale?
  - There is a tradeoff between traffic and computation?
- Hierarchical routing
- Policy routing: what is it, why not "performance"?

RIP - History

* Late 1960s: Distance Vector protocols were used in the ARPANET
* Mid-1970s: XNS (Xerox Network system) routing protocol is the precursor of RIP in IP (and Novell's IPX RIP and Apple's routing protocol)
* 1982: Release of routing software for BSD Unix
* 1988: RIPv1 (RFC 1058)
  - classful routing
* 1993: RIPv2 (RFC 1388)
  - adds subnet masks with each route entry
  - allows classless routing
* 1998: Current version of RIPv2 (RFC 2453)

RIP at a glance

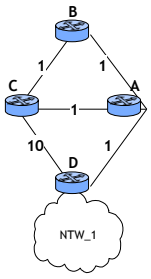
- A simple intradomain protocol
- Straightforward implementation of Distance Vector Routing…
  - Distributed version of Bellman-Ford (DBF)

  …with well known issues
  - slow convergence
  - works with limited network size
- Strengths
  - simple to implement
  - simple management
  - widespread use

RIP at a glance

- Metric based on hop count
  - maximum hop count is 15, with "16" equal to "∞"
    - imposed to limit the convergence time
  - the network administrator can also assign values higher than 1 to a single hop
- Each router advertises its distance vector every 30 seconds (or whenever its routing table changes) to all of its neighbors
  - RIP uses UDP, port 520, for sending messages
- Changes are propagated across network
- Routes are timeout (set to 16) after 3 minutes if they are not updated

Recall: "counting to infinity" problem



Router A

Dest	Next	Metric
NTW_1	D	2

Router B

Dest	Next	Metric
NTW_1	A	3

Router C

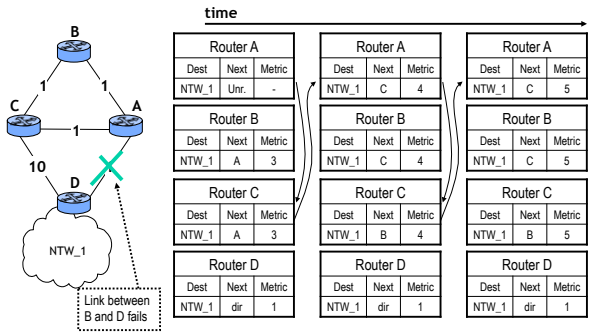
Dest	Next	Metric
NTW_1	A	3

Router D

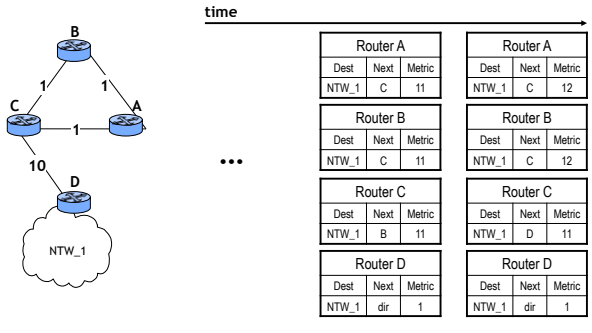
Dest	Next	Metric
NTW_1	dir	1

- Consider the entries in each routing table for network NTW_1
- Router D is directly connected to NTW_1

Recall: "counting to infinity" problem (2)



Recall: "counting to infinity" problem (3)



RIP: solution to "counting to infinity"

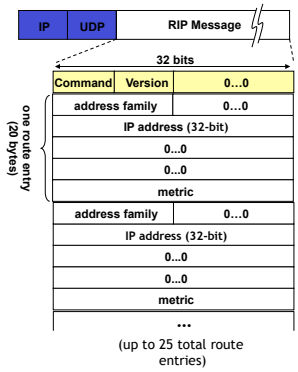
- Maximum number of hops bounded to 15
  - this limits the convergence time
- Split Horizon
  - simple
    - each node *omits* routes learned from one neighbor in update sent to that neighbor
  - with poisoned reverse
    - each node *include* routes learned from one neighbor in update sent to that neighbor, setting their metrics to infinity
      - drawback: routing message size greater than simple Split Horizon

RIP: solution to "counting to infinity" (cont' d)

- Triggered updates: nodes send messages as soon as they notice a change in their routing tables
  - only routes that has changed are sent
  - faster reaction…
  - …but more resources are used (bandwidth, processing)
    - cascade of triggered updates
  - superposition with regular updates

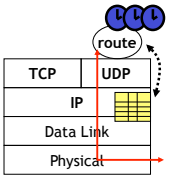
RIP-1: Message Format

- Command: 1=request 2=response
  - Updates are replies whether asked for or not
  - Initializing node broadcasts request
  - Requests are replied to immediately
- Version: 1
- Address family: 2 for IP
- IP address: non-zero network portion, zero host portion
  - Identifies particular network
- Metric
  - Path distance from this router to network
  - Typically 1, so metric is hop count



RIP procedures: introduction

- RIP routing tables are managed by application-level process
  - e.g., *routed* on UNIX machines
- Advertisements are sent in UDP packets (port 520)
- RIP maintains 3 different timers to support its operations
  - Periodic update timer (25-30 sec)
    - used to sent out update messages
  - Invalid timer (180 sec)
    - If update for a particular entry is not received for 180 sec, route is invalidated
  - Garbage collection timer (120 sec)
    - An invalid route in marked, not immediately deleted
    - For next 120 s. the router advertises this route with distance infinity

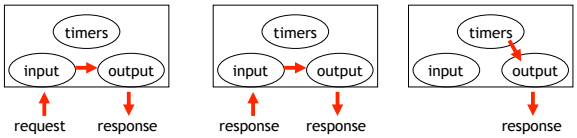


RIP procedures: input processing

- Request Messages
  - they may arrive from routers which have just come up
  - action: the router responds directly to the requestor' s address and port
    - request is processed entry by entry
- Response Messages
  - they may arrive from routers that perform regular updates, triggered updates or respond to a specific query
  - action: the router updates its routing table
    - in case of new route or changed routes, the router starts a triggered update procedure

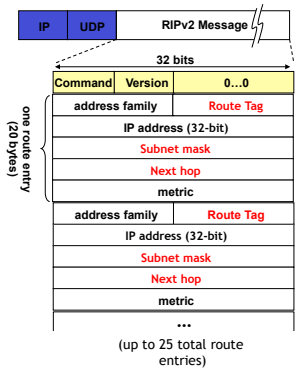
RIP procedures: output processing

- Output are generated
  - when the router comes up in the network
  - if required by the input processing procedures
  - by regular routing update
- Action: the router generates the messages according to the commands received
  - the messages contain entries from the routing table



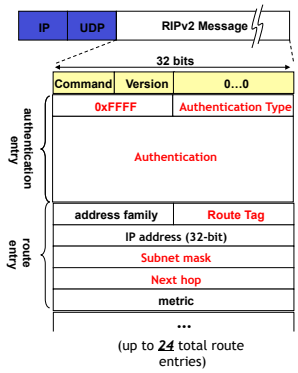
RIPv2: Message Format

- Version: 2
- Route Tag: used to carry information from *other routing protocols*
  - e.g., autonomous system number
- Subnet mask for IP address
- Next hop
  - identifies a better next-hop address on the same subnet than the advertising router, if one exists (otherwise 0….0)



RIPv2: authentication

- Any host sending packets on UDP port 520 would be considered a router
- Malicious users can inject fake routing entries
- With authentication, only authorized router can send Rip packets
  - Authentication type
    - password
    - MD5
  - Authentication
    - plain text password
    - MD5 hash



RIPv2: other aspects

- Explicit use of subnets
- Interoperability
  - RIPv1 and RIPv2 can be present in the same network since RIPv1 simply ignores fields not known
    - RIPv2 responds to RIPv1 Request with a RIPv1 Response
- Multicast
  - instead of broadcasting RIP messages, RIPv2 uses multicast address 224.0.0.9

RIP limitations: the cost of simplicity

- Destinations with metric more than 15 are unreachable
  - If larger metric allowed, convergence becomes lengthy
- Simple metric leads to sub-optimal routing tables
  - Packets sent over slower links
- Accept RIP updates from any device (if no security is implemented)
  - Misconfigured device can disrupt entire configuration

RIP Was the first ... but ...

- Why is RIP not enough to manage the Internet?
- Can Link-State protocols perform better?
  - OSPF
  - MOSPF (no MRIP exists!!)
- Inter-AS routing requires an entirely different approach ... if not for else for the sake of competition!

Non-RIP, DV Protocols: EXAMPLE IGRP (Interior Gateway Routing Protocol)

- CISCO proprietary; builds on RIP (mid 80' s)
- Distance Vector, like RIP
- several cost metrics (delay, bandwidth, reliability, **load** etc.)
- uses TCP to exchange routing updates
- routing tables exchanged only when costs change
- Loop free routing achieved by using a Distributed Updating Alg. (DUAL) based on *diffused computation*
- In DUAL, after a distance increase, the routing table is *frozen* until all affected nodes have learned of the change (cfr. split horizon in RIP)

Open Shortest Path First (OSPF)

- RIP limited in large internets
- OSPF is often preferred interior routing protocol for TCP/IP based internets
- Uses link state routing
- Floods the messages to all routers in the AS (area)

OSPF "advanced" features (not in RIP)

- Security: all OSPF messages are authenticated (to prevent malicious intrusion);
  - TCP or Unicast in genera connections used sometimes
- Multiple same-cost paths allowed
  - only one path in RIP
- For each link, multiple cost metrics for different TOS (eg, satellite link cost set "low" for best effort; high for real time)
- Integrated uni- and multicast support: Multicast (MOSPF) uses same topology data base as OSPF
- Hierarchical OSPF in large domains

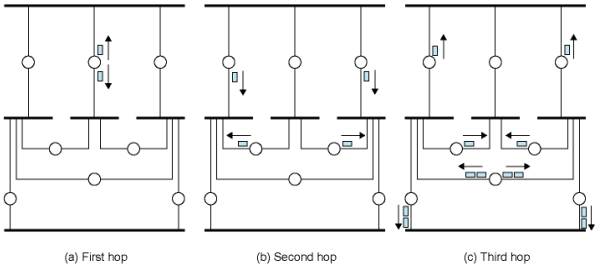
Link State Routing

- When initialized, router determines link cost on each interface
- Router advertises these costs to all other routers in topology
- Router monitors its costs
  - When changes occurs, costs are re-advertised
- Each router constructs topology and calculates shortest path to each destination network
- No distributed version of routing algorithm
- Can use any algorithm
  - Dijkstra is recommended and normally used
  - All routers in AS must use same algorithm

Flooding

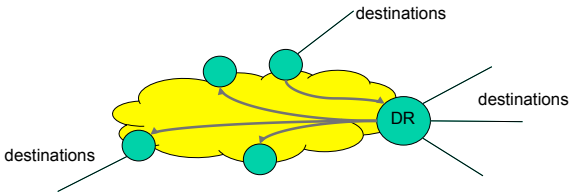
- Packet sent by source router to every neighbor
- Incoming packet resent to all outgoing links except source link
- Duplicate packets already transmitted are discarded
  - Prevent incessant retransmission
- All possible routes tried so packet will get through if route exists
  - Highly robust
- At least one packet follows minimum delay route
  - Reach all routers quickly
- All nodes connected to source are visited
  - All routers get information to build routing table
- High traffic load

Flooding Example



Alternative to flooding

- Designated Router (DR) election (with backup-DRB)
- Used on broadcast domains
- Link-State updates are sent to DR/DRB only which diffuse to all others (unicast confirmed communications)



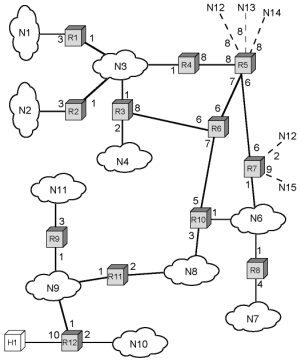
OSPF Overview

- Router maintains descriptions of state of local links
- Transmits updated state information to all routers it knows about (flooding)
- Router receiving update must acknowledge
  - Lots of traffic generated
- Each router maintains database
  - Directed graph

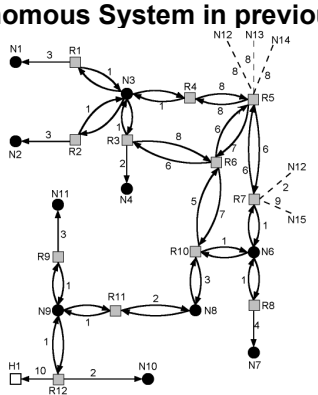
Router Database Graph

- Vertices
  - Router
  - Network
    - Transit
    - Stub
- Edges
  - Connecting two routers
  - Connecting router to network
- Built using link state information from other routers

Sample Autonomous System



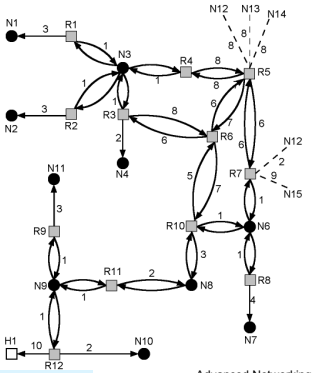
Directed Graph of Autonomous System in previous slide



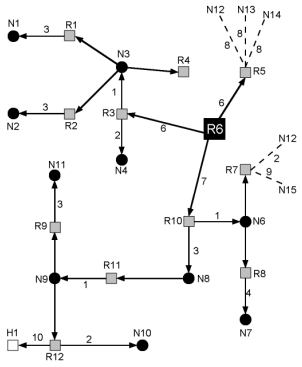
Link Costs

- Cost of each hop in each direction is called routing metric
- OSPF provides flexible metric scheme based on type of service (TOS)
  - Normal (TOS) 0
  - Minimize monetary cost (TOS 2)
  - Maximize reliability (TOS 4)
  - Maximize throughput (TOS 8)
  - Minimize delay (TOS 16)
- Each router can generate 5 spanning trees (and 5 routing tables) – AS decision!

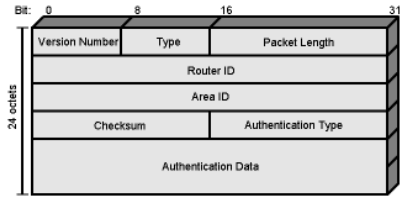
What is the SP for Router 6?



The Tree for Router R6



OSPF Packet Header



Packet Format Notes

- Version number: 2 is current
- Type: one of 5, see next slide
- Packet length: in octets including header
- Router id: this packet's source, 32 bit
- Area id: Area to which source router belongs
- Authentication type:
  - Null
  - Simple password
  - Encryption
- Authentication data: used by authentication procedure

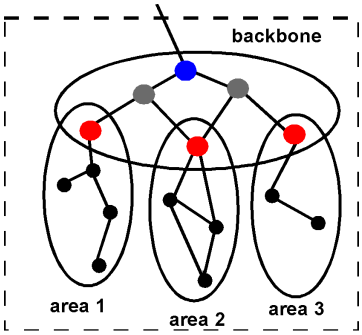
OSPF Packet Types

1. Hello: used in neighbor discovery
2. Database description: Defines set of link state information present in each router's database
3. Link state request
4. Link state update
5. Link state acknowledgement

Areas

- Make large internets more manageable
- Configure as backbone and multiple areas
- Area – Collection of contiguous networks and hosts plus routers connected to any included network
- Backbone – contiguous collection of networks not contained in any area, their attached routers and routers belonging to multiple areas

Hierarchical OSPF



Operation of Areas

- Each area runs a separate copy of the link state algorithm
  - Topological database and graph of just that area
  - Link state information broadcast to other routers in area
  - Reduces traffic
  - Intra-area routing relies solely on local link state information

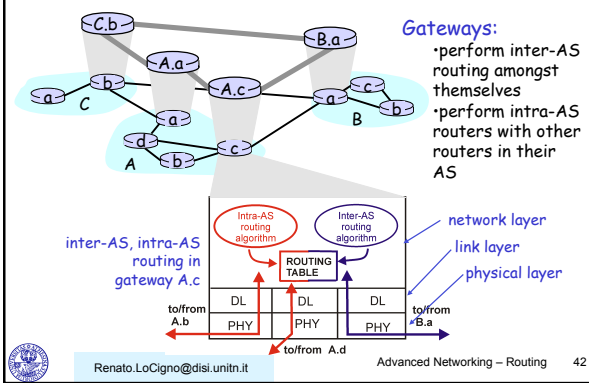
Inter-Area Routing

- Path consists of three legs
  - Within source area
    - Intra-area
  - Through backbone
    - Has properties of an area
    - Uses link state routing algorithm for inter-area routing
  - Within destination area
    - Intra-area

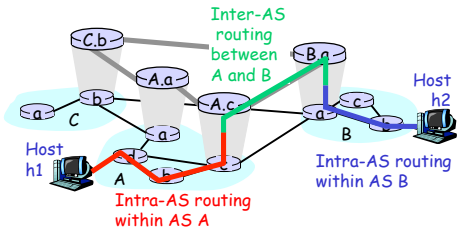
Hierarchical OSPF

- Two level hierarchy: local area and backbone
- Link state advertisements do not leave respective areas
- Nodes in each area have detailed area topology; they only know direction (shortest path) to networks in other areas
- **Area Border routers** "summarize" distances to networks in the area and advertise them to other Area Border routers
- **Backbone routers** run an OSPF routing alg limited to the backbone
- **Boundary routers** connect to other ASs

Intra-AS and Inter-AS routing



Intra-AS and Inter-AS routing



- We' ll examine specific inter-AS and intra-AS Internet routing protocols shortly

Inter-AS routing

- BGP (Border Gateway Protocol): the de facto standard
- **Path Vector** protocol – an extension of Distance Vector
- Each Border Gateway broadcast to neighbors (peers) the entire path (ie, sequence of AS' s) to destination
- For example, Gwy X may store the following path to destination Z:

  Path (X,Z) = X,Y1,Y2,Y3,…,Z

Inter-AS routing

- Now, suppose Gwy X send its path to peer Gwy W
- Gwy W may or may not select the path offered by Gwy X, because of cost, policy or loop prevention reasons
- If Gwy W selects the path advertised by Gwy X, then:

  Path (W,Z) = w, Path (X,Z)

Note: path selection based not so much on cost (eg,# of AS hops), but mostly on administrative and policy issues (eg, do not route packets of competitor' s AS)

Why different Intra- and Inter-AS routing ?

- **Policy**: Inter is concerned with policies (which provider we must select/avoid, etc). Intra is contained in a single organization, so, no policy decisions necessary
- **Scale**: Inter provides an extra level of routing table size and routing update traffic reduction above the Intra layer
- **Performance**: Intra is focused on performance metrics; needs to keep costs low. In Inter it is difficult to propagate performance metrics efficiently (latency, privacy etc). Besides, policy related information is more meaningful.

We need **BOTH**!

Border Gateway Protocol (BGP)

- Allows routers (gateways) in different ASs to exchange routing information
- Messages sent over TCP
  - Messages in next slide
- Three functional procedures
  - Neighbor acquisition
  - Neighbor reachability
  - Network reachability

BGP Messages

- Open
  - Start neighbor relationship with another router
- Update
  - Transmit information about single route
  - List multiple routes to be withdrawn
- Keepalive
  - Acknowledge open message
  - Periodically confirm neighbor relationship
- Notification
  - Send when error condition detected
  - Used for closing connections too

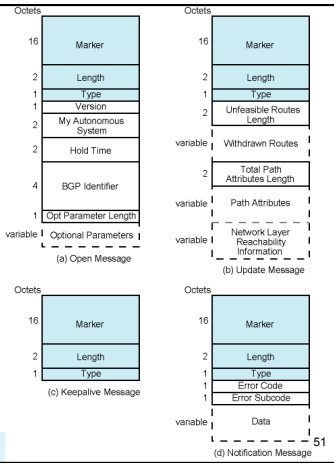
Neighbor Acquisition

- Neighbors attach to same subnetwork
- If in different ASs routers may wish to exchange information
- Neighbor acquisition is when two neighboring routers agree to exchange routing information regularly
  - Needed because one router may not wish to take part
- One router sends request, the other acknowledges
  - Knowledge of existence of other routers and need to exchange information established at configuration time or by active intervention

Neighbor Reachability

- Periodic issue of keepalive messages
- Between all routers that are neighbors
- Each router keeps database of subnetworks it can reach and preferred route
- When change is made, router issues update message (to neighbors only)
- All BGP routers build up and maintain routing information

BGP Message Formats



Neighbor Acquisition Detail

- Router opens TCP connection with neighbor
- Sends open message
  - Identifies sender's AS and gives IP address
  - Includes Hold Time
    - As proposed by sender
- If recipient prepared to open neighbor relationship
  - Calculate hold time
    - min [own hold time, received hold time]
    - Max time between keepalive/update messages
  - Reply with keepalive

Keepalive Detail

- Header only
- Enough to prevent hold time expiring
- If hold time expires a topology change is triggered
- 'Marker' is a field that used for authentication purposes

Update Detail

- Information about single route through internet
  - Information to be added to database of any recipient router
  - Network layer reachability information (NLRI)
    - List of network portions of IP addresses of subnets reached by this route
  - Total path attributes length field
  - Path attributes field (next slide)
- List of previously advertised routes being withdrawn
- May contain both

Path Attributes Field

- Origin
  - Interior (e.g. OSPF) or exterior (BGP) protocol
- AS_Path
  - ASs traversed for this route
- Next_Hop
  - IP address of boarder router for next hop
- Multi_Exit_disc
  - Information about routers internal to AS
- Local_Pref
  - Tell other routers within AS degree of preference
- Atomic_Aggregate, Aggregator
  - Uses subnet addresses in tree view of network to reduce information needed in NLRI

Withdrawal of Route(s)

- Route identified by IP address of destination subnetwork(s)
- May be issued because subnets are not reachable or because policies have changed

Notification Message

- Error notification
- Message header error
  - Includes authentication and syntax errors
- Open message error
  - Syntax errors and option not recognised
  - Proposed hold time unacceptable
- Update message error
  - Syntax and validity errors
- Hold time expired
- Finite state machine error
- Cease
  - Close connection in absence of any other error

BGP Routing Information Exchange

- R1 constructs routing table for AS1 using OSPF
- R1 issues update message to R5 (in AS2)
  - AS_Path: identity of AS1
  - Next_Hop: IP address of R1
  - NLRI: List of all subnets in AS1
- Suppose R5 has neighbor relationship with R9 in AS3
- R5 forwards information from R1 to R9 in update message
  - AS_Path: list of ids {AS2,AS1}
  - Next_Hop: IP address of R5
  - NLRI: All subnets in AS1
- R9 decides if this is prefered route and forwards to neighbors

Routing Domain Confederations

- Set of connected AS
- Appear to outside world as single AS
  - Recursive
- Effective scaling