Routing

Basic principles

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Outline

Outline

Directly Connected IP Networks

- Configuration under Unix with ifconfig
- Packets can be delivered immediately

  by the data link (layer 2 software)
- No explicit route commands needed under Linux,

  because ifconfig sets a route automatically

ifconfig command

```
ifconfig <interface> <ip_address>
         netmask <netmask> broadcast <broadcast_address>
```

Data link layer "routing"

- Only outgoing interface and layer 2 address is needed
- Packet is (selectively) flooded by layer 2
- Bridges and switches use a lookup table to map layer 2 addresses to outgoing interfaces
- Spanning tree protocol takes care of loops

Outline

Global routing

- Not directly connected networks need a gateway (next hop)
- Recursive lookup
  - In practice this is only one level deep
  - Hence the gateway needs to be directly connected
  - In theory a deeper recursion level would be possible and useful

Routing Table

- `netstat -r` shows the routing table

Route flags

Flag	Set	Unset
G	route needs gateway	route is directly connected
H	route to host	route to network
S	route added statically (mostly by admin)	route added dynamically (by a protocol)

Outline

route command

- Syntax varies between systems
  - Adding a (static) default route (Solaris)
    - `route add default <gateway>`
  - Adding a (static) default route (Linux)
    - `route add default gw <gateway>`
- Adding a (static) host route (Linux)
  - `route add -host <host> gw <gateway>`
- Adding a (static) network route (Linux)
  - `route add -net <network> netmask <netmask> gw <gateway>`

arp command

- Used to interact with the arp table
- Read the arp table
  - `arp` (without arguments)
- Delete an entry from the arp table
  - `arp -d <address>`
- Add an entry to the arp table
  - `arp -s <address> <hardware_address>`

ip command

- Introduced in the Linux iproute2 package
- General interface to kernel addressing and routing
- Replaces ifconfig, route and arp (almost) completely
- Has support for routing policies and multiple routing tables

ip subcommands

ip <subcommand>...

Subcommand	Meaning
link	layer 2 interface settings (MAC)
address	layer 3 interface settings (IP)
neighbor	arp cache data
route	routing table data
rule	routing table selection

Outline

Route selection

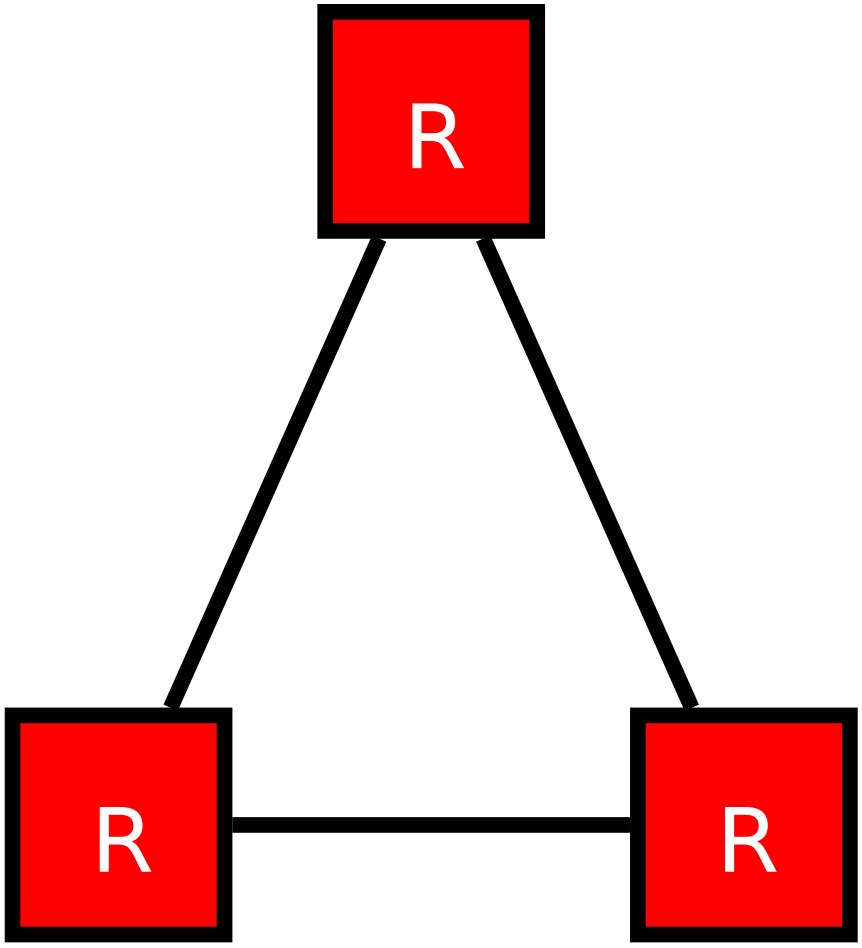
- Longest prefix match
  - Host routes are preferred over network routes
- Default route has shortest prefix
  - Route of last resort
  - Cannot be used in the Internet core

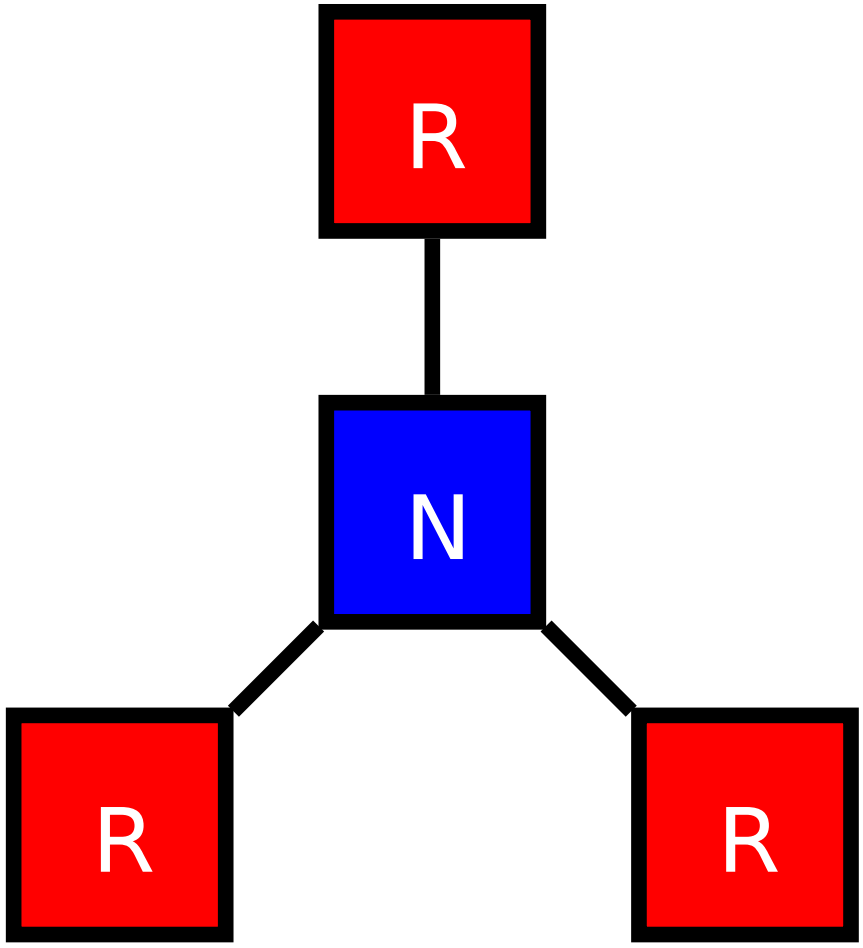
Outline

Mathematical representation

- Graphs (undirected, labeled)
  - Nodes are routers and hosts
  - Edges are (point to point) connections
  - Labels represent "cost" of the route
  - Undirected edges imply a restriction to
    - full duplex links
    - with the same cost in both directions

Broadcast networks



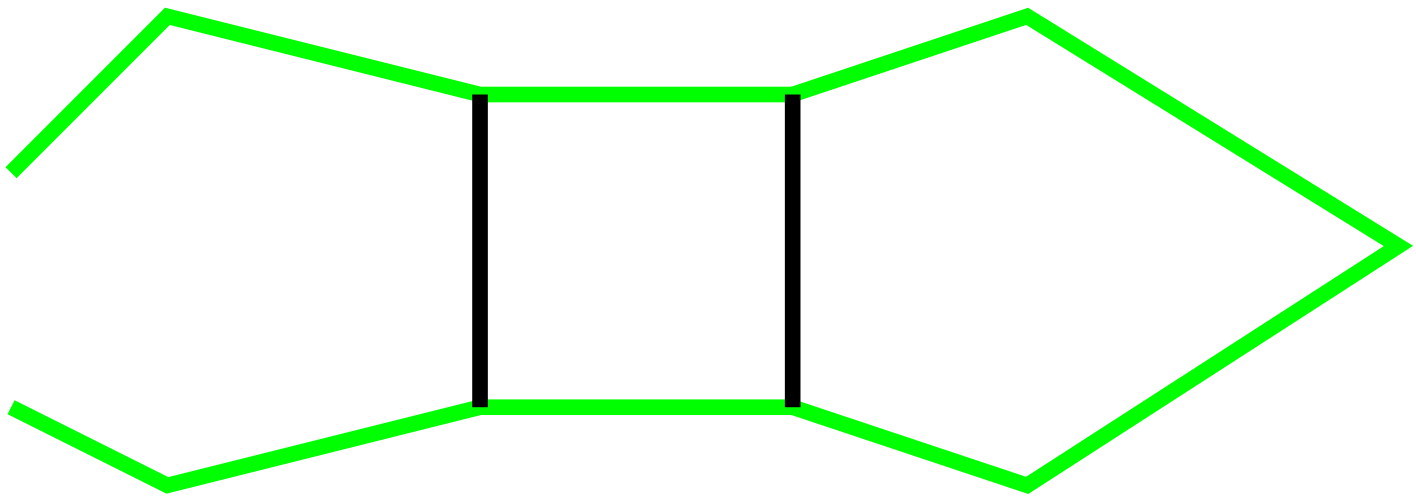


Node reduction

- LAN with $O(N)$ routers or hosts
- Full mesh of $O(N^2)$ edges
- Reduced with only 1 extra node to $O(N)$ edges
- Works for LAN's, but also for NBMA networks
  - In many situations
  - But not always (take care)

Edge reduction does not always work

- Using a virtual network node is not always equivalent to a full mesh of point to point links
- Example of the introduction of loops



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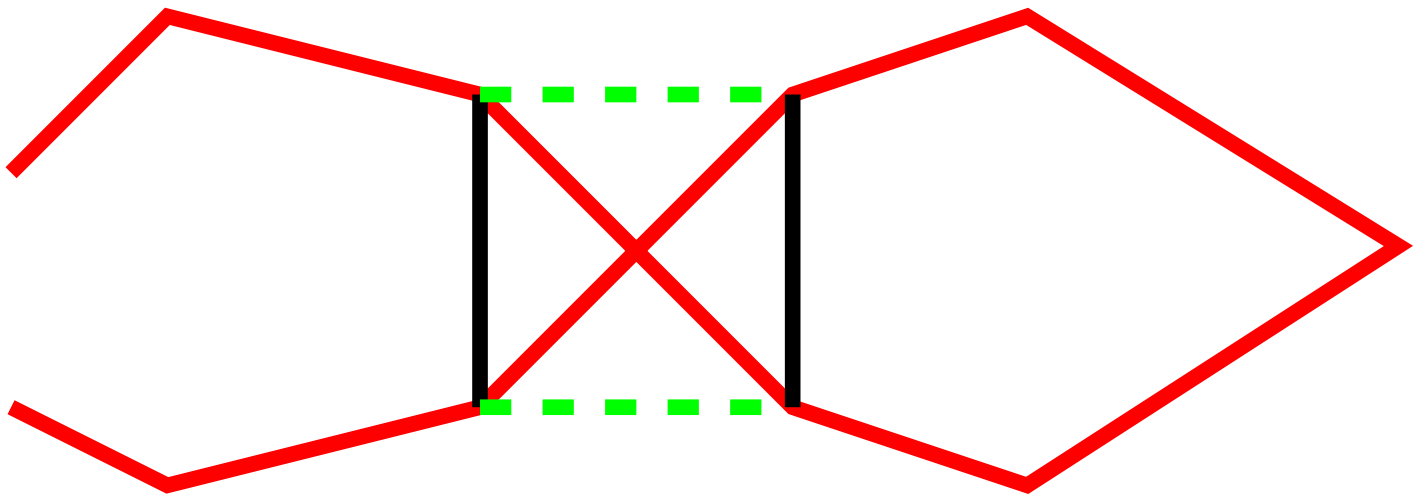

Outline

Internet Routing (1)

- Based on top level structure defined by Autonomous Systems (AS)
- Each AS has administrative control over a collection of
  - Routers (and hosts)
  - Networks

Definition (AS — Autonomous System (from RFC 1930))

An AS (Autonomous System) is a connected group of one or more IP prefixes run by one or more network operators which has a single and clearly defined routing policy.

Internet Routing (2)

- Edge routers inside an AS can be directly connected to edge routers in another AS
  - Used for inter-AS routing
  - Using an exterior routing protocol (EGP)
    - Example: BGP4
    - No other protocols in use (except variants of BGP)

Internet Routing (3)

- Routers within the boundary of a single AS communicate with each other to provide
  - Intra-AS routing
  - Using an interior routing protocol (IGP)
    - Examples: RIP, OSPF, IS-IS

Outline

Routing Protocol Classification

- Static
  - A "human" protocol
  - Explicit commands like "`route add`" or "`ip route add`"
  - Side effect of a script ("semi-automatic/semi-human")
- Dynamic (automatically by a routing protocol)
  - Distance Vector (for instance RIP)
  - Path Vector (for instance BGP)
  - Link State (for instance OSPF)

Distance Vector Routing

- Distance vector algorithm
  - Bellman-Ford (1957)
  - Distributed shortest path
- Original ARPANET routing algorithm
- Decentralised
- Asynchronous

Path Vector Routing

- Like distance vector routing, but
- Instead of the distance the complete path (on AS level)

  to the destination is given
- The algorithm is still
  - decentralised
  - asynchronous
- The algorithm might depend on explicit or implicit policies

Link State Routing

- Link state algorithm
  - Dijkstra (1959)
  - Single source shortest path
- Complete knowledge is distributed to all nodes in an area
- Knowledge about the local network topology

  is flooded to all participants in an area
- Every node executes the shortest path algorithm

  and draws the same conclusions