Computer Networks
CS 552

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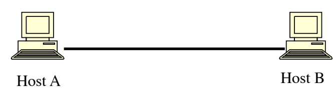
1. Link Layer, Multiple access, Bridges, Switching
2. IP addressing, CIDR, NAT
3. IP routing, OSPF (link state), RIP(DV), Issues

Communication over a link

- Information needs to be converted to a signal appropriate to the link
  - Wired, optics, wireless
  - 1s and 0s to appropriate signal levels
  - Bits per second = baud x $\log_2$(levels)

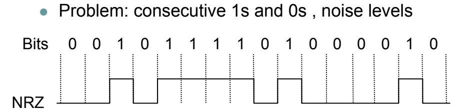


Data Link Layer Functionality

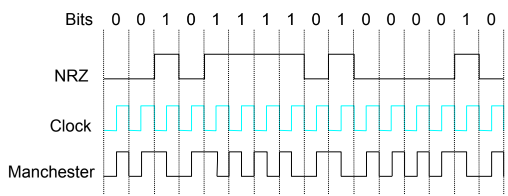
- Convert bits to signals and recover bits from received signals
  - Encoding
- Decide on a minimum unit for sending bits
  - Cannot send bit by bit (too much overhead)
  - Frame creation
- Error detection and/or correction of frames
  - Parity, CRC
- Flow control
  - ARQ, Sliding WINDOW
- Addressing
  - MAC address

Encoding

- Signals propagate over a physical medium
  - modulate electromagnetic waves
  - e.g., vary voltage
- Encode binary data onto signals
  - e.g., 0 as low signal and 1 as high signal
  - known as Non-Return to zero (NRZ)
  - Problem: consecutive 1s and 0s , noise levels



Encodings (cont)



•Manchester encoding: +ve transition → 0; -ve transition → 1
•XOR(bit,clock)

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Framing

- The data unit at the data link layer is called a "frame"
- A frame is a group of bits, typically in sequence
- Issues:
  - Frame creation
    - How many bits (size of frame)
    - Overhead
  - Frame delineation
  - Have meta tags
    - start and stop characters or bit sequence
  - What if the meta tags appear in the message?

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stuffing

- Character stuffing ($, #)
  - $# this prof is good $^
  - $# this prof s$^ks $^ .. Meta tag in message
    - $# this prof s$$^ks $^ at sender
    - $# this prof s$^ks $^ at receiver, remove stuffing
- Bit stuffing: have a unique bit sequence
  - 01111110 this prof is good 01111110
  - 01111110 this prof is 01111110 good 01111110
  - 01111110 this prof is 011111010 good 0111110 -- sender
  - Receiver checks for 5 1s, if next bit is 0 – stuff
  - If next bits are 10 end of frame else error

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Error Control

- No physical link is perfect
- Bits will be corrupted
- We can either:
  - detect errors and request retransmission
  - or correct errors without retransmission

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Error Detection

- Parity bits
  - For a fixed sequence, add a 1 bit (0/1) to have odd 1s (odd parity) or even 1s (even parity)
  - Extra bits are overhead, multiple bit errors
- Checksum
  - Divide msg into fixed size (16-bit) chunks
  - Add chunks (using 1s complement) and send check sum (complement of total) with message
  - Receiver add msg + checksum
  - Complement (result) = 0 accept else reject
- Polynomial codes or CRC
  - Divide the MSG by polynomial, add R to get CRC bits
  - Receiver : divides MSG + R, check if zero

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Flow Control

- What happens if the sender tries to transmit faster than the receiver can accept?
- Data will be lost unless flow control is implemented
- Has to be dynamic?
  - Can sender learn the receiver rate apriori

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Some Flow Control Algorithms

- Stop and wait
  - Send 1, wait for ack, then send next
  - Retransmit after timeout, use sequence numbers to detect duplicates
- Sliding window
  - Send W, wait for ack to advance the window
  - At any point in time Max (W) unacknowleded messages
- Sliding window with error control
  - Go Back N
  - Selective Repeat

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Handling errors

- GO back N
  - Receiver rejects any message in error or out of order
  - Only acks in-sequence
- Selective repeat
  - Receiver buffers correctly (out-of-sequence) received messages but acks only the last in-sequence message received correctly
  - Sender retransmits only the lost packet,

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Addressing

- Hosts need to be identified at the link layer
- MAC address
  - 48 bits unique address (permanent with adapter)
  - 24 bits: manufacturer; 24 bits Serial number
- No relationships between MAC addresses hosts connected by a link
  - No grouping or hierarchy possible
- Fixed length address
  - Look up is efficient but table size = number of hosts on the network
  - Scaling

Connecting multiple hosts

- All hosts share the same link
  - Simple, need to deal with contention
  - A pair at a time can communicate
- Each pair of hosts connected by separate link
  - Mesh connection required, complex
  - N/2 pairs can simultaneously communicate

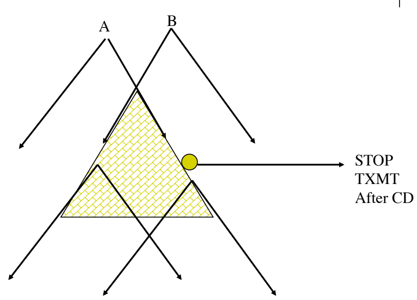
Contention Access Methods

- Determine when to transmit, sense the channel
- CSMA
  - 1-Persistent CSMA
    - Transmit if idle, else wait until idle and then transmit
  - Non-Persistent CSMA
    - Transmit if idle, else wait for random time, and then repeat
    - Spreads arrival times
  - P-Persistent CSMA
  - Transmit with probability p if idle, else wait until idle

CSMA/CD

- In CSMA protocols
  - If two stations begin transmitting at the same time, each will transmit its complete packet, thus wasting the channel for an entire packet time
- In CSMA/CD protocols
  - The transmission is terminated immediately upon the detection of a collision
  - CD = Collision Detect
- In wired links, transreceiver can send and receive simultaneously

Collision detection



Ethernet Backoff Algorithm: Binary Exponential Backoff

- If collision,
  - Choose one slot randomly from 2^k slots, where k is the number of collisions the frame has suffered.
  - One contention slot length = 2 x end-to-end propagation delay

This algorithm can adapt to changes in network load.

Algorithm (cont)

- If collision…
  - jam for 32 bits, then stop transmitting frame
  - minimum frame is 64 bytes (header + 46 bytes of data)
  - delay and try again
    - 1st time: 0 or 51.2us
    - 2nd time: 0, 51.2, or 102.4us
    - 3rd time51.2, 102.4, or 153.6us
    - *nth* time: *k* x 51.2us, for randomly selected
    - k=0…2^n - 1
    - give up after several tries (usually 16)
    - exponential backoff

CSMA/CD and Ethernet

- Ethernet:
  - Short end-to-end propagation delay
  - Broadcast channel
- Ethernet access protocol:
  - 1-Persistent CSMA/CD
  - with Binary Exponential Backoff Algorithm

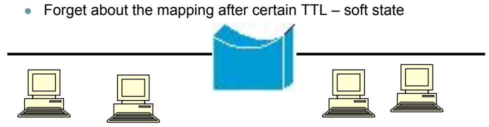
Ethernet Overview

- History
  - developed by Xerox PARC in mid-1970s
  - roots in Aloha packet-radio network
  - standardized by Xerox, DEC, and Intel in 1978
  - similar to IEEE 802.3 standard
- CSMA/CD
  - Available in 10 Mbps, 100 Mbps, 1 Gbps
  - Coax or twisted pair
- Frame Format

64	48	48	16		32
Preamble	Dest addr	Src addr	Type	Body	CRC

Interconnecting LANS

- Why not just one big LAN?
  - Limited amount of supportable traffic: on single LAN, all stations must share bandwidth
  - Single collision domain
- Physical layer extension
  - Repeaters
  - copies (amplifies, regenerates) bits between LAN segments
- Link Layer extensions
  - Bridges - connects (2) LAN segments
  - Each segment is its own collision domain
  - receives, stores, forward (when appropriate) packets between LANs
  - Learn which host is connected on which interface
  - Forget about the mapping after certain TTL – soft state



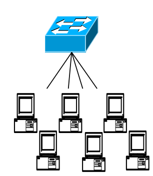
Forwarding Algorithm

1. bridge receives every packet transmitted on every attached LAN
2. bridge stores for each packet
   - physical address of sender
   - port (incoming LAN segment) on which pkt was received

3. for each packet received on any port: lookup dest. physical address in table
   - if not found, flood onto all attached LANs
   - if found, forward only out to specified LAN
4. forwarding table deleted if not refreshed

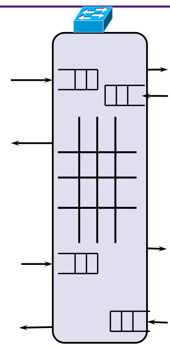
Switches

- Segments LANs (multi-port Bridge)
- Layer 2 Processing
- Directly connect hosts
- Multiport bridge
- Directly forward frames
- Cut-through switching
  - Forward as soon as header is processed
- Store-and forward
  - Buffer entire packet, check integrity (CRC)
  - Discard erroneous packets



Switches

- Can connect a large number of ports/ interfaces
- Switching fabric can send frames from any input to any output
- N/2 simultaneous transfers
- C=N/2*line speed



IP address hierarchy

IP Addresses

- 32 bits long
- Identifier for host, router *interface*
- Notation:
  - Each byte is written in decimal in MSB order, separated by dots
  - Example: 128.195.1.80

IP Address Classes (old)

Class	← 32 bits →		
A	0	Net	Host
B	10	Net	Host
C	110	Net	Host
D	1110	Multicast address	
E	11110	Reserved	

IP Address Classes (old way)

- Class A:
  - For very large organizations
  - 16 million hosts allowed
  - 0.*.*.* to 127.*.*.*
- Class B:
  - For large organizations
  - 65 thousand hosts allowed
  - 128.*.*.* to 191.*.*.*.*
- Class C
  - For small organizations
  - 255 hosts allowed
  - 192.*.*.* to 223.*.*.*
- Class D
  - Multicast addresses
  - No network/host hierarchy
  - 224.*.*.* to 239.*.*.*
- Class E
  - Reserved, not used
  - 240.*.*.* to 255.*.*.*

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IP Address Hierarchy

- Class A, B, C addresses support two levels of hierarchy
- However, the host portion can be further split into “subnets” by the address class owner
  - more than 2 levels of hierarchy

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Subnetting

Example: Class B address with 8-bit subnetting

	16 bits	8 bits	8 bits
	Network id	Subnet id	Host id
Example Address:	165.230	.24	.8

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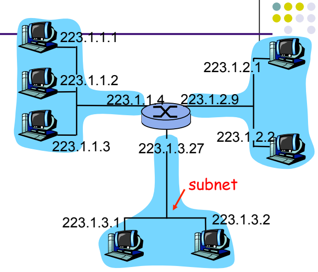
Subnets

- IP address:
  - subnet part (high order bits)
  - host part (low order bits)
- *What's a subnet ?*
  - device interfaces with same subnet part of IP address
  - can physically reach each other without intervening router



network consisting of 3 subnets

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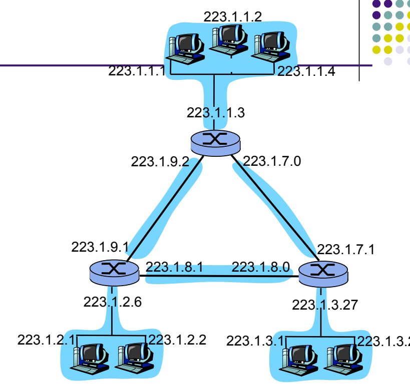
Subnet Masks

Subnet masks allow hosts to determine if another IP address is on the same subnet or the same network

	16 bits	8 bits	8 bits
	Network id	Subnet id	Host id
Mask:	1111111111111111	11111111	00000000
	255.255	.255	.0

Subnets

How many?



Subnet Masks *(cont'd)*

Assume IP addresses A and B share subnet mask M.

Are IP addresses A and B on the same subnet?

1. Compute (A and M).
2. Compute (B and M).
3. If (A and M) = (B and M) then A and B are on the same subnet.

Example: A and B are class B addresses

A = 165.230.82.52
B = 165.230.24.93
M = 255.255.255.0

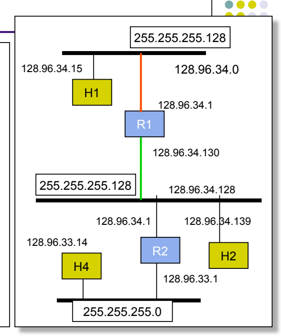
Same network?
Same subnet?

Routing across Subnet

- Packet to H2
- 128.96.34.139

Routing table at R1

Subnet number	Subnet mask	nexthop
128.96.34.0	255.255.255.128	Interface 0
128.96.34.128	255.255.255.128	Interface 1
128.96.33.0	255.255.255.0	R2
10.1.2.0/23	10.1.2.1	10.1.2.1
10.1.0.0/23	10.1.2.2	10.1.2.1



Problems with Class-based Routing

- Too many small networks requiring multiple class C addresses
- Running out of class B addresses, not enough nets in class A
- Addressing strategy must allow for greater diversity of network sizes

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IP addressing: CIDR

CIDR: Classless InterDomain Routing

- subnet portion of address of arbitrary length
- address format: a.b.c.d/x, where x is # bits in subnet portion of address

subnet part | host part

11001000 00010111 00010000 00000000

200.23.16.0/23

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CIDR

- An ISP can obtain a block of addresses and partition this further to its customers
  - Say an ISP has 200.8.4/24 address (256 addresses). He has another customer who needs only 4 addresses
  - from 200.8.4/24 a block of 4 addresses can be specified as 200.8.4.24/30
- Customer buys or is allocated a prefix by ISP
  - Addresses assigned to hosts by customer

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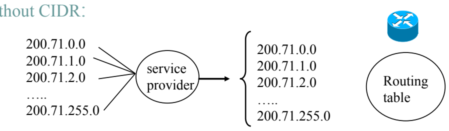
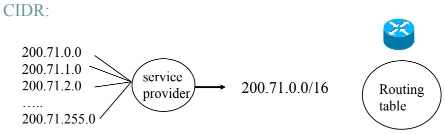
Reducing Routing Table Size

Without CIDR:



With CIDR:



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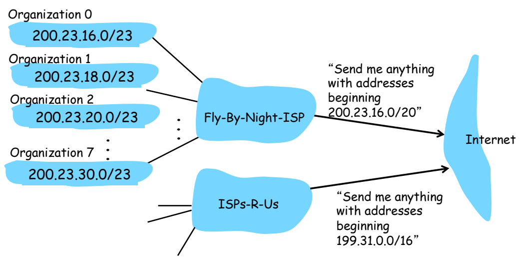
Hierarchical addressing: route aggregation

Hierarchical addressing allows efficient advertisement of routing information:



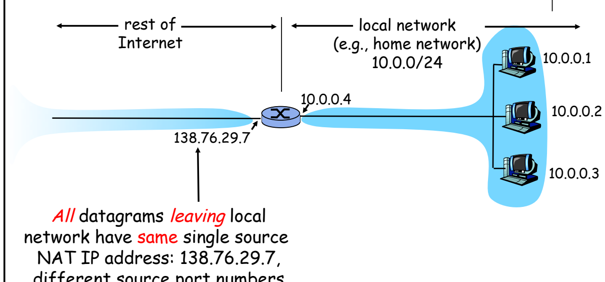
IPv4 Addresses may not suffice … If free?

- 2^{32} is 4G
  - Not all that many unique addresses
  - Plus, some are reserved for special purposes
  - And, addresses are allocated in larger blocks
- And, many more devices need IP addresses
  - Computers, smart phones, routers, sensors, , …
- Long-term solution: a larger address space
  - IPv6 has 128-bit addresses ($2^{128} = 3.403 \times 10^{38}$)
- Short-term solution: maybe winning
  - Use Private addresses with NAT

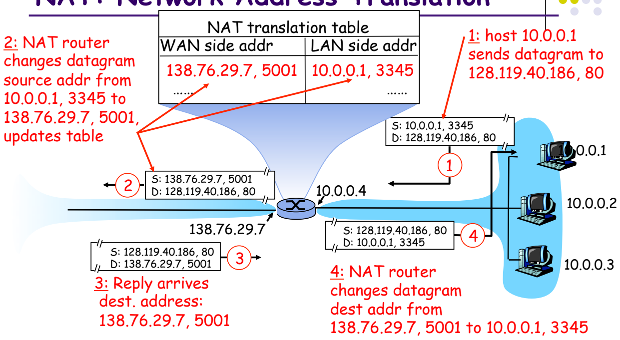
Private IP addresses

- **A block of addresses reserved for internal routing**
- **10.0.0.0 to 10.255.255.255 → 10.0.0.0/8**
- **172.16.0.0 to 172.31.255.255 → 172.16/12**
- **192.168.0.0 to 192.168.255 → 192.168/16**

NAT: Network Address Translation



NAT: Network Address Translation



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Types of NAT

- Full cone NAT
  - Aa:Ap Na:Np Bb:Bp
  - ←Na:Np;*.*
- IP restricted
  - Aa:Ap Na:Np Bb:Bp
  - ←Na:Np;Bb.*
- Port Restricted
  - Aa:Ap Na:Np Bb:Bp
  - ← Na:Np:*:Bp
- Symmetric NAT
  - Aa:Ap Na:Np Bb:Bp
  - ← Na:Np:Ba:Bp

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NAT: Network Address Translation

- Features: local network uses just one IP address as far as outside world is concerned:
  - range of addresses not needed from ISP: just one IP address for all devices
    - Major cost consideration
  - can change addresses of devices in local network without notifying outside world
  - can change ISP without changing addresses of devices in local network
  - devices inside local net not explicitly addressable, visible by outside world (a security plus).

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NAT: Network Address Translation

- 16-bit port-number field:
  - 60,000 simultaneous connections with a single LAN-side address!
- NAT is controversial:
  - routers should only process up to layer 3
  - violates end-to-end argument
    - NAT possibility must be taken into account by app designers, eg, VOIP, icoming notification applications
    - Pushing FB status updates on to device!!!
  - address shortage should instead be solved by IPv6
  - NAT is here to stay

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Recent Developments: IPv6

- IPv4 (the standard IP protocol) has limited address space
- Most importantly, IP is running out of addresses. 32 bits is not enough.
- Real-time traffic and mobile users are also becoming more common

IP version 6
(Also called IPng, or IP next generation)

IPv6: The Changes

- Large address space:
  - 128-bit addresses (16 bytes)
  - Allows up to 340,282,366,920,938,463,463,374,607,431,768,211,456 unique addresses
- Fixed length headers (40 bytes)
  - Improves the speed of packet processing in routers

IPv6 header

Version (4)	TrafficClass (8)	Flow Label (20)	4
PayloadLen (16)	Next Header (8)	Hop Limit (8)	4
Source Address			16
Destination Address			16

- Version field set to 6
- PayloadLen field gives the length in bytes of the packet excluding the header
- Next Header value gives the header (if any) that follows the IPv6 header

IPv6: The Changes *(cont'd)*

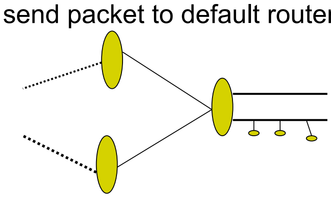
- Support for "flows"
  - Flows help support real-time service in the Internet
  - A "flow" is a number in the IPv6 header that can be used by routers to see which packets belong to the same stream
  - Guarantees can then be assigned to certain flows
  - Example:
    - Packets from flow 10 should receive rapid delivery
    - Packets from flow 12 should receive reliable delivery

IPv6 Addresses

- Classless addressing/routing (similar to CIDR)
- Notation: x:x:x:x:x:x:x:x (x = 16-bit hex number)
  - contiguous 0s are compressed: 47CD::A456:0124
  - IPv6 compatible IPv4 address: ::128.64.18.87

Simple routing

- Routing has 3 parameters
  - Name, address, route
- Destination directly connected?
  - If yes, forward
- If not send packet to default router



Internet Routing

- Internet hierarchy
- Networks/organization belong to AS or Autonomous systems
- Two types of routing
  - Routing within AS (intradomain routing)
    - Link state (OSPF) or Distance Vector (RIP)
  - Routing between ASes (interdomain routing)
    - BGP

Shortest Path Routing

- For a pair of communicating hosts, there is a shortest path between them
- Shortness may be defined by:
  - Number of router/switch hops
  - Geographic distance
  - Link delay
  - Cost

Routing Algorithms

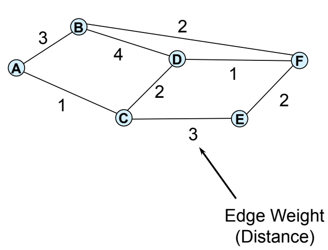
- Two types of routing algorithms:
  - Global Routing Algorithms
    - Complete state information is used in routing decisions
  - Decentalized Routing Algorithms
    - Local/neighborhood state
- Hierarchical Routing is used to make these algorithms scale to large networks

Routing Algorithms

- Static routing algorithms do not base their routing decisions on the current state of the network
  - Flooding
- Dynamic routing
  - Route path changes as link cost changes

Shortest Path

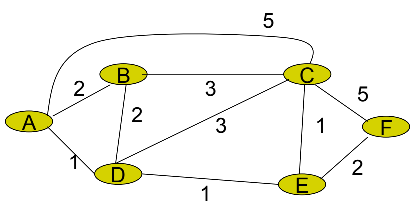
What is the shortest path between A and F?



Computing the Shortest Path

- Dijkstra's Shortest Path Algorithm:
  - Step 1: Draw nodes as circles. Fill in a circle to mark it as a "permanent node."
  - Step 2: Set the current node equal to the source node
  - Step 3: For the current node:
    - Mark the cumulative distance from the current node to each non-permanent adjacent node. Also mark the name of the current node. Erase this marking if the adjacent node already has a shorter cumulative distance marked
    - Mark the non-permanent node with the shortest listed cumulative distance as permanent and set the current node equal to it. Repeat step 3 until all nodes are marked permanent.

Graph model of a network



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Link State Routing

- Each router measures the distance (in delay, hop count, etc.) between itself and its adjacent routers
- The router builds a packet containing all these distances. The packet also contains a sequence number and an age field.
- Each router distributes these packets using flooding
- Each node builds a complete copy of graph
- Every node computes routes to every other node
  - Using single-source, shortest-path algorithm
- Process performed as needed
  - When connections die / reappear

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Link State Routing *(cont'd)*

- To control flooding, the sequence numbers are used by routers to discard flood packets they have already seen from a given router
- The age field in the packet is an expiration date. It specifies how long the information in the packet is good for.
- Once a router receives all the link state packets from the network, it can reconstruct the complete topology and compute a shortest path between itself and any other node using Dijsktra's algorithm.

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Distance Vectors

- Each router maintains lists of best-known distances to all other known routers. These lists are called "vectors."
- Each router is assumed to know the exact distance (in delay, hop count, etc.) to other routers directly connected to it.
- Periodically, vectors are exchanged between adjacent routers, and each router updates its vectors.

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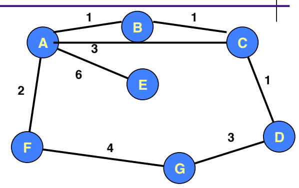
Distance-Vector Routing

Initial Table for A		
Dest	Cost	Next Hop
A	0	A
B	1	B
C	3	C
D	∞	–
E	6	E
F	2	F
G	∞	-



- Initially
  - Only have entries for directly connected nodes
  - Send DV table to all neighbors, update cost with local table
  - transitive
    - Transitive

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Problem: Count-to-Infinity

- With distance vector routing, good news travels fast, but bad news travels slowly
- When a router goes down, it takes can take a really long time before all the other routers become aware of it

Count-to-Infinity

A	B	C	D	E	
	1	2	3	4	Initially
	3	2	3	4	After 1 exchange
	3	4	3	4	After 2 exchanges
	5	4	5	4	After 3 exchanges
	5	6	5	6	After 4 exchanges
	7	6	7	6	After 5 exchanges

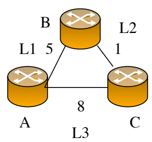
etc… to infinity

Improvements

- Split Horizon
  - Don't tell neighbor about routes obtained from it
  - Or never advertise a route out of the interface you learnt it
- Poison reverse
  - Advertise network unreachable back through the same interface you learnt about it
  - advertising all network IDs, but those network IDs learned in a given direction are advertised with a metric of 16, indicating that the network is unavailable.
- Triggered updates as opposed to periodic updates
- Path vectors, Store vectors or complete path as opposed to just next hop

Split-horizon

- C routes to A via B
- C does not advertise to B its cost to A
- If L1 breaks or cost increases to 50
- C does not announce to B the cost to A



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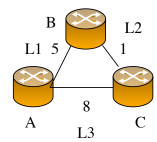
Poison-reverse

- C routes to A via B
- C tells B its (C’s) distance to A is infinite
- You know better
- Update table is fixed length
- If L1 breaks or cost increases to 50
- C announce to B the cost to A is infinite



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