Network Topologies
CS 118
Computer Network Fundamentals
Peter Reiher

Outline

- What is network topology?
- Types of network topologies
- Issues in relaying messages

Network Topologies

- So you've got a bunch of nodes
- And you can connect the nodes with channels
- So you can communicate to everyone with fewer total channels
  - And avoid limitations of broadcast media
- Which nodes do you connect?
- That's the question of network topology

Parties and nodes

- Shannon talked about parties
  - Entities that wished to communicate
  - Generally a sender and receiver
  - Very general
    - Machines, people, whatever
- In networking, we usually talk about *nodes*
  - Physical machines used to move information
- We'll be changing to talk primarily about nodes

Channels and Links

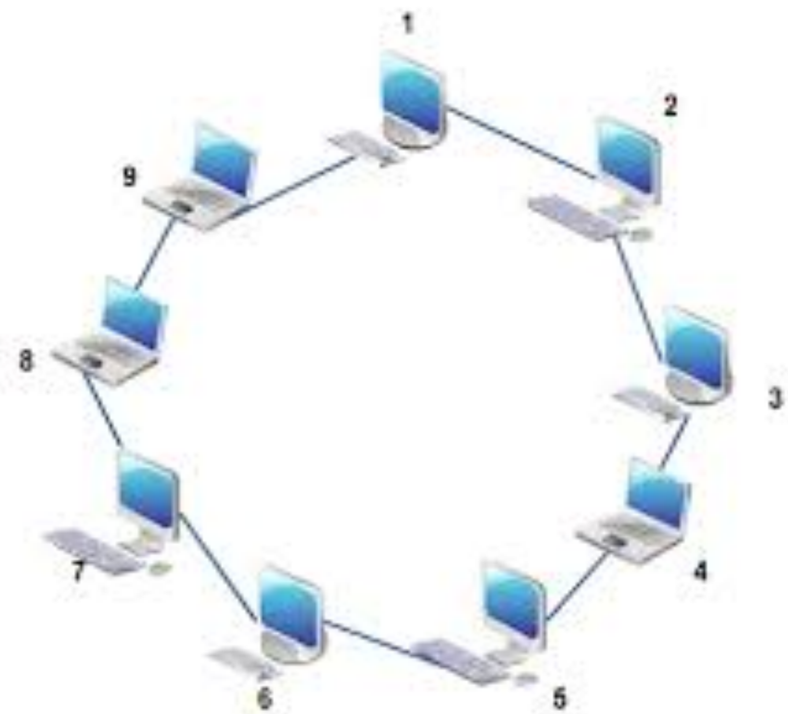
- Shannon talked about channels
  – Logical connections between two parties
- Physical networks tend to talk about *links*, instead
  – A physical connection between two nodes
- We'll be changing to talk primarily about links
- In network topologies, links connect nodes

Some simple topologies

- Ring
- Hub and spoke
- Regular mesh
- Manhattan network
- Torus
- Hypercube

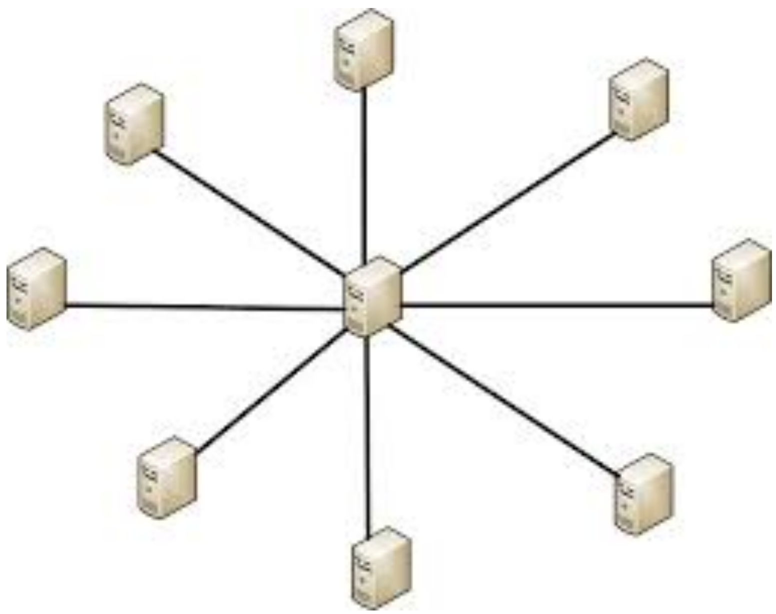
Ring

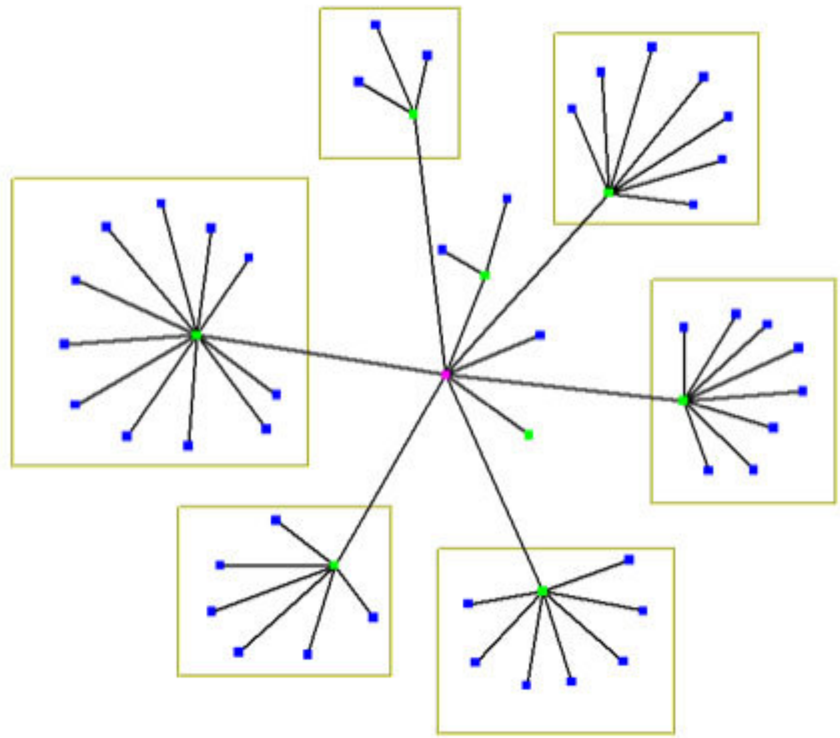
- Connected in a circle
  - N links
  - Can tolerate 1 link or node failure
  - Links can be simplex (one direction)
- Managing failures
  - "Pass through" on node failure
  - Dual-ring (duplex) allowing ends to "heal"



Hub and spoke

- Node as a switch
  - One or multiple levels

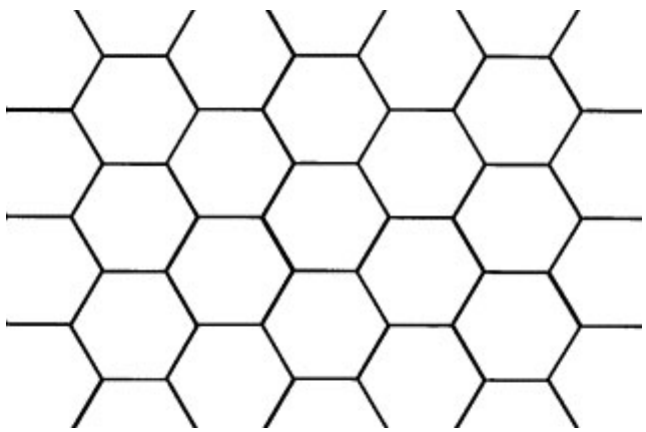


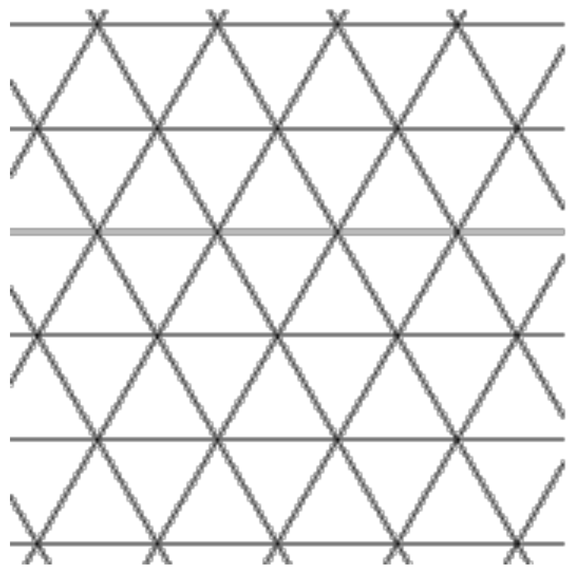


- Failure of the hub disconnects entire network

Regular mesh

- Any pattern
  - Nodes where lines meet

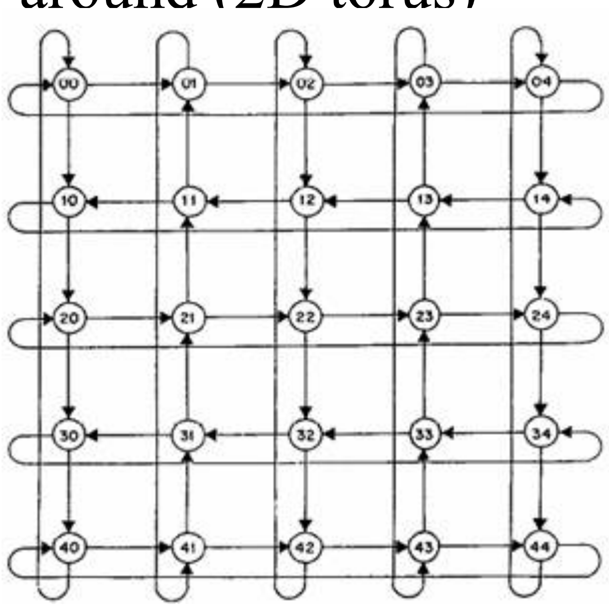




- Depending on pattern, tolerates multiple failures

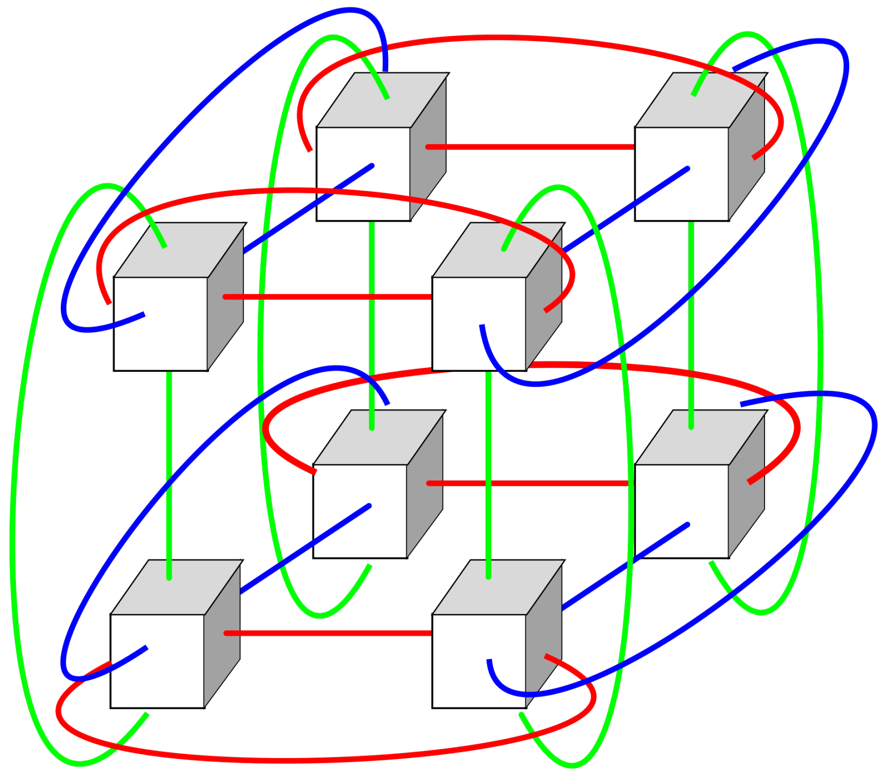
Manhattan network

- Grid of squares
  - Tend to wrap ends around (2D torus)



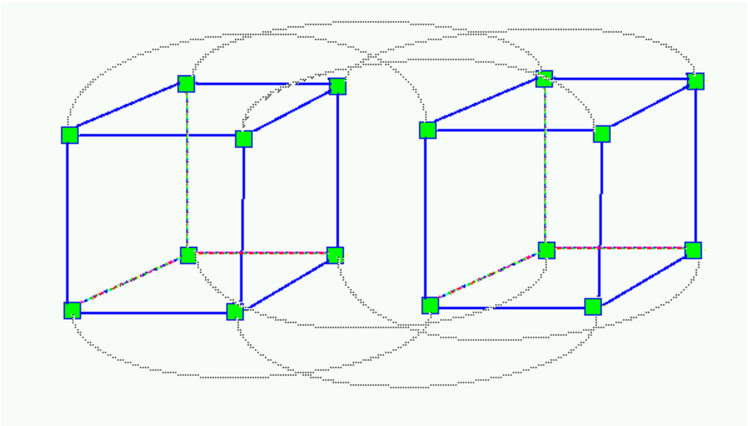
Torus

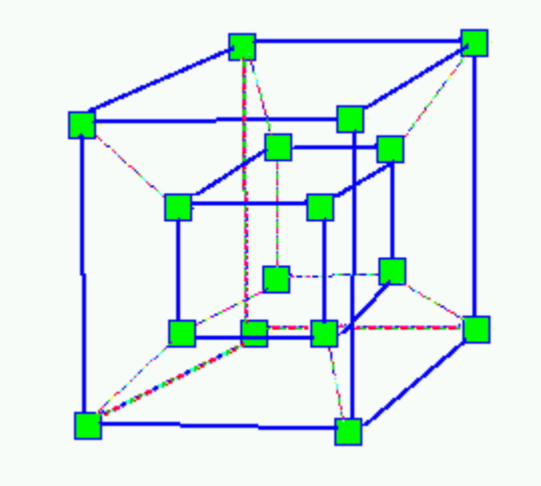
- Each dimension is a set of rings
  - 1D = ring
  - 2D = Manhattan network
  - 3D (see right)
  - …



Hypercube

- $\log_2 N$ links per node
  - 1D = 2-party (line)
  - 2D = square (ring)
    - Take 2 lines, link corresponding nodes
  - 3D = cube
    - Take two squares, link corresponding nodes
  - 4D (see right)
    - Take two cubes, link corresponding nodes
  - At each step, number of nodes doubles but links per node increases by 1





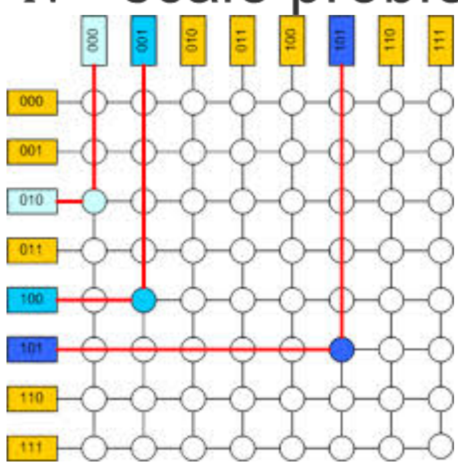
Multistage Interconnection Net (MIN)

- Stages of nodes
  - Either new nodes, or nodes “reused”
  - Entire stage “switches” at the same time
- Phased switching implications
  - Fixed message size (“cells”)
  - “Rearrangeable” vs. “not”
- E.g., butterfly/banyan

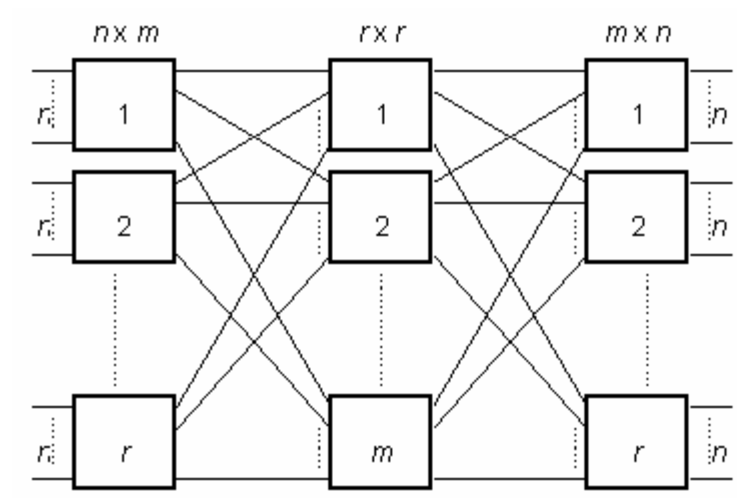
Not usually used as general relays, but often used “inside the black box” to emulate a link

Examples

- Crossbar
  - Original phone switch
  - The “anti-MIN”
  - N^2 scale problem

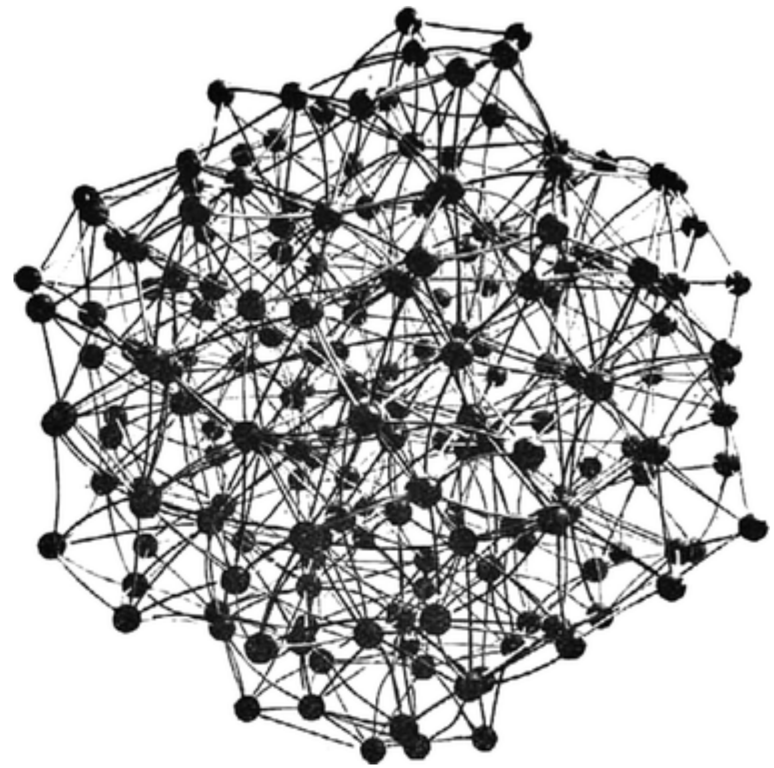


- Clos
  - 3-stage: in, middle, out



Irregular mesh

- Lacking a pattern
  - Euclidean or NOT
- Recall from your math
  - Euclidean means the triangle inequality: $|A{:}B| + |C{:}D| \geq |A{:}C|$
  - Affects path selection



Impact of topology

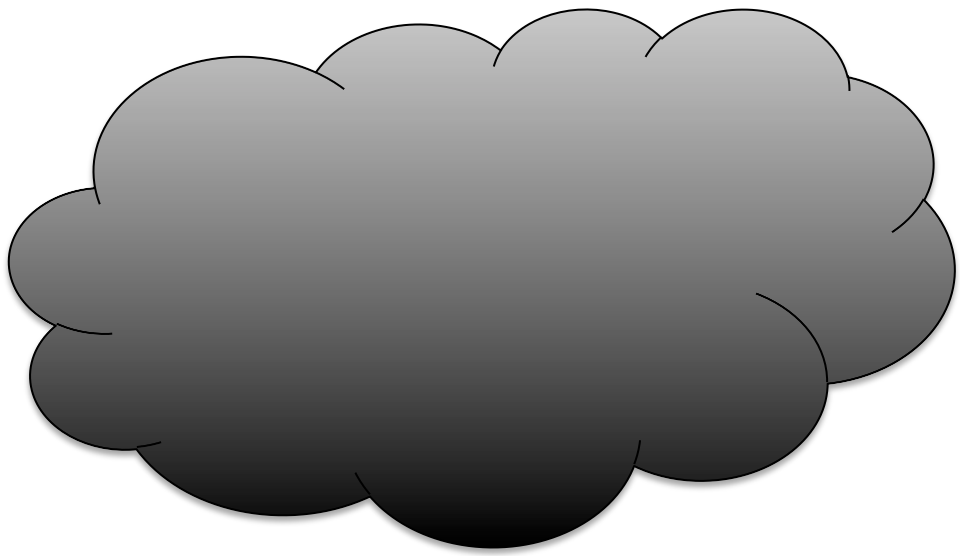
- Naming
  - Node labels can describe location
  - Location can indicate route
- Use cases
  - Distributed problems can be mapped to nodes
  - Communication patterns can align to topology
    - E.g., ATM cash machines and the bank map well to a hub-and-spoke

Scale and size

- Limits of a single link
  - Power limits distance
  - Can fix with repeaters, but they're not free
- Limits of a shared link
  - Protocol limits distance
  - Fan-out power limits node count
- Limits of relaying
  - No distance limit (relay using nodes)
  - No node count limit (fan-out using nodes)
  - Complexity (nodes do more work)
  - Overhead (communication takes more time)

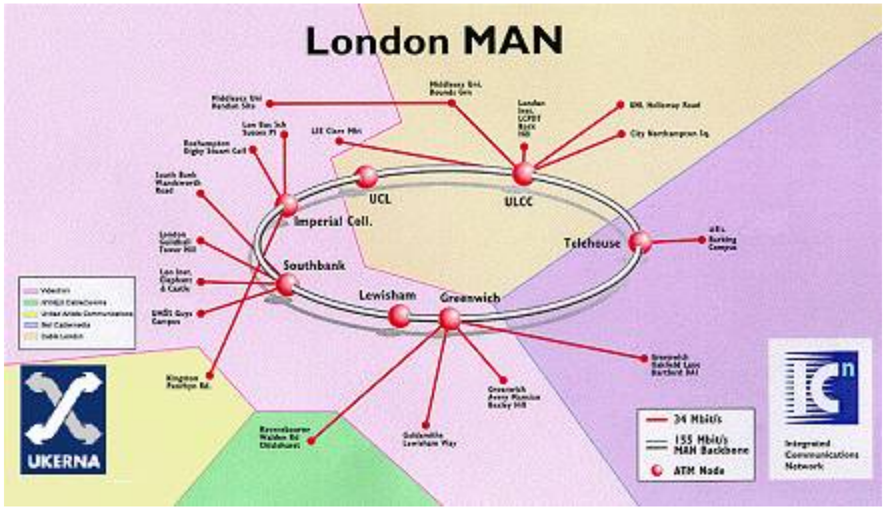
WAN

- Wide-area network
  - Typically inter-city to global
  - 100-20,000 km



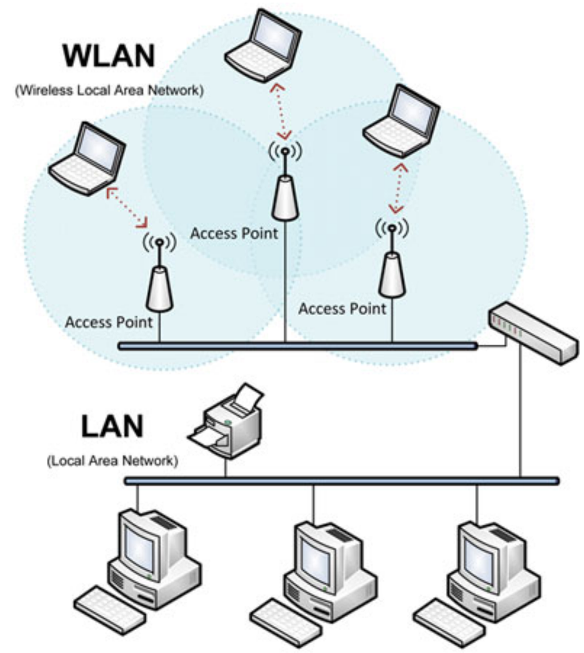
MAN

- Metropolitan …
  - Several buildings to a city and its suburbs
  - 0.1-100 km



LAN

- Local area network
  - Inter-desktop to intra-building
  - The first *AN
  - 1-100 m
  - WLAN = wireless



Other *ANs

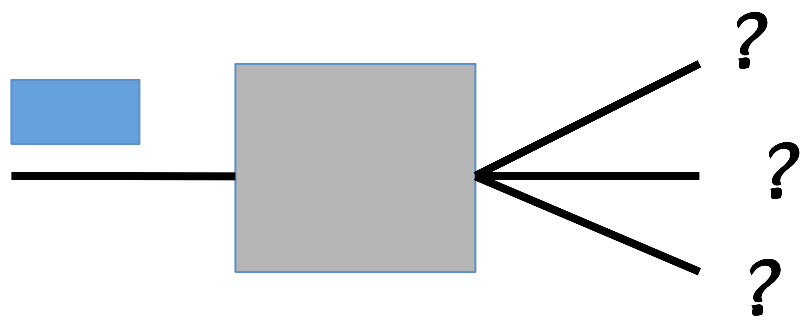
- DAN
  - Desktop
  - Interconnecting devices inside a PC
- PAN / BAN
  - Personal / body
  - Devices within one person's space
  - Phone, watch, tablet, sensors
- SAN
  - Storage
  - LAN or DAN focused on storage devices
- CAN
  - Car or campus
  - Car is maxi PAN
  - Campus is mini MAN
- HAN
  - Home
  - LAN with privacy limits

Networks without a "AN"

- Intranet
  - Network internal to a corporation
- Internet
  - Network of heterogeneous networks ("inter")
- Access / Aggregation
  - Connects multiple LANs and WAN
- Interplanetary
  - Very large delays
  - Intermittent links

Relaying and choices

- Nodes in a topology must relay messages
- Except for simple topologies, choices must be made
  - Multiple outgoing links
  - Which to send it on?



Relaying rules

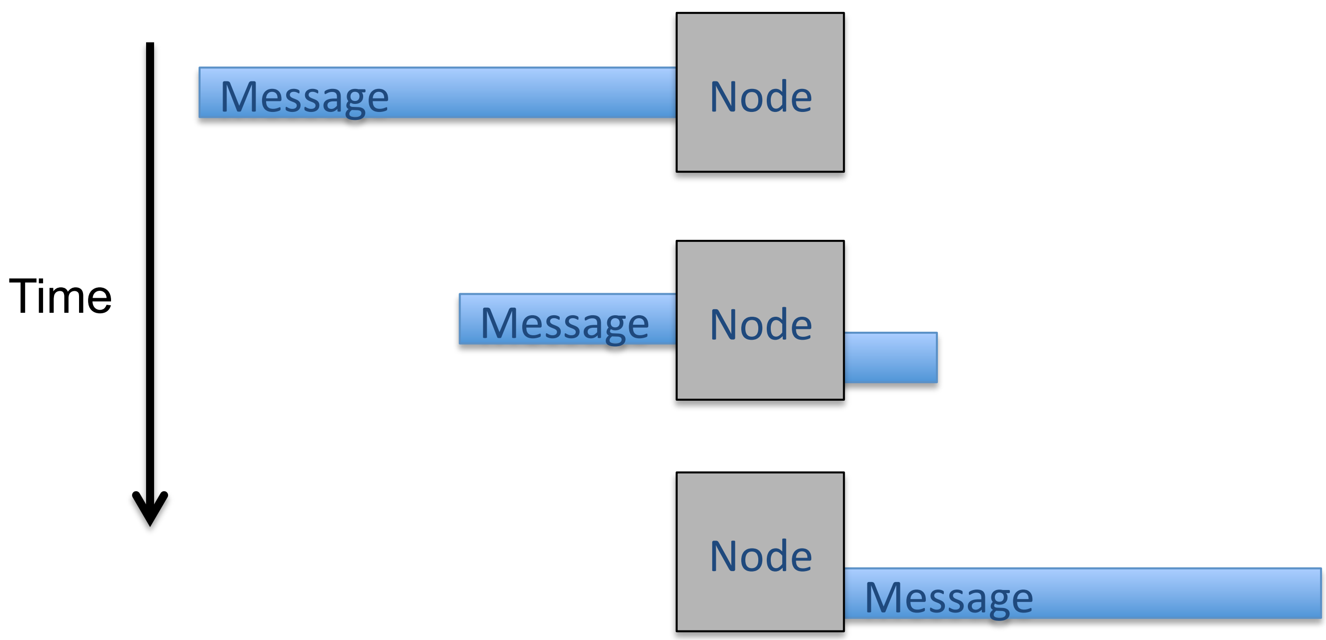
- What do you do when you get a message?
  - Deliver it if it's for you
  - Otherwise, relay it!
- How?
  - (for now, assume everyone knows a-priori)
- When?
- What about collisions?

The when question

- A message starts to come in
  - And it isn't for you
- *When* do you start sending it out?
- As soon as you know where to send it?
  - Possibly before you've gotten all of it
- Or only when the entire message has arrived?

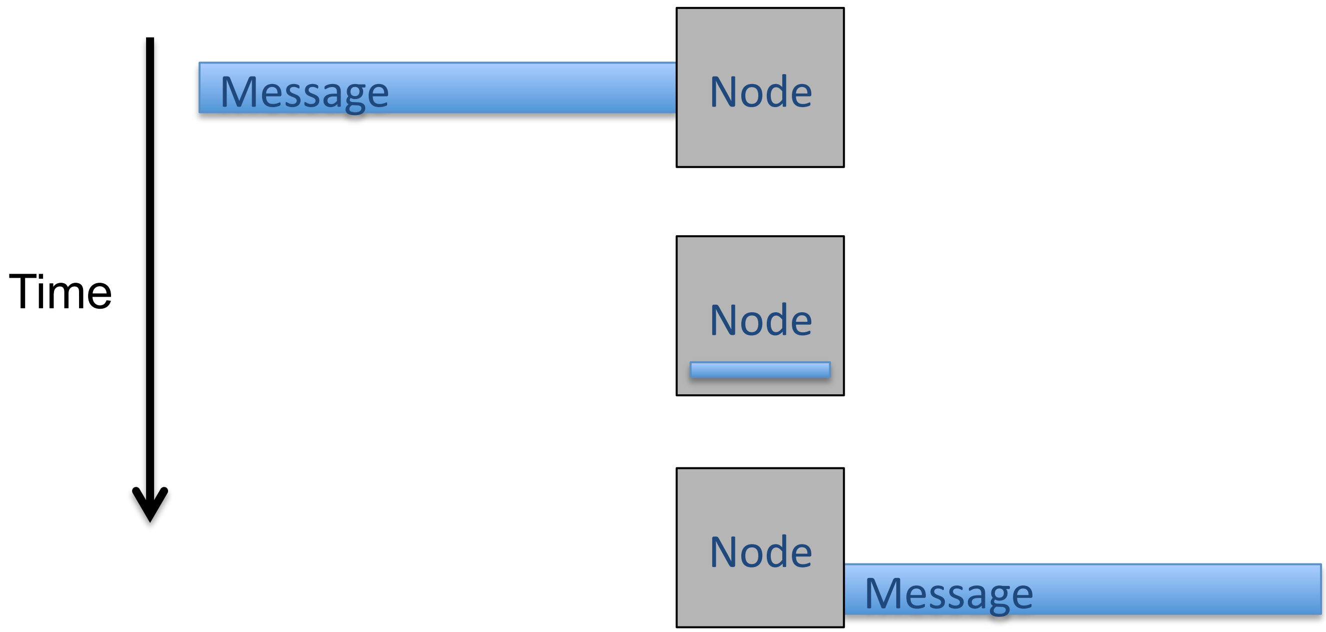
Cut-through

- Delay only long enough to decide



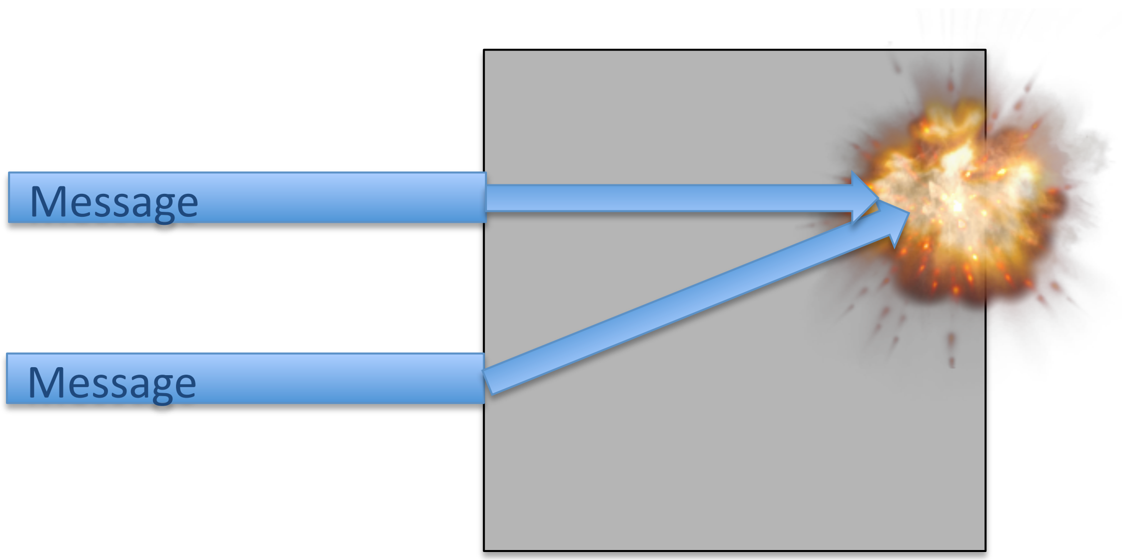
Store and forward

- Message "stops" inside the node



Collisions

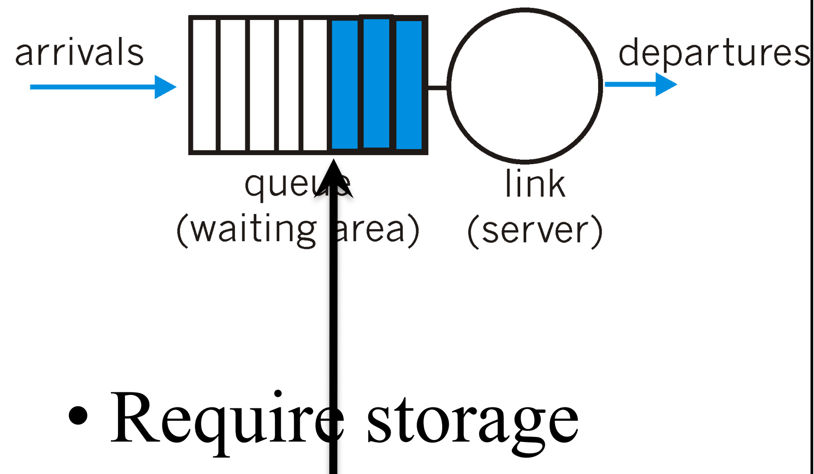
- Multiple messages arrive at a node
  - More than one seeks the same output
  - (output) contention, collision



Avoiding collisions

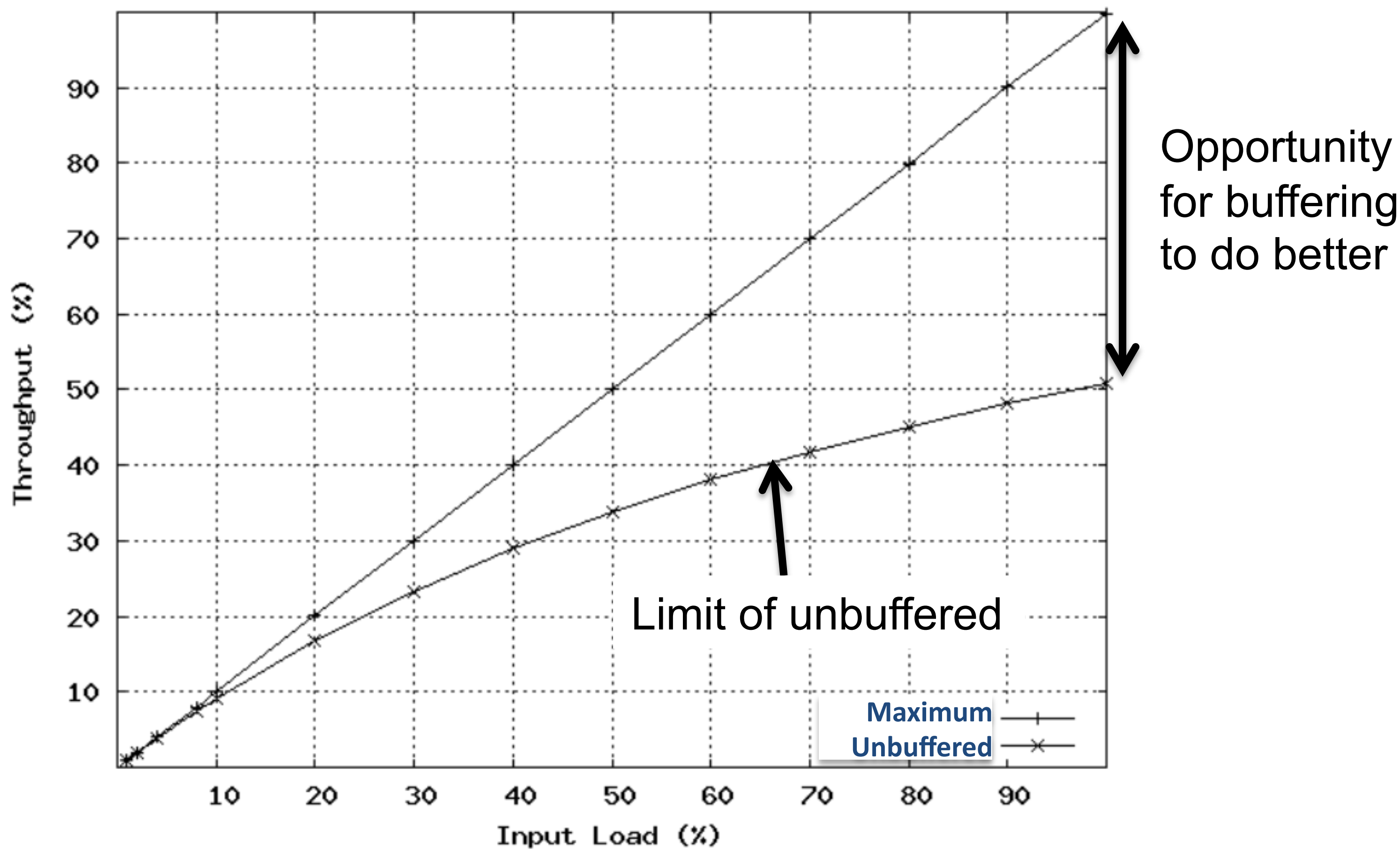
- Delete one
  - Which one?

- Save one
  - Which one?
  - How long?



- Require storage
  - A *buffer*

Buffered vs. bufferless



Queuing

- Store and forward provides an opportunity
  - Messages can be managed as a set
  - Messages can be reordered
  - Messages can be dropped

- Critical issue – what do you do when buffer is full?

A short foray into queueing theory

- Queueing theory is mathematical theory of handling lines
- Highly applicable to networking
- In particular, to the issue of handling messages as they arrive at a node
- A fundamental question –
  - Under what circumstances will we need to drop a message?

Answering that question

- Informally, if you can't keep up with the work

- How can we formalize that idea?
- Through queueing theory

The basics of queueing theory

- We have a server
- It has an input queue
- The server takes work out of the input queue and sends it to an output
  - Taking some amount of time to do so
  - On average, W seconds to complete a piece of work
- Work arrives at some rate λ items per second
- When are we in trouble?

What's trouble?

- Trouble could be dropping any message
- Or it could be getting into a state where we'll never catch up
  - And messages will always need to be dropped
- Clearly, the latter is worse than the former
- If we occasionally drop a message, maybe we can recover
- If we always are dropping messages, that implies an unstable system

Little's result

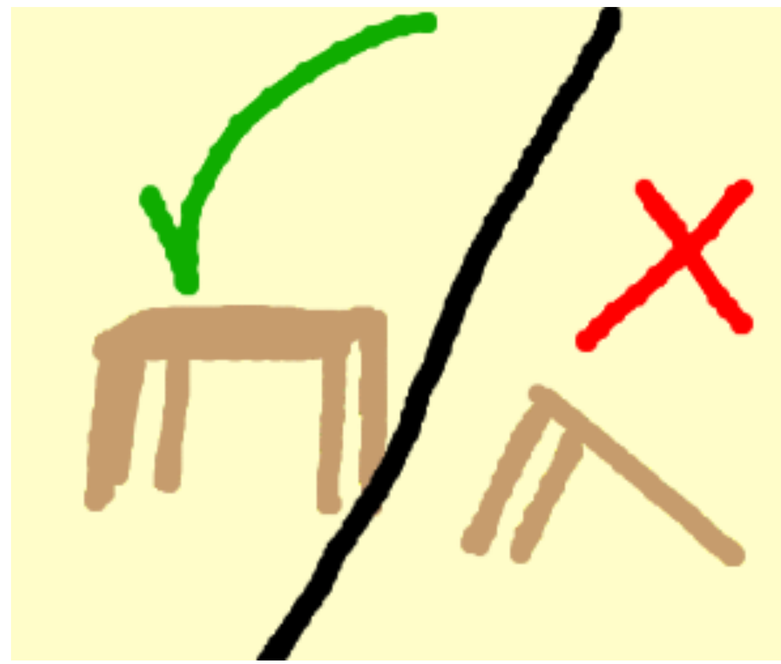
- Under what conditions will our system be stable?
- Say our arrival rate at the network element in question is λ messages per second
- And we can forward a message in time W
- Both on average
- How many messages will be in the system, on average?
- $L = \lambda W$
- So if we can handle L messages, we'll be stable
  - BUT we might still drop some messages

Drop behaviors

- Tail drop
  - Delete arrivals to a full queue
- Head drop
  - New arrivals push oldest members out
- Random drop
  - Delete randomly from both new arrivals and existing members
- Random early drop
  - Random drop before the queue reaches its limit
  - Increase probability of drop as space decreases

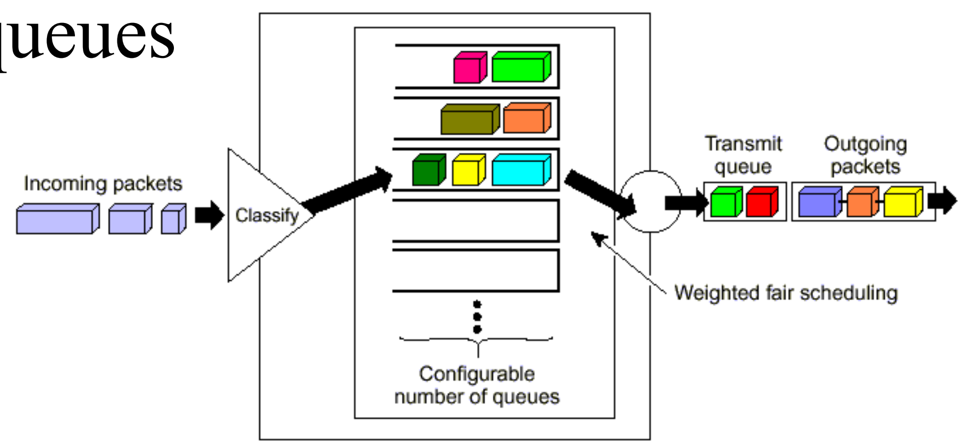
Priority

- Some messages are "more equal" than others
  - See George Orwell
  - Messages are associated with priority
  - Priority biases decisions



QoS

- Quality of service
  - Guarantees to a node about their messages
  - Per-message or long-term average behavior
  - Fixed guarantees or statistical
  - Complex set of queues



Returning to the question of choice

- Where do we relay the message to?
- Post office does it by looking at the address
- Implies a need for naming
  - Specifying who to deliver something to

Naming and relaying

- So a message arrives at a relay node
- It's not for that node
- How does the relay node know where to send it?
- A problem (partially) in naming
- The message can be associated with a name
- Which can allow the relay node to know how to relay it

Terminology

- Name space
  - A set of possible names
  - Usually indicated by syntax or semantic range
  - E.g., N.N.N.N, where N=0..255
- Name
  - An instance within a name space
- Identifier
  - Another way to say “name”

Naming vs. identification

- Naming:
  - The act of assigning an identifier to an item
- Identification:
  - The act of selecting a subset of items based on a name

What can be "named"?

- Place (source or sink of data)
  - Endpoint, node, process (inside an OS)
  - Location
- Communications medium (path of data)
  - Channel / link
  - Path (sequence of adjacent links)
- Information (the data itself)
  - Group of data, e.g., a record or file
- A behavior (the way data evolves)
  - A sequence of events, an algorithm, etc.

Finding names

- You have to know these things…
  - A-priori knowledge
  - A directory

Basically, some *<u>other</u>* way

Not associated directly with the message itself

Purpose of Names

- Support shared channels
- Support relaying
- Support layering
- Provide other information
- Support naming itself

Support shared channels

- Source identifier (N:1)
- Destination identifier (1:N)
- Group identifier (all, some, any)

Source vs. Destination ID

- Distinct
  - Source in the context of a destination
    - "*Reza's* professor named Peter"
  - Destination in the context of a source
    - "*Peter's* student named Nora"
  - Allows localized naming
  - Easier to ensure unique names
- One name for both
  - Avoids need for context
  - Requires coordination of all names

Types of group identifiers

- All
  - Broadcast
- Some
  - Multicast
- Any
  - Anycast

Broadcast

- All everywhere
  - Very rarely actually true
  - At best, true within part of a network
- All within a range of names
  - I.e., all names between Jenny and Morton
  - The metric is internal to the name space
  - Assumes an ordered name space
- All within some metric
  - Where the metric is external to the names
  - E.g., within 3 hops, within 2 ms, within 600m

Multicast

- A group of selected members
  - Indicated by the source
  - Indicated by an external membership protocol
- A subset of such a group (N of M)
  - Exactly N of M
  - At least N of M

Anycast

- Any member
  - Any available party responds
  - More than one can “offer”; originator selects
- Any ONE member
  - At most one party responds
  - The network (or the receivers) select
  - Originator is given no choice

Support relaying

- Structure in the name can help
  - Name space is a hierarchy
    that matches the network topology
    - E.g., IPv6
    - E.g., telephone country codes, area codes, exchanges
  - Name space can match geographic areas
    - Where you are determines part of your name
    - E.g., DNS country code suffixes (.us, .jp, .in)
    - Zip codes on letters
    - E.g., telephone country codes, area codes

Types of Names

- Flat
  - I.e., unstructured
- Structured
  - Syntax
  - Semantics
- Single-level
  - One organization for the entire name space
- Multi-level
  - A sequence of organizations
  - Organizations can repeat or vary
  - Levels can represent a hierarchy (subdivision)

People

- Size
  - 1-N Characters (var. charset)
- Organization
  - 2-3 level hierarchy of flat
    - Right, left, middle in US, most of EU
    - Left, right in Japan
- Content
  - Surname (family)
    - Usually flat
    - Can change (marriage)
  - Given name
    - Flat
  - Nickname
    - Flat
- Broad/multicast support?
  - Geographically limited (hey you all!); geo-limited multicast (all the brown-eyed people)
- Example
  - Henry Jones, Jr.

Houses

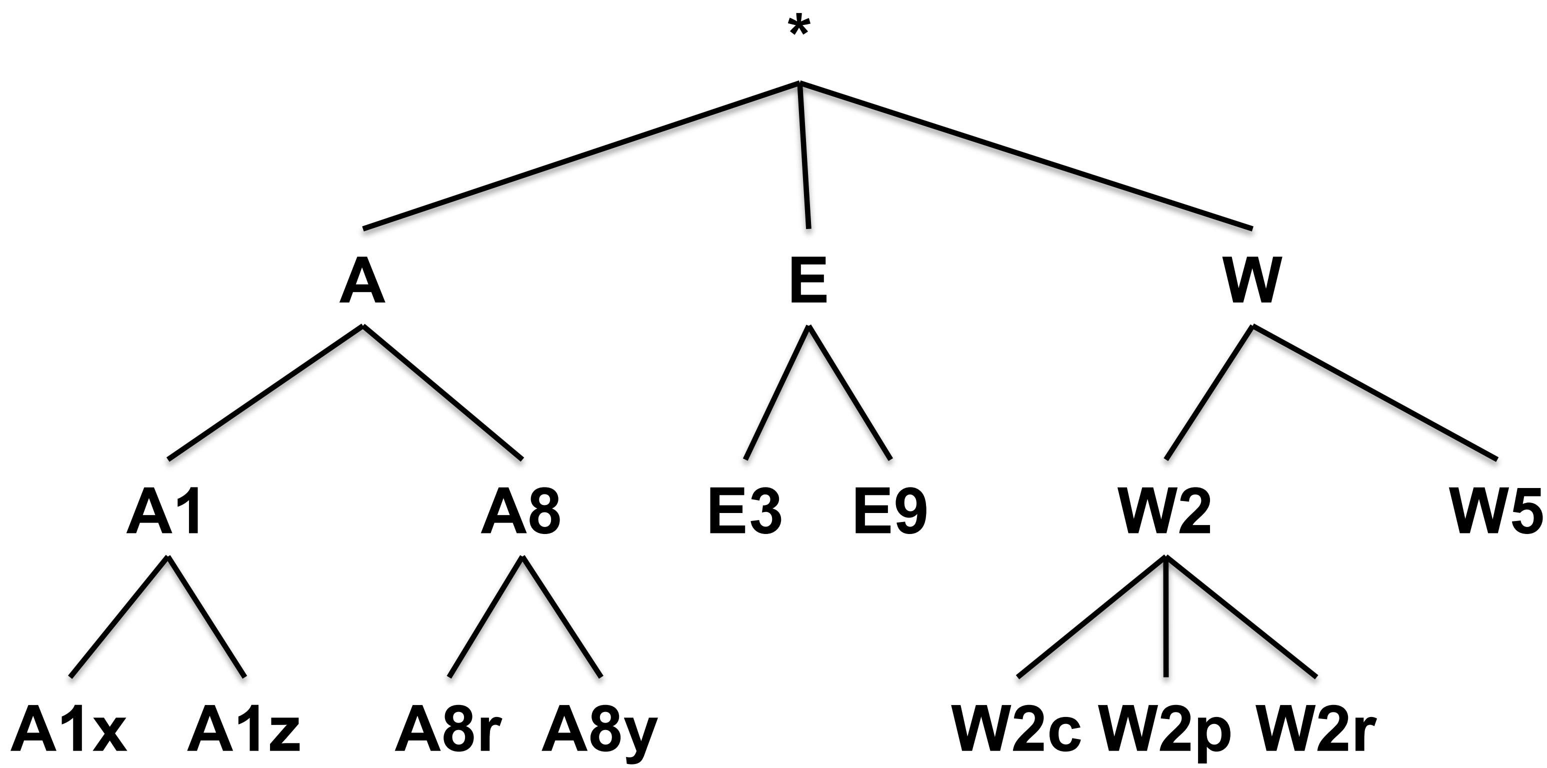
- Size
  - 1-N Characters (var. charset)
- Organization
  - 4-6 level hierarchy of flat
    - Country, region, city, street, unit, subunit
- Content
  - Flat in general
  - Units
    - Geographic in US
    - Chronological in Japan
- Broad/multicast support?
  - No broadcast; no multicast
- Example
  - 123 Main Street, Apt. 33, Boston, MA, USA

Geographic

- Size
  - 3 groups: Latitude, longitude, altitude
- Organization
  - 2-level independent
- Content
  - Latitude and longitude
    - Degrees, minutes, seconds
    - Or degrees and fractions
  - Altitude
    - Meters
- Broad/multicast support?
  - Geographic broadcast; no multicast
- Example
  - 34° 1’ 16.86”, -118 °17’ 27.5352” (elevation unknown)

Geographic names

Topological names

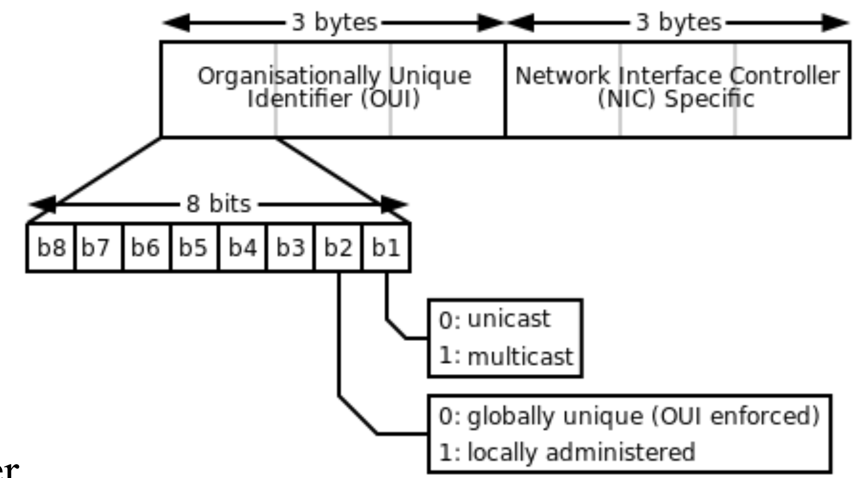


Telephone

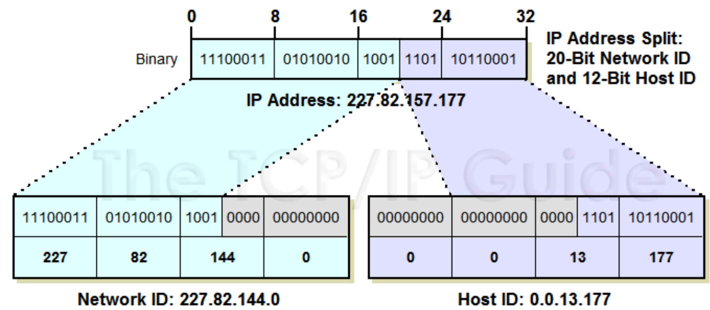
- Size
  - 6-N digits
- Organization
  - 3-4 level hierarchy of flat, variable
- Content
  - Flat variable country code
  - Flat variable region code
  - Flat variable exchange code
  - Flat variable line number
- Broad/multicast support?
  - No broadcast; no multicast
- Example
  - +49-89-636-48018

Ethernet

- Size
  - 6 bytes
- Organization
  - 2-level hierarchy of flat, fixed
- Content
  - Flat 3-byte OUI
    - Organizationally Unique Identifier
    - E.g., F0-F6-1C = Apple (one of many!)
  - Flat 3-byte NIC
    - Network Interface Controller
- Broad/multicast support?
  - Global broadcast; global multicast as configured
- Example
  - F0-F6-1C-24-E3-15

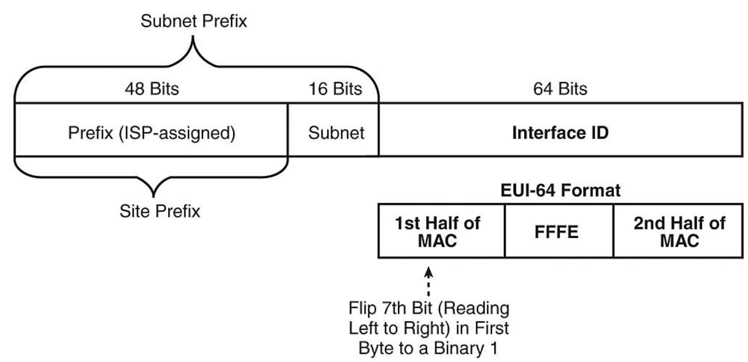


IPv4



- Size
  - 4 bytes
- Organization
  - 2-level hierarchy of flat, variable
- Content
  - Flat high-order network part
    - Assigned by IANA
    - Of variable length
  - Flat low-order host part
    - Assigned locally, either statically or via automation
    - Of variable length
- Broad/multicast support?
  - One-hop broadcast; global multicast as configured
- Example
  - 128.9.160.161

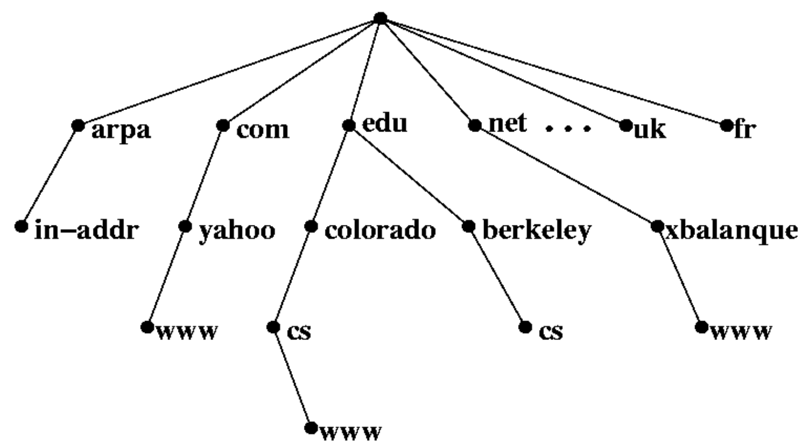
IPv6



- Size
  - 8 bytes
- Organization
  - 3-level hierarchy of flat, fixed
- Content
  - Flat, multi-level 6-byte site prefix
    - Assigned by IANA, variable
    - Assigned to ISPs hierarchically
  - Flat 2-byte subnet
    - Assigned locally, either statically or via automation
  - Flat 8-byte interface ID
    - Derived from Ethernet MAC address
- Broad/multicast support?
  - One-hop broadcast; multicast to preassigned groups or as configured
- Example
  - 2001:0:9d38:6ab8:3c1f:108d:b898:6b35

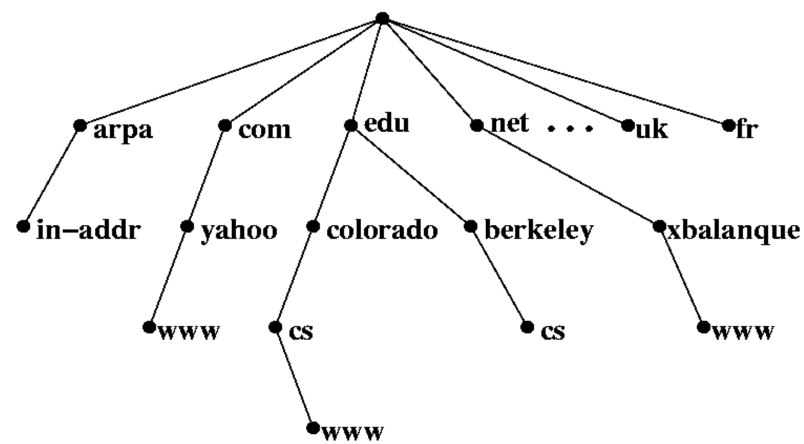
Host names (hosts.txt)

- Size
  - 1-N characters
- Organization
  - Variable-level sequence of flat, variable
- Content
  - Labels separated by "."
  - Organized right to left
    - Assigned and managed *globally*
- Broad/multicast support?
  - No broadcast; no multicast
- Example
  - lever.cs.ucla.edu
  - Each level can have different number of characters



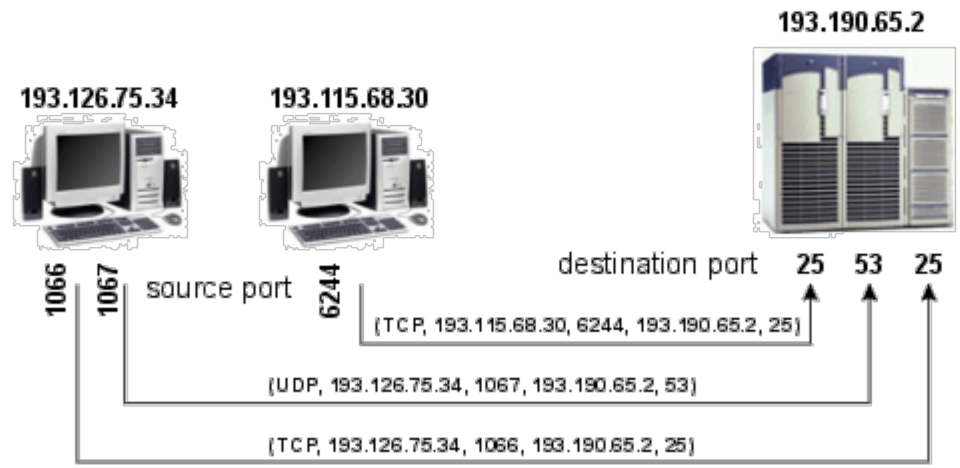
DNS

- Size
  - *1-63 byte labels, 1-253 bytes total*
- Organization
  - Variable-level *hierarchy* of flat, variable
- Content
  - Labels separated by “.”
  - *Delegated* right to left
    - Assigned and managed *locally*
- Broad/multicast support?
  - No broadcast; no multicast
- Example
  - lever.cs.ucla.edu
  - Again, possibly different number of characters at each level



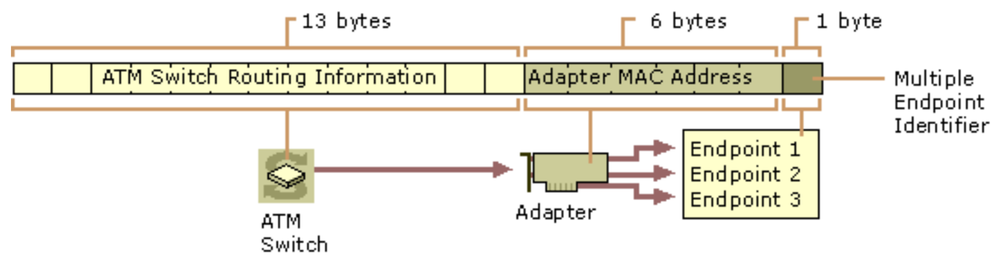
TCP, UDP, SCTP, etc.

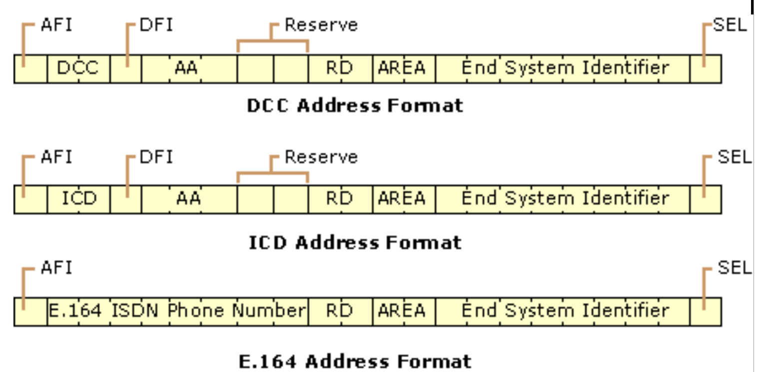
- Size
  - 2 4 byte labels, plus IPv4 or IPv6
- Organization
  - Three groups of flat
- Content
  - System (registered)
    - 0-1023, "privileged"
  - User (registered)
    - 1024-49151
  - Dynamic (self-assigned)
    - 49152-65535
- Broad/multicast support?
  - No broadcast; no multicast
- Example
  - 80 for HTTP, 53 for DNS



ATM

- Size
  - 20 bytes
- Organization
  - 3-level hierarchy of flat, fixed
- Content
  - 13-byte switch part
    - Three hierarchies
  - 6-byte interface part
    - Borrows Ethernet MAC
  - 1-byte selector part
    - Multiple endpoints within an interface
- Broad/multicast support?
  - No broadcast (emulation); no multicast
- Example
  - 47.0091810000000001604799FD01.0050A219F03B.0





Names also provide other information

- Names do more than identify
  - Cell area code – where/when you first got it
  - Social security – where/when you were born
  - People – lineage (typ. paternal)
  - Ethernet – who made your device and when
  - IPv6 – who your ISP is

Summary

- We can build more scalable networks by connecting nodes and relaying messages
- Nodes are connected in some topology
  – Different topologies have different characteristics
- Relaying needs more shared rules
  – And often also a place to wait
- Naming is one way to enable relaying