Distributed Systems

Communication and models

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Recap: Mutual exclusion

- Lamport's algorithm
  - Maintains a queue at each node
  - Takes 3(n-1) messages per CS
- Ricart and Agrawala's algorithm
  - Does not have a queue, delays replies
  - Takes 2(n-1) messages per CS
- We want ME with fewer messages

Maekawa’s Quorum algorithm

- Idea: instead of getting permission from all processes, get permission from only a subset of processes

- For each process i, we have a voting set (quorum) V_i
  - For all i,j: $V_i \cap V_j \neq \emptyset$
  - For all i, $i \in V_i$
  - Voting sets are same size, each node is part of same number of sets

Maekawa's Quorum algorithm

- Idea:
  - Arrange nodes in a square grid
  - Quorum for node i:
    - All nodes in same row or same column as i
  - Any two quorums intersect

- Complexity?

- Complexity per CS: $O(\sqrt{n})$

Communication & modeling

- Modeling: How we think about it
- Communication between nearby nodes
- Communication between distant nodes
- Communication with many nodes

Some terminology:

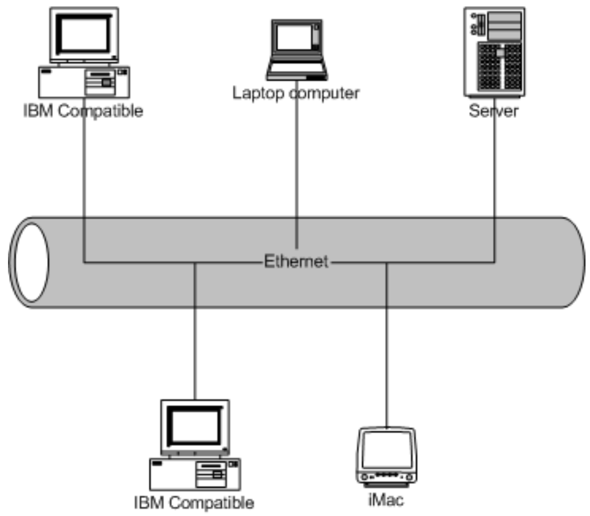
- One to “all”: Broadcast
  - All: in some set of interest
- One to one: point to point

Packets

- Networks communicate data in messages of fixed (bounded) size – called packets
- More data requires more packets
- Number of messages or packets transmitted is a measure of communication used

Local area networks

- **Medium: Broadcast**
  – Message goes from one computer to *all* other computers (restricted to some set)
    - For example, all other computers in the LAN, or some other system in consideration
  – Ethernet LAN is a broadcast medium
    - All computers are connected to a wire. They transmit messages on the wire and all can receive
  – Wireless LAN (WiFi) is a broadcast medium
    - Electromagnetic waves is the common medium



Local area networks

Advantages:

- Sending a common message to everyone is easy
- Finding destination is easy
  - Message goes to everyone
  - Just have a “destination” field

Main issue: Medium access

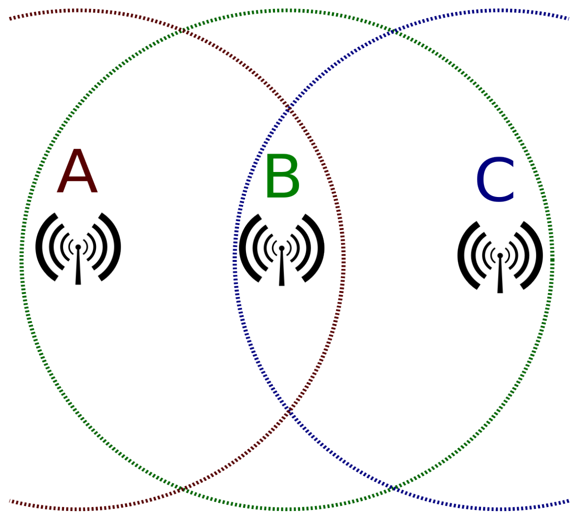
- Since medium is broadcast, two people transmitting at the same time garbles message

Medium access

- Only one transmission at a time can be allowed
  - Mutual exclusion problem (shared resource of communication wire)
  - We cannot use messages to solve it
  - Protocols:
    - TDMA: Everyone has a periodic slot
    - CSMA: See if anyone else is transmitting. If so, defer.
    - Usually acks are also used to ensure transmission
      - Retransmit if necessary
  - Bandwidth reduces with number of nodes trying to transmit.
    - One LAN should not have too many nodes

Medium access

- Wireless: more complicated
- Hidden terminal problem
- More complex protocol using acks

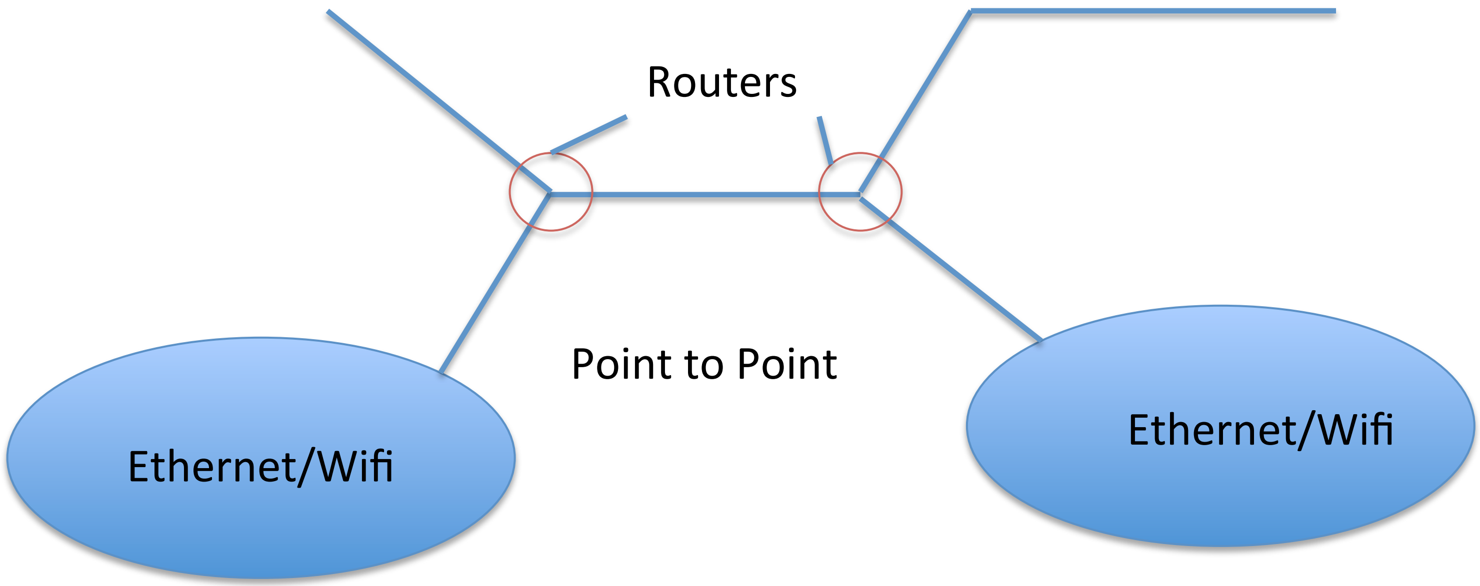


Our models

- Graph: Every node has an edge to every other
- We often assume that to send a message (packet) to a node on the same network takes one unit of time (or, at most a constant)
- This may not be true if there can be many nodes in the same LAN
  - But usually the number is not very large

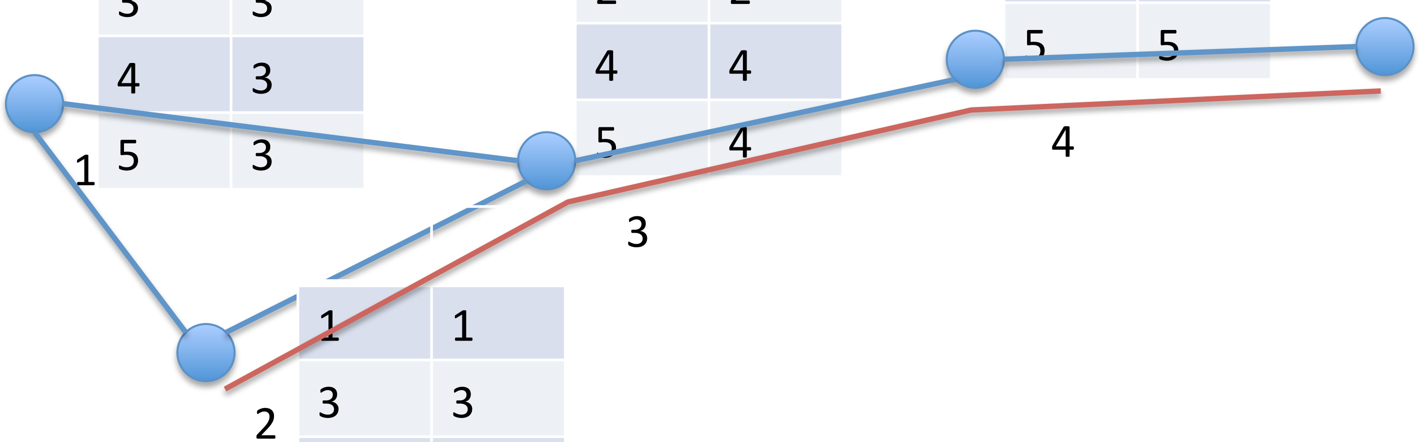
Real life networks

- LANs connected by routers



Routing

- Finding a path in the network
- Every node has a routing table
- Equivalent to a BFS tree for every node



Node 1:

2	2
3	3
4	3
5	3

Node 2:

1	1
3	3
4	3
5	3

Node 3:

1	1
2	2
4	4
5	4

Node 4:

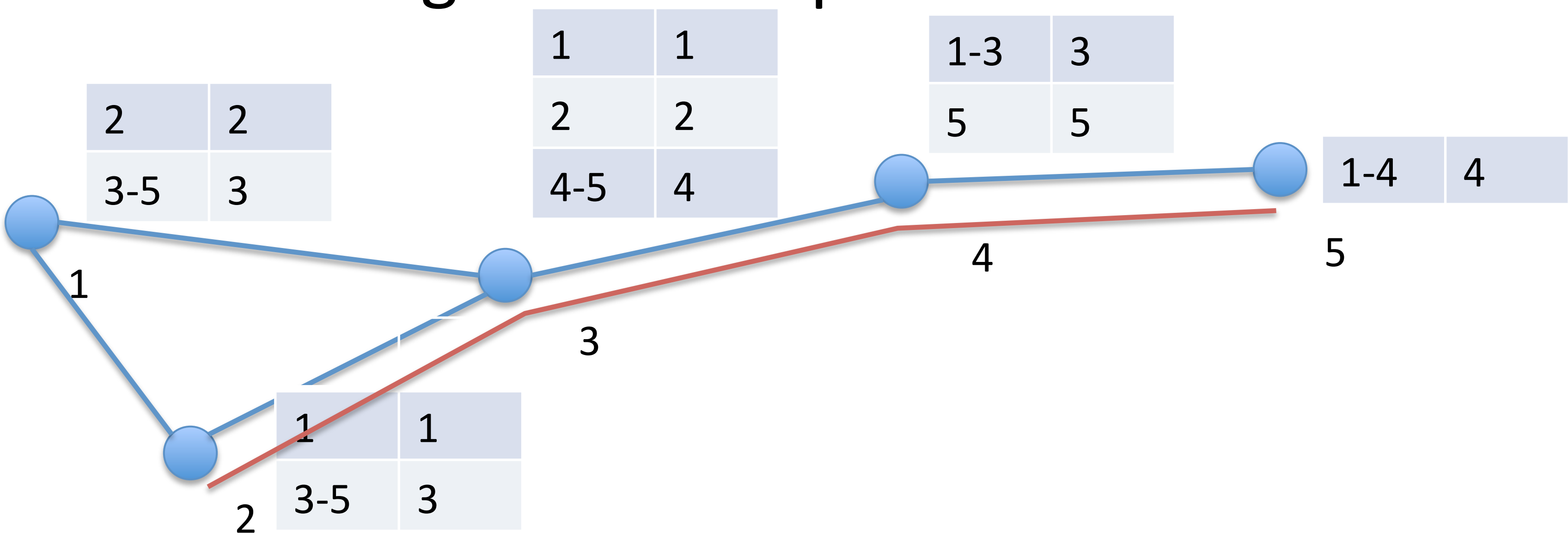
1	3
2	3
3	3
5	5

Node 5:

1	4
2	4
3	4
4	4

Routing: Distributed search for a path

- Smaller routing tables by combining addresses
- Used in IP (Internet) routing
- Smaller routing tables are preferable

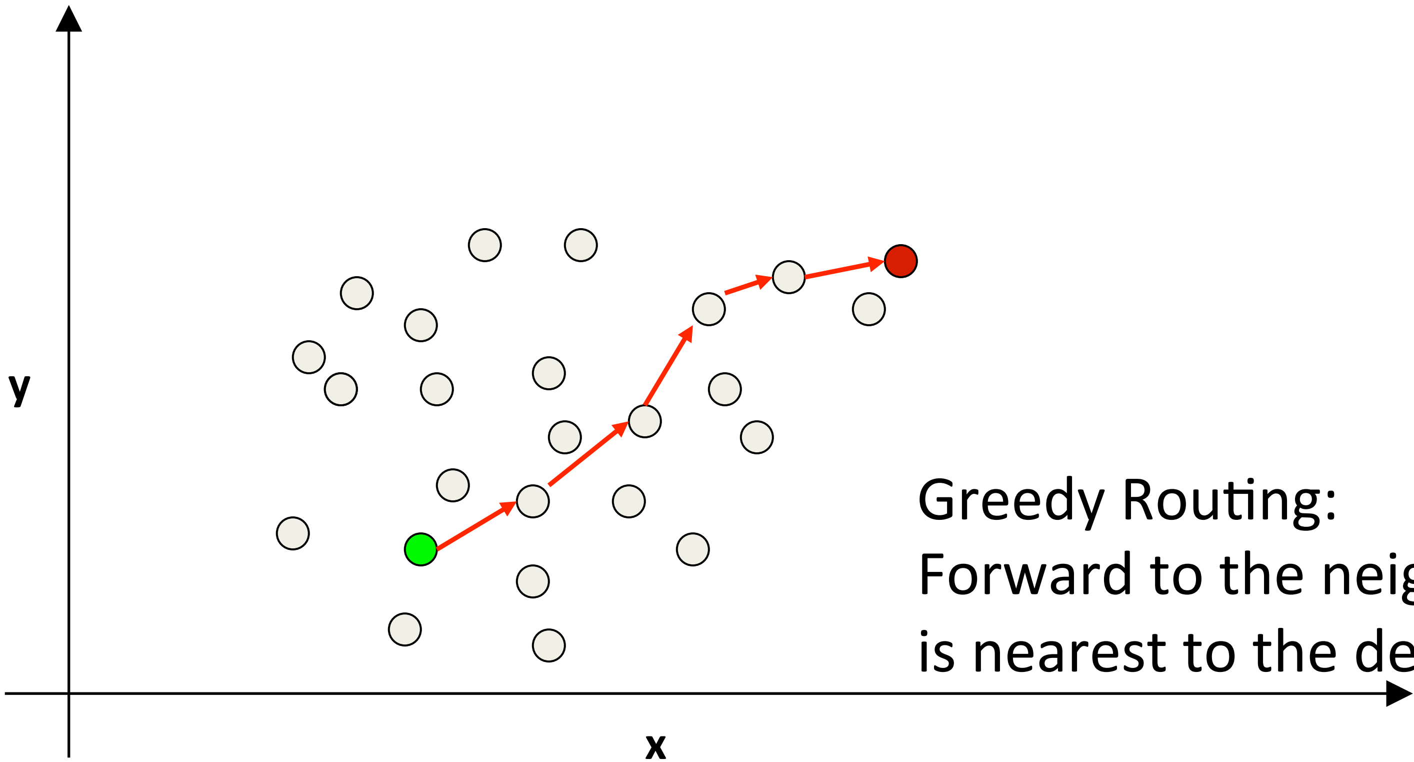


Routing

- Real routing is more complicated
- With more than one path to a destination, backups etc

Diversion: Location based routing

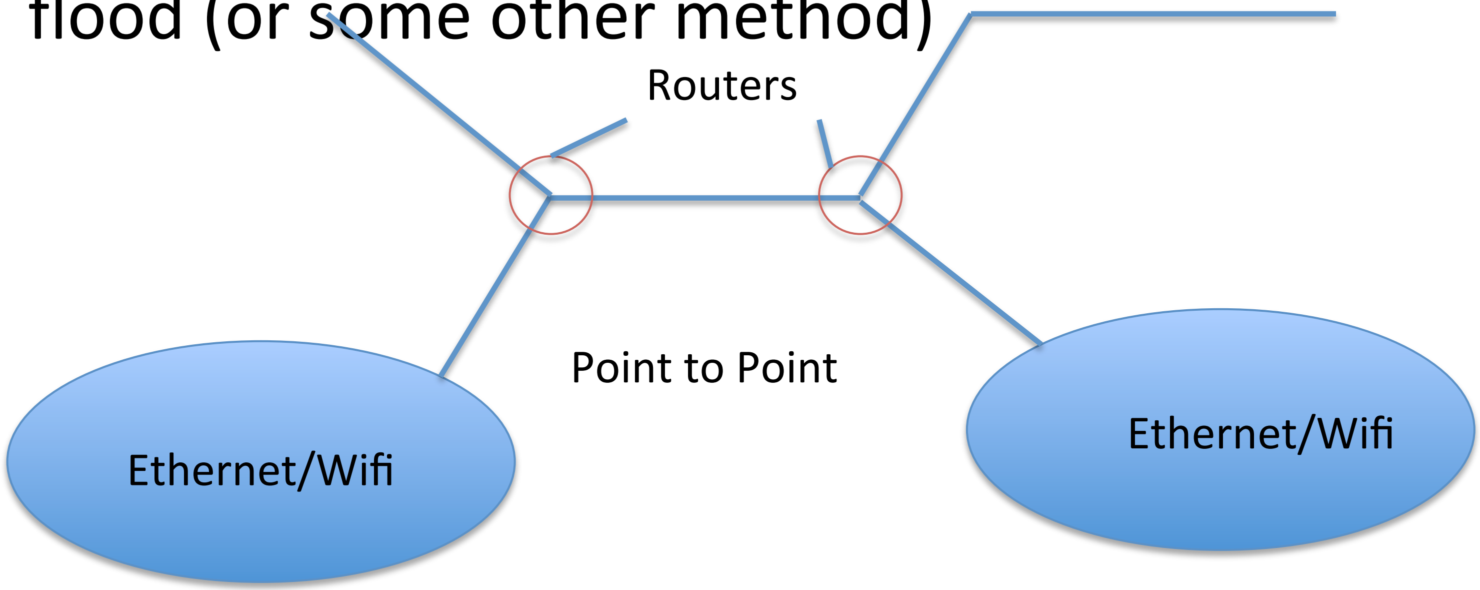
- Geographical routing uses a node's location to discover path to that node.



Greedy Routing:
Forward to the neighbor that is nearest to the destination

Large networks

- Communication is typically point-to-point using routing
- Broadcast is not automatic
  - If we need broadcast, we will have to arrange a flood (or some other method)



Transport management

- UDP:
  - Send a packet, hope that the network routes and delivers it, in time
  - No Sequence number
    - Not necessarily FIFO
  - Useful in streaming audio/video. Not for important data.

- TCP:
  - Send a packet (or few packets)
  - Packets have sequence number
    - FIFO
  - If no acks arrive, resend packets
  - If no acks are found after many tries, return error

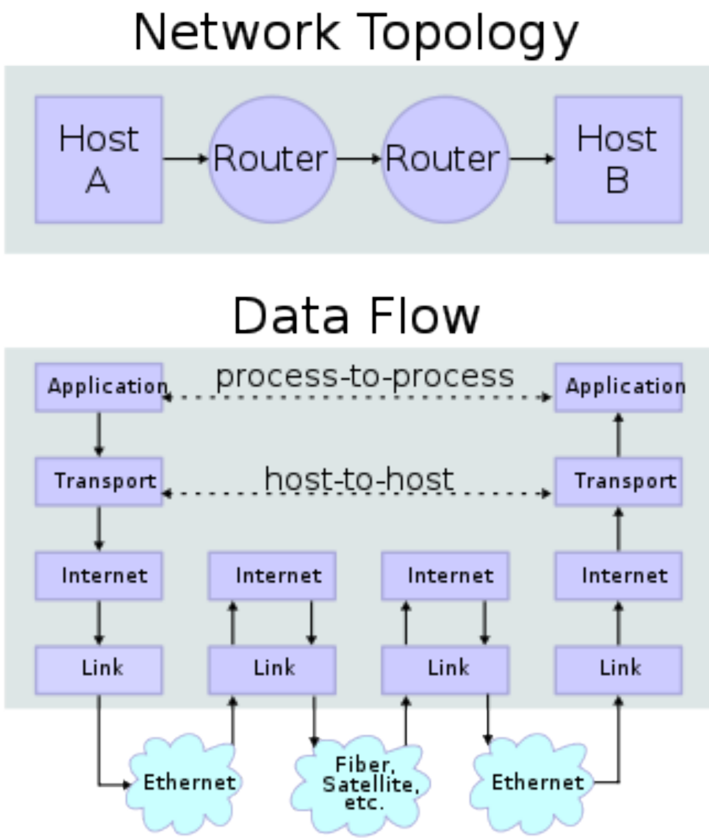
TCP

- Does distributed congestion control
  - When packets don’t get delivered, TCP slows down the stream
    - Assumption: routers drop packets when there are too many

- Difficulty
  - Acks may not arrive due to other factors
    - Some connection failed temporarily
    - User moved from one network to another

Network stack

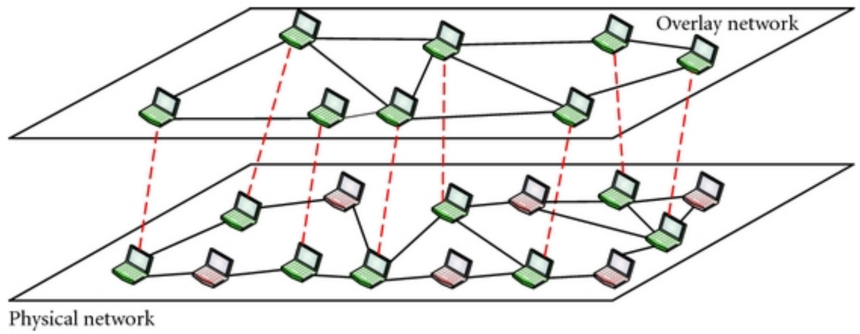
- Each layer solves a different distributed problem



Form wikipedia

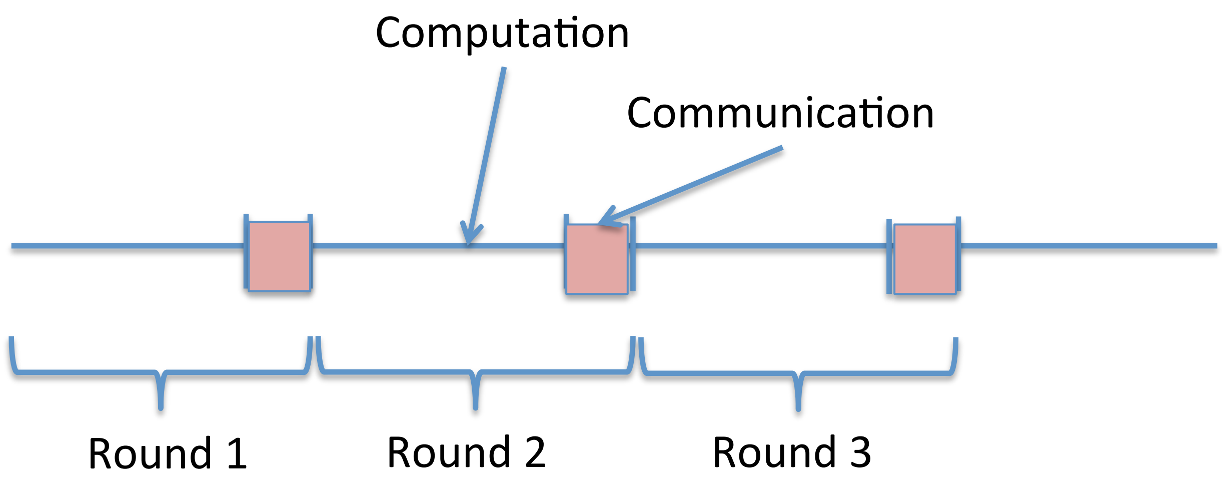
Communication: Overlay network

- We may sometimes ignore parts of the network
  - Nodes that carry messages but do not directly participate eg. routers
  - Or edges that exist but we are not using
  - Or we don't know about
- Often used in peer-to-peer networks
  - Not every node knows all other nodes in the network
  - But communicates to known nodes through routing



Computation

- Synchronous:
  - Operation in rounds
  - In a round, a node performs some computation, and then sends some messages
  - All messages sent at the end of round x are available to recipients at start of round x+1
    - But not earlier



Communication

- Synchronous
  - Can be implemented if message transmission time is bounded by some constant say m
  - Computation times for all nodes are bounded by some constant c
  - Clocks are synchronized (sufficiently)
  - Then set each round to be m+c in duration

Asynchronous Communication

- No synchronization or rounds
  - Nodes compute at different and arbitrary speeds
  - Messages proceed at different speeds: may be arbitrarily delayed, may be received at any time
- Worst case model
  - No assumption about speeds of processes or channel
  - (But does not include communication/computation errors)

Asynchronous Communication

- Harder to manage
  - Message can arrive at any time after being sent, must be handled suitably
  - Possible to make some simplifying assumptions E.g.:
    - Channels are FIFO: order of messages on a channel are preserved
    - Some code blocks are atomic (not interrupted by messages)
    - Either communication or computation times bounded

Synchronous communication in Real systems

- Synchronous communication can be a fair model
- Modern computers and networks are fast
  - (though not arbitrarily fast)
- Easier to design algorithms and analyze
- Well designed algorithms are faster and more efficient
- Often can be adapted to asynchronous systems
  - Often a starting point for design

Failures

- Nodes may fail
  - Hardware failure
  - Run out of energy or power failure
  - Software failure (crash)
  - Permanent
  - Temporary (what happens when it restarts? Recovers the state? Starts from initial state?)
  - Model depends on system. E.g. different types of failures occur with corresponding probabilities

Node failures

- Common abstract models
  - Stopping failure: node just stops working
    - May need assumptions about which computation/communication it finishes before stopping
    - May need assumption about neighbors knowing of failure
  - Byzantine failure: node behaves as an adversary
    - Imagine your enemy has taken control of the node
    - Is trying to spoil your computation
- Nodes may fail individually
  - E.g. each node fails with probability p
- Nodes may have correlated failure
  - E.g. all nodes fail in a region (data center, sensor field)

Link/communication failure

- May be temporary/permanent
- May happen due to
  - Hardware failure
  - Noise: electronic devices (microwaves etc) may transmit radio waves at similar frequencies and disrupt communication
  - Interference: Other communicating nodes nearby may disrupt communication
- Effects
  - Channel silent and unusable (hardware failure)
  - Channel active, but unusable due to noise and interference
  - Channel active, but may contain erroneous message (may be detected by error correcting codes)

Security

- Issues:
  - Unauthorized access, modification. Making systems unavailable (DOS)
  - Attack on one or more nodes
    - Causing to it fail
    - Read data
    - Taking control to read future data, disrupt operation
  - Attack on communication links/channel
    - Block communication
    - Read data in the channel (easy in wireless without encyption)
    - Corrupt data in the channel

Security

- Solutions usually have specific assumptions of what the adversary can do
- E.g. If adversary has access to channel
  - Cryptography may be able to prevent reading/ corrupting data

Mobility

- Movement makes it harder to design distributed systems
  - Communication is difficult
    - Delays, lost messages
    - Edge weights can change
  - Applications that depend on location must adapt to movement
- How do people move? What is a model of movement?
  - Not yet well understood

Modeling distributed systems

- Many possibilities
- Choose your assumptions carefully for your problem
- Pay close attention to what is known about communication/network
- Start with simpler models
  - Usually more assumptions, fewer parameters
  - See what can be achieved
  - Then try to drop/relax assumptions