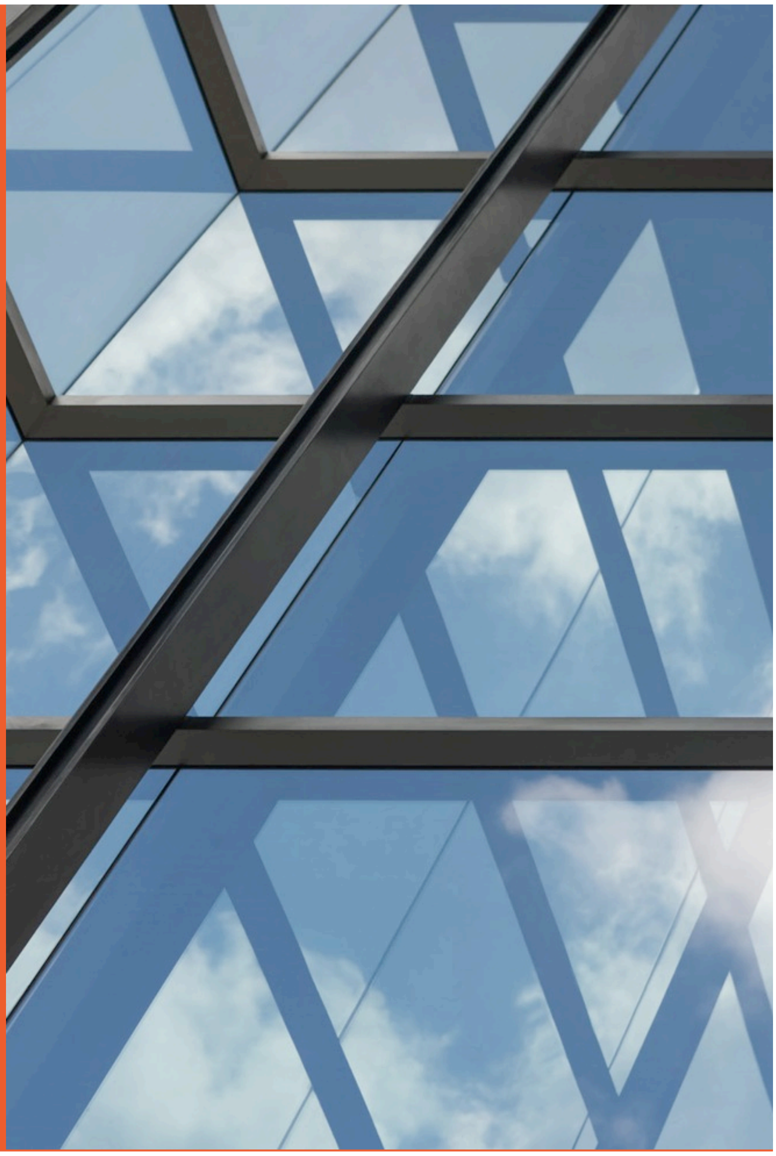
COMP3221: Distributed Systems

Communciation 1/2

Unit coordinator Dr. Vincent Gramoli
Lecturer Dr. Guillaume Jourjon
School of Information Technologies

THE UNIVERSITY OF SYDNEY



Introduction

- Previous lecture:
  - Shared memory allows multiple programs to communicate

- Today's lecture:
  - What if we don't have shared memory?
  - How to implement an alternative communication medium, like message channel?

Outline

- Layered protocols
- Routing
- Socket
- Message passing interface (MPI)
- Message-oriented middleware (MOM)

Layered Protocols

Communication problem

Communicating is about transmitting encoded information

- Problem: two computers must agree on the code (language) they use
- Open standards give rules for everyone to communicate with each other
  - International Standards Organization (ISO)

  The Open Systems Interconnection (OSI) reference model names communication levels, and assigns roles to each level

  - Internet Engineering Task Force (IETF)

  The Request For Comments (RFC) are a public description of internet communication protocols (e.g., TCP->RFC793, UDP->RFC768, SMTP->RFC2821, ICMP->RFC792)
- Private "closed" protocols exist
  - Skype: people did reverse engineering to discover the protocol, find security issues, or to implement IM clients

Two modes of communication

Connection oriented vs. Connectionless

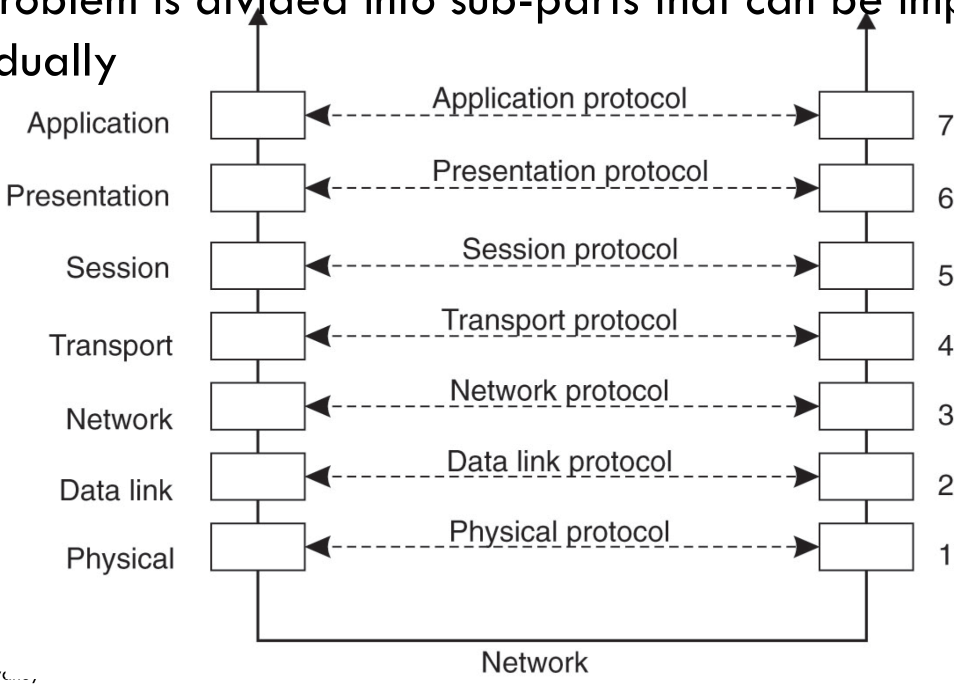
- Connection oriented
  - Establish explicitly a connection with a partner before exchanging data
  - Protocol example: Transmission Control Protocol (TCP)
  - Application usage: file transfer, web browsing, email

- Connectionless
  - No setup in advance is needed
  - Protocol example: User Datagram Packet (UDP, IP)
  - Application usage: VoIP (Skype), IPTV

Layers

OSI layers

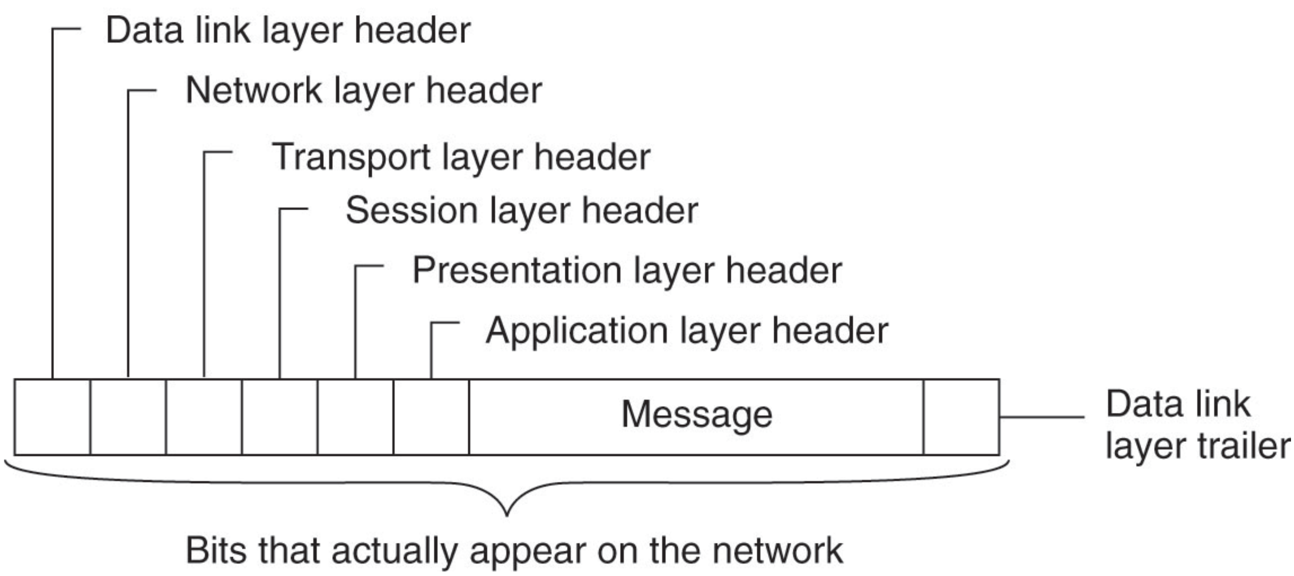
- Each layer deals with one specific aspect of the communication
- The problem is divided into sub-parts that can be implemented individually



Layers

Message structure

- As the message go through lower layers before being sent, each layer adds its header to the message.
- Upon reception, the message is unmarshalled by the successive layers from bottom to top



Network communication

Low-level layers

- Physical layer: send bits (0 and 1)

- Data link layer :
  - groups bits into frames
  - assigns sequence numbers to frames and adds special bits at the beginning and end
  - adds a checksum (the result of some operation on the frame content)
  - If receiver disagree about the checksum, then it asks the sender to resend
  - Example: Ethernet for *Local Area Network (LAN)* or PPTP in *Virtual private network (VPN)*

- Network layer
  - Example: *Internet Protocol* (IP) for *Wide Area Network* (WAN)

Network communication

Transport and higher level layers

- Transport layer:
  - split the message from the application layer
  - number them
  - add the amounts of sent and remaining packets

- Reliable transport layer can be built on top of:
  - Connection-oriented protocol: packet would be ordered
  - Connectionless protocol: packet could be reordered

- Example of transport layer protocol: Transmission Control Protocol (TCP)
- Example of transport layer and network layer combination: TCP/IP

Network communication

High level layers

- OSI specifies three higher level layers:
  - Session layer: dialog control, transfer check-pointing
  - Presentation layer: says how information is represented
  - Application
- Session
  - Example:
    - Domain Name Service (DNS)
    - Lightweight Directory Protocol (LDAP)
  - Sometimes the session layer is omitted: Internet protocol suite.
- Application
  - Hypertext Transfer Protocol (HTTP)
  - File Transfer Protocol (FTP)
  - TCP/IP Terminal Emulation Protocol (Telnet)
  - X-Window

Network communication

<ins>Analogy</ins>: Mail service vs. Web service

- Application (no clue of intermediary steps):
  - You post a letter with some address, the receiver reads it
  - HTTP: A user types a URL in a browser, a server sends back the web page
- Transport (error control):
  - Upon writing a wrong address on a letter, the letter will be sent back to you
  - TCP initialized a connection, checks for potential errors and may retransmit
- Internet (recipient is unknown):
  - An airplane moves letters between cities without knowing the recipients
  - IP brings packets over the WAN potentially from one LAN to another
- Data link:
  - Trucks move letters within a city
  - Ethernet handles transmission within the LAN
- Physical layer:
  - Use pen to write and glasses to read letters
  - Specifying fiber, wire, radio to transmit the one and zero encoding the message

IPv6

Internet Protocol version 6 (IPv6): new version of IP based on IPv4

- IPv6 packets are carried over Ethernet with the content type 86DD (hexadecimal) instead of IPv4's 0800.

End 2011, there were ~2.3x10^9 users

- Scalability in the number of addresses
  IPv6 increases the IP address size from 32 bits (4,294,967,296 in total) to 128 bits, to support more levels of addressing hierarchy, a much greater number of addressable nodes and simpler auto-configuration of addresses

- Scalability of multicast addresses is introduced
  A new type of address called an *anycast address* is also defined, to send a packet to any one of a group of nodes

- Efficient forwarding
  Changes in the way IP header options are encoded: Hop-by-Hop Option, Routing (Type 0), Fragment, Destination Option, Authentication, Encapsulation Payload

- Greater flexibility for additional options

Routing

Routing Problem

What are routing protocols used for?

- Related to path finding problem in graphs
- Graph nodes represent internet routers, edges are communication links
- Dijkstra thought about the shortest path algorithm in Amsterdam when trying to find his way [Frana&Misa, CACM'10]

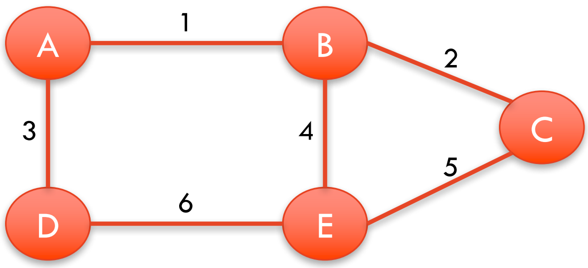
GPS clients use shortest path algorithms

- Two main classes of protocols/algorithms:
  1. Distance-vector: neighbours exchange their routing table
  2. Link-state: neighbours only exchange connectivity information
- Routing is necessary in all networks except *Local Area Networks (LANs)* where Ethernet provides direct communication between all pairs of attached hosts
- The routing protocol is implemented in the network layer of each router to determine the route for the transmission of packets to their destination
- In large networks, adaptive routing is employed: the best route for communication between two points in the network is re-evaluated periodically, taking into account the current traffic in the network

Distance-vector routing algorithm

Router Information Protocol (RIP)

- Mainly used in internet up to 1979
- Relies on Bellman-Ford algorithm: Bellman algorithm [1957] distributed by Ford and Fulkerson [1972]



Routing table of router A		
Dest.	**Dir**	**Cost**
A	local	0
B	1	1
C	1	2
D	3	1
E	1	2

- General idea: maintain a table representing the direction for each destination

1. Every period t (=30sec) and whenever the local routing table T_L changes, send T_L to all accessible neighbours
2. Upon reception of a table T_R with a new destination or a lower-cost route to an existing destination, update the local table T_L

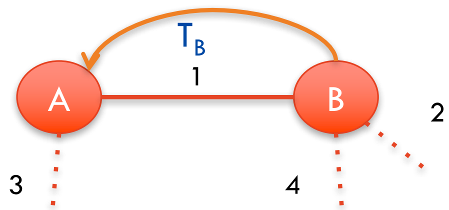
If a node detects a link failure, it sets ∞ as the associated cost of such a link and sends its local table to neighbours

Eventually (when failures stop) each router gets for each destination the direction leading to the minimal cost

Distance-vector routing algorithm

RIP (con't)

Example: A receives table T_B from B



Routing table T_L of router A		
Dest.	**Dir**	**Cost**
A	local	0
D	3	1

Received routing table T_R		
Dest.	**Dir**	**Cost**
A	1	1
B	local	0
C	2	1
D	1	2
E	4	1

Each router executes the same code:

1. Send: Each t seconds or when T_L changes, send T_L on each non-faulty outgoing link

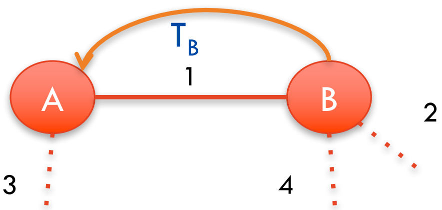
1. Receive: Whenever a routing table T_R is received on link n:

```
for all rows R_R in T_R {
  if (R_R.dir ≠ n) {
     R_R.cost = R_R.cost + 1
     R_R.dir = n
     // add new destination to T_L
     if (R_R.dest is not in T_L) add R_R to T_L
     else for all rows R_L in T_L {
       if (R_R.dest = R_L.dest and
          (R_R.cost < R_L.cost or R_L.dir = n))
          R_L = R_R
          // R_R.cost < R_L.cost: remote node's better route
          // R_L.dir = n: remote node is more authoritative
     }
  }
}
```

Distance-vector routing algorithm

RIP (con't)

Example: A receives table T_B from B



Routing table T_L of router A		
Dest.	**Dir**	**Cost**
A	local	0
D	3	1

Received routing table T_R		
Dest.	**Dir**	**Cost**
A	1	1
B	local	0
C	2	1
D	1	2
E	4	1

Each router executes the same code:

1. Send: Each t seconds or when T_L changes, send T_L on each non-faulty outgoing link

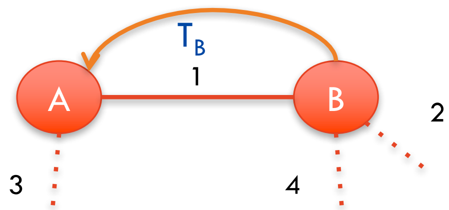
1. Receive: Whenever a routing table T_R is received on link n:

for all rows R_R in T_R {
  $\boxed{\textbf{if } (R_R.dir \neq n) \{}$
    R_R.cost = R_R.cost + 1
    R_R.dir = n
    // add new destination to T_L
    if (R_R.dest is not in T_L) add R_R to T_L
    else for all rows R_L in T_L {
      if (R_R.dest = R_L.dest **and**
        (R_R.cost < R_L.cost **or** R_L.dir = n))
        R_L = R_R
        // R_R.cost < R_L.cost: remote node's better route
        // R_L.dir = n: remote node is more authoritative
    }
  }
}

Distance-vector routing algorithm

RIP (con't)

Example: A receives table T_B from B



Routing table T_L of router A		
Dest.	Dir	Cost
A	local	0
D	3	1

Received routing table T_R		
Dest.	Dir	Cost
A	1	1
B	~~local~~ 1	~~0~~ 1
C	~~2~~ 1	~~1~~ 2
D	~~1~~ 1	~~2~~ 3
E	~~4~~ 1	~~1~~ 2

Each router executes the same code:

1. Send: Each t seconds or when T_L changes, send T_L on each non-faulty outgoing link

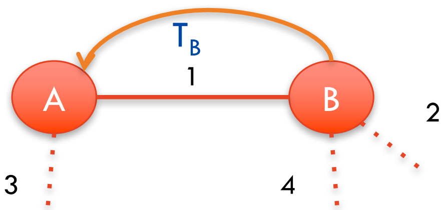
1. Receive: Whenever a routing table T_R is received on link n:

```
for all rows R_R in T_R {
  if (R_R.dir ≠ n) {
    R_R.cost = R_R.cost + 1
    R_R.dir = n
    // add new destination to T_L
    if (R_R.dest is not in T_L) add R_R to T_L
    else for all rows R_L in T_L {
      if (R_R.dest = R_L.dest and
        (R_R.cost < R_L.cost or R_L.dir = n))
        R_L = R_R
        // R_R.cost < R_L.cost: remote node's better route
        // R_L.dir = n: remote node is more authoritative
    }
  }
}
```

Distance-vector routing algorithm

RIP (con't)

Example: A receives table T_B from B



Routing table T_L of router A		
Dest.	**Dir**	**Cost**
A	local	0
B	1	1
C	1	2
D	3	1
E	1	2

Received routing table T_R		
Dest.	**Dir**	**Cost**
A	1	1
B	~~local~~ 1	~~0~~ 1
C	~~2~~ 1	~~1~~ 2
D	~~1~~ 1	~~2~~ 3
E	~~4~~ 1	~~1~~ 2

Each router executes the same code:

1. Send: Each t seconds or when T_L changes, send T_L on each non-faulty outgoing link

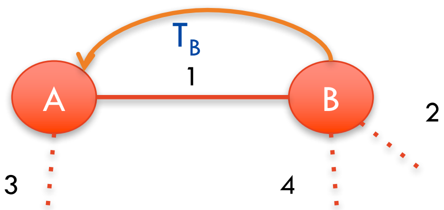
1. Receive: Whenever a routing table T_R is received on link n:

for all rows R_R in T_R {
  if (R_R.dir ≠ n) {
    R_R.cost = R_R.cost + 1
    R_R.dir = n
    // add new destination to T_L
    if (R_R.dest is not in T_L) add R_R to T_L
    else for all rows R_L in T_L {
      if (R_R.dest = R_L.dest **and**
        (R_R.cost < R_L.cost **or** R_L.dir = n))
        R_L = R_R
        // R_R.cost < R_L.cost: remote node's better route
        // R_L.dir = n: remote node is more authoritative
      }
    }
}

Distance-vector routing algorithm

RIP (con't)

Example: A receives table T_B from B



Routing table T_L of router A		
Dest.	**Dir**	**Cost**
A	local	0
B	1	1
C	1	2
D	3	1
E	1	2

Received routing table T_R		
Dest.	**Dir**	**Cost**
A	1	1
B	~~local~~ 1	~~0~~ 1
C	~~2~~ 1	~~1~~ 2
D	~~1~~ 1	~~2~~ 3
E	~~4~~ 1	~~1~~ 2

Each router executes the same code:

1. Send: Each t seconds or when T_L changes, send T_L on each non-faulty outgoing link

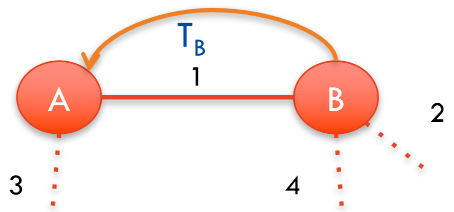
1. Receive: Whenever a routing table T_R is received on link n:

```
for all rows R_R in T_R {
  if (R_R.dir ≠ n) {
     R_R.cost = R_R.cost + 1
     R_R.dir = n
     // add new destination to T_L
     if (R_R.dest is not in T_L) add R_R to T_L
     else for all rows R_L in T_L {
       if (R_R.dest = R_L.dest and
         (R_R.cost < R_L.cost or R_L.dir = n))
          R_L = R_R
          // R_R.cost < R_L.cost: remote node's better route
          // R_L.dir = n: remote node is more authoritative
     }
  }
}
```

Distance-vector routing algorithm

RIP (con't)

<u>Example</u>: A receives table T_B from B



Routing table T_L of router A		
Dest.	**Dir**	**Cost**
A	local	0
B	1	1
C	1	2
D	3	1
E	1	2

Received routing table T_R		
Dest.	**Dir**	**Cost**
A	1	1
B	~~local~~ 1	~~0~~ 1
C	~~2~~ 1	~~1~~ 2
D	~~1~~ 1	~~2~~ 3
E	~~4~~ 1	~~1~~ 2

<u>Each router executes the same code:</u>

1. <u>Send</u>: Each t seconds or when T_L changes, send T_L on each non-faulty outgoing link

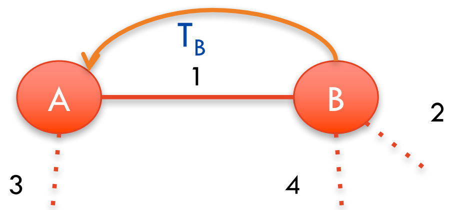
1. <u>Receive</u>: Whenever a routing table T_R is received on link n:

```
for all rows R_R in T_R {
    if (R_R.dir ≠ n) {
        R_R.cost = R_R.cost + 1
        R_R.dir = n
        // add new destination to T_L
        if (R_R.dest is not in T_L) add R_R to T_L
        else for all rows R_L in T_L {
            if (R_R.dest = R_L.dest and
             (R_R.cost < R_L.cost or R_L.dir = n))
             R_L = R_R
             // R_R.cost < R_L.cost: remote node's better route
             // R_L.dir = n: remote node is more authoritative
        }
    }
}
```

Distance-vector routing algorithm

RIP (con't)

<u>Example</u>: A receives table T_B from B



Routing table T_L of router A		
Dest.	**Dir**	**Cost**
A	local	0
B	1	1
C	1	2
D	3	1
E	1	2

<u>Each router executes the same code:</u>

1. <u>Send</u>: Each t seconds or when T_L changes, send T_L on each non-faulty outgoing link

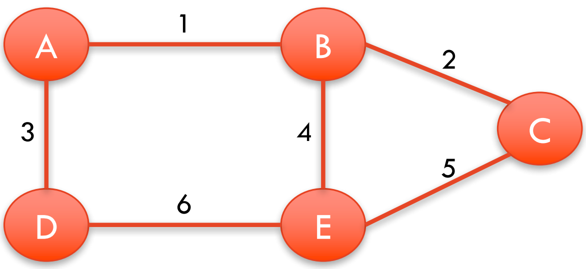
1. <u>Receive</u>: Whenever a routing table T_R is received on link n:

```
for all rows R_R in T_R {
    if (R_R.dir ≠ n) {
        R_R.cost = R_R.cost + 1
        R_R.dir = n
        // add new destination to T_L
        if (R_R.dest is not in T_L) add R_R to T_L
        else for all rows R_L in T_L {
            if (R_R.dest = R_L.dest and
             (R_R.cost < R_L.cost or R_L.dir = n))
              R_L = R_R
             // R_R.cost < R_L.cost: remote node's better route
             // R_L.dir = n: remote node is more authoritative
        }
    }
}
```

Distance-vector routing algorithm

RIP (con't)

<u>Let's re-start the algorithm from scratch</u>: all routing tables are empty



Routing table of router A		
Dest.	**Dir**	**Cost**
A	local	0

Routing table of router B		
Dest.	**Dir**	**Cost**
B	local	0

Routing table of router C		
Dest.	**Dir**	**Cost**
C	local	0

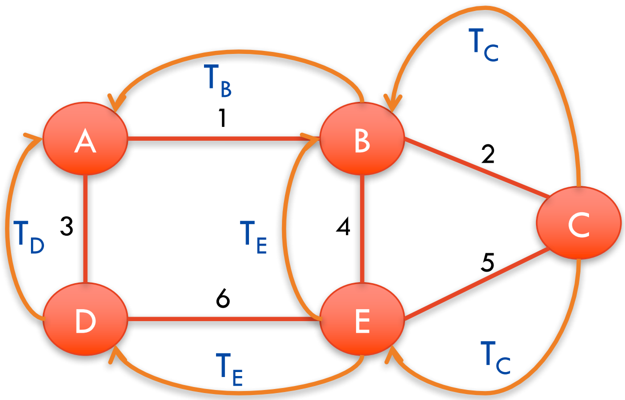
Routing table of router D		
Dest.	**Dir**	**Cost**
D	local	0

Routing table of router E		
Dest.	**Dir**	**Cost**
E	local	0

Distance-vector routing algorithm

RIP (con't)

– <u>Example</u>: How is routing table A built from scratch?

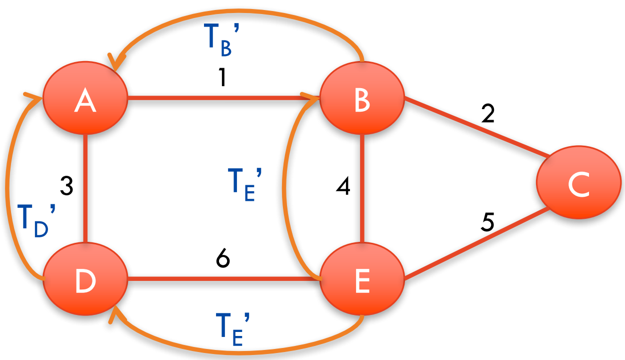


Routing table of router A		
Dest.	**Dir**	**Cost**
A	local	0
B	1	1
D	3	1

Distance-vector routing algorithm

RIP (con't)

– <u>Example</u>: How is routing table A built from scratch?

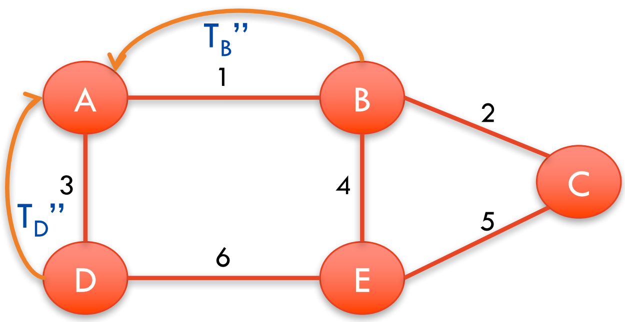


Routing table of router A		
Dest.	**Dir**	**Cost**
A	local	0
B	1	1
C	1	2
D	3	1
E	1	2

Distance-vector routing algorithm

RIP (con't)

– <u>Example</u>: How is routing table A built from scratch?



Routing table of router A		
Dest.	**Dir**	**Cost**
A	local	0
B	1	1
C	1	2
D	3	1
E	1	2

Distance-vector routing algorithm

RIP (con't)

- Advantages:
  - Simple
  - Efficient in small networks

- Limitations:
  - Costs based on the number of hops is unrealistic (bandwidth of links counts)
  - No big deal: this is just a matter of defining link weights (support negative values)
  - Inefficient in large networks as loops may occur before the convergence state is reached

To address this inefficiency more scalable routing protocols, called linked state, were proposed

Link-state routing protocol

Dijkstra's Algorithm: find the shortest path from a node i to other nodes

- Edsger Dijkstra 1956
  - Assume that each link (from i to j) has an associated non-negative cost (Cij)
  - N, set of nodes
  - s, source node that starts the algo
  - V = {s}, set of visited nodes
  - Find the shortest distance Dj from s to every node j
- Used in IS-IS (IP) and OSPF protocols

<u>Init the routing table for node s:</u>

```
  for all nodes in N:
    if j neighbor of s: Dj = Csj
    else Dj = ∞
    Ds = 0
```

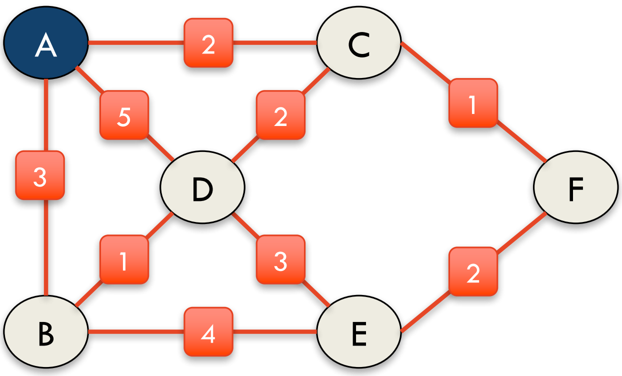
<u>Algo for routing table of node s:</u>

```
while (V ≠ N) { // while some nodes are unvisited
   select node i such that
       Di = min{ Dj : j ∉ V} // i, closer unvisited node
   for all nodes j ∉ V: // for all unvisited node j
       if (Dj > Di + Cij)  // if cheaper through i
          Dj = Di + Cij    // update the distance to j
          Lj = i → j       // take link i to route to j
   V = V U {i}
}
```

Link-state routing protocol

Dijkstra's Algorithm (con't)

– Example: routing table A



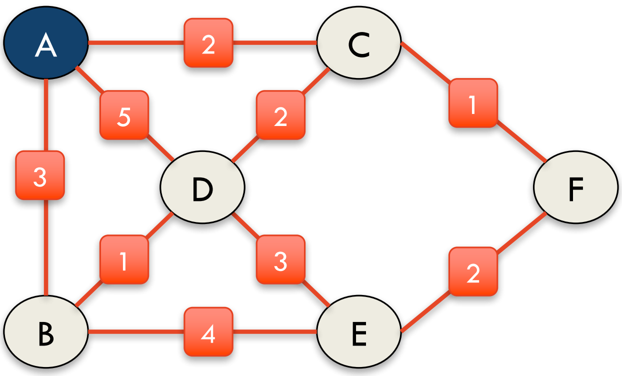
i = C

Routing table of router A		
Dest.	**L**	**D**
A	∅	0
B	A→B	3
C	A→C	2
D	A→D	5
E	?	∞
F	?	∞

Link-state routing protocol

Dijkstra's Algorithm (con't)

– <u>Example: routing table A</u>



i = C

Routing table of router A		
Dest.	**L**	**D**
A	∅	0
B	A→B	3
C	A→C	2
D	A→D	5
E	?	∞
F	?	∞

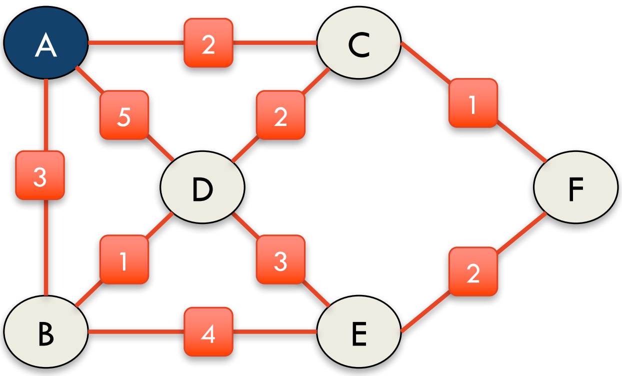
$D_D > D_C + C_{CD}$

$D_F > D_C + C_{CF}$

Link-state routing protocol

Dijkstra's Algorithm (con't)

– Example: routing table A



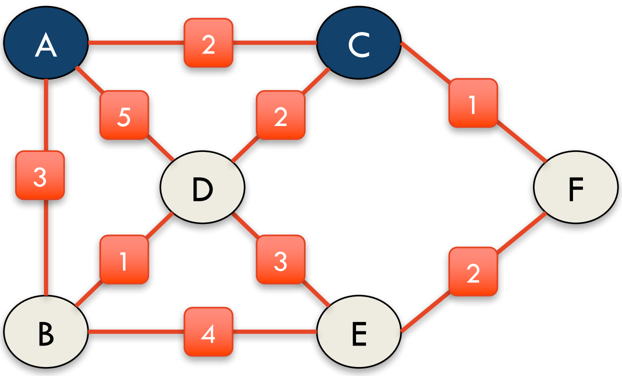
i = C

Routing table of router A		
Dest.	**L**	**D**
A	∅	0
B	A→B	3
C	A→C	2
D	C→D	4
E	?	∞
F	C→F	3

Link-state routing protocol

Dijkstra's Algorithm (con't)

– <u>Example: routing table A</u>



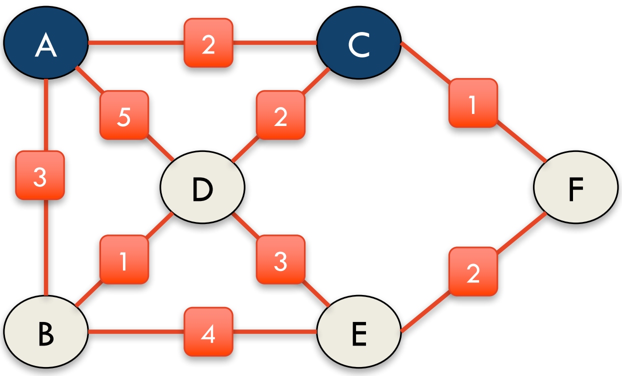
i = B

Routing table of router A		
Dest.	**L**	**D**
A	∅	0
B	A→B	3
C	A→C	2
D	C→D	4
E	?	∞
F	C→F	3

Link-state routing protocol

Dijkstra's Algorithm (con't)

– Example: routing table A



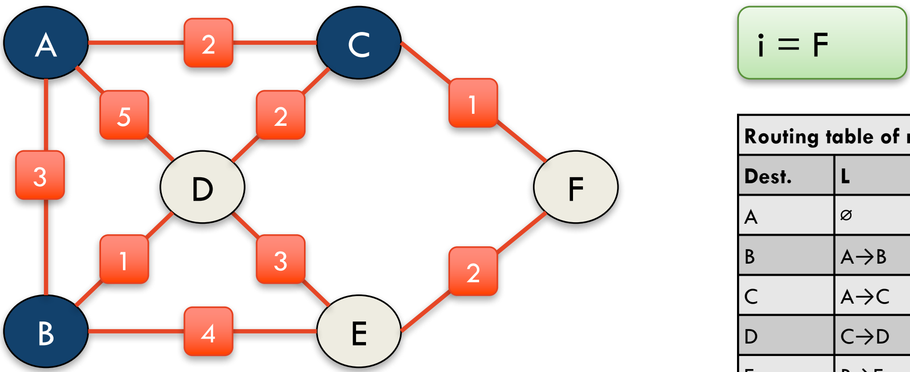
i = B

Routing table of router A		
Dest.	**L**	**D**
A	∅	0
B	A→B	3
C	A→C	2
D	C→D	4
E	B→E	7
F	C→F	3

Link-state routing protocol

Dijkstra's Algorithm (con't)

– Example: routing table A

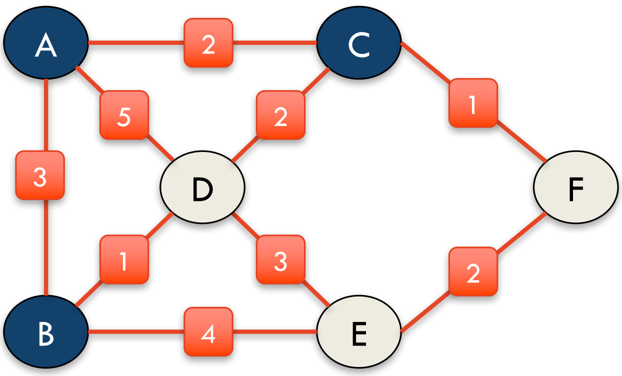


Routing table of router A		
Dest.	**L**	**D**
A	∅	0
B	A→B	3
C	A→C	2
D	C→D	4
E	B→E	7
F	C→F	3

Link-state routing protocol

Dijkstra's Algorithm (con't)

– <u>Example: routing table A</u>



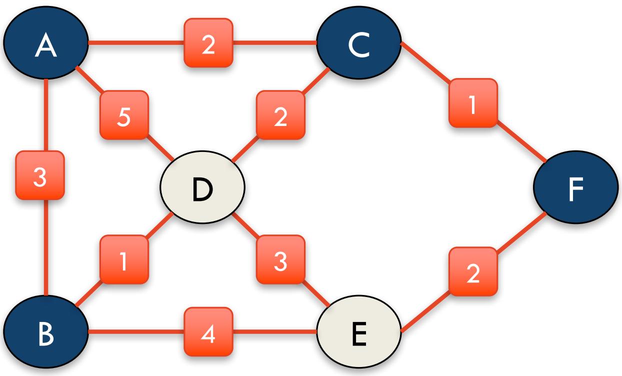
i = F

Routing table of router A		
Dest.	**L**	**D**
A	∅	0
B	A→B	3
C	A→C	2
D	C→D	4
E	F→E	5
F	C→F	3

Link-state routing protocol

Dijkstra's Algorithm (con't)

– <u>Example: routing table A</u>



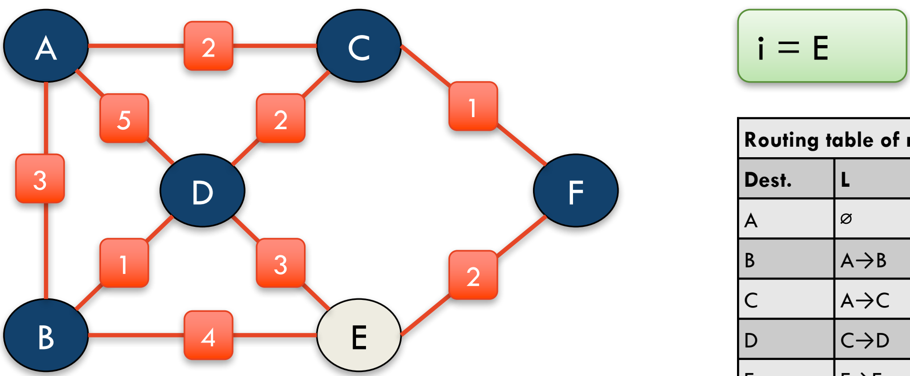
i = D

Routing table of router A		
Dest.	**L**	**D**
A	∅	0
B	A→B	3
C	A→C	2
D	C→D	4
E	F→E	5
F	C→F	3

Link-state routing protocol

Dijkstra's Algorithm (con't)

– <u>Example: routing table A</u>

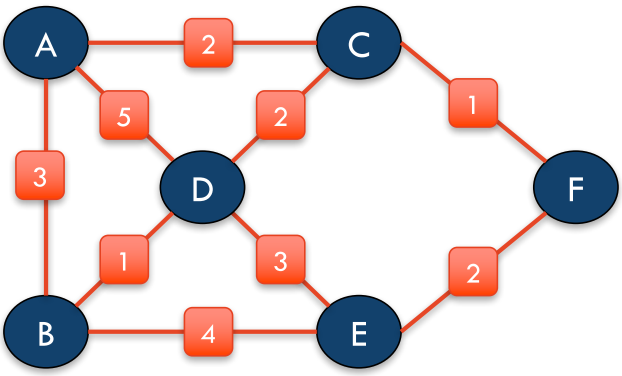


Routing table of router A		
Dest.	**L**	**D**
A	∅	0
B	A→B	3
C	A→C	2
D	C→D	4
E	F→E	5
F	C→F	3

Link-state routing protocol

Dijkstra's Algorithm (con't)

– Example: routing table A



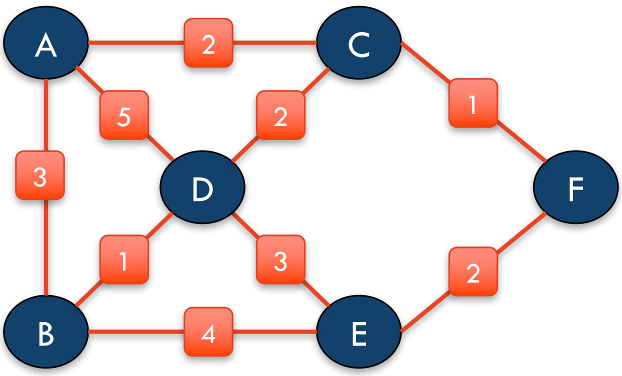
done

Routing table of router A		
Dest.	**L**	**D**
A	∅	0
B	A→B	3
C	A→C	2
D	C→D	4
E	F→E	5
F	C→F	3

Link-state routing protocol

Dijkstra's Algorithm (con't)

– <u>Example: routing table A</u>



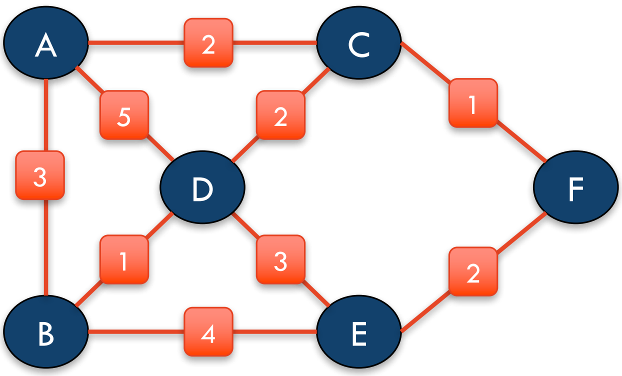
Routing table of router A		
Dest.	**L**	**D**
A	∅	0
B	A→B	3
C	A→C	2
D	C→D	4
E	F→E	5
F	C→F	3

– How to exploit such an inverted routing table?

Link-state routing protocol

How to route?

– <u>Example: routing from A to E</u>



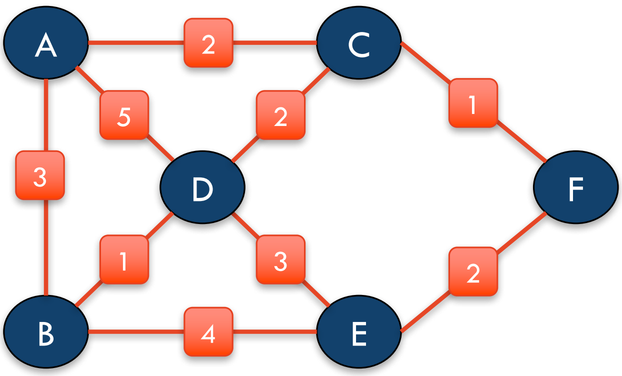
E

Routing table of router A		
Dest.	**L**	**D**
A	∅	0
B	A→B	3
C	A→C	2
D	C→D	4
E	F→E	5
F	C→F	3

Link-state routing protocol

How to route?

– Example: routing from A to E



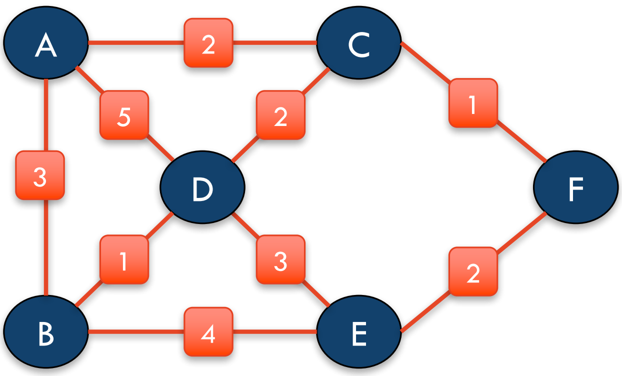
F→E

Routing table of router A		
Dest.	**L**	**D**
A	∅	0
B	A→B	3
C	A→C	2
D	C→D	4
E	F→E	5
F	C→F	3

Link-state routing protocol

How to route?

– <u>Example: routing from A to E</u>



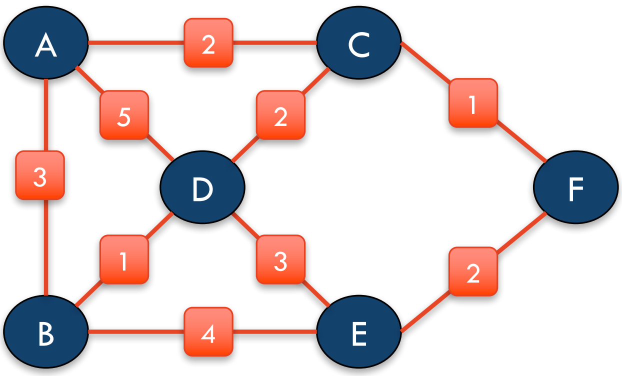
C→F→E

Routing table of router A		
Dest.	**L**	**D**
A	∅	0
B	A→B	3
C	A→C	2
D	C→D	4
E	F→E	5
F	C→F	3

Link-state routing protocol

How to route?

– Example: routing from A to E



A→C→F→E

Routing table of router A		
Dest.	**L**	**D**
A	∅	0
B	A→B	3
C	A→C	2
D	C→D	4
E	F→E	5
F	C→F	3

– A→C→F→E is the shortest path from A to E

Socket

THE UNIVERSITY OF SYDNEY

Socket

Definition

- *Socket*: a communication end-point to which an application can write data that is to be sent out over the underlying network, and from which incoming data can be read

- A pair of processes communicating over a network employ a pair of sockets, one for each process

- A socket is identified by an IP address concatenated with a port number

- In general, sockets use the client-server model:
  - The server waits for incoming client requests by listening to a specified port
  - Once a request is received, the server accepts a connection from the client socket to complete the connection

Socket

Berkley Sockets: Socket interface as proposed in Berkley UNIX in the 70's

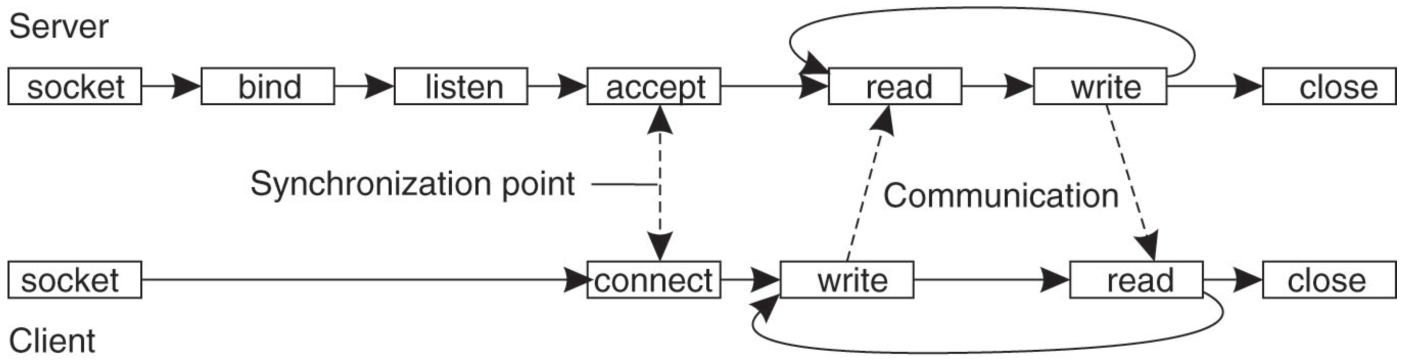
1. Servers generally execute the first 4 primitives and block on accept
2. Bind associates the newly created socket to a local address and a port; the client binds implicitly to any available port
3. The client connects to a specified address which blocks until response
4. Once the connection is accepted by the server, the system creates a new socket with the same properties as the original one; the client and server can communicate with send and receive.

Primitive	Meaning
Socket	Create a new communication end point
Bind	Attach a local address to a socket
Listen	Announce willingness to accept connections
Accept	Block caller until a connection request arrives
Connect	Actively attempt to establish a connection
Send	Send some data over the connection
Receive	Receive some data over the connection
Close	Release the connection

Socket

Berkley Sockets: Socket interface as proposed in Berkley UNIX in the 70's

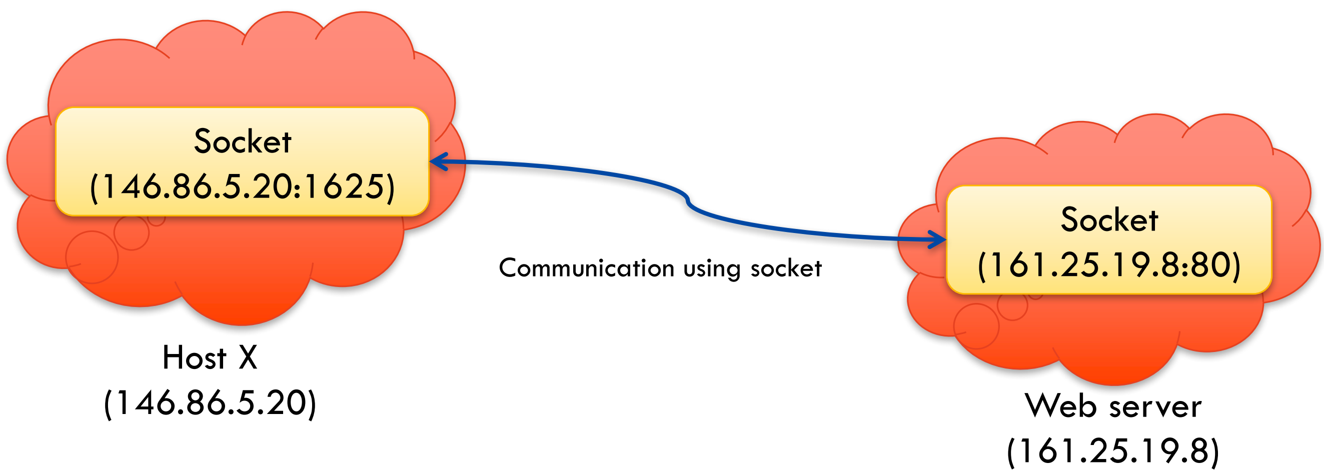
1. Servers generally execute the first 4 primitives and block on accept
2. Bind associated the newly created socket to a local address and a port; the client binds implicitly to any available port
3. The client connects to a specified address which blocks until response
4. Once the connection is accepted by the server, the system creates a new socket with the same properties as the original one; the client and server can communicate with send and receive.



Socket

Port

- Port numbers <1024 are for specific service protocols
  e.g., 80:HTTP, SSH:22, FTP:21, SMTP:25
- A client initiating a connection is assigned a free port number (>1024) by its host



Socket

Java Sockets

- Three socket classes:
  - DatagramSocket: Connectionless (UDP) socket, to open a lightweight communication favoring throughput rather than reliability
  - MulticastSocket: Multicast socket (subclass of DatagramSocket) to send data to multiple recipients
  - Socket: Connection-oriented (TCP) socket, to open a connection for reliable communication

Socket

Java TCP Sockets

```java
public class Server {

  public static void main(String[] args) {
    try {
      // Create a socket on port 6013
      ServerSocket sock = new ServerSocket(6013);
      while (true) {
        Socket client = sock.accept();
        … // communicate with the client
        client.close(); // close socket
      }
    } catch (Exception e) {
        System.err.println("I/O problem");
    }
  }
}
```

```java
public class Client {

  public static void main(String[] args) {
    try {
      // Specify server address and port for socket
      Socket sock = new Socket("127.0.0.1", 6013);


      … // communicate with the server
      sock.close(); // close socket

    } catch (Exception e) {
        System.err.println("server? or I/O problem");
    }
  }
}
```

Backup

Message-Passing Interface (MPI)

THE UNIVERSITY OF SYDNEY

MPI

MPI vs. Sockets

- Sockets
  - Limited set of primitives, providing only send and receive for communication
  - Exploits general purpose communication layered protocols (e.g., TCP/IP, UDP)
  - For example, TCP/IP aims at being tolerant to message losses

- MPI
  - Hardware and platform independent
  - Direct use of underlying network (no multiple layers)
  - Assume no failures, communication involves a group of processors

MPI

Some of the MPI communication primitives:

- Blocking synchronous send (MPI_ssend) and asynchronous send (MPI_bsend)
- RPC-like mechanism (MPI_sendrecv)
- Pointers passed as a parameter to MPI_isend and MPI_issend, MPI takes care of communication
- Blocking recv (MPI_recv) and non-blocking one (MPI_irecv)
- Variety of communication primitives allows for optimizations but makes it more complex

Primitive	Meaning
MPI_bsend	Append outgoing message to a local send buffer
MPI_send	Send a message and wait until copied to local or remote buffer
MPI_ssend	Send a message and wait until receipt starts
MPI_sendrecv	Send a message and wait for reply
MPI_isend	Pass reference to outgoing message, and continue
MPI_issend	Pass reference to outgoing message, and wait until receipt starts
MPI_recv	Receive a message; block if there is none
MPI_irecv	Check if there is an incoming message, but do not block

MPI is used in high-performance parallel applications

Message-Oriented Middleware (MOM)

THE UNIVERSITY OF SYDNEY

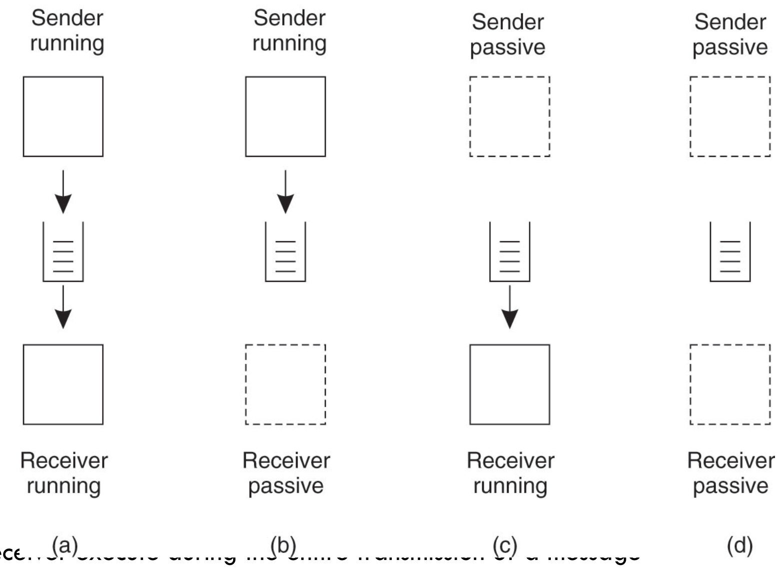
MOM

- Characteristics:
  - Do not require sender and receiver to be active during communication ($\neq$RMI cf. next week)
  - Offering intermediate storage capacity for messages
  - Typically target long (> minutes) message transfers

- Principles:
  - Each application maintains its local queue
  - And sends messages to other application queues
  - Unaware of the reading of its messages (recipient can be down at sending time)

MOM

Scenarios



- (a) Both sender and receiver execute during the entire transmission of a message
- (b) Only the sender is executing while the receiver is passive
- (c) The sender is passive while the receiver is active
- (d) The system is storing message (and potentially sending to intermediate servers) while sender and receiver are passive

MOM

Interface

- The sender uses put to enqueue a message in a non-blocking way
- The get primitive returns the longest pending message of the queue or may be tuned to return the highest priority message (in a priority queue)
- poll is the non-blocking variant of the get
- Callbacks can be used to automatically fetch new messages from the receiver side via notify

Primitive	Meaning
Put	Append a message to a specified queue
Get	Block until the specified queue is nonempty, and remove the first message
Poll	Check a specified queue for messages, and remove the first. Never block
Notify	Install a handler to be called when a message is put into the specified queue

Conclusion

- Network protocols are divided into layers
- IPv6 is necessary for the Internet Protocol scalability

- Routing protocols are
  - simple but not scalable (distance-vector) or
  - more complex but scalable (link-state)

- There are various ways of communicating depending on the needs:
  - General-purpose communication (Socket)
  - High performance parallel communication (MPI)
  - Very long message transmission (MOM)

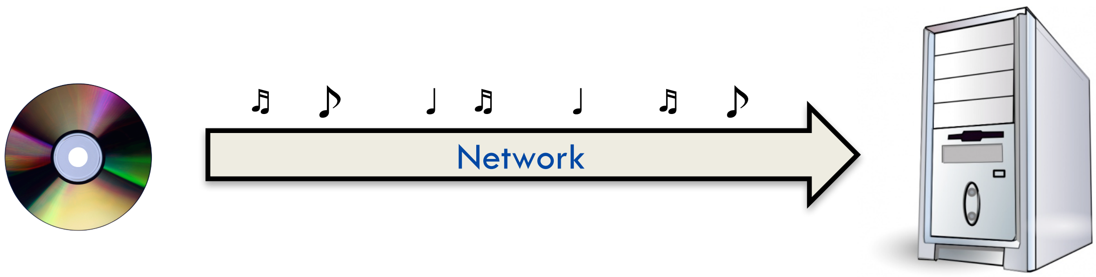
Stream-Oriented Communication

THE UNIVERSITY OF SYDNEY

Stream-oriented communication

When timing is crucial

- Previous communication modes do not guarantee transmission rate
- In stream-oriented communication, the stream should not be interrupted, i.e., messages should kept being received at regular (typically small) time intervals

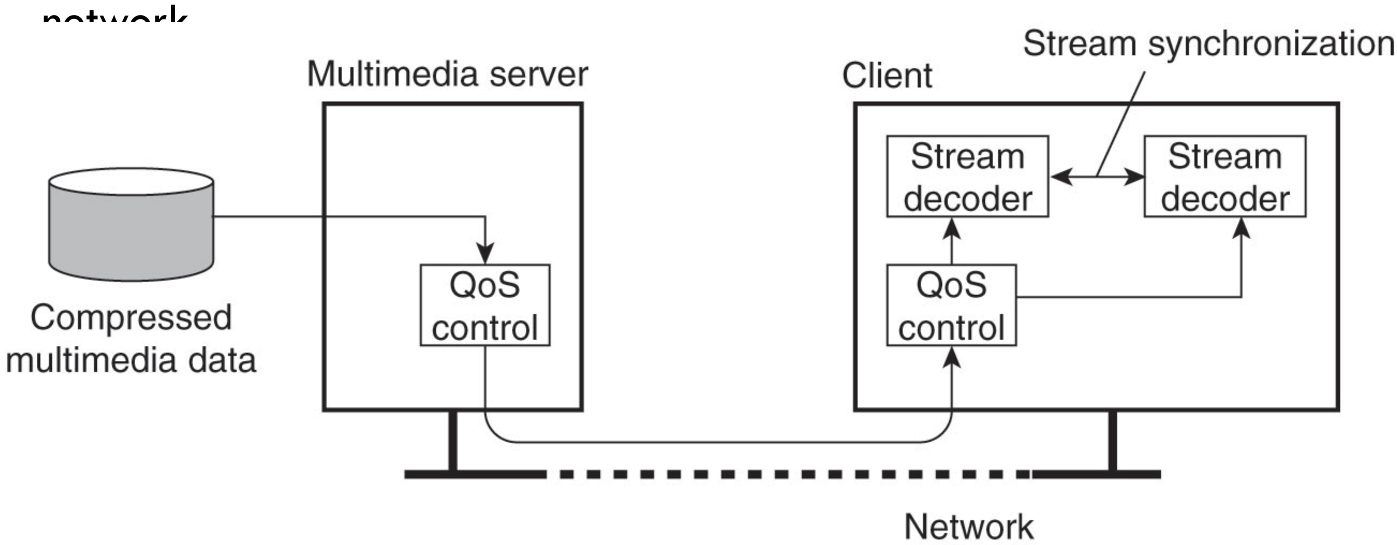


- <u>Example</u>: an *audio stream* in CD quality w/ sound wave at 44,100Hz
  - Destination starts reading before the entire information has been transmitted
  - Each piece of data should be read in order at fixed rate: every 1/44,100 seconds.

Stream-oriented communication

Supporting streams in a distributed system

- Example: architecture for streaming stored multimedia data over a network



- The streaming of live data leaves less opportunity for tuning the stream

Stream-oriented communication

Quality of Service (QoS)

- Requirements to ensure that the temporal relationships in a stream can be preserved:
  - The required bit rate at which data should be transported
  - The maximum delay until a session has been set up (i.e., when an application can start sending data)
  - The maximum end-to-end delay (i.e., how long it will take until a data unit makes it to a recipient)
  - The maximum delay variance, or jitter
  - The maximum round-trip delay

Stream-oriented communication

Best effort protocols do not guarantee delivery of QoS

- Problem: how to stream over internet?
  - Internet Protocol (IP) is best effort, it drops packet
  - IP rarely implements QoS

- But packets can be marked as belonging to one of several classes
  - Expedited forwarding class: packet should be forwarded with absolute priority
  - Assured forwarding class: defines a range of priority on packets to be dropped

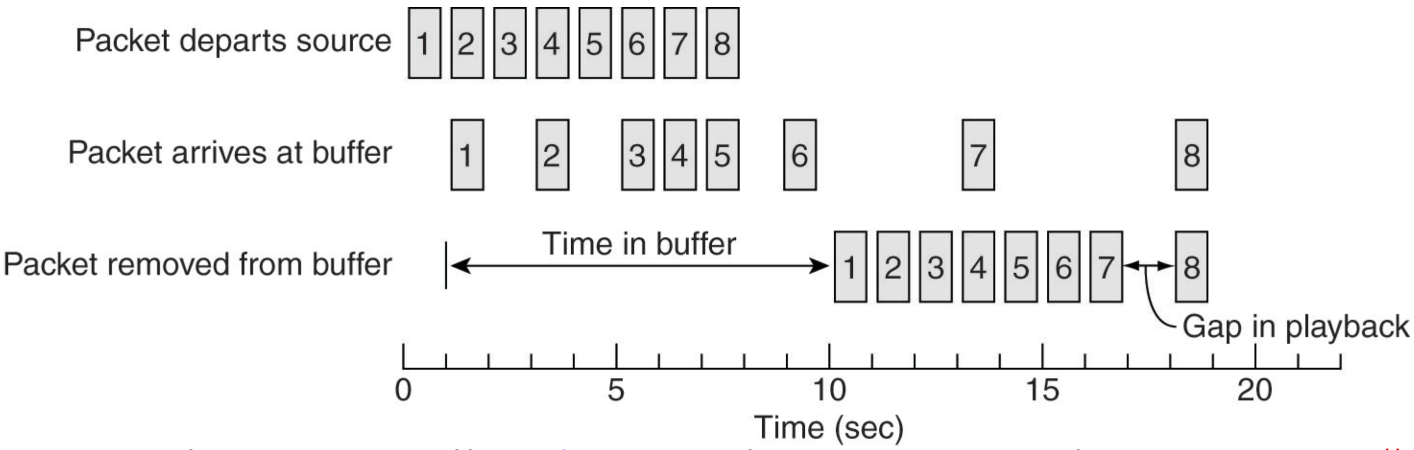
Stream-oriented communication

Buffer to cope with variable delays

› Use a buffer to store several data in advance at the receiver

› If packets are delayed with a certain variance but the average rate is sustainable

› The receiver can pass packets to the application at regular time intervals

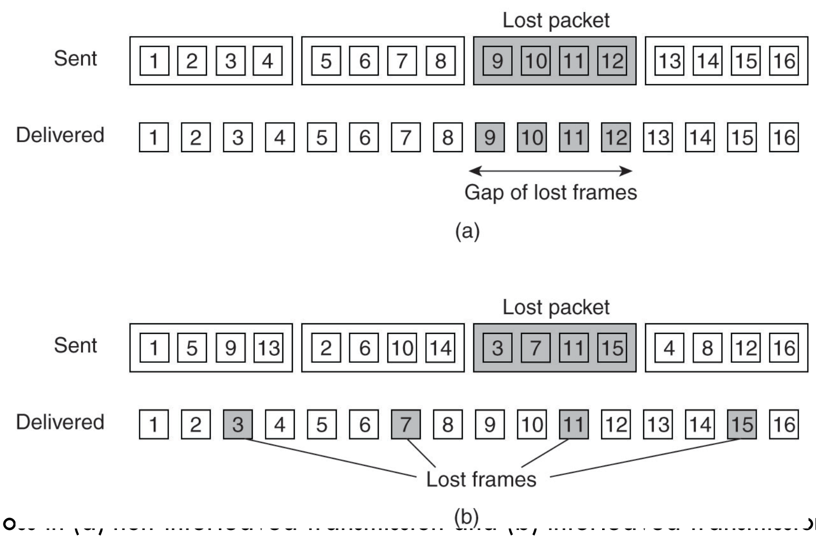


› The size of the receiver buffer is 9 seconds of packets to pass, unfortunately packet #8 took 11 seconds to reach the receiver at which time the buffer was empty.

Stream-oriented communication

Error correction and interleaving to cope with message losses

- With best effort protocols, packets can be dropped
- TCP/IP retransmit drops packets, yet this is too heavy for streaming application
- Forward error correction: k out of n packets are enough to reconstruct k packets
- Interleaving circumvents dropped packet to contain multiple consecutive audio and video frame



- The effect of packet loss in (a) non interleaved transmission and (b) interleaved transmission