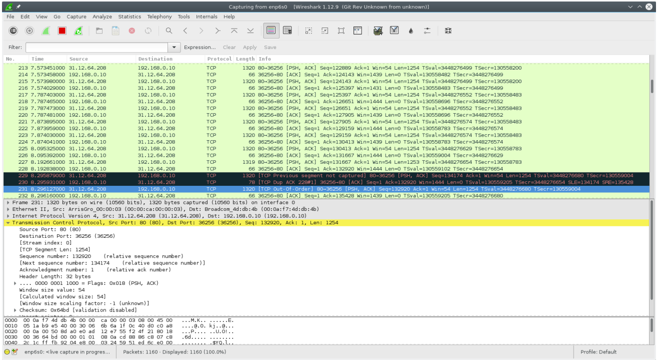
Networks and Network Programming

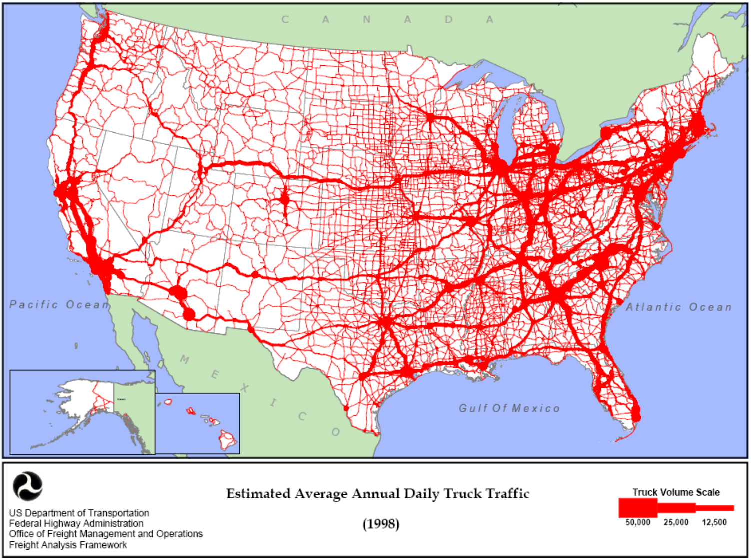


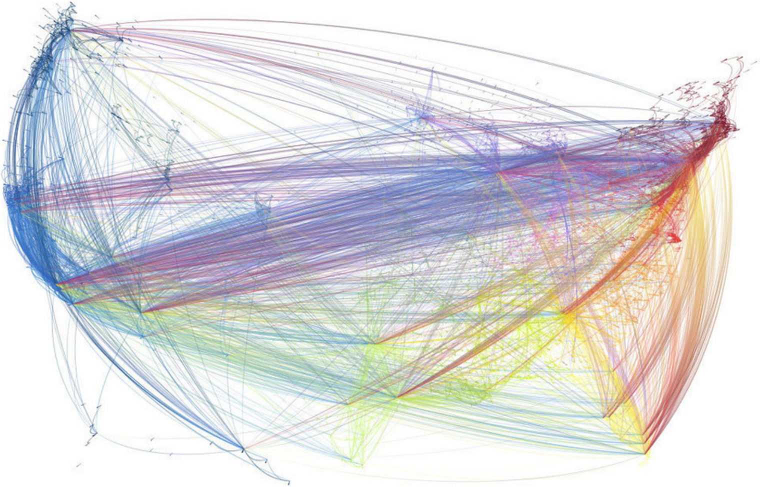
Wireshark screenshot of network traffic

Networking

- Hardware
- Protocols
- Software

The network is the computer. (John Gage)


C A N A D A
Pacific Ocean
Atlantic Ocean
Gulf Of Mexico
M E X I C O
US Department of Transportation
Federal Highway Administration
Office of Freight Management and Operations
Freight Analysis Framework
Estimated Average Annual Daily Truck Traffic
(1998)
Truck Volume Scale
50,000
25,000
12,500



Networking Options

Network type	maximum bandwidth (Mbits/second)	latency (microsecs)
Fast Ethernet	100	200
Gigabit Ethernet	1000	20–62
10 Gigabit Ethernet	10,000	4
Infiniband	2,000-290,000	0.5–5

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Internet backbone uses specialized hardware and has speeds up to 500G/s. Experimental systems are available for much higher speeds.

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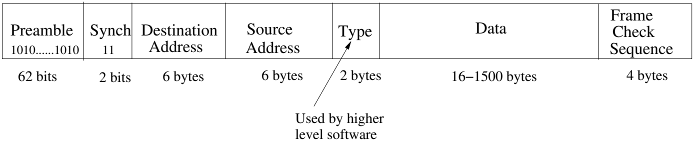
- If packets collide, then the machines choose a random number from the interval $(0, k)$ and try again.
- On subsequent collisions, the value k is doubled each time, making it a lot less likely that a collision would occur again. This is an example of an *exponential backoff protocol*.

Ethernet Packets

- The Ethernet packet has the format shown below.

Ethernet Packet Format



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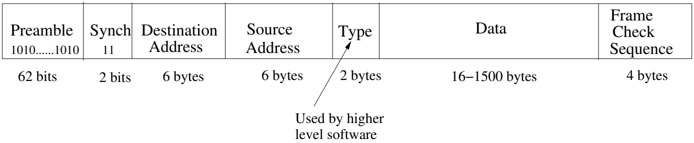

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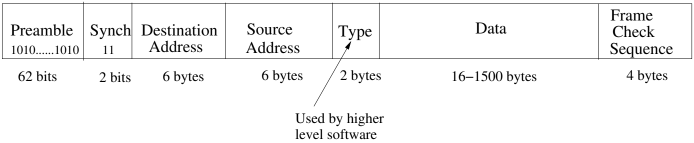

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Use the program `wireshark` to watch Ethernet packets on your network live!

Network Topology Design

Ranges of possibilities.

- Shared multi-drop passive cable, or

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Network Topology Options

Hubs and Switches.

- Direct wire. Two machines can be connected directly by a Ethernet cable (usually a Cat 5e cable) without needing a hub or a switch. With multiple NICs per machine, we can create networks but then we need to specify routing tables to allow packets to get through. The machines will end up doing double-duty as routers.

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- Hubs and Repeaters All machines are visible from all machines and the CSMA/CD protocol is still used. A hub/repeater receives signals, cleans and amplifies, redistributes to all nodes.
- Switches. Accepts packets, interprets destination address fields and send packets down only the segment that has the destination node. Allows half the machines to communicate directly with the other half (subject to bandwidth constraints of the switch hardware). Multiple switches can be connected in a tree or sometimes other schemes. The root switch can become a bottleneck. The root switch can be a higher bandwidth switch.

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- Stackable, High bandwidth Switches. Stackable switches with special high bandwidth interconnect in-between the switches. For example, Cisco has 24-port Gigabit stackable switches with a 32 Gbits/sec interconnect. Up to 8 such switches can be stacked together. All the stacked switches can be controlled by one switch and managed as a single switch. If the controlling switch fails, the remaining switches hold an election and a new controlling switch is elected. Baystack also has stackable switches with a 40 Gbits/sec interconnect.

Network Interface Cards

- The Ethernet card, also known as the Network Interface Controller (NIC), contains the Data Link Layer and the Physical Layer (the two lowest layers of networking). Each Ethernet card has a unique hardware address that is know as its MAC address (MAC stands for Media Access Controller). The MAC address is usually printed on the Ethernet card.

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- Another issue to consider is that having multi-processor boards may cause more load on the network cards in each node. Certain network cards have multiple network processors in them, making them better candidates for multi-processor motherboards.

Networking Models

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- ISO Open System Interconnection (OSI). A reference model for networking prescribes seven layers of network protocols and strict methods of communication between them. Most systems implement simplified version of the OSI model. The ARPANET Reference Model (ARM) can be seen as a simplified OSI model.

Network Models (contd.)

ISO	ARM	4.2 BSD Layers	Example
application presentation session	process applications	user programs/libraries	ssh
		sockets	sock_stream
transport network data link	host–host network interface	protocols network interface	TCP/IP Ethernet driver
hardware	network hardware	network hardware	interlan controller

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  - Java Remote Method Invocation (`RMI`), Distributed Component Object Model (`DCOM`)

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- The address with all 0's in the host address, for example 192.168.1.0, is the network address and cannot be assigned to any machine. The address with all 1's in the host address, for example 192.168.1.255, is the network broadcast address.

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- These addresses are permanently unassigned, not forwarded by Internet backbone routers and thus do not conflict with publicly addressable IP addresses.

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Typical communication domains:

domain type	symbolic name	address format
Unix domain	`AF_Unix`	pathnames
Internet domain	`AF_INET`	Internet address and port number

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- *Raw sockets.* Allows access to TCP, IP or Ethernet protocol

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- `close(...)`, `shutdown(...)`: Close both or one end of a socket respectively.

Client-Server Setup Using Sockets

Server side	Client side
socket(...)	
bind(...)	socket(...)
listen(...)	connect(...)
accept(...)	
read/write	read/write
close/shutdown	

TCP/IP and Linux/Unix Networking

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- The file `/etc/services` contains the port numbers for well known servers. For example:
  - port 37 is reserved for getting the time from a system
  - port 7 is used for echoing the data sent by a client back
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- A multi-process server forks off a copy of itself after a connection to handle the client, while the original server process goes back to accept further connections.

Client/Server Examples in C

The examples are in folder `sockets-C/tcp`

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- Note that read/write on sockets is slightly different than read/write on files. A read/write on a socket may return a count less than asked for. This is not an error since with sockets, the buffer in the kernel may be full. We can just keep calling read/write until the right amount of data has been read or written.

Useful Tools

- Use `netstat -ni` to find information on the network interfaces.
- Use `netstat -rn` to see the routing table.
- Use `netstat -nap` to see the processes that are using specific interfaces and ports. You need to be superuser to be able to see complete process information. Nice way of determining who has a port bound up!
- Use `netstat -s` to see a summary of network statistics. For example, `netstat -s -udp` summarizes all UDP traffic.

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- Use `lsof -w -n -i tcp:<port num>` gives the pid of the process using that port so you can kill a process that didn't clean up or properly release the port.

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- Use `netstat -rn` to see the routing table.
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- Use `wireshark` to watch network packets in real time! You will need superuser access to be able to use `wireshark` fully.

Client/Server Communication Using Sockets in Java

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- Now the server and the client can read/write to the streams associated with the sockets.
- Always open `OutputStream` before `InputStream` on a socket to avoid deadlock and synchronization problems.

Client Example (Java)

```java
try {
    Socket server = new Socket("www.party.com",1234);
    OutputStream out = server.getOutputStream();
    InputStream in = server.getInputStream();

    out.write(42); //write a byte

    //write a newline or carriage return delimited string
    PrintWriter pout = new PrintWriter(out, true);
    pout.println("Hello!");

    //read a byte
    Byte response = in.read();

    //read a newline or carriage return delimited string
    BufferedReader bin = new BufferedReader (new
   InputStreamReader(in));
    String answer = bin.readLine();

    //send a serialized Java object
    ObjectOutputStream oout = new ObjectOutputStream(out);
    oout.writeObject(new java.util.Date());
    oout.flush();

    server.close();
} catch (IOException e) {System.err.println(e);}
```

Server Example (Java)

```
try {//meanwhile, on www.party.com...
    ServerSocket listener = new ServerSocket(1234);
    while (!finished) {
        Socket client = listener.accept();
        InputStream in = client.getInputStream();
        OutputStream out = client.getOutputStream();

        Byte someByte = in.read(); //read a byte

        //read a newline/carriage return delimited string
        BufferedReader bin =
             new BufferedReader(new InputStreamReader(in));
        String someString = bin.readLine();

        out.write(42); //write a byte
        PrintWriter pout = new PrintWriter(out, true);
        pout.println("Goodbye!");

        //read a serialized Java object
        ObjectInputStream oin = new ObjectInputStream(in);
        Date date = (Date) oin.readObject();

        client.close();
        //...
    }
    listener.close();
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See the folder and subfolders in `sockets`.

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public class Request implements java.io.Serializable {}

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- A sample work request class: MyCalculation.java

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- A sample work request class: MyCalculation.java
- The Server.java, Client.java that ties it all together.

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- It is possible to overcome this restriction with the help of reflection. (More on this later)

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- How would you implement two processes playing ping pong across the network? Are they both servers? Are they both clients?

Socket and ServerSocket Options

- `ServerSocket` and `Socket` classes have several useful options.
- For example: we can set a timeout on a socket, we can set the receive buffer sizes, etc.
- See examples ServerSocketOptions.java and ClientSocketOptions.java in the package `tcp.socketoptions`.

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- Example: UdpServer1.java and UdpClient1.java in package `tcp.udp`.

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- Requests/Methods in the HTTP Protocol:

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GET <pathname> HTTP/x.y  (e.g. GET /sample.html HTTP/1.0)
HEAD <pathname> (same as GET except only metadata is returned)
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       (the server accepts the entity enclosed in the request)
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- Response from server:

```
HTTP-Version status-code reason-phrase <CR><LF>
```

Selected status codes in the HTTP Protocol

Status codes:

```
200 OK
201 Created

301 Moved permanently
305 Use Proxy
307 Temporary redirect

400 Bad request (bad syntax)
401 Unauthorized
402 Payment required
403 Forbidden
404 Not found

500 Internal server error
501 Not implemented
503 Service unavailable
505 HTTP version not supported
```

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- Warning! This web server will serve files without any protection from a system!

Using the Built-In Security Manager

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- Recompile and run the server as follows.
  `java -Djava.security.manager`
  `-Djava.security.policy=mysecurity.policy TinyHttpd 5005`

Adding a Custom Security Manager to TinyHttpd

```
class TinyHttpdSecurityManager extends SecurityManager {
  public void checkAccess(Thread g) {};
  public void checkListen(int port) {};
  public void checkLink(String lib) {};
  public void checkPropertyAccess(String key) {};
  public void checkAccept(String host, int port) {};
  public void checkWrite(FileDescriptor fd) {};
  public void checkRead(FileDescriptor fd ) {};

  public void checkRead(String s) {
    if (new File(s).isAbsolute() || (s.indexOf("..") != -1))
      throw new SecurityException("Access to file: " + s
                                              + " denied.");
  }
}
//add the following to the TinyHttpd at the start of the
//main method but after creating the ServerSocket

System.setSecurityManager(new TinyHttpdSecurityManager());
```

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66.249.69.87 - - [28/Jan/2016:23:16:04 -0700]
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Scalable I/O with java.nio package

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- Starting one thread per client request can consume a lot of resources. One strategy is to use nonblocking I/O operations to manage a lot of communications from a single thread. The second strategy is to use a configurable pool of threads, taking advantage of machines with many processors.
- The `java.nio` package provides selectable channels. A selectable channel allows for the registration of a special kind of listener called a selector that can check the readiness of the channel for operations such as reading and writing or accepting or creating network connections.

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int interestOps = SelectionKey.OP_READ | SelectionKey.OP_WRITE;
SelectionKey key = channelA.register(selector, interestOps);
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- Once one or more channels are registered with the Selector, we can perform a select operations by using one of the `select()` methods.

```
int readyCount = selector.select(); //block until a channel is ready
int readyCount = selector.selectNow(); //returns immediately
int readyCount = selector.select(50); //timeout of 50 millisecs

while (selector.select(50) == 0);
```

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Once `select()` comes back with a non-zero ready count, then we can get the set of ready channels from the `Selector` with the `selectedKeys()` method and iterate through them.

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```
Set readySet = selector.selectedKeys();
for (Iterator itr = readySet.iterator(); itr.hasNext();) {
    SelectionKey key = (SelectionKey) itr.next();
    itr.remove(); //remove the key from the ready set
    //use the key in the application
}
```

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- Example: LargerHttpd.java, HttpdConnection.java, ClientQueue.java.
- A single thread executes the main loop that accepts new connections and checks the readiness of existing client connections for reading or writing.
- Whenever a client needs attention, it places the job in a queue where a thread from our thread pool waits to service it.
- Run it as follows (on one line!):

```
java -Djava.security.manager
     -Djava.security.policy=mysecurity.policy
      LargerHttpd <port> <maxthreads>
```

Exercises

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- Modify the object server example to use the Executor interface.
- Create a EC2 virtual machine using AWS (Amazon Web Services) and run the object server on it. Connect with your laptop or a lab machine as a client.
- Convert the object server example to send JSON objects instead of Java objects.

Exercises

- Modify the object server example to be single threaded.
- Modify the object server example to use the Executor interface.
- Create a EC2 virtual machine using AWS (Amazon Web Services) and run the object server on it. Connect with your laptop or a lab machine as a client.
- Convert the object server example to send JSON objects instead of Java objects.
- Write a Ping Pong program (two processes) using sockets and an object to represent the ping-pong ball.