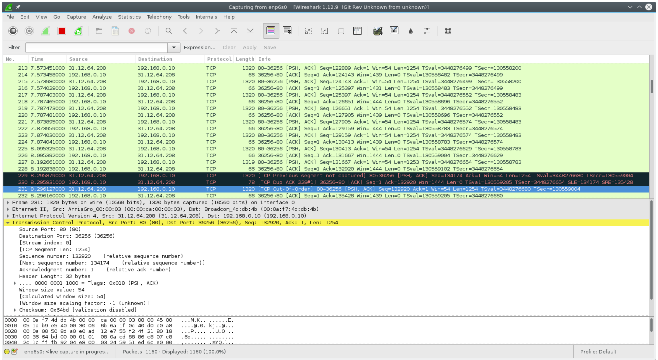
# Networks and Network Programming

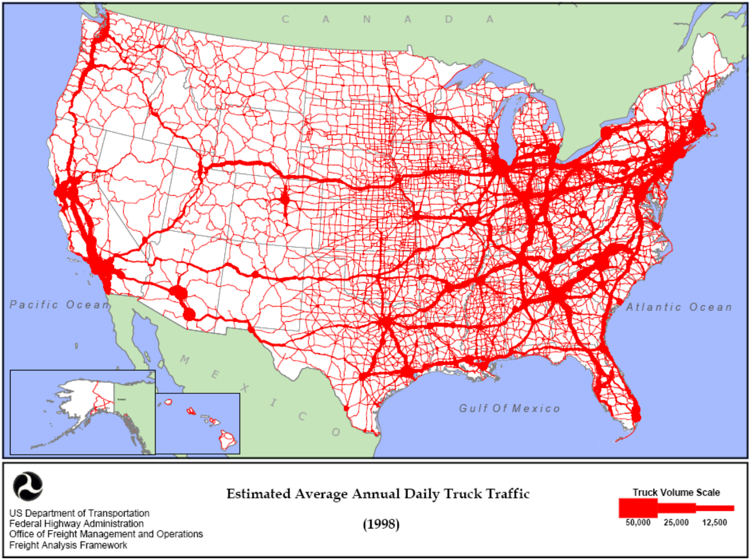



Wireshark screenshot of network traffic

# Networking

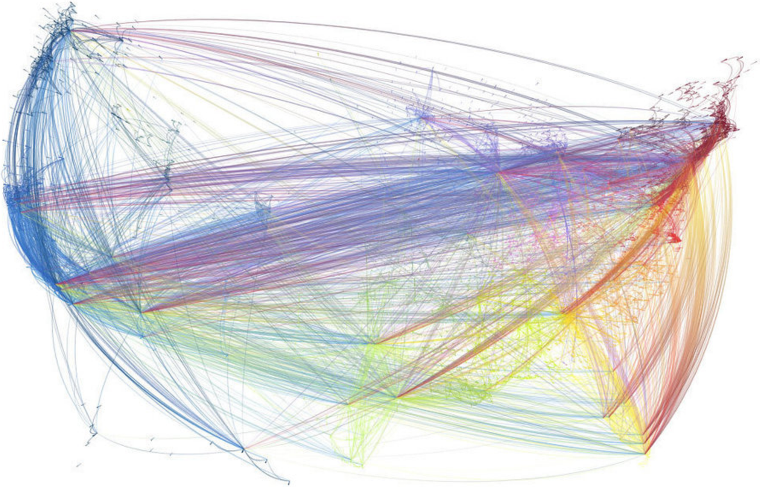
- Hardware
- Protocols
- Software

*The network is the computer. (John Gage)*




Estimated Average Annual Daily Truck Traffic

(1998)



# 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 |
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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**

| Preamble 1010......1010 | Synch 11 | Destination Address | Source Address | Type | Data | Frame Check Sequence |
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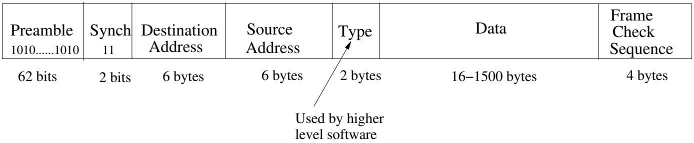


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Use the program `wireshark` to watch Ethernet packets on your network live!

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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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- Switch Meshing. Allows up to 24 ports between switches to be treated as a single logical port, creating a very high bandwidth connection. useful for creating custom complicated topologies.
- 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.

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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<br>presentation<br>session | process<br>applications | user programs/libraries | ssh |
| | | sockets | sock_stream |
| transport<br>network<br>data link<br>hardware | host–host<br>network interface | protocols<br>network interface | TCP/IP<br>Ethernet driver |
| | network hardware | network hardware | interlan controller |

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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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- *Reliably delivered message sockets.*
- *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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  - port 37 is reserved for getting the time from a system
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# Servers

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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

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- Multi-threaded server: Left as an exercise....
- 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

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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)

```
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)

```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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- A server could run a proxy that lets the application communicate indirectly with anyone the server likes and allows. *How would you design a proxy server?*

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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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- Note that the server machine must have all the classes that the client has in order to be able to execute them on the client's behalf. That may be an unreasonable assumption since you may want to serve many kinds of clients without having to store all their classes.

# 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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# The HTTP Protocol and Web Servers

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- Requests/Methods in the HTTP Protocol:

```
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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- 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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- Now, 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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- Log all requests in a log file. A sample entry is shown below (taken from the access log of Apache web server):

```
66.249.69.87 - - [28/Jan/2016:23:16:04 -0700]
 "GET /~amit/teaching/555/cs455-555.html HTTP/1.1" 200 7343 "-"
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# Scalable I/O with java.nio package

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- 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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- 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 one channel is ready
int readyCount = selector.selectNow(); // returns immediately
int readyCount = selector.select(50); // timeout of 50 milliseconds

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

# Checking for ready channels

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.

```
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
}
```

# LargerHttpd

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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

- Write a Ping Pong programs using sockets and an object to represent the ping-pong ball. Are the two programs playing ping pong servers? Or are they clients?