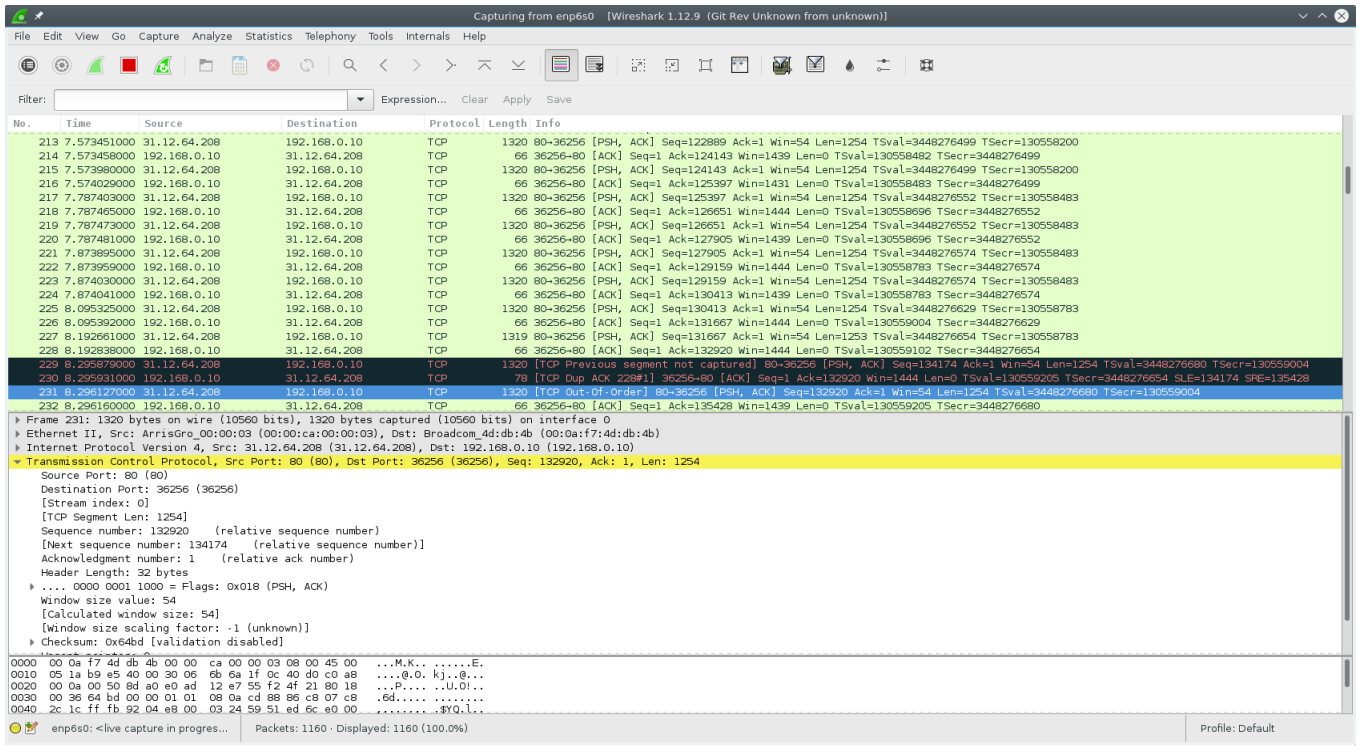
Networks and Network Programming

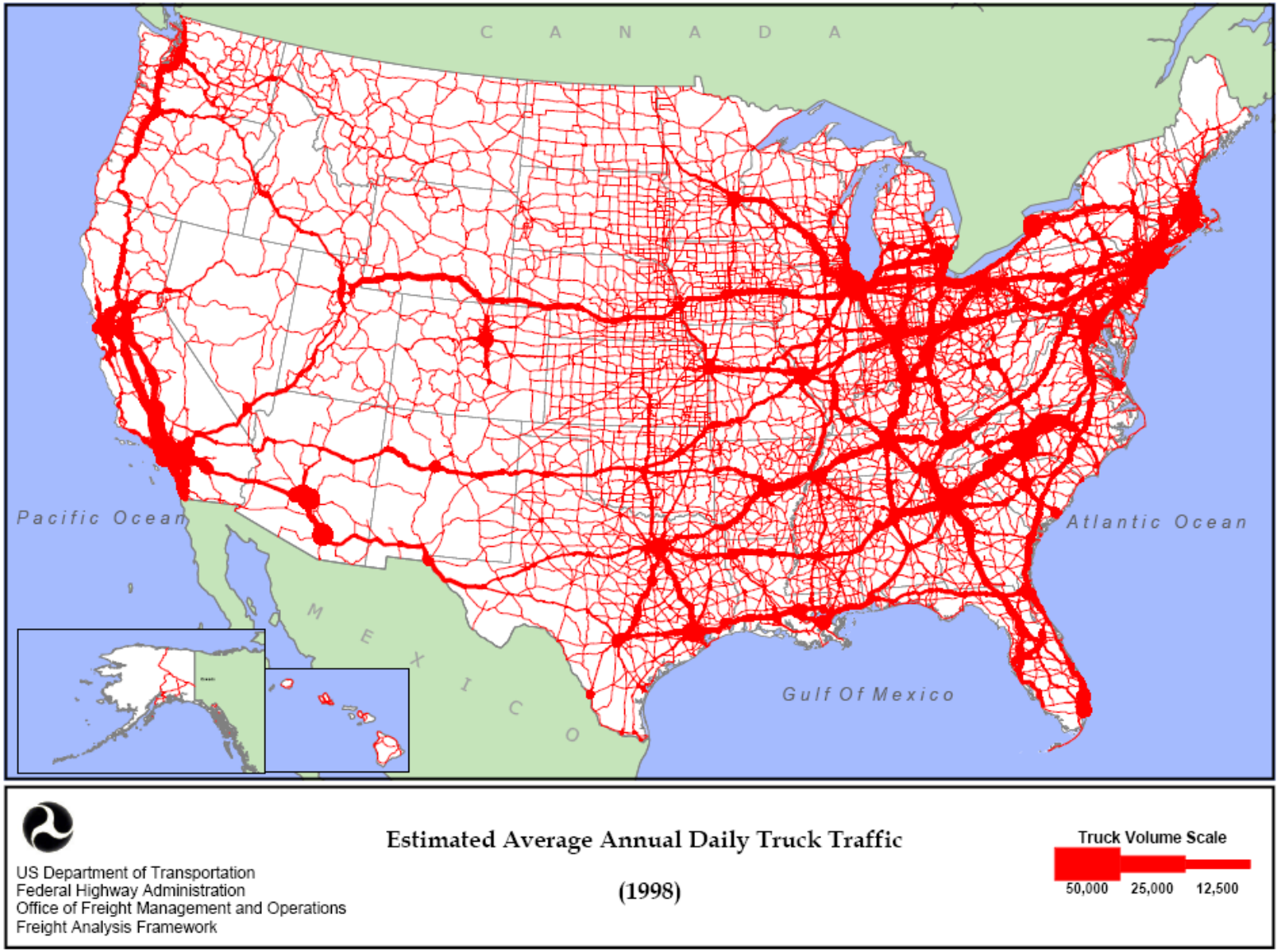


Wireshark screenshot of network traffic

Networking

- Hardware
- Protocols
- Software

The network is the computer. (John Gage)



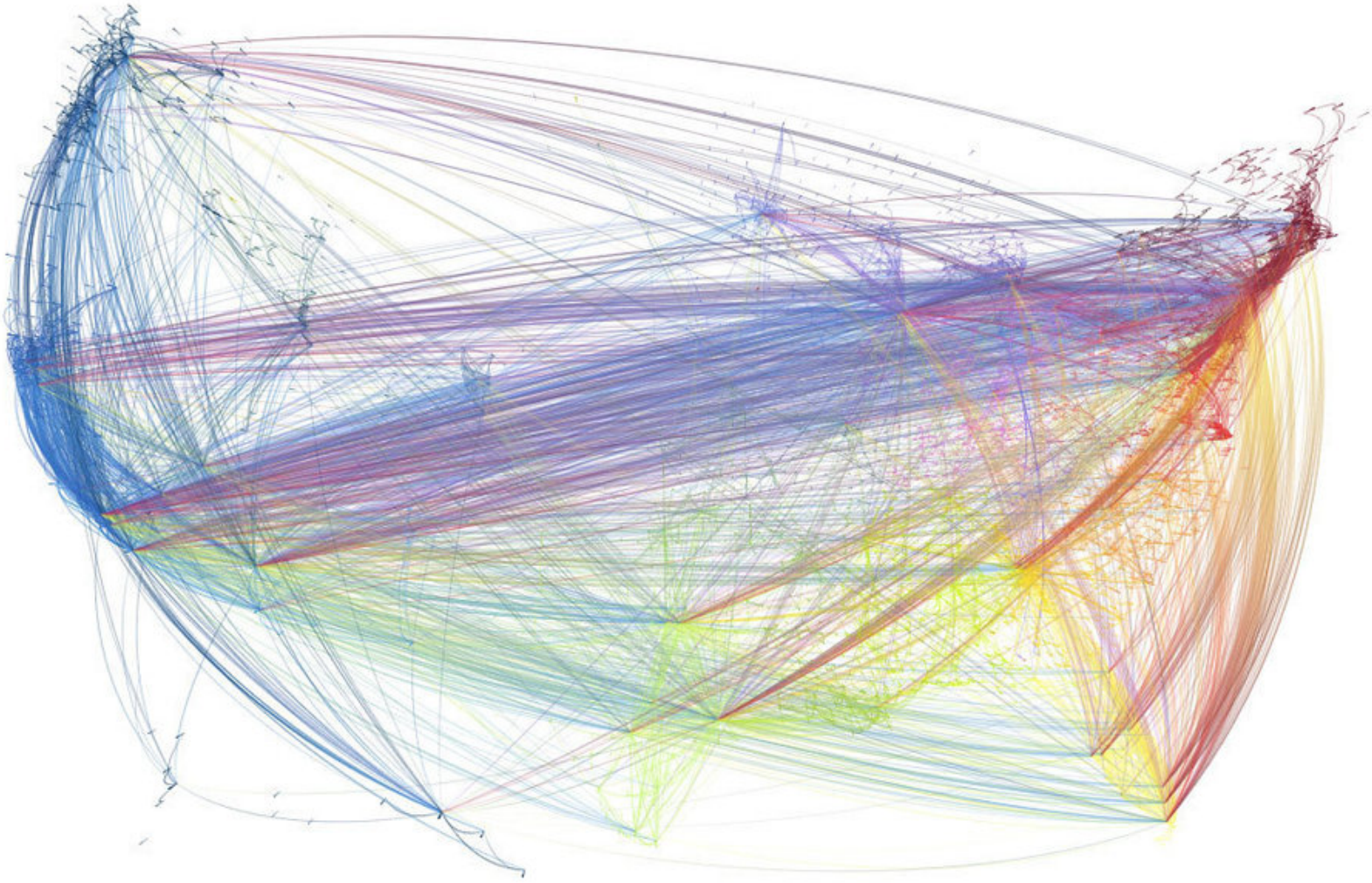
US Department of Transportation
Federal Highway Administration
Office of Freight Management and Operations
Freight Analysis Framework

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

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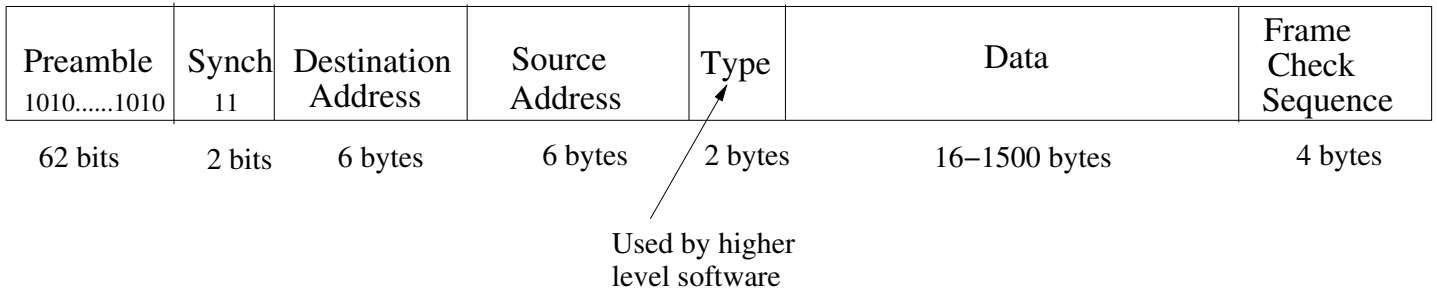
- If packets collide, then the machines choose a random number from the interval $(0, k)$ and try again.
- On subsequent collisions, the value k is doubled each time, making it a lot less likely that a collision would occur again. This is an example of an *exponential backoff protocol*.

Ethernet Packets

- The Ethernet packet has the format shown below.

Ethernet Packet Format



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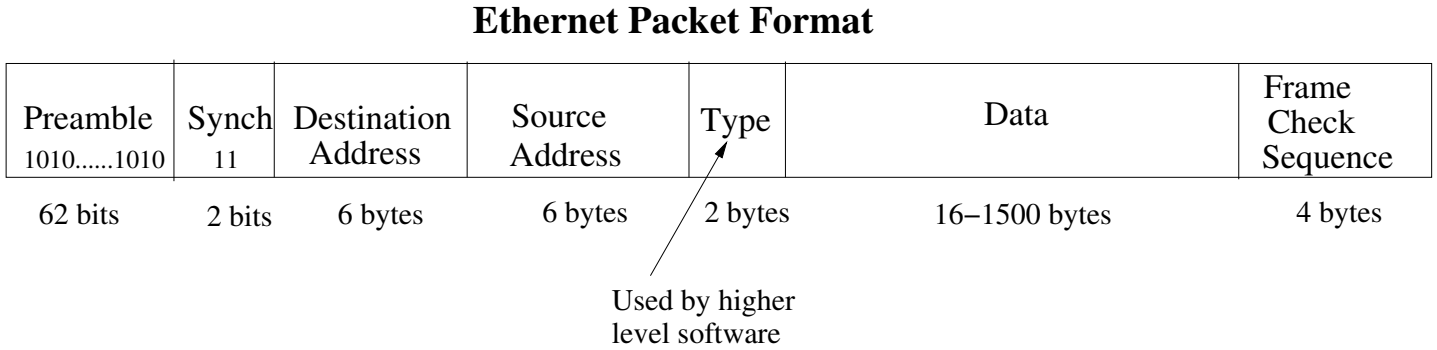

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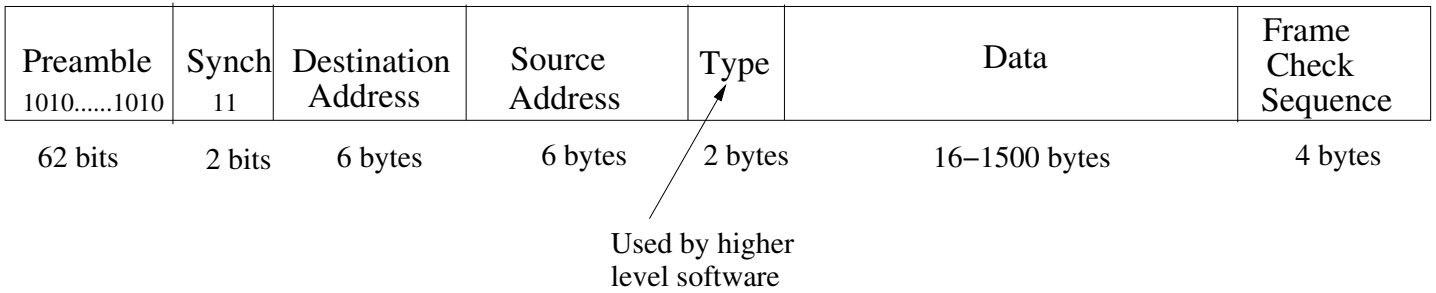

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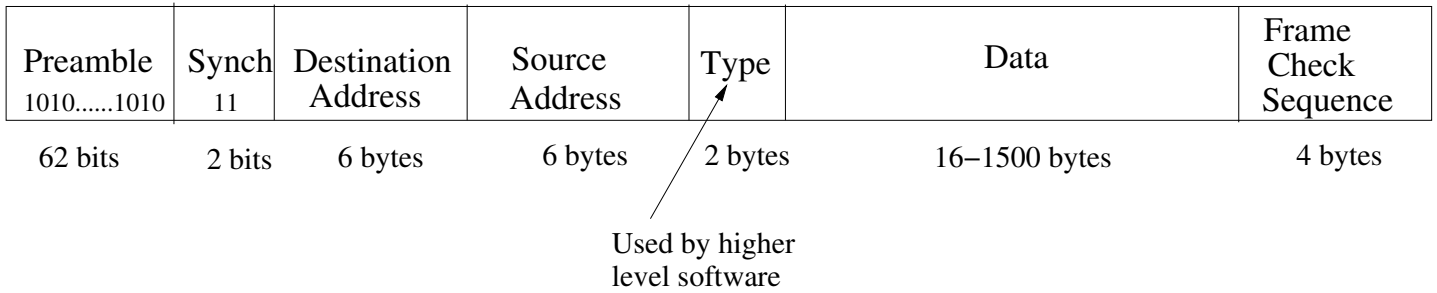

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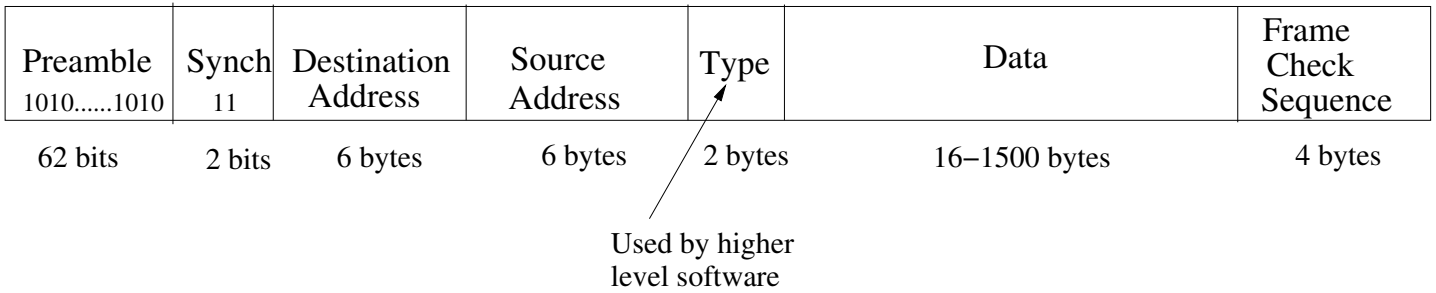

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Use the program `wireshark` to watch Ethernet packets on your network live!

Network Topology Design

Ranges of possibilities.

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- Tree structure of hubs and switches, or
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- One big switch.

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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- 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.

Switches

Switches can be managed or unmanaged. Managed switches are more expensive but they also allow many useful configurations. Here are some examples.

- Port trunking (a.k.a Cisco EtherChannel). Allows up to 4 ports to be treated as one logical port. For example, this would allow a 4 Gbits/sec connection between two Gigabit switches.

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

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- Link to state diagram for the operation of TCP.

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- Three IP ranges are reserved for private networks.
  - 10.0.0.0 – 10.255.255.255
  - 172.16.0.0 – 172.31.255.255
  - 192.168.0.0 – 192.168.255.255

  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	

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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
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  - port 21 is used by the FTP (File Transfer Protocol) client/server
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- The configuration directory `/etc/xinetd.d/` contains several files, one per service type, that control what is provided by the internet super-daemon `xinetd` under Linux.

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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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- Multi-process server: `tcpserver.c` and client `tcpclient.c`
- 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

- 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!
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- Use `/sbin/ifconfig eth0` to get details on the interface `eth0`. Running `ifconfig` without any options gives details on all interfaces.

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- 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.
- 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.
- Use `/sbin/ifconfig eth0` to get details on the interface `eth0`. Running `ifconfig` without any options gives details on all interfaces.
- Use `ping` to check if a machine is alive. Use ping -b with a network address to find all machines on a local area network.

Useful Tools

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- Use `ping` to check if a machine is alive. Use ping -b with a network address to find all machines on a local area network.
- 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);
    InputStream in = server.getInputStream();
    OutputStream out = server.getOutputStream();

    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) {}
```

Server Example (Java)

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

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

        // read a newline or 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();
} catch (IOException e) {}
```

TCP examples in Java

See the folder and subfolders in `sockets`.

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TCP examples in Java

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- A remote date client. tcp.client.DateAtHost.java.
- Single-threaded server and client: See TimeServer.java and TimeClient.java in package `tcp.singlethreaded`.
- Multi-threaded server and client: See TimeServer.java and TimeClient.java in package `tcp.multithreaded`.

Sockets and Security in Java

- The `SecurityManager` can impose arbitrary restrictions on applets and applications as to what hosts they may or may not talk to, and whether they can listen for connections.
- The web browser allows socket connections only to the host that served them. Untrusted applets are not allowed to open server sockets themselves.
- A server could run a proxy that lets the applet communicate indirectly with anyone it likes.

Object Based Server/Clients Example

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- We will use a base class `Request` for the various kinds of requests.

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public class Request implements java.io.Serializable {}

public class DateRequest extends Request {}

public class WorkRequest extends Request {
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- The client sends a `WorkRequest` object to the server to get the server to perform work for the client. The server calls the request object's `execute` method and returns the resulting object as a response.
- A sample work request class: MyCalculation.java

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

Running the Object Server/Client

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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 SpcketOptions.java in the package `tcp.socketoptions`.

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- Domain Name Service (DNS) and Network File System (NFS) use UDP.

Datagram Sockets Example

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

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- How to implement a web server?

The HTTP Protocol and Web Servers

- A Web Server implements at least the `HTTP` protocol. In order to talk to a Web server, a client program (e.g. a web browser) must speak the HTTP protocol.
- Details of the `HTTP` protocol can be found at the home page for the World Wide Web consortium (`www.w3.org`).

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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)
POST <string>  (the server should accept the entity enclosed i
                (useful for running CGI-scripts)
```

  Response from server:

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

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
```

A Tiny Web Server

This web server will serve files without any protection from a system.

```
import java.net.*;
import java.io.*;
import java.util.*;

public class TinyHttpd {
    public static void main(String argv[]) throws IOException {
        ServerSocket ss = new ServerSocket(Integer.parseInt(argv[0]));
        System.out.println("starting...");
        while (true) {
            new TinyHttpdConnection(ss.accept()).start();
            System.out.println("new connection");
        }
    }
}

class TinyHttpdConnection extends Thread {
    Socket client;
    TinyHttpdConnection (Socket client) throws SocketException {
        this.client = client;
        setPriority(NORM_PRIORITY - 1);
    }
}
```

A Tiny Web Server (contd.)

```
public void run() {
    try {
        BufferedReader in = new BufferedReader(
            new InputStreamReader(client.getInputStream(), "8859_1"));
        OutputStream out = client.getOutputStream();
        PrintWriter pout = new PrintWriter(
            new OutputStreamWriter(out, "8859_1"), true);
        String request = in.readLine();
        System.out.println("Request: "+request);

        StringTokenizer st = new StringTokenizer(request);
        if ((st.countTokens() >= 2) && st.nextToken().equals("GET")) {
            if ((request = st.nextToken()).startsWith("/"))
                request = request.substring(1);
            if (request.endsWith("/") || request.equals(""))
                request = request + "index.html";
            try {
                FileInputStream fis = new FileInputStream (request);
                byte [] data = new byte [ fis.available() ];
                fis.read(data);
                out.write(data);
                out.flush();
            } catch (FileNotFoundException e) {
                pout.println("404 Object Not Found"); }
        } else { pout.println("400 Bad Request");}
        client.close();
    } catch (IOException e) {System.out.println("I/O error " + e);}
}
```

Using the Built-In Security Manager

Java has a built-in security manager, which if activated gives the same level of access as given to applets (that is, not much). The security manager can be activated with a command line option.

```
java -Djava.security.manager TinyHttpd
```

However, we want to give access to create and use sockets. So we create a policy file (using the tool `policytool` that comes with the Java toolkit).

```
grant {
        permission java.net.SocketPermission
                "*:1024-", "listen,accept,connect";
};
```

Add the following after the catch for FileNotFoundException.

```
catch (SecurityException e) { pout.println("403 Forbidden");}
```

Now, recompile and run the server as follows.

```
java -Djava.security.manager
-Djava.security.policy=mysecurity.policy TinyHttpd 1234
```

Adding a Custom Security Manager to TinyHttpd

```
 import java.io.*;

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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- Allow applets to communicate via proxies.
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- Use scalable I/O with `java.nio` package.

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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- 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
}
```

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- 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.

```
/* appropriate import statemenst */

public class LargerHttpd {
    Selector clientSelector;
    ClientQueue readyClients = new ClientQueue();

    public void run(int port, int threads) throws IOException {
        clientSelector = Selector.open();
        ServerSocketChannel ssc = ServerSocketChannel.open();
        ssc.configureBlocking(false);
        InetSocketAddress sa =
            new InetSocketAddress(InetAddress.getLocalHost(), port);
        ssc.socket().bind(sa);
        ssc.register(clientSelector, SelectionKey.OP_ACCEPT);

        for (int i=0; i<threads; i++)
            new Thread() { public void run() {
                while (true) try { handleClient(); } catch (IOException e) { }
            } }.start();

        while (true) try {
            while (clientSelector.select(50) == 0);
            Set readySet = clientSelector.selectedKeys();
            for(Iterator it = readySet.iterator(); it.hasNext();) {
                SelectionKey key = (SelectionKey)it.next();
                it.remove();
                if (key.isAcceptable())
                    acceptClient(ssc);
                else {
                    key.interestOps(0);
                    readyClients.add(key);
                }
            }
        } catch (IOException e) { System.out.println(e); }
    }
...
```

```
...
    void acceptClient(ServerSocketChannel ssc) throws IOException {
        SocketChannel clientSocket = ssc.accept();
        clientSocket.configureBlocking(false);
        SelectionKey key =
            clientSocket.register(clientSelector, SelectionKey.OP_READ);
        HttpdConnection client = new HttpdConnection(clientSocket);
        key.attach(client);
    }

    void handleClient() throws IOException {
        SelectionKey key = (SelectionKey)readyClients.next();
        HttpdConnection client = (HttpdConnection)key.attachment();
        if (key.isReadable())
            client.read(key);
        else
            client.write(key);
    }

    public static void main(String argv[]) throws IOException {
        new LargerHttpd().run(Integer.parseInt(argv[0]), 3);
    }
}
```

```
class HttpdConnection {
    static Charset charset = Charset.forName("8859_1");
    static Pattern httpGetPattern = Pattern.compile("(?s)GET /?(\\S*).*");
    SocketChannel clientSocket;
    ByteBuffer buff = ByteBuffer.allocateDirect(64*1024);
    String request;
    String response;
    FileChannel file;
    int filePosition;

    HttpdConnection (SocketChannel clientSocket) {
        this.clientSocket = clientSocket;
    }

    void read(SelectionKey key) throws IOException {
        if (request == null && (clientSocket.read(buff) == -1
                || buff.get(buff.position()-1) == '\n'))
            processRequest(key);
        else
            key.interestOps(SelectionKey.OP_READ);
    }

  ...
```

```
...
    void processRequest(SelectionKey key) {
        buff.flip();
        request = charset.decode(buff).toString();
        Matcher get = httpGetPattern.matcher(request);
        if (get.matches()) {
            request = get.group(1);
            if (request.endsWith("/") || request.equals(""))
                request = request + "index.html";
            //System.out.println("Request: "+request);
            try {
                file = new FileInputStream (request).getChannel();
            } catch (FileNotFoundException e) {
                response = "404 Object Not Found";
            }
        } else
            response = "400 Bad Request" ;

        if (response != null) {
            buff.clear();
            charset.newEncoder().encode(
                CharBuffer.wrap(response), buff, true);
            buff.flip();
        }
        key.interestOps(SelectionKey.OP_WRITE);
    }
...
```

```
...
    void write(SelectionKey key) throws IOException {
        if (response != null) {
            clientSocket.write(buff);
            if (buff.remaining() == 0)
                response = null;
        } else if (file != null) {
            int remaining = (int)file.size()-filePosition;
            long got = file.transferTo(filePosition, remaining, clientSocket);
            if (got == -1 || remaining <= 0) {
                file.close();
                file = null;
            } else
                filePosition += got;
        }
        if (response == null && file == null) {
            clientSocket.close();
            key.cancel();
        } else
            key.interestOps(SelectionKey.OP_WRITE);
    }
}

class ClientQueue extends ArrayList {
    synchronized void add(SelectionKey key) {
        super.add(key);
        notify();
    }
    synchronized SelectionKey next() {
        while (isEmpty())
            try { wait(); } catch (InterruptedException e) { }
        return (SelectionKey)remove(0);
    }
}
```