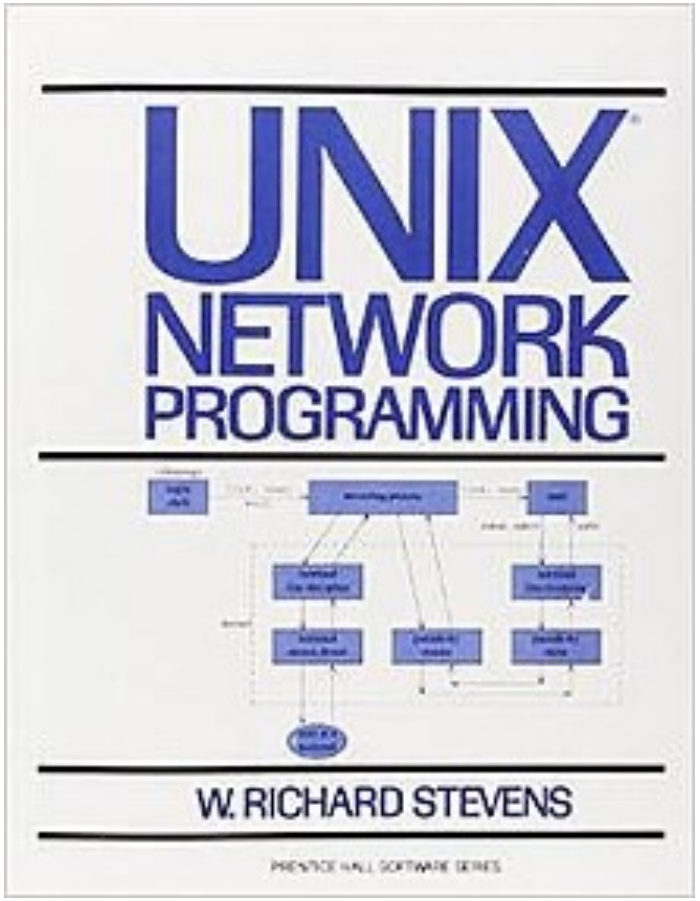
Application Programming Interface

- Interface exported by the network
- Since most network protocols are implemented (those in the high protocol stack) in software and nearly all computer systems implement their network protocols as part of the operating system, when we refer to the interface "*exported by the network*", we are generally referring to the interface that the OS provides to its networking subsystem
- The interface is called the network Application Programming Interface (API)



Application Programming Interface (Sockets)

- Socket Interface was originally provided by the Berkeley distribution of Unix
  - Now supported in virtually all operating systems

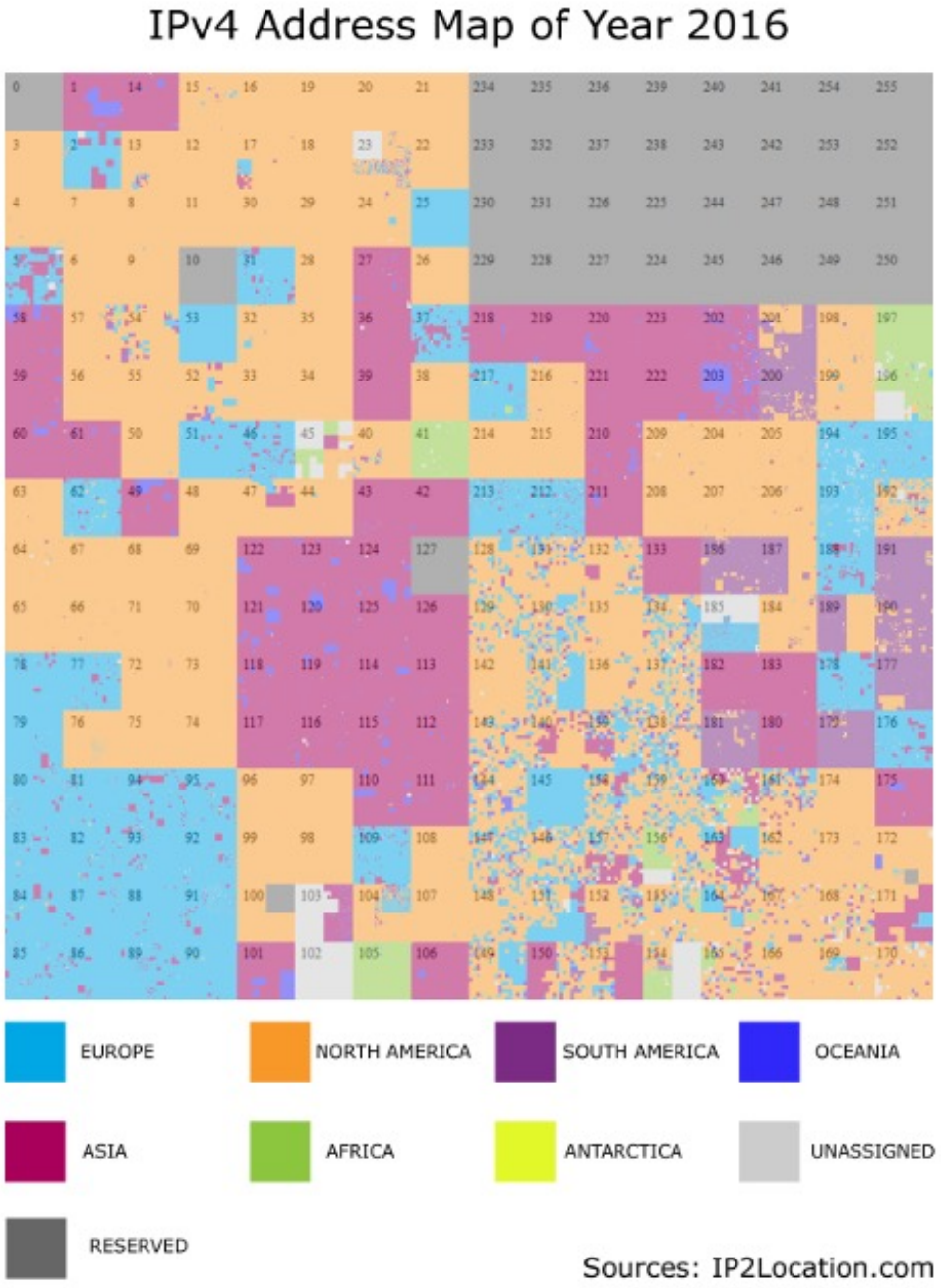
- Each protocol provides a certain set of *services*, and the API provides a syntax by which those services can be invoked in this particular OS

IP Address

- **Internet Protocol address (IP address)** identifies a device in the network
- Network-layer addressing
- Two versions in use
  - IPv4 has 32-bit addresses written like 192.0.2.1
  - Only 4 billion IPv4 addresses, not enough for current Internet usage
  - IPv6 has 128-bit addresses written like *2001:db8:0:1234:0:567:8:1*

IP Address Geography

- IP Addresses are geographical
- Routers do not need to know every IP Address on the entire Internet
- First few bits of address indicate where to forward the packet



Port

- **Port** numbers identify individual process
- Transport-layer addressing
- Port number is 16-bits unsigned, can range from 0 to 65,535

Common Port Assignments

Port numbers 0 to 1023 are typically reserved for well-known applications

Notable well-known port numbers

Number	Assignment
20	File Transfer Protocol (FTP) Data Transfer
21	File Transfer Protocol (FTP) Command Control
22	Secure Shell (SSH) Secure Login
23	Telnet remote login service, unencrypted text messages
25	Simple Mail Transfer Protocol (SMTP) email delivery
53	Domain Name System (DNS) service
67, 68	Dynamic Host Configuration Protocol (DHCP)
80	Hypertext Transfer Protocol (HTTP) used in the World Wide Web
110	Post Office Protocol (POP3)
119	Network News Transfer Protocol (NNTP)
123	Network Time Protocol (NTP)
143	Internet Message Access Protocol (IMAP) Management of digital mail
161	Simple Network Management Protocol (SNMP)
194	Internet Relay Chat (IRC)
443	HTTP Secure (HTTPS) HTTP over TLS/SSL

Socket

- What is a socket?
  - The point where a local application process attaches to the network
  - An interface between an application and the network
  - An application creates the socket
- A **socket** is a combination of IP Address, transmission protocol, and port
- Servers **bind** to a socket to **listen** for incoming connections and then **accept** the connection
- Clients **connect** to a socket and then send/receive messages over the socket

Socket

- Socket Family
  - PF_INET denotes the Internet family
  - PF_UNIX denotes the Unix pipe facility
  - PF_PACKET denotes direct access to the network interface (i.e., it bypasses the TCP/IP protocol stack)

- Socket Type
  - SOCK_STREAM is used to denote a byte stream (e.g., TCP)
  - SOCK_DGRAM is an alternative that denotes a message oriented service (e.g., UDP)

Creating a Socket

```
int sockfd = socket(address_family, type, protocol);
```

- The socket number returned is the socket descriptor for the newly created socket

- `int sockfd = socket (PF_INET, SOCK_STREAM, 0);`
- `int sockfd = socket (PF_INET, SOCK_DGRAM, 0);`

The combination of PF_INET and SOCK_STREAM implies TCP
PF_INET and SOCK_DGRAM implies UDP

Client-Serve Model with TCP

Server

- Passive open
- Prepares to accept connection, does not actually establish a connection

Server invokes

```
int bind (int socket, struct sockaddr *address,
                                    int addr_len)
int listen (int socket, int backlog)
int accept (int socket, struct sockaddr *address,
                                int *addr_len)
```

Client-Serve Model with TCP

Bind

- Binds the newly created socket to the specified address i.e. the network address of the local participant (the server)
- Address is a data structure which combines IP and port

Listen

- Defines how many connections can be pending on the specified socket

Client-Serve Model with TCP

Accept

- Carries out the passive open
- Blocking operation
  - Does not return until a remote participant has established a connection
  - When it does, it returns a new socket that corresponds to the new established connection and the address argument contains the remote participant's address

Client-Serve Model with TCP

Client

- Application performs active open
- It says who it wants to communicate with

Client invokes

```
int connect (int socket, struct sockaddr *address,
                                    int addr_len)
```

Connect

- Does not return until TCP has successfully established a connection at which application is free to begin sending data
- Address contains remote machine's address

Client-Serve Model with TCP

In practice

- The client usually specifies only remote participant's address and let's the system fill in the local information
- Whereas a server usually listens for messages on a well-known port
- A client does not care which port it uses for itself, the OS simply selects an unused one

Client-Serve Model with TCP

Once a connection is established, the application process invokes two operations

```
int send (int socket, char *msg, int msg_len,
                                    int flags)

int recv (int socket, char *buff, int buff_len,
                                      int flags)
```

Example Application: Client

```
#include <stdio.h>
#include <sys/types.h>
#include <sys/socket.h>
#include <netinet/in.h>
#include <netdb.h>

#define SERVER_PORT 5432
#define MAX_LINE 256

int main(int argc, char * argv[])
{
        FILE *fp;
        struct hostent *hp;
        struct sockaddr_in sin;
        char *host;
        char buf[MAX_LINE];
        int s;
        int len;
        if (argc==2) {
                host = argv[1];
        }
        else {
                fprintf(stderr, "usage: simplex-talk host\n");
        exit(1);
        }
```

Example Application: Client

```
/* translate host name into peer's IP address */
hp = gethostbyname(host);
if (!hp) {
        fprintf(stderr, "simplex-talk: unknown host: %s\n", host);
        exit(1);
}
/* build address data structure */
bzero((char *)&sin, sizeof(sin));
sin.sin_family = AF_INET;
bcopy(hp->h_addr, (char *)&sin.sin_addr, hp->h_length);
sin.sin_port = htons(SERVER_PORT);
/* active open */
if ((s = socket(PF_INET, SOCK_STREAM, 0)) < 0) {
        perror("simplex-talk: socket");
        exit(1);
}
if (connect(s, (struct sockaddr *)&sin, sizeof(sin)) < 0) {
        perror("simplex-talk: connect");
        close(s);
        exit(1);
}
/* main loop: get and send lines of text */
while (fgets(buf, sizeof(buf), stdin)) {
        buf[MAX_LINE-1] = '\0';
        len = strlen(buf) + 1;
        send(s, buf, len, 0);
}
}
```

Example Application: Server

```
#include <stdio.h>
#include <sys/types.h>
#include <sys/socket.h>
#include <netinet/in.h>
#include <netdb.h>
#define SERVER_PORT 5432
#define MAX_PENDING 5
#define MAX_LINE 256

int main()
{
        struct sockaddr_in sin;
        char buf[MAX_LINE];
        int len;
        int s, new_s;
        /* build address data structure */
        bzero((char *)&sin, sizeof(sin));
        sin.sin_family = AF_INET;
        sin.sin_addr.s_addr = INADDR_ANY;
        sin.sin_port = htons(SERVER_PORT);

        /* setup passive open */
        if ((s = socket(PF_INET, SOCK_STREAM, 0)) < 0) {
                perror("simplex-talk: socket");
                exit(1);
        }
```

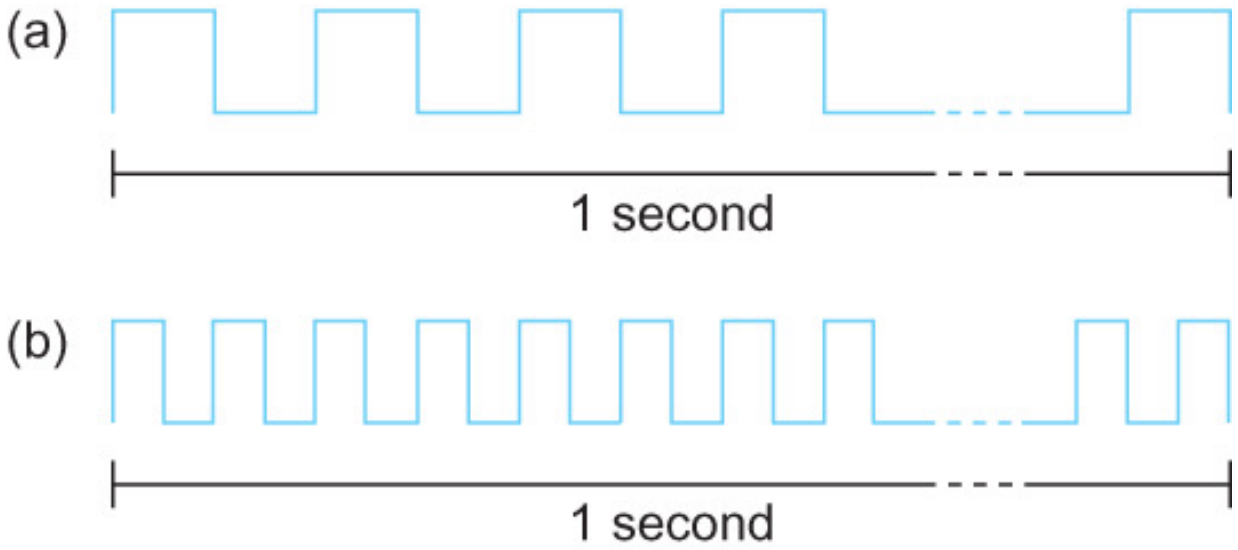
Example Application: Server

```
        if ((bind(s, (struct sockaddr *)&sin, sizeof(sin))) < 0) {
                perror("simplex-talk: bind");
                exit(1);
        }
        listen(s, MAX_PENDING);
        /* wait for connection, then receive and print text */
        while(1) {
                if ((new_s = accept(s, (struct sockaddr *)&sin, &len)) < 0) {
                perror("simplex-talk: accept");
                exit(1);
        }
        while (len = recv(new_s, buf, sizeof(buf), 0))
                fputs(buf, stdout);
                close(new_s);
        }
}
```

Performance

- Bandwidth
  - Width of the frequency band
  - Number of bits per second that can be transmitted over a communication link
- 1 Mbps: 1 x 10^6 bits/second = 1x2^{20} bits/sec
- 1 x 10^{-6} seconds to transmit each bit or imagine that a timeline, now each bit occupies 1 micro second space.
- On a 2 Mbps link the width is 0.5 micro second.
- Smaller the width more will be transmission per unit time.

Bandwidth



Bits transmitted at a particular bandwidth can be regarded as having some width:

(a) bits transmitted at 1Mbps (each bit 1 μs wide);

(b) bits transmitted at 2Mbps (each bit 0.5 μs wide).

Performance

- Latency = Propagation + transmit + queue
- Propagation = distance/speed of light
- Transmit = size/bandwidth

- One bit transmission => propagation is important
- Large bytes transmission => bandwidth is important

Delay X Bandwidth

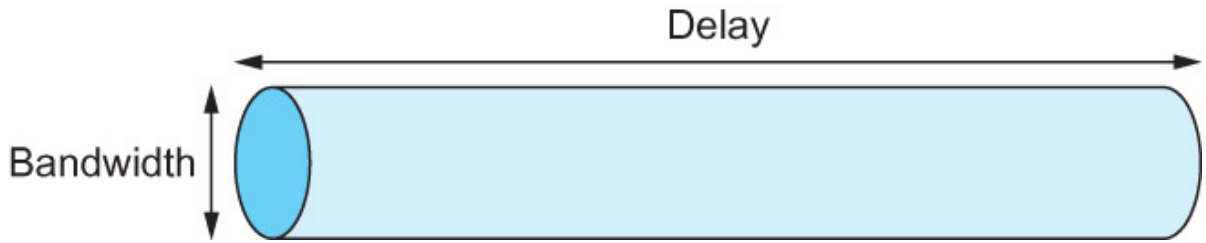
- Relative importance of bandwidth and latency depends on application
  - For large file transfer, bandwidth is critical
  - For small messages (HTTP, NFS, etc.), latency is critical
  - Variance in latency (jitter) can also affect some applications (*e.g.*, audio/video conferencing)

Delay X Bandwidth

- We think the channel between a pair of processes as a hollow pipe
- Latency (delay) length of the pipe and bandwidth the width of the pipe
- Delay of 50 ms and bandwidth of 45 Mbps

⇒ 50×10^{-3} seconds x 45×10^{6} bits/second

⇒ 2.25×10^{6} bits = 280 KB data.



Network as a pipe

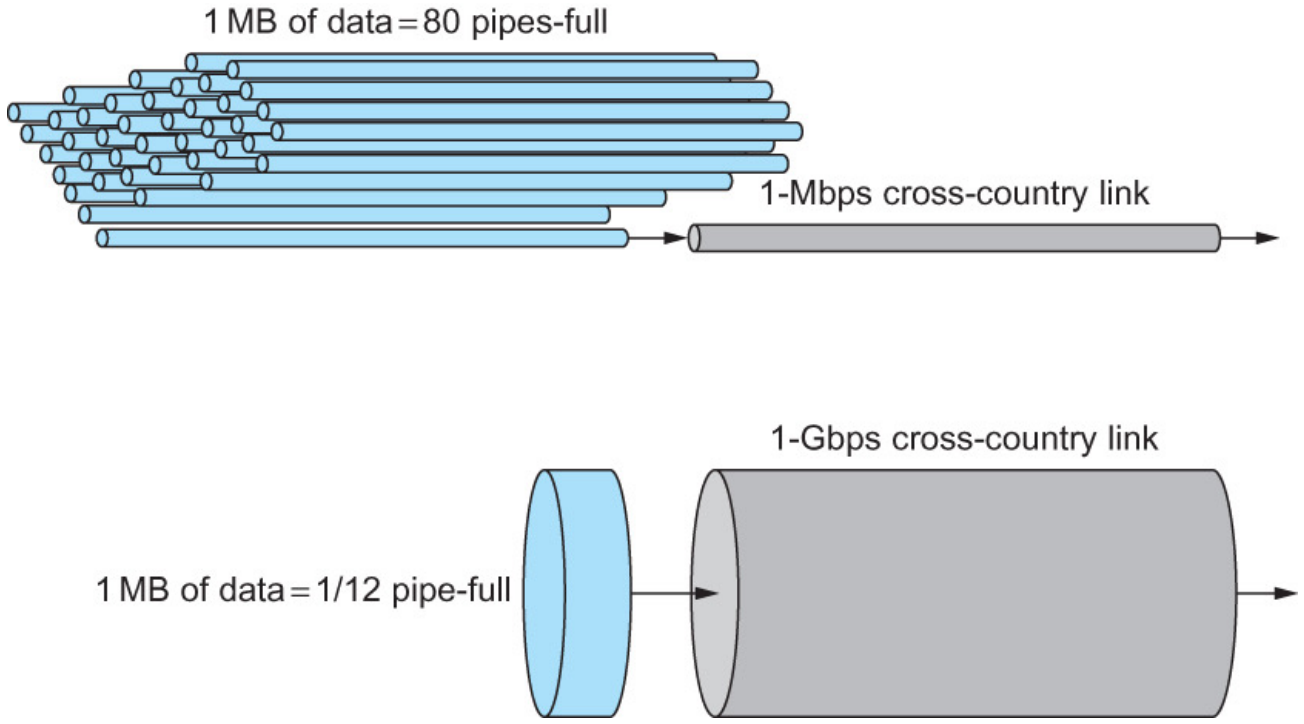
Send and reply time

- How many bits the sender must transmit before the first bit arrives at the receiver if the sender keeps the pipe full
- Takes another one-way latency to receive a response from the receiver
- If the sender does not fill the pipe—send a whole delay × bandwidth product's worth of data before it stops to wait for a signal—the sender will not fully utilize the network

Send and reply time

- Infinite bandwidth
  - RTT dominates
  - Throughput = TransferSize / TransferTime
  - TransferTime = RTT + 1/Bandwidth x TransferSize
- Its all relative
  - 1-MB file to 1-Gbps link looks like a 1-KB packet to 1-Mbps link

Relationship between bandwidth and latency



A 1-MB file would fill the 1-Mbps link 80 times, but only fill the 1-Gbps link 1/12 of one time

Summary

- We have identified what we expect from a computer network
- We have defined a layered architecture for computer network that will serve as a blueprint for our design
- We have discussed the socket interface which will be used by applications for invoking the services of the network subsystem
- We have discussed two performance metrics using which we can analyze the performance of computer networks