CHAPTER VIII: SOCKETS

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INTRODUCTION TO COMPUTER NETWORKS

Computers : evolution

- **The old model :** A single computer serving users who bring their works for processing
  $\rightarrow$ became obsolete.
- **The new model :** A large number of separate but interconnected computers are serving users.
  $\rightarrow$ **computer networks**.

Some definitions

- **Interconnected computers :** they are able of exchanging information
- **Computer network :** interconnected collection of autonomous computers.
- **Process :** a program that is running in the computer.

Some typical network applications :

- Exchange electronic mail (e-mail).
- Exchange files
- Remote login
- Share peripheral devices
- Execute a program on another computer

Layering

Given a specific task, say file transfer, it is hard to solve the entire problem in one step. Solving this problem needs in particular :

- A user interface
- Coding data into packets
- Observing some protocols
- Routing the packets
- A physical data transmission

Networks design is complex → networks are organized in **layers**, where :

- the number of layers and their functions differ from network to network
- each layer offers some services to the higher layer.
- a same level 'layer peer' on different machines can converse using a **protocol :** rules and conventions used in this conversation.
- the **ISO** proposed the **open systems interconnection** model(**OSI**) with 7 layers.

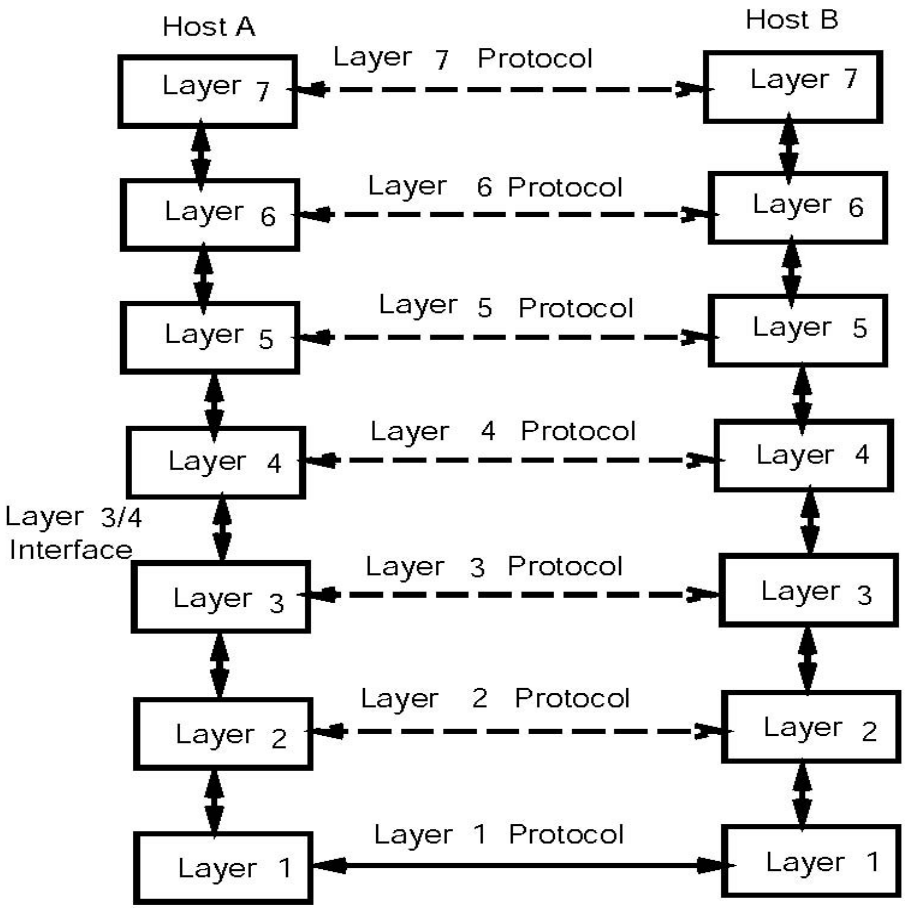


Figure 1: Layers, protocols and interfaces

A simplified model

To simplify this course, we combine the top three layers of the **OSI** into one : **process** layer and the bottom two layers into one : **data link** layer.

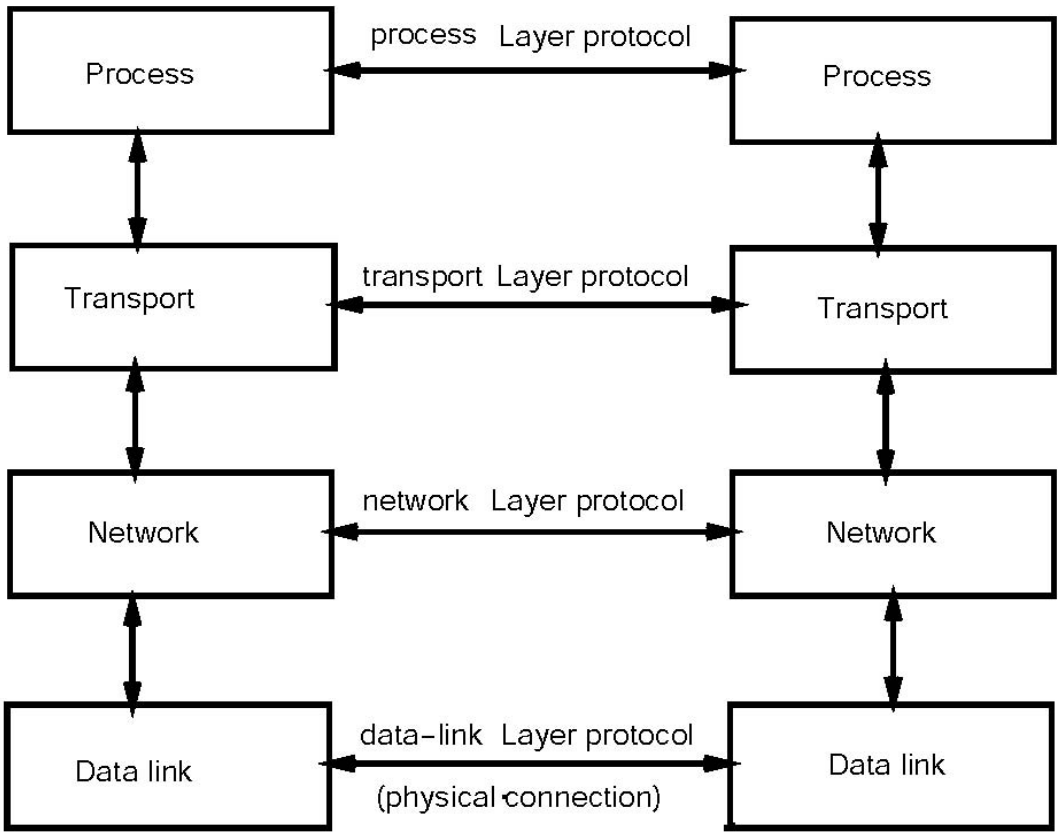


Figure 2: Simplified 4 layers model

Where :

- The **physical layer** consists of cable and connectors and is responsible for converting analog signals into bits.
- The **data link layer** transmits frames of bits across a single link between two machines.
- The **network layer** routes packets through a network to a destination node.
- The **transport layer** transmits messages from a process on one machine to a process on another machine.

Client/Server model

The client/server model is the standard model for network applications, a typical scenario is :

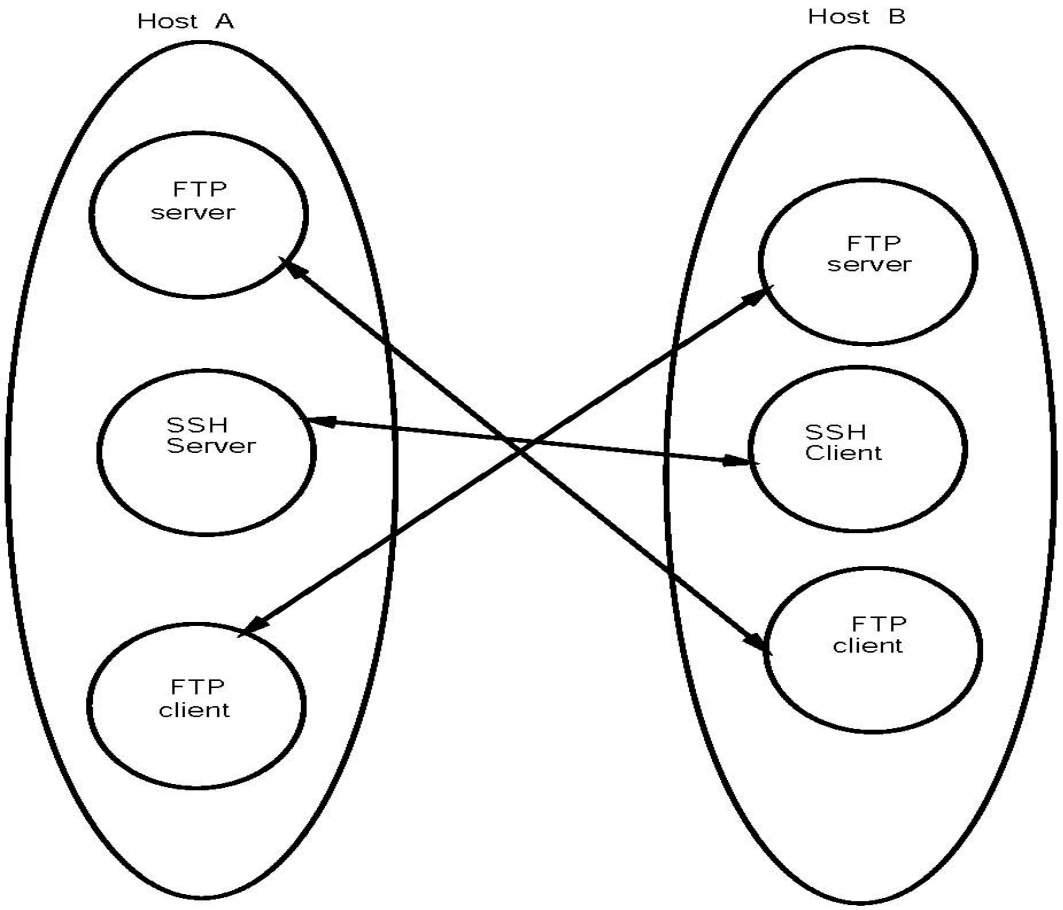
- The server process is started on some computer. It initializes itself, then goes to sleep waiting to be contacted by a client process for some service.

- A client process is started on some computer connected to the server's computer with a network. It sends a request across the network to the server asking for some service, remote login for instance.

- The server provides its service in two ways :

  1. for a short amount of time service, the server process handle the service itself and goes back to sleep, waiting for new requests.

  2. otherwise, the server invokes another process to handle each client request, so that the server process can go back to sleep

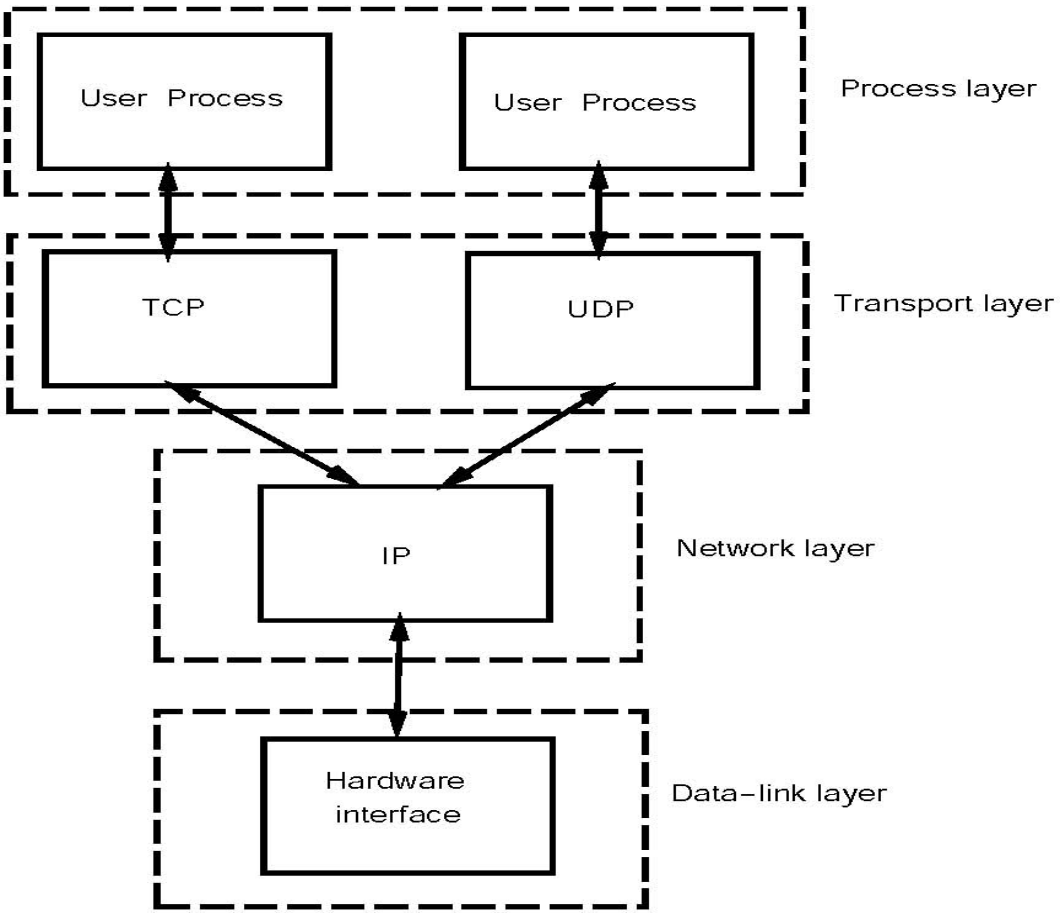

Host A
FTP server
SSH Server
FTP client
Host B
FTP server
SSH Client
FTP client

What is TCP/IP

The **TCP/IP** (Transmission Control Protocol/Internet Protocol) protocol suite supports the Internet and is by far the most widely used.
Some interesting points about **TCP/IP**:

- It is not vendor-specific.
- It has implemented on everything from PC to the largest supercomputers.
- It is used for both LANs and WANs

TCP/IP protocol family contains more members than **TCP** and **IP**.



- TCP : Transmission Control Protocol. A connection-oriented protocol that provides a reliable, full-duplex, byte stream for a user process(most used by Internet application).
- UDP : User Datagram Protocol. A connectionless protocol for user processes.
- IP : Internet Protocol. IP is the protocol that provides the packet delivery service for TCP and UDP.

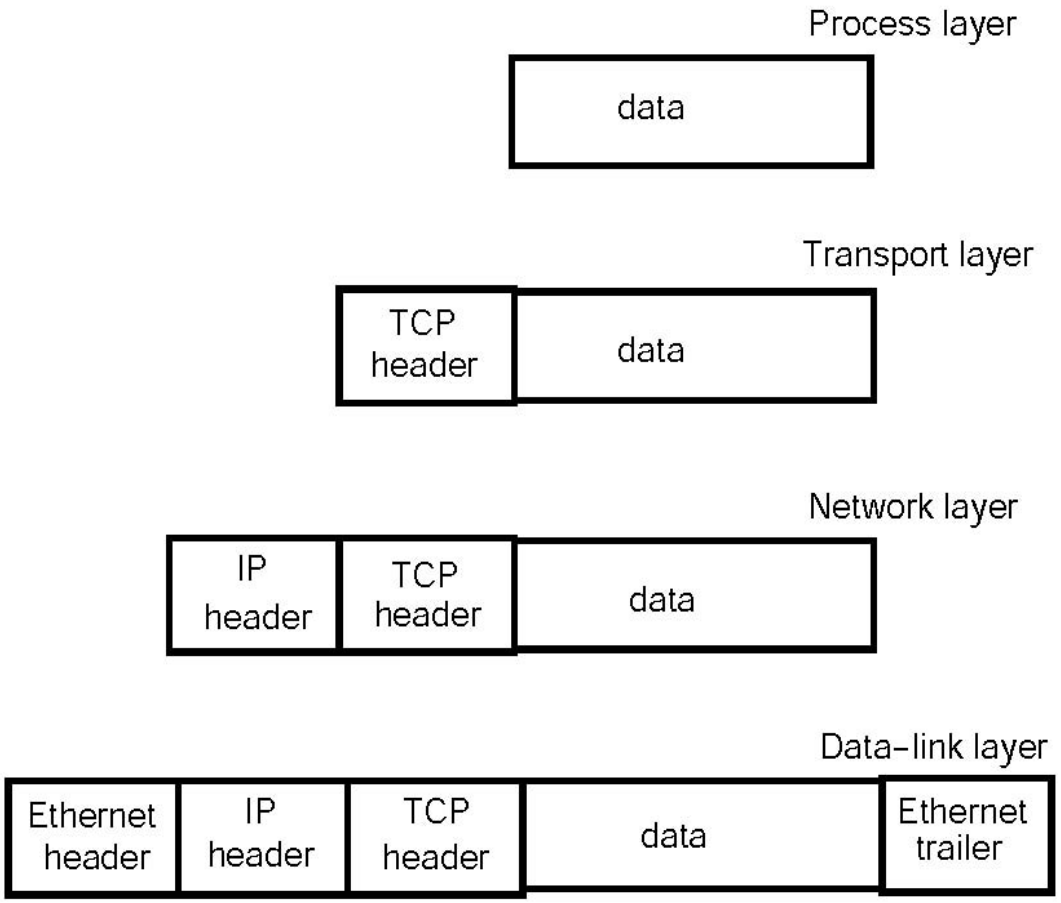
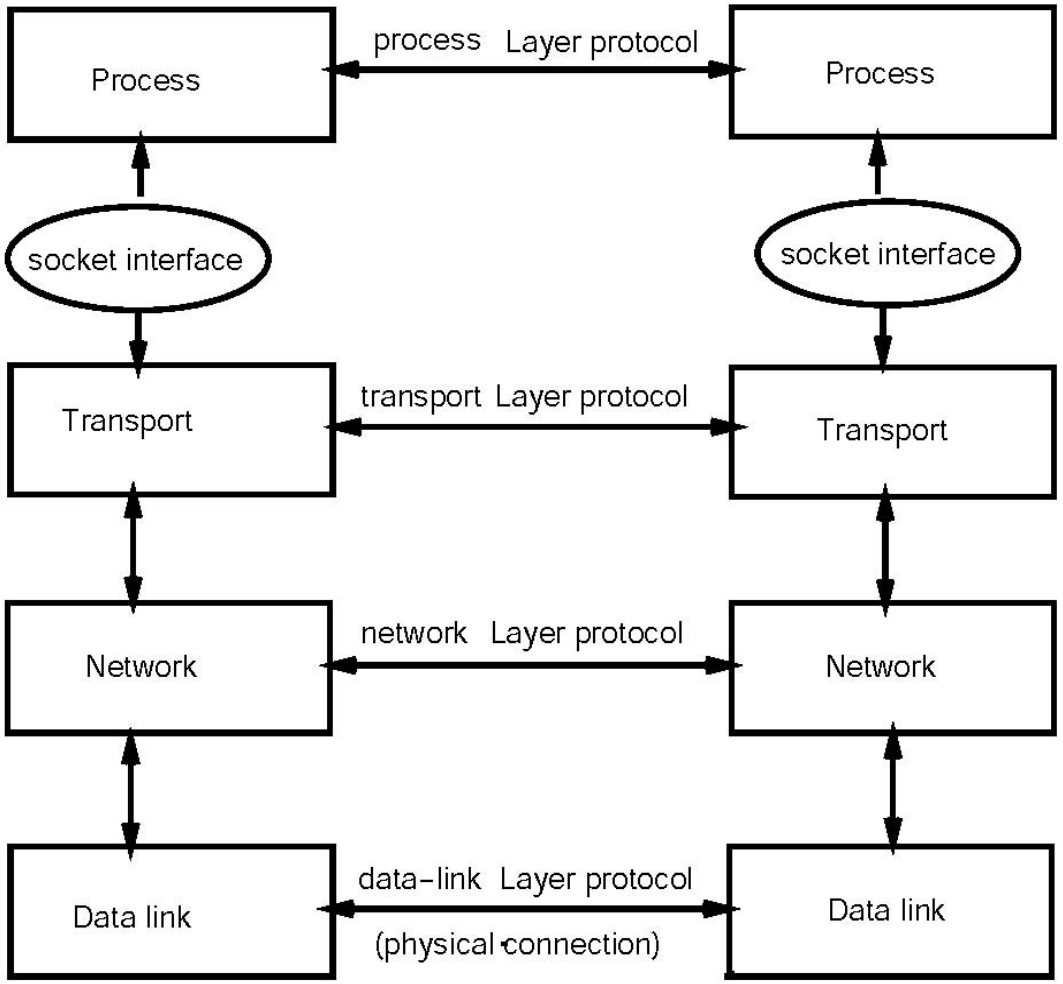


Figure 3: Encapsulation of data in TCP/IP layers and Ethernet

AN APPLICATION PROGRAM INTERFACE: THE SOCKETS

It is possible to use directly the TCP/IP protocol to implemente network applications. However, it is difficult and time consuming(compare an assembler language with a high level one).
The socket interface acts between the user process and TCP/IP :


Process
process Layer protocol
Process
socket interface
socket interface
Transport
transport Layer protocol
Transport
Network
network Layer protocol
Network
Data link
data-link Layer protocol
(physical connection)
Data link

Sockets

Sockets are the tradional UNIX IPC mechanism that allows local/distant processes to talk to each other.
IPC using sockets is based on the client/server paradigm.
A typical scenario can be described as follows.

- The server process creates a named socket, whose name is known by client processes, and listens on that sockets for requests from clients.
- A client process can talk to the server process by
  - creating an unnamed socket then,
  - requesting it to be connected to the server's named socket
- If succesful, one file descriptor is returned to the client and another one to the server. These file descriptors can be used for read and write allowing the server and client to communicate.

Note : Socket coonections are bidirectional.

Different kinds of sockets

Three attributes may differentiate between different kinds of sockets :

- The domain : **AF_INET** for internet and **AF_UNIX** for same machine IPC.
  Note that **AF** stands for Address Family.
- The type of communication : **SOCK_STREAM**, reliable byte stream connection(TCP) and, **SOCK_DGRAM**,unreliable connectionless (UDP).
- The protocol : the low-level protocol used for communication. This parameter is usually set to 0 in system calls, which means "use the correct/default protocol".

Socket Address Structure

Most socket functions require an argument pointer to a socket address structure, **which is protocol dependent**.

→ **Internet socket address structure**

The structure is called *sockaddr_in*, defined in $< netinet/in.h >$

Here is a version for **IPv4** :

```
typedef uint32_t in_addr_t;
typedef unsigned short  sa_family_t;
struct in_addr {
  in_addr_t    s_addr;
};
struct sockaddr_in {
  uint8_t         sin_len;//length of structure(16)
  sa_family_t     sin_family;// AF_INET or AF_INET6
  in_port_t       sin_port; // 16-bit port number
  struct in_addr  sin_addr; // 32-bit IP4 address
  char            sin_zero[8]; // unused
};
```

Here is a version for **IPv6** :

```
struct sockaddr_in6{
  sa_family_t     sin6_family;   // AF_INET6
  in_port_t       sin6_port;     // port number
  uint32_t        sin6_flowinfo; // IPv6 flow
                                 // information
  struct in6_addr sin6_addr;     // IPv6 address
  uint32_t        sin6_scope_id; // Scope ID
                                 // (new in 2.4)
};

struct in6_addr {
    unsigned char   s6_addr[16]; // IPv6 address
};
```

→ **Unix socket address structure**

The structure is called *sockaddr_un*, defined in
$< sys/un.h >$ ($< linux/un.h >$)
Here is a version from **Solaris** :

```
struct sockaddr_un {
sa_family_t sun_family;  // AF_UNIX
char sun_path[108];  // path name
};
```

→ **Generic Socket Address Structure**

Socket address structures are always passed by address when passed as a parameter.
Because there are several kinds of socket structures, socket functions prototypes take a pointer to the generic socket address structure, which represents any socket address structure parameter.

The generic address structure is called *sockaddr*, defined in $< sys/socket.h >$
Here is the definition of the structure :

```
struct   sockaddr{
  uint8_t          sa_len;
  sa_family_t      sin_family;
  char sa_data[14]; // protocol-specific address
};
```

Example : The *bind()* function prototype is
int bind(int, struct sockaddr *, socklen_t);

→ Any call to these function should cast the pointer to the protocol-specific socket address structure to be a point to a generic socket address structure.
For example :
struct sockaddr_in sv; // IPv4 socket, server
:
bind(sfd, (struct sockaddr*)&sv, sizeof(sv));

Creating endpoints for communication : socket()

Synopsis :
int socket(int domain, int type, int protocol);
socket() creates an endpoint for communication and returns a file descriptor referencing the socket. In case of failure, *socket()* returns -1.

Calling *socket()* is the first thing a process must do in order to perform any network I/O operation.
Example:
sd = socket(AF_INET, SOCK_STREAM, 0);
When a realiable byte-stream connection is requested across the internet.

Notes: header files and libraries to be linked are

- Includes : $< sys/types.h >$ and $< sys/socket.h >$

Initiating a connection on a socket : connect()

Synopsis :
int connect(int s,struct sockaddr *srv,int len)
Returns 0 when successful and -1 otherwise.

connect() is used by a *TCP* client to establish a connection with a *TCP* server.
The parameters have the following meanings :

- **s** is a socket decsriptor that was returned by *socket()*.
- *srv* is a pointer to a socket address structure object, which must contain the IP address and port number of the server
- *len* is the size of the socket address structure.

connect() only returns when a connection is established or when an error occurs.

Binding a name to a socket : bind()

Synopsis :
int bind(int s, struct sockaddr *sp, int len);
Returns 0 when successful and -1 otherwise.
bind() assigns a local protocol address to a socket.
In case of the Internet, the protocal address consists of a 32-bit IPv4 address and a 16-bit port number.
Another description from the manual page :
When a socket is created with *socket()*, it exists in a name space (address family) but has no name assigned.
bind() requests that the name pointed to by *sp* be assigned to the socket specified by *s*.

bind() is usually called by a server to bind their local IP and a well-known port number to a socket.

Listening for connections on a socket : listen()

Synopsis : int listen(int s, int backlog);
Returns 0 when successful and -1 otherwise.

listen() is called only by a TCP server to accept connections from client sockets that will issue a *connect()*.
s is a file desciptor of a socket that has been already created.
backlog defines the maximum length the queue of pending connections may grow to.

listen() is normally called after the calls to *socket()* and *bind()*.

Accepting a connection on a socket : accept()

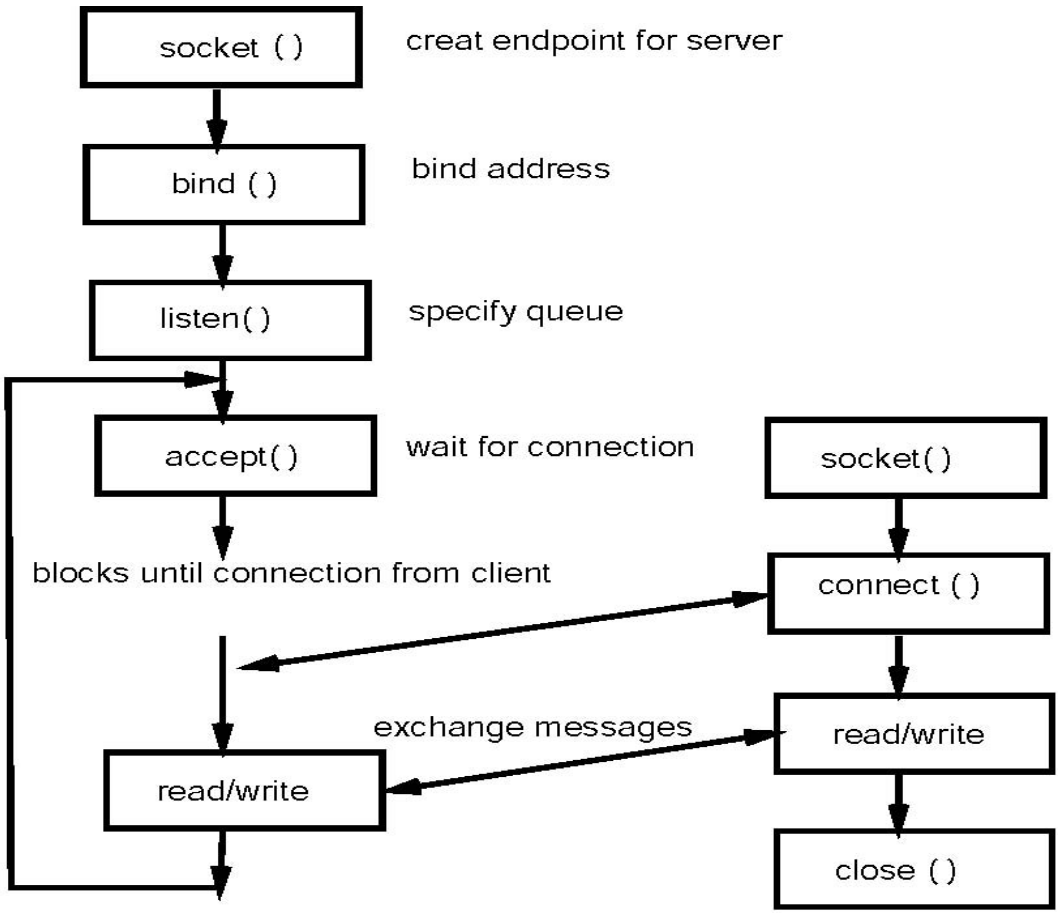
Synopsis :
int accept(int s, struct sockaddr *addr,
socklen_t *addrlen);
Returns a file descriptor for a new socket when successful and -1 otherwise.

accept() is called by a TCP server to extract he first connection on the queue of pending connections, creates a new socket with the properties of s, and allocates a new file descriptor for the newly created socket.
If no pending connections are present on the queue, accept() blocks the caller until a connection is present.

Usually, the file descriptor *s* is called the listening socket while the returned value is called the connected socket.

Socket based client/server IPC

The following figure shows the typical scenario for a connection-oriented communication using sockets.



EXAMPLES : IMPLENTATION OF CLIENT/SERVER APPLICATION

Two examples are presented here:

- A date/time client/server, where the server sends its date/time to clients.
- A synchronized client/server message exchange(1 to 1).

Useful helpers :

- Function **inet_pton():** converts an address from presentation to network format.
- Command **hostname -I** displays machine IP.
- Include <**arpa/inet.h**> and <**sys/socket.h**>

```
int main(int argc, char *argv[]){//E.g., 1, server
 char *myTime;
 time_t currentUnixTime; // time.h
 int sd, client, portNumber;
 socklen_t len;
 struct sockaddr_in servAdd;

 if(argc != 2){
  fprintf(stderr,"Call model: %s <Port#>\n",argv[0]);
  exit(0);
 }
 if((sd = socket(AF_INET, SOCK_STREAM, 0))<0){
  fprintf(stderr, "Could not create socket\n");
  exit(1);
 }
  servAdd.sin_family = AF_INET;
  servAdd.sin_addr.s_addr = INADDR_ANY;
  sscanf(argv[1], "%d", &portNumber);
  servAdd.sin_port = portNumber;
```

```
  bind(sd, (struct sockaddr *) &servAdd,
       sizeof(servAdd));
  listen(sd, 5);

  while(1){
    client=accept(sd,(struct sockaddr*)NULL,NULL);
    printf("Got a date/time request\n");
    currentUnixTime = time(NULL);
    myTime = ctime(&currentUnixTime);
    write(client, myTime, strlen(myTime) + 1);
    close(client);
    printf("Date and Time sent\n");
  }
}
```

```
int main(int argc, char *argv[]){//E.g., 1, client
  char message[100];
  int server, portNumber;
  socklen_t len;
  struct sockaddr_in servAdd;

 if(argc != 3){
    printf("Call model:%s <IP> <Port#>\n",argv[0]);
    exit(0);
  }
  if ((server=socket(AF_INET,SOCK_STREAM,0))<0){
     fprintf(stderr, "Cannot create socket\n");
     exit(1);
  }
  servAdd.sin_family = AF_INET;
  sscanf(argv[2], "%d", &portNumber);
  servAdd.sin_port = portNumber;
```

```
  if(inet_pton(AF_INET, argv[1],
               &servAdd.sin_addr) < 0){
    fprintf(stderr, " inet_pton() has failed\n");
    exit(2);
  }
  if(connect(server, (struct sockaddr *) &servAdd,
     sizeof(servAdd))<0){
    fprintf(stderr, "connect() failed, exiting\n");
    exit(3);
 }
 if (read(server, message, 100)<0){
  fprintf(stderr, "read() error\n");
  exit(3);
 }
 fprintf(stderr, "%s\n", message);
 exit(0);
}
```

```
int main(int argc, char *argv[]){//E.g., 2: Server
 int sd, client, portNumber;
 socklen_t len;
 struct sockaddr_in servAdd;

 if(argc != 2){
    printf("Call model: %s <Port #>\n", argv[0]);
    exit(0);
 }
 if ((sd=socket(AF_INET,SOCK_STREAM,0))<0){
   fprintf(stderr, "Cannot create socket\n");
   exit(1);
 }
 servAdd.sin_family = AF_INET;
 servAdd.sin_addr.s_addr = INADDR_ANY;
 sscanf(argv[1], "%d", &portNumber);
 servAdd.sin_port = portNumber;
 bind(sd,(struct sockaddr*)&servAdd,sizeof(servAdd));
 listen(sd, 5);
```

```
 while(1){
    client=accept(sd,(struct sockaddr*)NULL,NULL);
    printf("Got a client\n");
    if(!fork())
      child(client);
    close(client);
  }
}
```

```
void child(int sd){
  char message[255];

  while(1){
   fprintf(stderr, "Enter line to send to client\n");
   fgets(message, 254, stdin);
   write(sd, message, strlen(message)+1);

   if(!read(sd, message, 255)){
    close(sd);
    fprintf(stderr,"Bye, client dead, wait for
                    a new client\n");
    exit(0);
   }
   fprintf(stderr, "Clent send back: %s\n", message);
  }
}
```

```
        // Example 2: Client
int main(int argc, char *argv[]){
  char message[255];
  int server, portNumber;
  socklen_t len;
  struct sockaddr_in servAdd;

 if(argc != 3){
  printf("Call model:%s <IP> <Port#>\n",argv[0]);
  exit(0);
 }
 if((server = socket(AF_INET, SOCK_STREAM, 0))<0){
  fprintf(stderr, "Cannot create socket\n");
  exit(1);
 }

 servAdd.sin_family = AF_INET;
 sscanf(argv[2], "%d", &portNumber);
 servAdd.sin_port = portNumber;
```

```
if(inet_pton(AF_INET,argv[1],&servAdd.sin_addr)<0){
 fprintf(stderr, " inet_pton() has failed\n");
 exit(2);
}
if(connect(server,(struct sockaddr *)&servAdd,
           sizeof(servAdd))<0){
 fprintf(stderr, "connect() has failed, exiting\n");
 exit(3);
}
```

```
 while(1){
  if(read(server, message, 255)<0){
   fprintf(stderr, "read() error\n");
   exit(3);
  }
  fprintf(stderr, "Server's messgae: %s\n",message);
  fprintf(stderr, "Enter the $ sign to quit or
                   a message for the server\n");
  fgets(message, 254, stdin);
  if(message[0] == '$'){
   close(server);
   exit(0);
  }
  write(server, message, strlen(message)+1);
 }
}
```