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Nuts and Bolts Description

- Internet : a network of interconnected computer systems.
- Hosts are connected using a combination of communication links and packet switches.
- Communication Links : cables. Transmit data at varying rates known as transmission rate.
- Packet Switch : forwards inbound packets over some outbound link.
    - Link Layer switches : for access networks
    - Routers : used in network core.
- Route : the sequence of communication channels utilized in the communication.
- End systems access the network with the help of ISPs.
- ISP : Internet Service Providers. Basically an interconnection of links and packet switches.
- End systems and switches and other network devices run protocols that control how the data is sent over the network.
    - Internet Protocol(IP)
    - Transmission Control Protocol(TCP)
- The internet standards were developed by the Internet Engineering Task Force(IETF).
- The documentation is known as the Request For Comments(RFC).

Services Description

- View of the internet as an infrastructure for services to applications.
- Distributed Applications : run on different end systems.

Protocols

- Defines the format and order of transmission of messages between 2 communicating entities and the action taken on sending or receiving a message.
- On the internet the communication between any 2 communication devices is almost always governed by a protocol.

Network Edge

Access Networks

DSL

- Digital Subscriber Line
- The ISP is same as the telephone provider.
- At each home there is a splitter to split telephone and modem signals coming from the telco.
- The line connects each home to the Digital Subscriber Line Access Multiplexer(DSLAM) which is located in the telco Central Office(CO).
- The modem at the house converts the digital signals to analog and increases the frequency.
- The DSLAM converts this back into digital and sends it to a telco router.
- The upload and download rates of DSL are different. This is why they are said to have asymmetric access.
- Connected using a twisted pair copper cable.

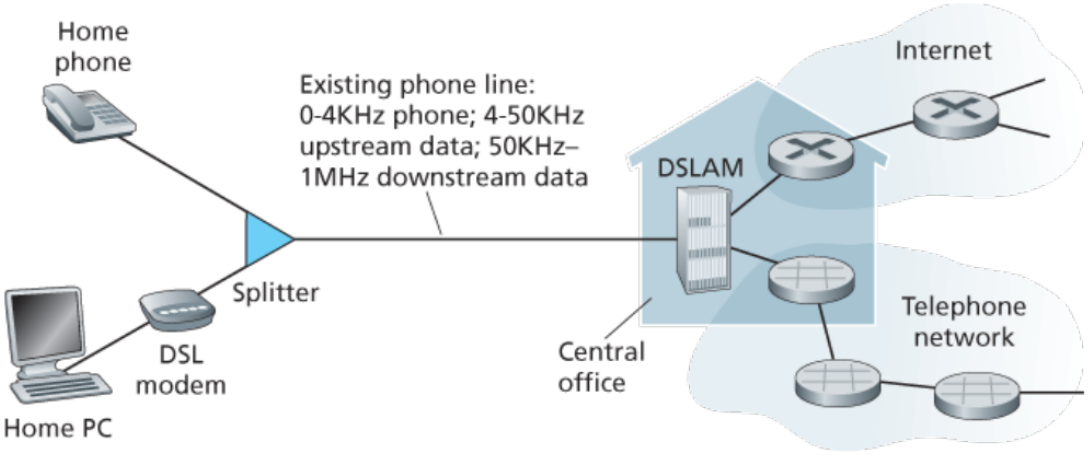


Figure 1.5 DSL Internet access

Cable

- Similar to DSL but the cable television provider acts as the ISP.
- Coaxial cables used to connect to the homes and fiber used to connect to the neighbourhood hubs. Since both types are used this type is called hybrid fiber coax(HFC)
- Even this type of access network is asymmetric.
- The neighbourhood hubs are connected to the CMTS which is similar to the DSLAM interms of functionality.
- Since all the houses are connected in serial, if all users on the line are downloading concurrently, then all of them may face a slowdown.
- We may also need protocols that handle collision control for uploads.

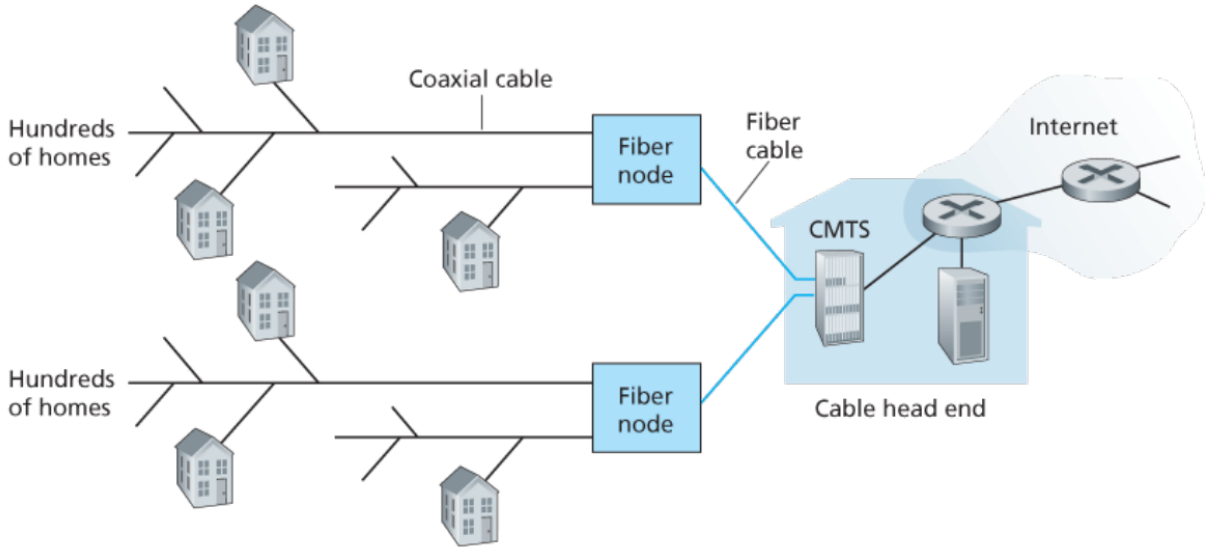


Figure 1.6 A hybrid fiber-coaxial access network

FTTH

- Fiber to the Home
  - Active Optical Network(AON)
  - Passive Optical Network(PON)
- In PON type networks, every house is equipped with a Optical network Terminator(ONT) connected by an optical fiber to a neighbourhood splitter.
- Usually a single line originates from the CO and splits into multiple fibers that run into the homes.
- Each line terminates at the Optical Line Terminator(OLT)

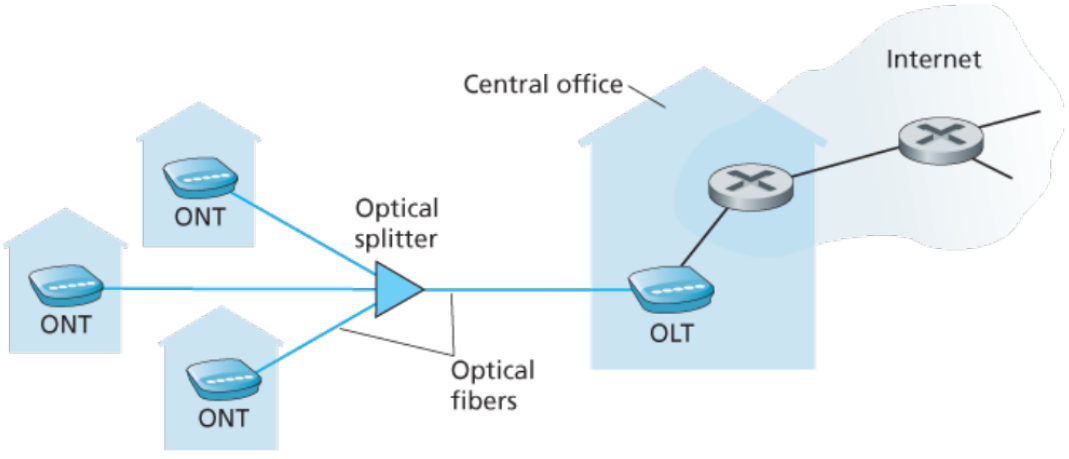


Figure 1.7 FTTH Internet access

Physical Media

- The medium of communication between 2 network nodes.
  - Guilded - a physical medium is present
  - Unguided - no physical medium

- Twistesd Pair
  - 2 copper wires twised around each other.
  - This reduces electrical interference.
  - used largely for telephone communications.
  - Can transfer signals over upto 100 KMs.
  - UTP - Unsheilded twisted pair - no covering sheath.
- Coaxial
  - 2 copper wires arranged in concentric manner.
  - This reduces any electrical interference.
  - Used popularly in TV signal transfer.
  - Can be used as a *guided shared medium* where any number of hosts can be connected to it and all of them can receive data that any other one sends.
- Fiber Optics
  - Conducts light pulses.
  - Really fast and little to no signal attenuation(loss) over large distances.
  - Hard to tap signals.
  - Optical Carrier(OC) - ranges from 51.8Mbps to 39.8Gbps.
    - OC-n : multiply $n * 51.8 Mbps$ to get payload of the link.
- Terrestrial Radio
  - Carry signals using electromagnetic spectrum.
  - No physical wire required.
  - Prone to :
    - Path/shadow loss : losses due to obstructions in the path
    - Multipath fading : losses due to reflection or refraction
    - Interference
- Satellite Radio
  - Between 2 earth based satellite stations.
  - Ground station transmits signals to the satellite.
  - This satellite acts as a repeater and regenerates these signals and sends them to the destination station.
    - Geostationary : stays over one location of the earth and rotates with the earth.
    - Low Earth Orbit(LEO) : at a lower level that the geostationary satellites. Not stationed over singular point. Multiple satellites are needed at this level to communicate.

Network Core

- Packet Switching :
  - To transmit L bits over a link of rate $Rbits/sec$, time to transmit is L/R

    - Store and forward :
        - router waits to receive all the bits of a packet before forwarding it.
    - Queuing Delays:
        - Routers have an output buffer.
        - Packets wait in this output buffer if the outbound link is congested.
        - The amount of waiting time depends on the congestion in the network.
        - Sometimes if there are incoming packets and the buffer is already full then some of the packets get dropped.
    - Forwarding table:
        - Each router has a forwarding table that maps IP addresses to its outbound links.
        - The router reads the destination IP of the packet from its header and forwards it along that link.
- Circuit Switching :
    - Circuit is reserved for a particular communication
        - Time Division Multiplexing : divides timeframes into slots
            - if framerate is x and number of bits per slot is y then transmission rate is xy
            - if bit rate is a and number of slots is b then transmission rate is a/b
        - Frequency Division Multiplexing : divides frequency into bandwidths
- Drawback of Packet switching :
    - variable and unpredictable delays
- Pros of Packet switching :
    - Better sharing of transmission capacity
    - simpler,more efficient, cheaper

Network of Networks :

- Network Structure 1 : One global ISP to which all the access ISPs connect. Access ISPs pay the global ISP as a function of the traffic exchanged.
- Network Structure 2 :
    - Multiple tier-1 ISPs. Consumers can choose amongst them based on the services and price that they offer.
- Network Structure 3 :
    - Introduction of regional ISPs. The access ISP connects to the regional ISP which inturn connects to the tier-1 ISP.
    - Sometimes there may be multiple regional ISPs or one regional ISP that is larger than the others.
- Network Structure 4 :
    - Addition of Points of Presence(PoP), Multi-homing, peering, IXPs.

    - PoP : any points in the provider's network where the access ISP can connect to by leasing a link.
    - Multi-homing : any ISP(except tier 1) connecting to multiple ISPs. This helps incase one of them incurs a failure.
    - Peering : ISP must pay money to access traffic from tier-1 ISP and hence multiple ISPs on the same level can exchange data with each other without any charge. This is called peering.
    - IXP : a building of routers and switches where multiple ISPs can peer togeather.
- Network Structure 5 :
  - Content provider networks are added.
  - Private companies like Google set up own datacenters which connect to the network by peering with ISPs. This allows it to bypass the upper layers and deliver content for free.

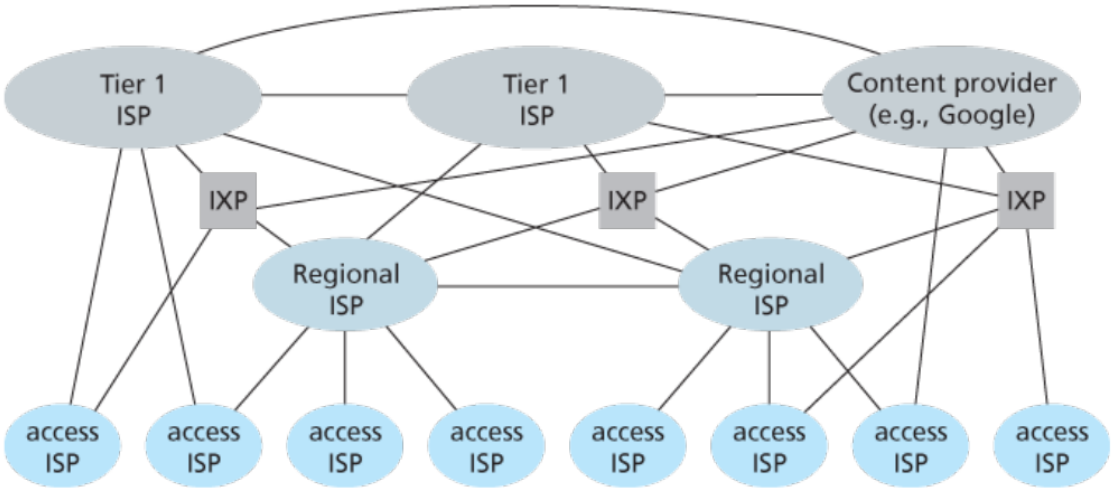
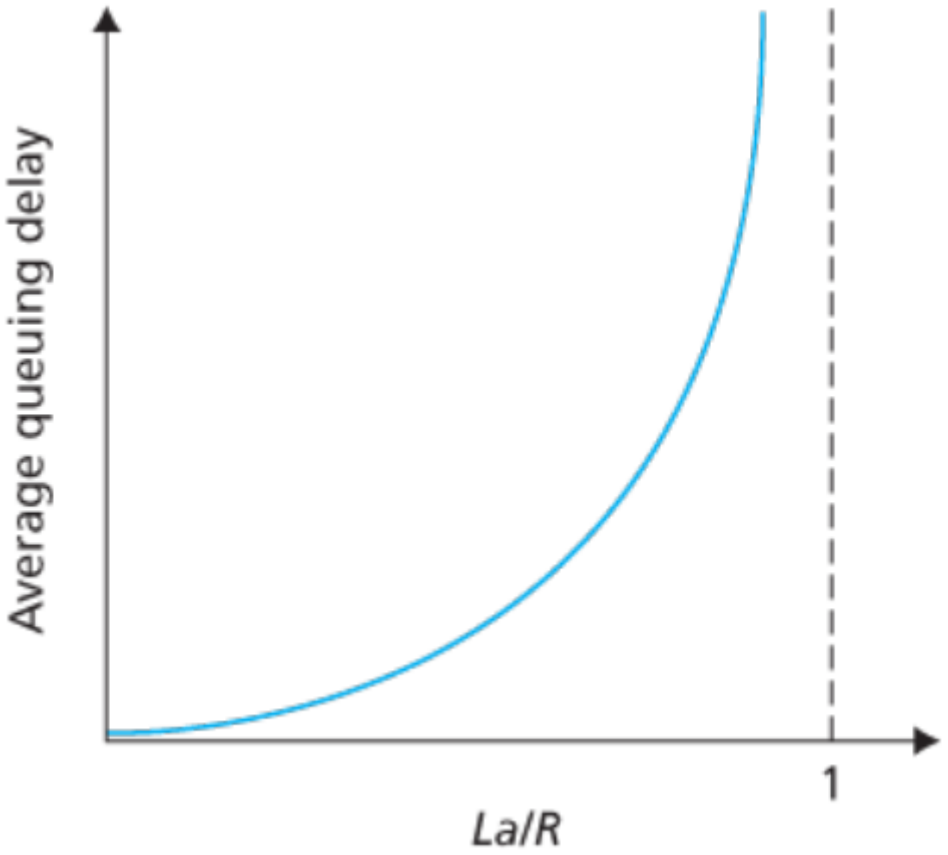


Figure 1.15 Interconnection of ISPs

Delays

- Processing Delay - delay in parsing packet headers and mapping to outbound link
- Transmission Delay - delay in pushing out the packet into the outbound link
    - $d_{trans} = L/R$
- Queuing Delay - delay incurred due to queuing of packets in the output buffer of the router.
  - traffic intensity = La/R
  - if La/R>1, rate of arrival exceeds rate of transmission from queue.



- Propagation Delay - time taken to propagate till the destination from the start of the link.
  - $dprop = d/s$
- $d_{nodal} = d_{prop} + d_{trans} + d_{queue} + d_{proc}$
- $d_{end-to-end} = N(d_{proc} + d_{trans} + d_{prop})$

OSI Layer Model

- Layering increases modularity and makes it easier to update system components.

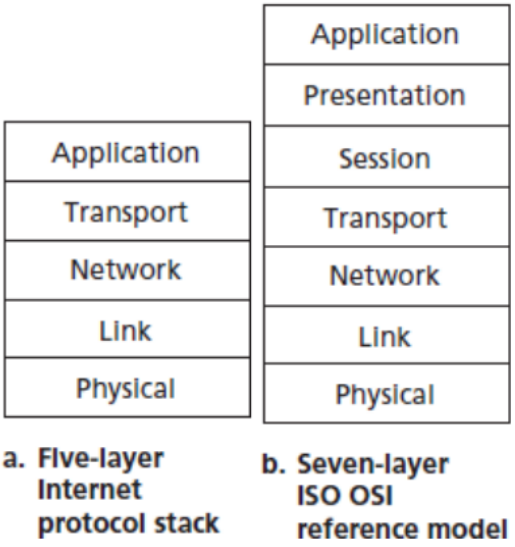


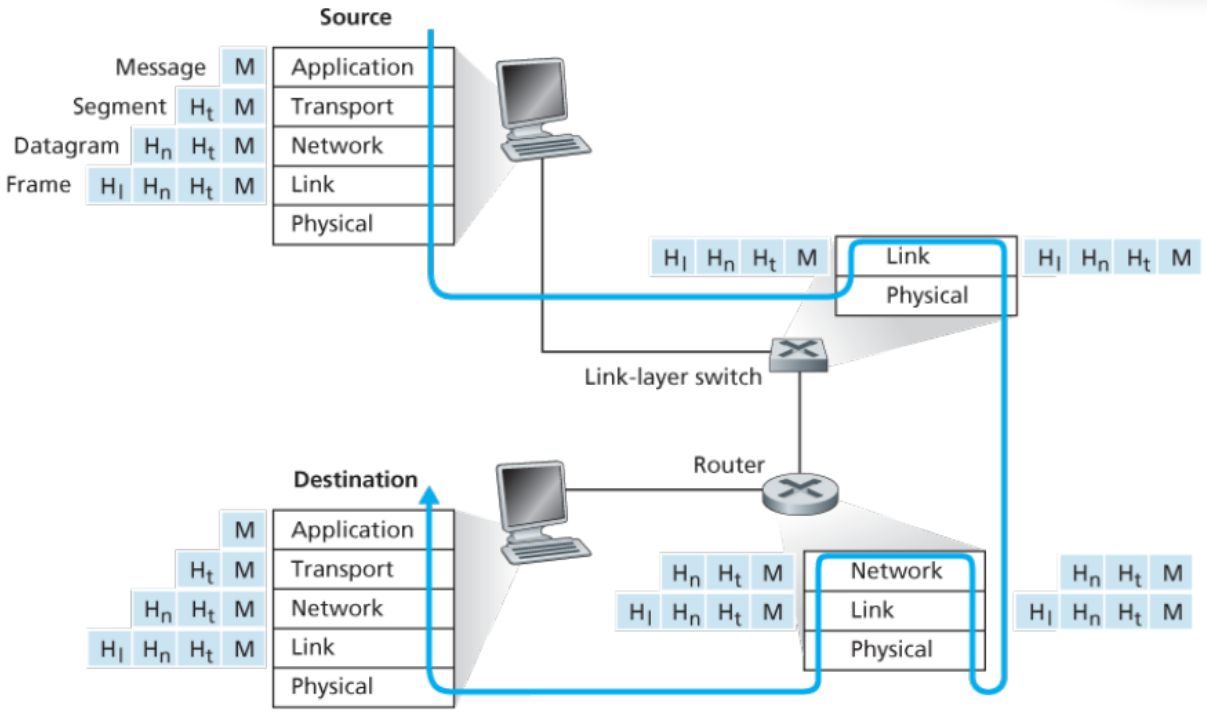
Figure 1.23 The Internet protocol stack (a) and OSI reference model (b)

- Drawbacks:
  - Duplication of functionality

    - Dependance of one layer on data present in another layer.
- Layers:
    - Application Layer :
        - Protocols : HTTP,SMTP,FTP,DNS
        - Format : Message
        - Interfaces between process and host
    - Transport Layer :
        - Protocols : TCP,UDP
        - Format : Segment
        - Process to Process communication
    - Network Layer :
        - Protocols : IP
        - Format : Datagram
        - Host to host communication
    - Link Layer :
        - Protocols : Ethernet,WiFi, DOCSIS
        - Format : Frames
        - Communication between nodes
    - Physical Layer :
        - Protocols : Link dependant
        - Format : Bits
        - transmits bits between adjacent network elements
- Additional Layers in the 7 layer model:
    - Presentation Layer :
        - Compression
        - Encryption
        - Formatting
    - Session Layer :
        - Checkpointing
        - Sync of data exchange

Encapsulation

- Each layer appends a header to the payload from the layer above it to be used by the receiver system.
- This is called encapsulation.
- Additionally the layer even attaches a trailer that helps detect the end of the data.



- Routers implement layers only from 1-3. They can therefore use the IP.
- Link layer switches though implement only layers 1-2.

Network Architechtures

- Client Server
  - Always on host - server
  - Services request from the clients
  - Server - fixed IP
  - No direct client-client communication
  - Web,FTP,telnet,email
- P2P
  - Clients communicate amongt themselves
  - Self scalable - each added peer adds workload but also adds service capacity to the network
  - Fault tolerant - no dependence on one singular server

Process Communication

- Every program running on the host is called a process.
- Processes can be classified as :
  - Client : process that initially requests data from the other process
  - Server : process that waits for requests
- The application developer must send the data into the network using the Socket API.
- Socket API : interface between application and transport layer.
- Developers usually have little control over the parameters of the network:
  - choose between UDP and TCP

    - maximum buffer and MSS.
- To send data to the correct process we must address it right:
  - IP - addresses the host machine
  - Port number - to address the exact process in the host machine.

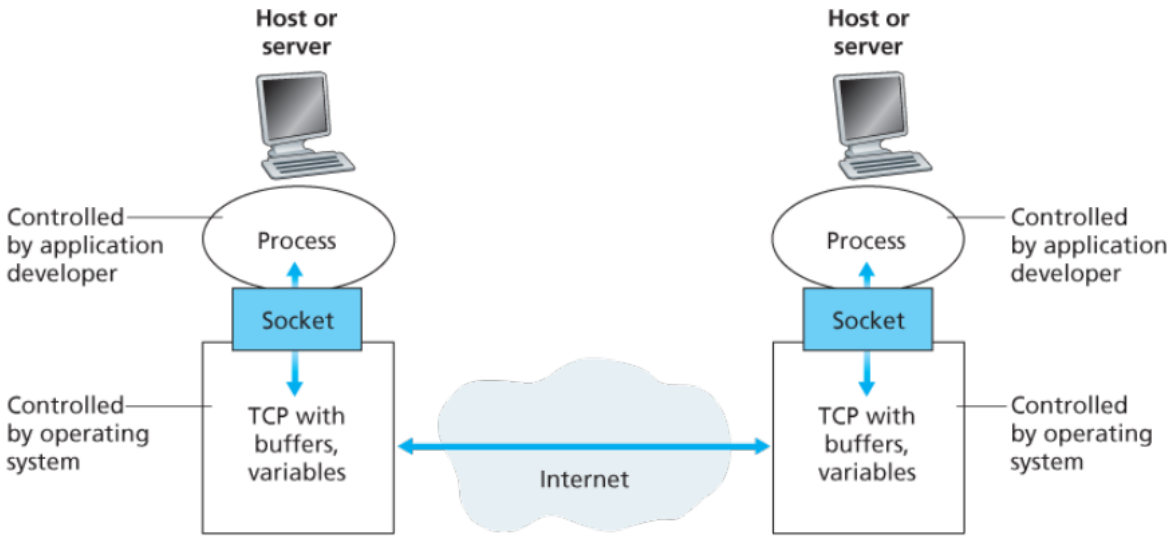
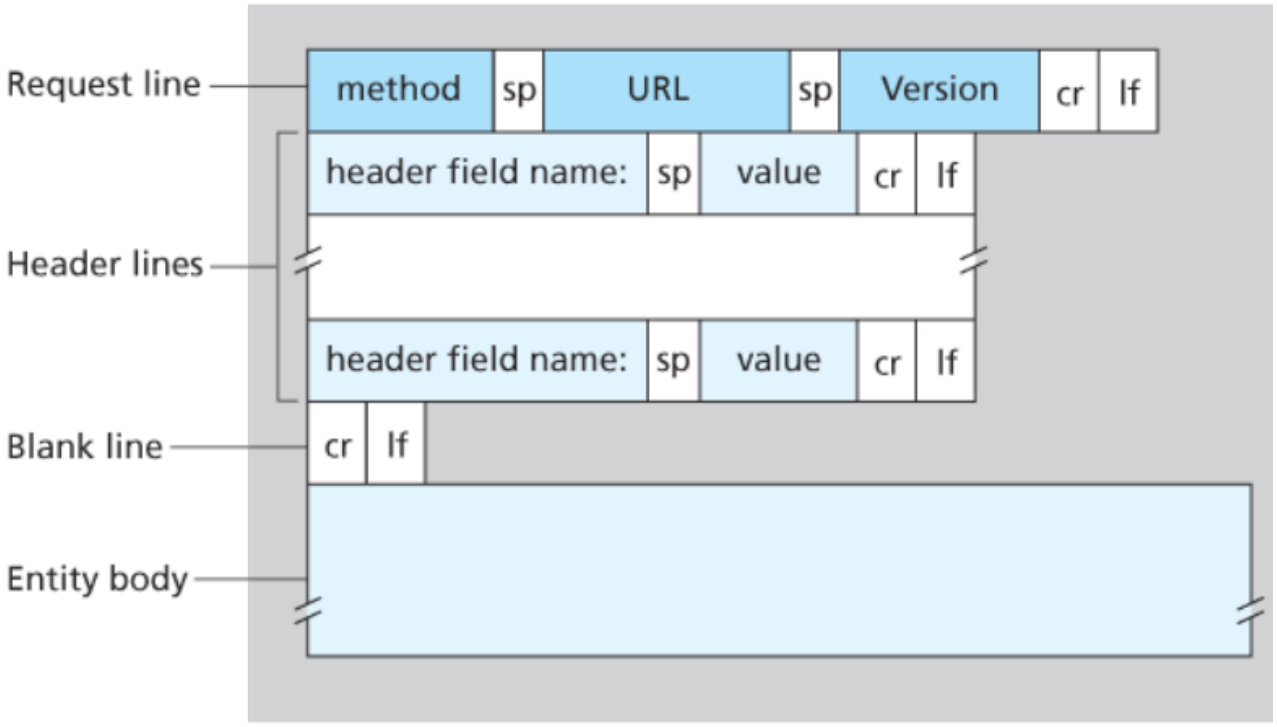


Figure 2.3 Application processes, sockets, and underlying transport protocol

HTTP

- Port 80
- Client-Server architecture
- Stateless(past history not stored)
- Uses TCP
- Object : anything addressable by a URL(images,other pages etc).
- RTT: Round Trip Time - time taken to send TCP packet from client to server and back.
- Types :
  - Persistent
    - Leaves TCP connection open after transfer
    - 2RTT for connection establishment
  - Non-Persistent
    - TCP connection closed after each transfer of an object.
    - Drawback : new TCP variables and buffers must be created each time an object is requested.
    - 2RTT + File Transfer time
- HTTP adopts Persistent with pipelining by default

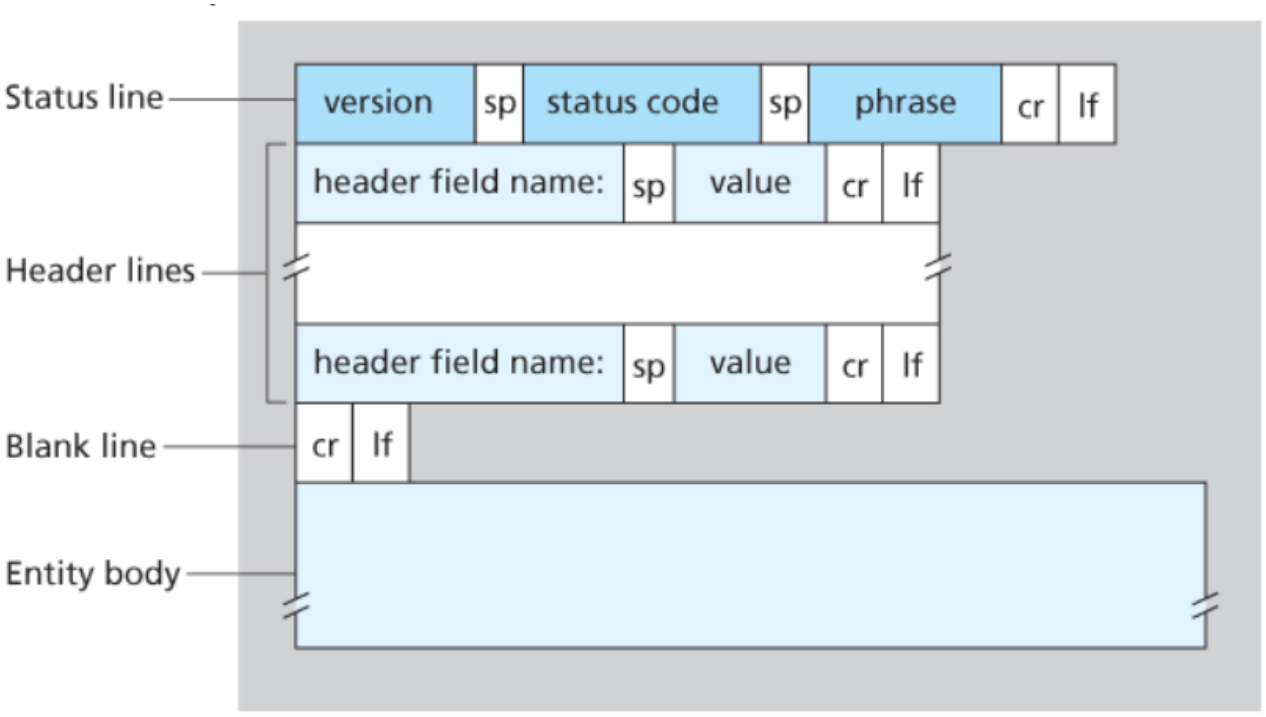
HTTP Request format




```
GET /somedir/page.html HTTP/1.1
Host: www.someschool.edu
Connection: close
User-agent: Mozilla/5.0
Accept-language: fr
```

- GET - Empty entity body
- POST - entity body is filled with form contents
  - Not always the case since HTML forms add the form fields to the URL and do a GET request
- HEAD - similar to GET but respose is an HTTP message with no requested object. Used to debug.
- PUT - To upload contents to a webserver
- DELETE - to delete contents from a webserver

HTTP Response




```
HTTP/1.1 200 OK
Connection: close
Date: Tue, 18 Aug 2015 15:44:04 GMT
Server: Apache/2.2.3 (CentOS)
Last-Modified: Tue, 18 Aug 2015 15:11:03 GMT
Content-Length: 6821
Content-Type: text/html
(data data data data data ...)
```

- 200 ok
- 301 moved permanently
    - One of the header lines will be Location which will indicate new location. Client will automatically reroute there.
- 400 Bad request
- 404 Not found
- 505 HTTP version not supported

Cookies

- HTTP is stateless and hence can't store user sessions.
- We use cookies where such action is necessary
- Components:
    - Cookie header line in request
    - Cookie header line in response
    - List of cookies on the client
    - Database on the backend

- The first time a user visits a website, it replies with a response containing the header line :

```
set-cookie : 8008
```

- Now this cookie ID is stored in the client's cookies file and everytime a request is made to this site, this ID is appended to the header lines.

Web Caching

- Proxy servers to speed access to web objects.
- These servers store copies of frequently requested resources.
- Clients request these servers directly.
- If resource not in cache, it forwards request to the webserver
- This reduces response times and web traffic
- Conditional GET:
    - To prevent content in cache from getting stale.
    - It stores the last modified date and an `if-modified-since` header line.
    - On the first request to cache , it sends a request to the webserver and notes the last modified date.
    - If not modified webserver sends a response with no entity body and a 304-not modified status code.