OS & Network Summary

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Chapter 1

Parts of a Network

Component	Function	Example
Application, or app, user	Uses the network	Skype, iTunes, Amazon
Host , or end-system, edge device, node, source, sink	Supports apps	Laptop, mobile, desktop
Router, or switch, node, hub, intermediate system	Relays messages between links	Access point, cable / DSL moden
Link, or channel	Connects nodes	Wires, wireless

Key interfaces

- Network-application interfaces define how apps use the network (Sockets widely used)
- Network-network interfaces define how nodes work together (ex : Traceroute)

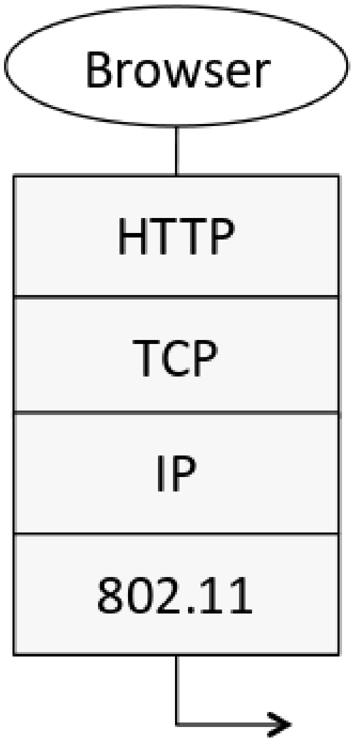
Network service API hides details (Apps don't know what is inside the network)

Protocols and layers

To divide up network functionality

- Each instance of a protocol talks virtually to its peer using the protocol
- Each instance of a protocol uses only the services of the lower layer

Protocol stack example :



Encapsulation : Lower layer wraps higher layer content and add its own information

Advantage of layering : Information hiding and reusability
Disadvantages of layering : Overhead and hides information

OSI "7 layer" Reference Model

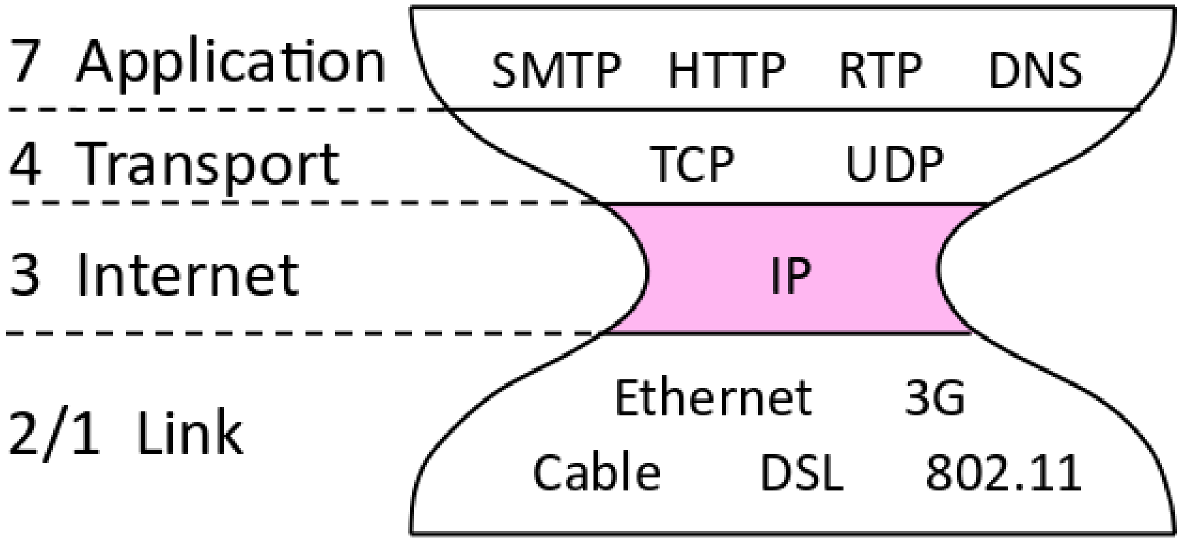
	Layer	**Description**
7	Application	Provides functions needed by users
6	Presentation	Converts different data representations
5	Session	Manages task dialogs
4	Transport	Provides end-to-end delivery
3	Network	Sends packets over multiple links
2	Data link	Sends frames of information
1	Physical	Sends bits as signals

Four layer model

Based on experience

	Layer	Description
7	Application	Programs that use network service
4	Transport	Provides end-to-end data delivery
3	Internet	Send packets over multiple networks
2 (/1)	Link (/Physical)	Send frames over a link (/Sends bits using signals)

Internet Reference Model



Layer-based names

Layer	Unit of Data
Application	Message
Transport	Segment
Network	Packet
Link	Frame
physical	Bit

Devices in the network :

- Repeater (Hub) : Physical/Physical
- Switch (bridge) : Link/Link
- Router : Network+Link / Network+Link
- Proxy (middlebox, gateway) : App+Transport+Network+Link

Chapter 2 : Physical Layer

Socket API

Primitive	Meaning
SOCKET	Create a new communication endpoint
BIND	Associate a local address with a socket
LISTEN	Announce willingness to accept connections; give queue size
ACCEPT	Passively wait for an incoming connection
CONNECT	Actively attempt to establish a connection
SEND	Send some data over the connection
RECEIVE	Receive some data from the connection
CLOSE	Release the connection

Simple link model

Properties : Rate, Delay/Latency, wether the channel is broadcast, its error rate

Rate

Or bandwith, capacity, speed
in bits/second

Delay / latency

- Transmission delay T: Time to put M-bit message on the wire

$$T = \frac{M[bits]}{Rate\left[\frac{bits}{s}\right]} = \frac{M}{R}\,[s]$$

- Propagation delay D : time for bits to propagate across the wire

$$D = \frac{Length}{Speed of signals} = \frac{L}{\frac{2}{3}\,C}$$

- Latency L : delay to send a message over a link

$$L = T + D = \frac{M}{R} + \frac{L}{\frac{2}{3}C}$$

Bandwidth-delay product

The amount of data “in flight”

$$BD = R \cdot D$$

Types of Media

Media propagate signals that carry bits information.
Common types :

- Wires
- Fiber
- Wireless

Wireless

- Travel at speed of light
- Spread out and attenuate faster than $\frac{1}{d^2}$
- Interference between signals on the same frequency (=> spatial reuse of same freq)
- Multipath : signal interferes with itself after reflexion

Modulation

How the signals represent bits

- NRZ : A high voltage +V represents a 1 and a low voltage -V represents a 0

Clock recovery

Receiver needs frequent signal transitions to decode bits (synchronisation)

4b/5b

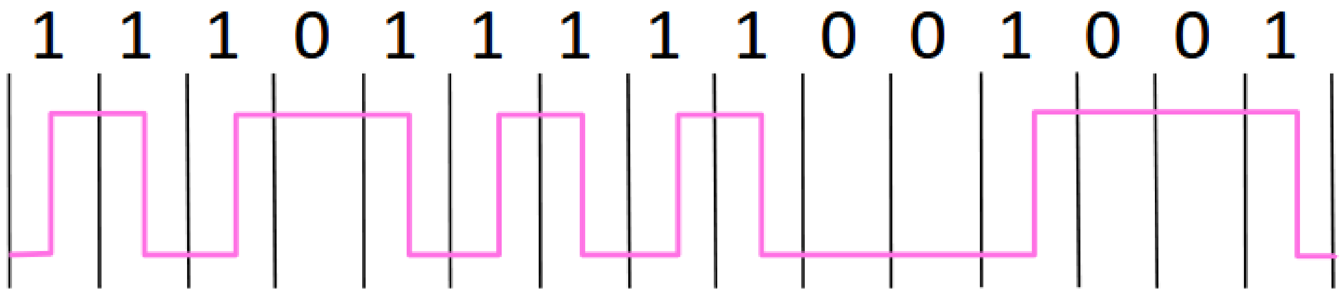
- Map every data bits into 5 code bits without long runs of zeros

4b	5b
0000	11110
0001	01001

1110	11100
...	...
1111	11101

- Invert signal level on every 1 (NRZI)

Example :
message : 1111 0000 0001

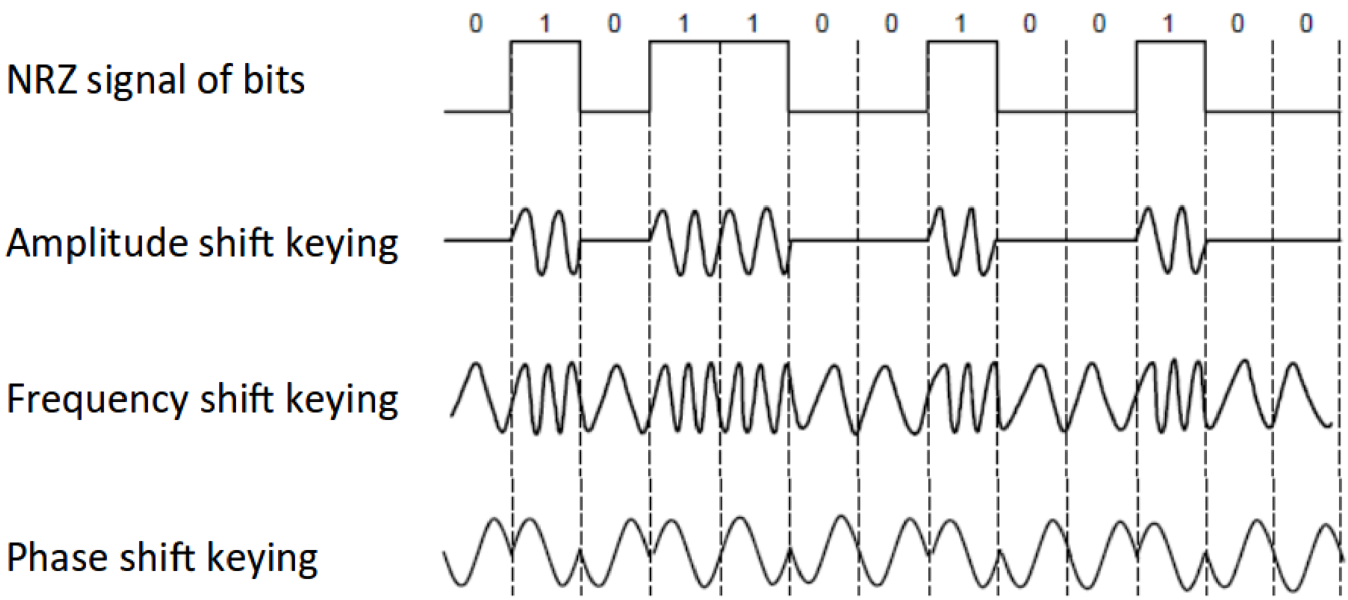


Baseband vs Passband modulation

Baseband : Signal is sent directly on a wire (wires)
Passband : Modulation carries a signal by modulating a carrier (fiber / wireless)

Passband

Carrier is a signal oscillating at desired frequency. We modulate it by changing amplitude, frequency or phase



Fundamental limits

Key channel properties

- Bandwidth B
- Signal strength S
- Noise strength N

Nyquist limit/frequency

If we have a channel with a bandwidth B, the maximum symbol rate is $2B$.
If we have V signal levels ($log_2 V$ different bits), the maximum bit rate is

$$R = 2B \cdot log_2 V \left[\frac{bits}{s}\right]$$

Shannon capacity

The number of levels we can distinguish on a channel depends on the SNR (~ S/N)

The Shannon capacity C is the maximum information carrying rate of the channel

$$C = B \cdot log_2 \left(1 + \frac{S}{N}\right) \left[\frac{bits}{s}\right]$$

Wires / Fiber :
Engineer SNR for data rate

Wireless :
Adapt data rate to SNR (can't design for worst case)

Chapter 3 : Link Layer

Concerns how to transfer messages (frames, of limited size) over one or more connected links

Framing

Transform stream of bits from physical layer to sequence of frames

Byte count

- Start each frame with a length field
- Difficult tu resynchronize after framing error

Byte stuffing

- Use a flag byte value for start/end of frame
- Escape the flag (and the escape code) inside the message replacing (stuffing) it with an escape code

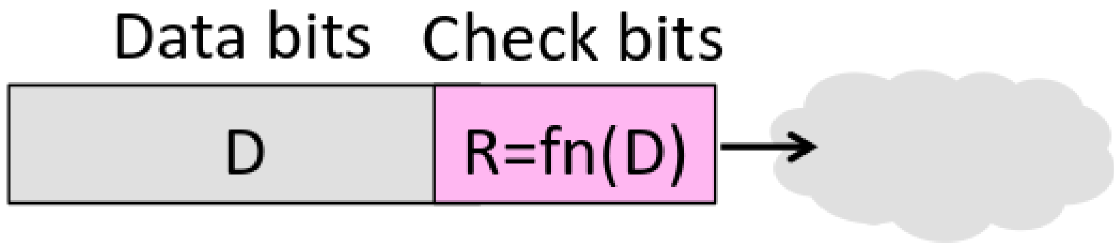
Bit stuffing

- Flag with six consecutive 1
- In the message, insert a 0 after five 1 when sending and remove every 0 after five 1 when receiving
- Slightly less overhead than byte stuffing but more complicated -> byte stuffing used in practice

Error coding

Using error codes

Codeword consists of data bits D plus check bits R



Hamming distance

- The distance is the number of bit flips needed to change $D + R_1$ to $D + R_2$
- The Hamming distance of a code is the minimum distance between a pair of codewords
- For a code of Hamming distance d+1, up to d errors will always be detected
- For a code of Hamming distance 2d + 1, up to d errors can always be corrected by mapping to the closest codeword

Error Detection

- Parity bit : The parity bit is the sum of the bits of D (distance : 2 -> detect 1 error); Little used
- Checksum : Sum up data in N-bit word (Stronger than parity)
- Internet Checksum
- CRC

In practice :

- CRCs used on links (Ethernet, 802.11, ADSL, Cable)
- Checksum used in Internet (IP, TCP, UDP)

Internet Checksum

Sending :

1. Arrange data in 16-bit words
2. Add
3. Add any carryover back to get 16 bits
4. Negate (complement) to get the checksum

Receiving :

1. Arrange data in 16-bit words (including checksum)
2. Add
3. Add any carryover back to get 16 bits
4. Negate the result and check if 0

Example :

```
1.      0001
        f203
        f4f5
2.    + f6f7
      ------
       2ddf0
```

```
        ddf0
3.    +    2
      ------
        ddf2


4. -> 220d
```

Transmit to physical layer : 0001 f203 f4f5 f6f7 220d

```
1.      0001
        f203
        f4f5
        f6f7
2.    + 220d
      ------
       2rffd
```

```
        fff0
3.    +    2
```

```
      ------
        ffff

4. -> 0000
```

- Distance of the code : 2
- Will always detect up to 1 error
- Will detect all burst errors up to 16
- For random errors, probability of miss is $\frac{1}{2^{16}}$ (2^{16} different checksums)

Cyclic redundancy check

For data D of length n, generate check bits R of length k such that the n+k bits are evenly divisible by a generator C.

- Protection depend on generator (standard has 32bits C)
- Humming distance of 4
- Detects odd numbers of errors
- Detects bursts of up to k bits in error
- Not vulnerable to systematic errors

Example :
D = 302, C = 3, k (length of R) = 1
=> R = 1 because $\frac{3021}{3} = 0$

Send procedure :

1. Extend D with k zeros
2. Divide by the generator C
3. Ignore quotient
4. Set check bits R as the remainder

Receive procedure :

1. Divide by C and check for zero remainder

Example :
D = 10111
C = 100
k = length(C) - 1 = 2

```
101 | 1011100
      101
      ---
       001
```

```
    000
    ---
     011
     000
     ---
      110
      101
      ---
        10 = R
```

Transmitted frame : 1011110

Error correction

It is difficult because errors can be in the check bits

Hamming code

Gives a method for constructing a code with a distance of 3.

To encode :

- With k check bits, we can check data of length $n = 2^k - k - 1$; ex: $k = 3, n = 4$
- The check bits are in positions p_i that are powers of 2, starting with position 1 (1, 2, 4, 8...)
- Fill the free positions with the data bits (positions 3, 5, 6, 7...)
- Check bit in position p_i is the parity of the bits at positions p_j for which the i^{th} bit in j is 1 (ex: p_2 is the sum of all the bits at positions p_j where the second bit in j is 1 => 10 (2), 11 (3), 110 (6), 111 (7), 1010 (10), ...)

To decode :

- Recompute check bits p_i (with parity sum including the check bit)
- Arrange as a binary number ($\dots p_8 p_4 p_2 p_1$)
- If the value (syndrome) is zero, it means there is no error
- Otherwise the syndrome is the position of the error, flip the bit at this position

Detection vs Correction

Correction

- When error are expected and in small number
- When no time for retransmission
- Used in physical layer (LDPC)
- Sometimes used in the application layer

Detection

- When errors are not expected
- When errors are generally large
- Used in the link layer and above

Retransmissions (ARQ)

- Receiver automatically acknowledges correct frames with an ACK
- Sender automatically resends after a timeout if no ACK is received
- Frames and ACKs must carry sequence numbers to avoid duplicates

Stop and wait

Use one bit to distinguish the current frame from the next one. Send one frame at a time

Sliding Window

Generalization of stop-and-wait

Allows W frames to be outstanding

Multiplexing

Network word for the sharing of a resource

- Time Division Multiplexing : Users take turns on a fixed schedule (ex : Round-Robin)
- Frequency Division Multiplexing : Put different users on different frequency bands

Multiple Access Control or Medium Access Control (MAC)

Basis for classic Ethernet

ALOHA protocol

- Node sends when it has traffic
- If there was a collision (no ACK received), wait a random amount of time and resend
- Works well only under low load

Carrier Sense Multiple Access(CSMA)

- Improve ALOHA by listening for activity before sending
- Collision can still occur because of delays

Carrier Sense Multiple Access with Collision Detection(CSMA/CD)

- Reduce the cost of collision by detecting them and aborting (jam) the rest of the frame

For a wire of max length (time) D, we impose a minimum frame size that lasts for 2D seconds. This way everyone who collides knows that it happened. A node can't finish before a collision

CSMA persistence

To avoid collision between nodes who queued up waiting for the current sender to finish
For N queued senders, each one sends with next with probability $\frac{1}{N}$

Binary Exponential Backoff (BEB)

Estimates the probability for CSMA persistence

- Double interval for each successive collision
- Quickly gets large enough to work and very efficient in practice

1st collision : wait 0-1 time frames
2nd collision : wait 0-3 time frames
3rd collision : wait 0-7 time frames
...

Acronyms

Acronym	Meaning	Description
Pan	Personal Area Network	ex : Bluetooth
Lan	Local Area Network	ex : WiFi, Ethernet
Man	Metropolitan Area Network	ex : Cable, DSL
Wan	Wide Area Network	Large ISP
NRZ	Non Return to Zero	
SNR	Signal to Noise Ratio	S/N
CRC	Cyclic redundancy check	
LDPC	Low Density Parity Check	State of the art today to correct errors in messages
ARQ	Automatic Repeat reQuest	

TDM	Time Division Multiplexing	
TDM	Frequency Division Multiplexing	
MAC	Multiple Access Control or Medium Access Control	
CSMA	Carrier Sense Multiple Access	
CSMA/CD	Carrier Sense Multiple Access with Collision Detection	
BEB	Binary Exponential Backoff	