Imperial College London

Computer Networks and Distributed Systems

Part 2 – Computer Networks: Physical Layer

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Part 2 – Contents

Physical Layer
- Properties of communications media
- Signalling, modulation and multiplexing
- Overview of common physical layer technologies

Think about impact on design decisions of layers above

Physical Layer

Provides communications path between nodes

Uses standards
- Agreed ways of connecting devices and signalling
  - Be able to interpret signals
  - Must deal with limitations of physical world

Not going into EE details (or physics)!

Properties of Wired Connections

Signals travel through wires at fixed speed
- Medium can carry signals at many frequencies

Attenuation: signals get weaker over distance

Signals may suffer from interference
- Shielded wires help with attenuation & interference
- Twisting also helps with interference
- Often wires require termination

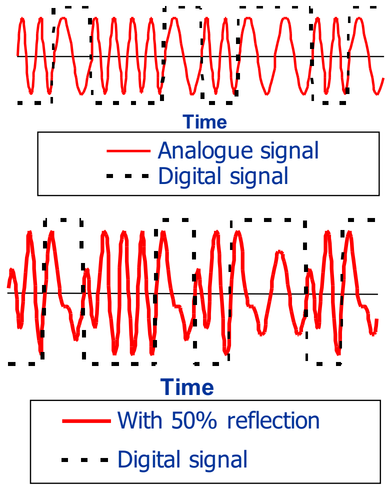
Network goes only where you lay it
- Wires costs money, fibre-optics cost even more

Reflection and Termination

Reflection from ends of wires causes interference

Need **termination** to absorb signal at ends

– e.g. coax-based Ethernet and SCSI use terminators



Properties of Wireless Connections

Signal travels through wireless at fixed speed

– Medium can carry signals at many frequencies
– Different radio frequencies disperse differently

Radio signal suffer from attenuation and interference

– From other transmitters and from reflected signals
– Need to manage power to avoid interference

Radio signal goes wherever it can

– Radio bandwidth subject to regulation
– Environment can block radio waves

Modulation

Modulation: transform information signal into signal more appropriate for transmission on physical channel

Data and signal may each be <u>digital</u> or <u>analogue</u>

– Digital ➔ only values are zero and one
– Analogue ➔ continuous range of values

Digital Data ➔ Digital Signals	NRZ, Manchester
Digital Data ➔ Analogue Signals	ASK, FSK, PSK
Analogue Data ➔ Digital Signals	PCM (pulse code)
Analogue Data ➔ Analogue Signals	AM, FM, PM

Baseband vs. Broadband

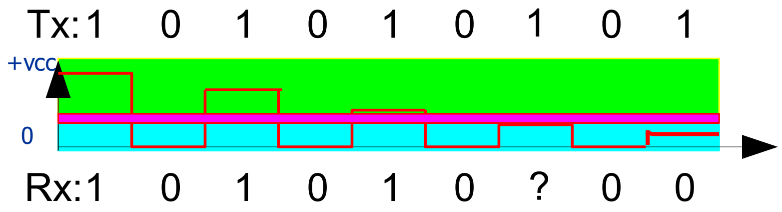
Baseband network (Ethernet, serial, …)

– Medium directly transmits digital/analogue data
– Uses single frequency band (0…f Hz)
– Very simple
  - e.g. Ethernet, serial, …

Broadband network (television, ADSL, …)

– Modulate <u>analogue carrier</u> wave to transmit data
– Can choose good frequency for channel
– Can use multiple bands (f1..f2 Hz, f3..f4 Hz, …)
– Can share channel among multiple users

Line Coding: TTL Signals



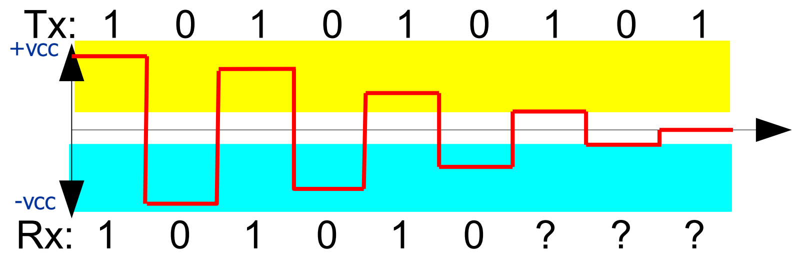
Binary value represented by state

- "High" voltage defines a 1
- "Low" voltage defines a 0
- Undefined between levels

As signal degrades with distance:

- 1 becomes undefined and then becomes 0

Differential TTL Signals e.g. RS232



Binary value represented by state

- "Positive" voltage defines a 1
- "Negative" voltage defines a 0
- Undefined around 0

Value becomes undefined as signal degrades

- But never incorrect as polarity not lost

Synchronisation: Clocks

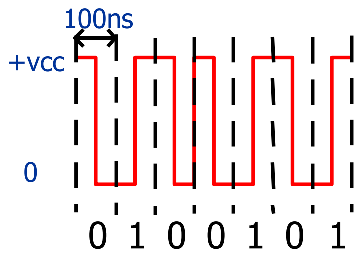
Receiver must identify which bit of data is being sent

- Easy if sending 0101010
- Harder if sending 0001100
  - Could be heard as 001100 if timing wrong

Need **synchronisation** between sender + receiver

1. Slow data rate so slight inaccuracy doesn't matter
2. Separate signal with clock in it
3. Modify signal so that clock is built in

Manchester Encoding



Ethernet encoding (inverse)
0: high-to-low
1: low-to-high

Thomas encoding
0: low-to-high
1: high-to-low

XOR signal with clock 1 clock cycles/bit

- Every bit has at least one transition

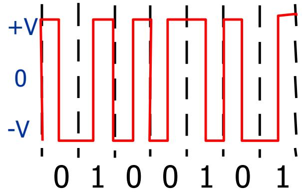
Binary value represented by type of transition

- Signal changes simplify clock synchronisation
- Signal changes enable fast detection of signal
- Requires twice bandwidth of simple binary encoding
- Transition at start has no meaning.

Differential Manchester Encoding

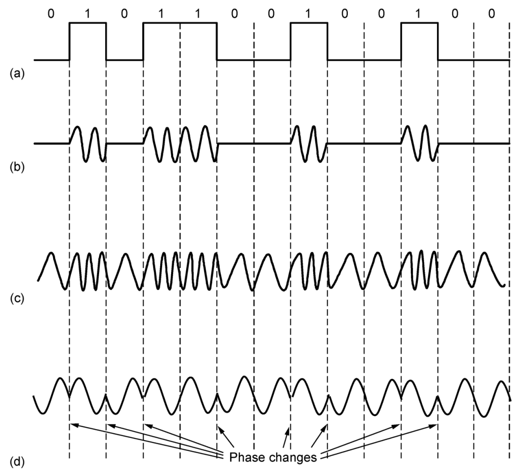
Binary value represented by presence/absence of transitions

- Every bit has at least one transition
- Better noise immunity
- Polarity doesn't matter
- But requires more complex equipment



0: transition at start
1: no transition at start

Broadband Modulation



(a)A binary signal. (b)Amplitude shift keying (BASK). (c)Frequency shift keying (BFSK). (d)Phase shift keying (BPSK).

E.g. to transmit digital data over analogue channel

Use **carrier signal** (periodic wave form) and vary:

- amplitude
- frequency
- phase

Combination of amplitude and phase often used

More Terminology

Baud

- Rate at which signal level (modulation) changes (signal elements per second)

Data rate

- Rate of data transmission (bits per second)

Multiplexing: Sharing Channels

Signal occupies bandwidth in channel

- But it need not occupy whole channel
- e.g. many radio stations operate in parallel

Multiplexing

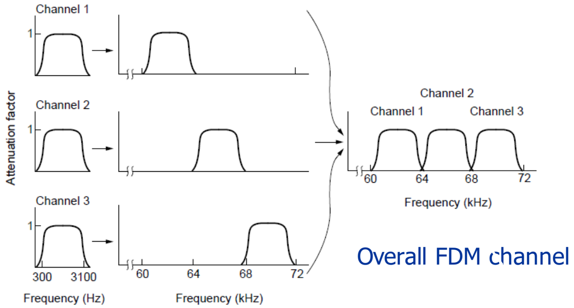
- We examine three techniques for sharing a medium

Frequency Division Multiplexing (FDM)

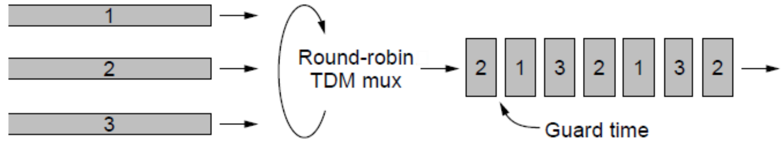
Encode different signals by sending at different frequencies
- e.g. Radio, TV, GSM, …

Need guards bands because filters imprecise

Someone must allocate frequencies to users



Time Division Multiplexing (TDM)



Subdivide channel into fixed time **slots**

Encode many signals by sending at different times
- Examples: phone calls in trunks, TV schedule, …

Issues in TDM

Whole bandwidth channel usable for duration of slot
- But input signals must have bandwidth less than medium bandwidth / number of channels

Introduces delay while waiting for slot
- Gap between slots must not interfere with requirements

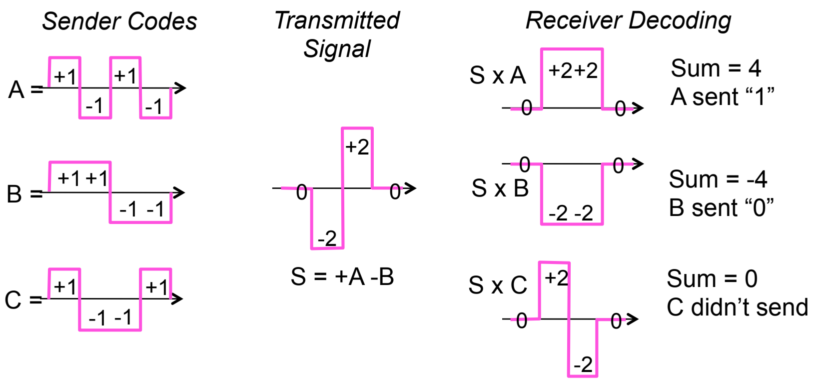
Someone must allocate time slots
- Needs synchronisation to keep track of slots
- Fixed allocation bad for bursty data

Code Division Multiple Access (CDMA)

Imagine many groups having conversations in same room
- TDM ➔ taking turns to talk
- FDM ➔ talking in isolated groups not heard by others
- **CDMA** ➔ everyone talking in different languages

Stations transmit over entire frequency spectrum
- Transmission divided in intervals (chips)
- Stations combine data bits with own code sequence
- Interference between signals occurs
- Separation made using coding theory

Examples: UTMS, satellite transmission, …



Issues in CDMA

Only practical for communication with central station

- Interference needs to be controlled
- Requires sophisticated signal power management
  - “Everyone can talk as long as no-one talks too loud”

Flexible allocation of channel resources

- Soft degradation as number of stations increases

Common Connection Standards

☛ No need to know all the details of wiring!

PC Parallel Port

25 pin connector

- 8 data bits at a time
- 4 control lines to printer,
  5 signals from printer

TTL voltage signals

- 0 to 0.8V = OFF = 0   2.0 to 5.0V = ON = 1

100 kBytes/sec max transfer speed

- Note: Bytes as its parallel

5-15m max cable length

- 1 can become 0 with long wires

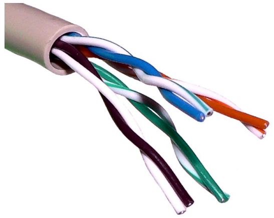
PC Serial Port (RS-232)

- 9 or 25 pin connector
  - 2 data lines (send and receive)
  - 2 control lines, 4 status signals

- Differential TTL signals
  - +3.0 to 12v = space = 0 -3.0 to –12v = mark = 1
- 256kb/s max transfer speed
- 15m max cable length
  - Even with attenuation polarity maintained

Analogue Phone Lines

- Twisted pair cable
  - Send/receive wires are twisted together to reduce interference/radiation
  - Different versions (shielded/unshielded, CAT3, CAT5)



- Use **modem** to send data using tones
  - Telephone system has filters to limit range of tones
    - Only permits 300Hz–3kHz (human voice)
  - Approx 2400 distinct tones/sec (2400 baud)
  - 56k bits/sec best practical data rate

Digital Phone Lines

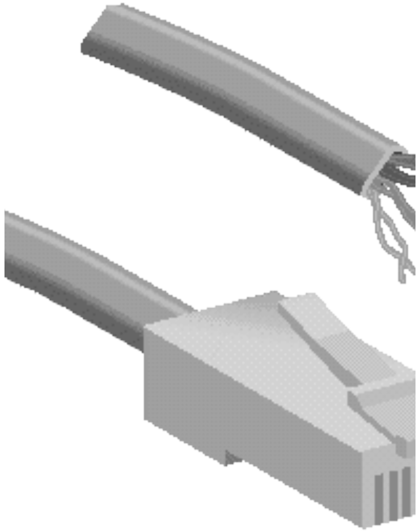
- ISDN Basic Rate Interface (BRI)
  - 2 x 64kb/s bearer/data (B-channels)
  - 1 x 16kb/s control/signalling (D-channel)
- Two twisted pair cables

- ISDN Primary Rate Interface (PRI)
  - 23 (US) or 30 (EU) x 64kb/s data channels
  - 1 x 64kb/s control
  - T1=1.544Mb/s (US), E1=2.048Mb/s (Europe & Asia)
- Many others, including OC3 = 155.52Mb/s (optical)

ADSL

- (Asymmetric) Digital Subscriber Line
  - Data rate: 128kb/s - 8Mb/s
  - “Always-on” behaviour
  - Slower sending than receiving
- Uses <u>digital</u> phone system
  - Remove voice filter to increase bandwidth
  - Subdivide channel into frequency bands and use good ones
  - Limited range from exchange (typically 5km)

Ethernet (802.3 10/100Base-T)

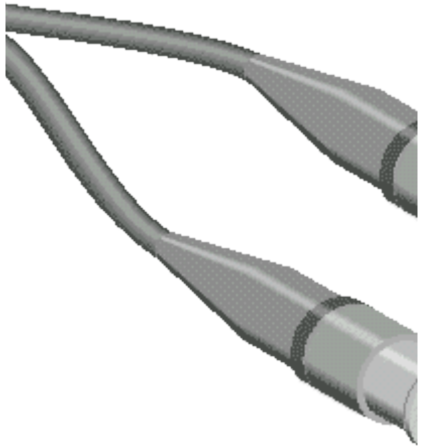


100Base-TX most common cabling in office LANs today (allows 100Mb/s)

10Base-T is phone wire, allows 10Mb/s, found in older networks

100m max segment length
- 1024 connections per segment (with hub)

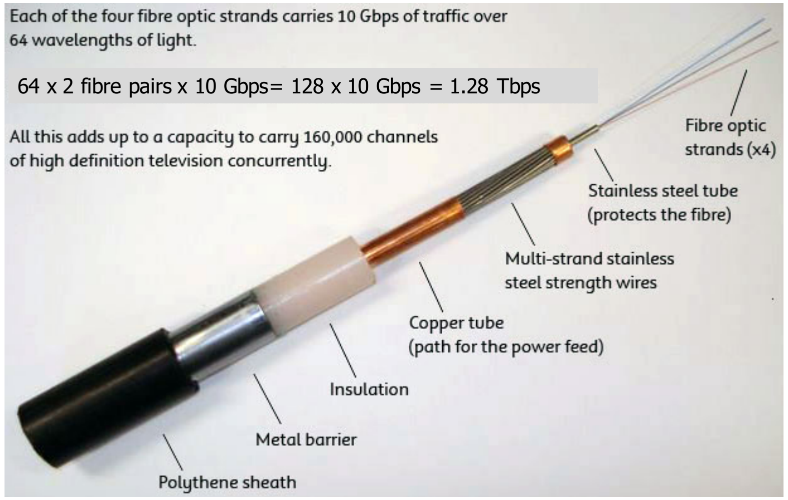
Fibre Optics (10/100Base-F)



Commonly used for:
- Backbones
- High speed networks
- Environments with high electrical noise
- Highly secure networks
  - Taps hard to make

2km max segment length
- Max 1024 connections per segment

Internet Cables



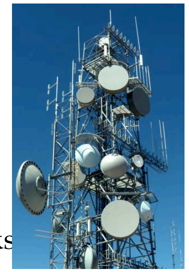
Microwave (Satellite Links)

Satellite acts as relay between two ground stations

Uses two frequencies: **uplink** and **downlink**
- Useful frequency range 1-10GHz
- Needs well-aligned parabolic dish with clear sight
- Satellite signal is typically broadcast over a wide area

Has long latencies (approx. ¼ second)
- Noticeable in speech
- Problems where protocols assume far lower latencies

Also used for point-to-point terrestrial links
- Good for long distance/rapid deployment links



Wireless Ethernet

IEEE 802.11, 802.11b, 802.11a, 802.11g, 802.11n, …

1Mb/s – 54Mb/s (and more)

2.4 GHz and 5 GHz
- Frequency band not restricted

500m range (at 1Mb/s in open)
- Affected by walls, microwave ovens, …

☛ *More later on this*

Mobile Telephones

Operate as cells transmitting to/from base station

GSM (2G)
- Based on TDM & FDM
- Widespread
- 9.6kb/s maximum

GPRS (2.5G)
- Development of GSM
- 115kb/s possible; 28kb/s typical

UMTS (3G)
- Based on CDMA
- 115kb/s – 2Mb/s range
- 384kb/s downstream normal

Bluetooth

Networking of personal devices
- Deliberately short range (typical max. 10m)
- Aims to be power efficient
- Provides serial link abstraction

Data rates between 57.6kb/s - 723.2kb/s
- Centralised TDM: master/slave design
- Frequency-hopping spread spectrum
- Interferes with 802.11b