Computer Networks and Distributed Systems

Physical Layer

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Overview

- How to transmit data on physical channel
- Properties of connections
- Modulation, encoding, and multiplexing techniques
- Common communication standards

Physical Layer

- Provides communications path between nodes (transmission of bit-streams over medium)
- Uses standards (agreed ways of connecting devices and signalling)
  - Be able to interpret signals
  - Must deal with limitations of physical world
- Guided and unguided media
  - Copper wire and fibre optics
  - Terrestrial wireless, satellite, and lasers through the air
- Not going into electrical details or physics

Terminology

- **Voltage:** Is the difference in electric potential energy between two points; unit is volt (V)
- **Frequency:** Is the number of occurrences of a repeating event per time unit; unit is hertz (Hz)
- **Signal:** A function that conveys information. Data is encoded to a signal, which is carried to a receiver by the channel. Main types: analog and digital signals

Properties of Wired Connections

- Signals travel at fixed speed and medium can carry signals at many frequencies
- Signals get weaker over distance (attenuation)
- Signals may suffer from interference
  - Shielded wires help with interference
  - Often wires require termination
- Network goes only where you put it
- Wires costs money, fibre-optics cost even more

Properties of Wireless Connections

- Signals travel at fixed speed
  - Medium can carry signals at many frequencies
  - Different frequencies[1] disperse differently
- Radio signals 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

[1] radio (kHz - GHz), microwaves, infrared, visible light, ultraviolet,...

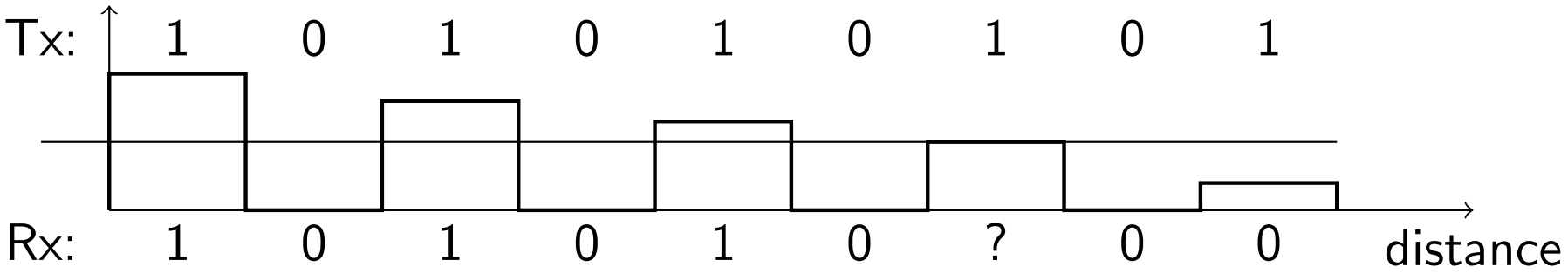
Modulation

How do we send information over physical channels?

- **Modulation:** transform information signal into a signal more appropriate for transmission over a channel
- **Digital modulation:** the process of converting digital data (bits) into a signal more appropriate for transmission
- Data and signal may each be digital or analogue
  - Digital: only values are zero and one
  - Analogue: continuous range of values

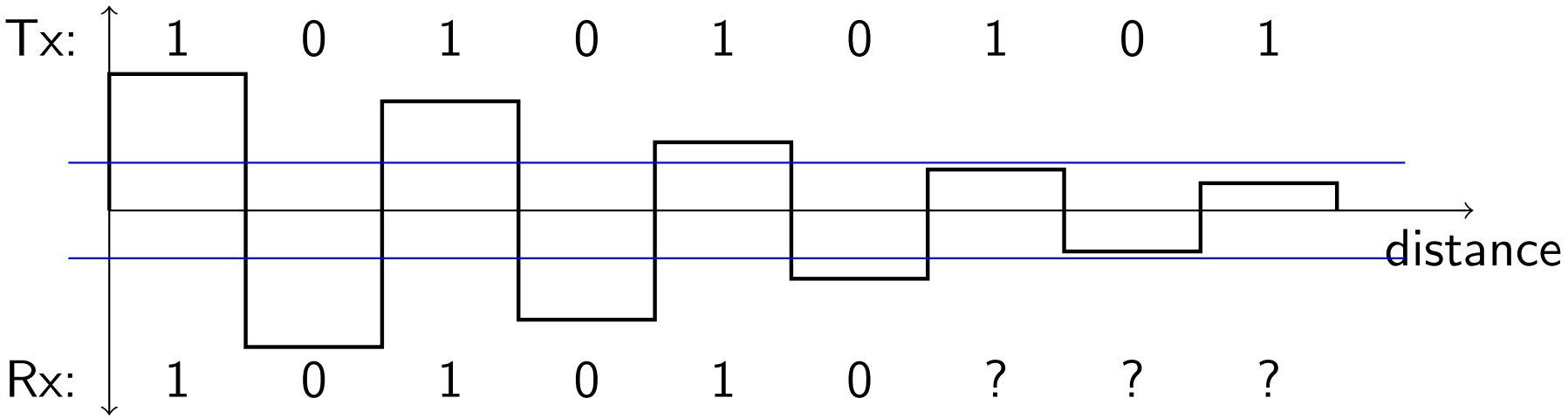
- Baseband transmission
  - Medium directly transmits digital/analogue data
  - E.g. high voltage to represent 1 and low voltage to represent 0
  - Uses single frequency band (0..f Hz)
  - Most straightforward form and common for wires
  - E.g. Ethernet, serial, ...
- Passband transmission
  - Regulates amplitude, phase, or frequency of a carrier signal
  - Can choose good frequency for channel
  - Common for wireless and optical channels

Binary Signaling



- 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 Signals

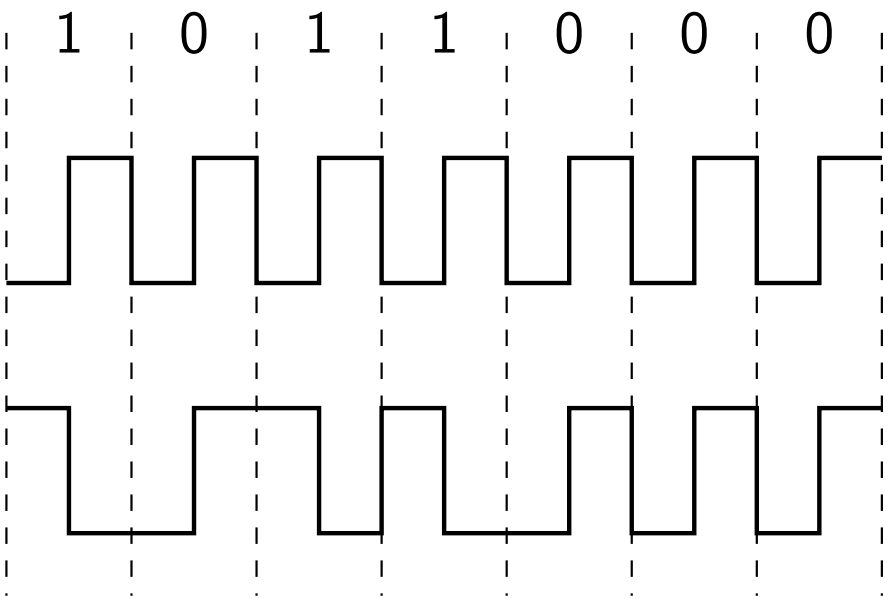


- Binary value represented by state
  - "Positive" voltage defines a 1
  - "Negative" voltage defines a 0
  - Undefined around 0
- Value becomes undefined as signal degrades but never incorrect as polarity is not lost

Clock Synchronisation

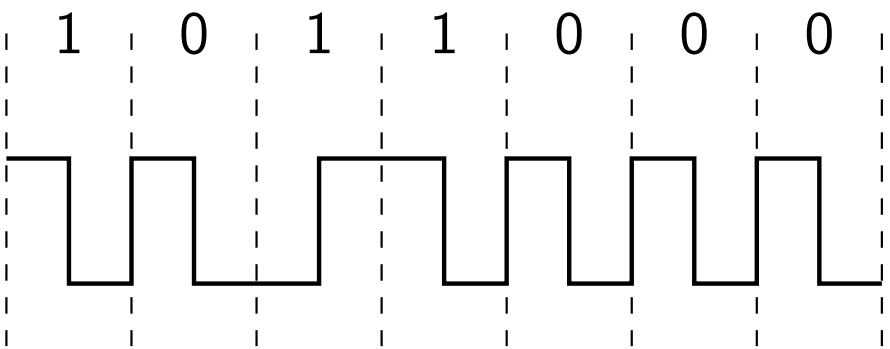
- Receiver must identify which bit of data is being sent
  - Sending 0001100 could be heard as 001100 if timing wrong
- Need synchronisation between sender and receiver, especially for high speed transmissions (Mb/s)
  - Accurate clocks, which are expensive
  - Separate signal with clock in it
  - Modify signal so that clock is built in

Manchester Encoding



- Binary value represented by type of transition (0: low-to-high; 1: high-to-low)
- *XOR* clock and data signal
- Every bit has at least one transition
- Signal changes simplify clock synchronisation
- Requires twice the bandwidth of simple binary encoding
- Opposing conventions: 0: high-to-low; 1: low-to-high used for 10BASE-T Ethernet IEEE 802.3

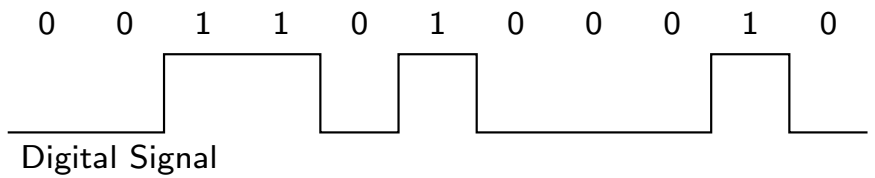
Differential Manchester Encoding



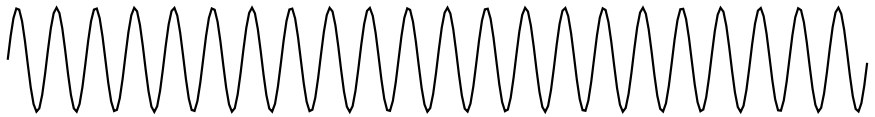
- Binary value represented by presence/absence of transitions (0: preceding transition; 1: no preceding transition)
- Every bit has at least one transition
- Polarity does not matter
- But requires more complex equipment

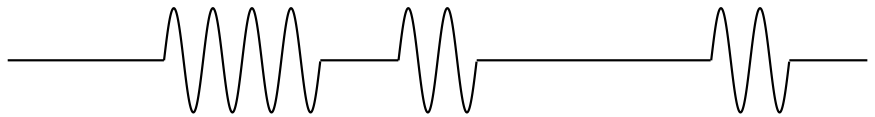
Modulation Examples
Passband Transmission

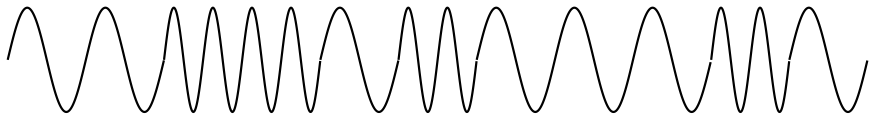
- Example: transmit digital data over analogue channel
- Use carrier signal (periodic wave form) and vary:
  - amplitude (strength of wave)
  - frequency
  - phase
- Combination of amplitude and phase often used



Digital Signal


Carrier Signal


Amplitude-Shift Keying

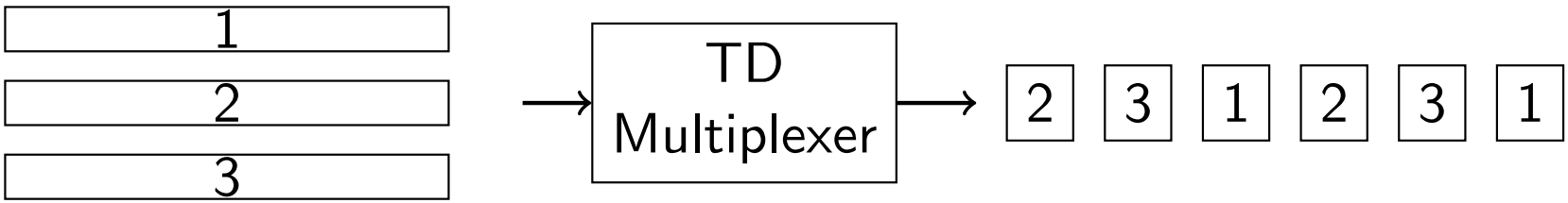

Frequency-Shift Keying


Phase-Shift Keying

Multiplexing: Sharing Channels

- Signal occupies bandwidth in channel
- But it need not occupy whole channel
- E.g. many radio stations operate in parallel
- We examine 3 techniques for sharing a medium

Time Division Multiplexing (TDM)

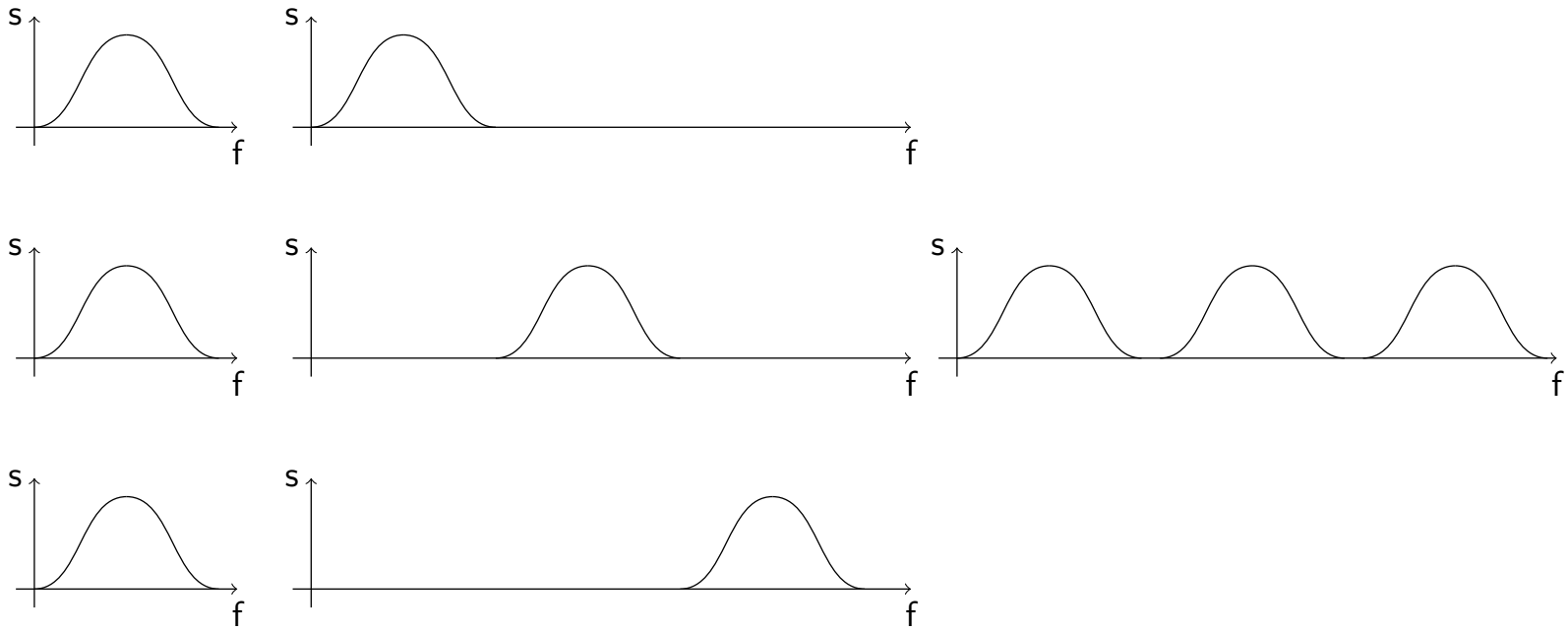


- Subdivide channel into fixed time slots
- Encode many signals by transmitting them at different times (round-robin fashion)
  - E.g. telephone networks, TV schedule, ...

TDM - Considerations

- Whole bandwidth of the 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

Frequency Division Multiplexing (FDM)



- Encode different signals by sending at different frequencies (e.g. radio, TV, GSM[2])
- Need guard bands because filters imprecise
- Someone must allocate frequencies to users

[2] Global System for Mobile Communication

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

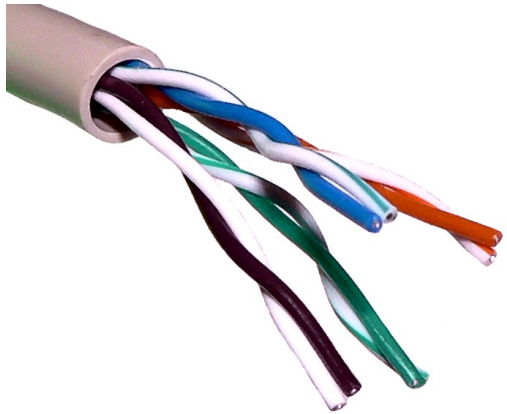
  - Stations transmit over entire frequency spectrum
  - Stations combine data bits with own code sequence
  - Interference between signals occurs
  - Separation made using coding theory
- E.g. UTMS[3], satellite transmission, ...

[3] Universal Mobile Telecommunications System; 3rd generation system based on GSM

CDMA - Considerations

- Interference needs to be controlled
- Requires sophisticated signal power management (everyone can talk as long as no one talks too loudly)
- Soft degradation as number of stations increases
- Only practical for communication with central station

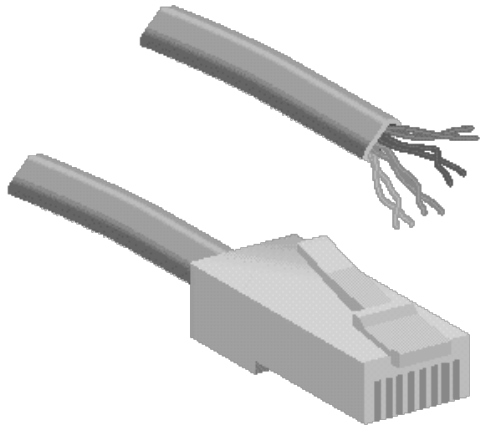
- Twisted pair cable
  - Send/receive wires are twisted together to reduce interference/radiation
  - Different versions (shielded/unshielded, CAT3, CAT5)
- Use modem to send data using tones
  - Telephone system has filters to limit range of tones
  - Only permits 300Hz-3kHz (human voice)
  - Approx. 2400 distinct tones/sec (2400 baud)
  - Boud: rate at which signal level changes per second
  - 56kbits/s best practical data rate



- Two twisted pair cables
- ISDN Basic Rate Interface (BRI)
  - Integrated Services for Digital Network (ISDN): set of communication standards for digital transmission
  - 2 x 64kbit/s bearer/data (B-channels)
  - 1 x 16kbit/s control/signalling (D-channel)
- ISDN Primary Rate Interface (PRI)
  - 23 (US) or 30 (EU) x 64kbit/s data channels
  - 1 x 64kbit/s control
  - T1=1.544Mbit/s (US), E1=2.048Mbit/s (Europe and Asia)

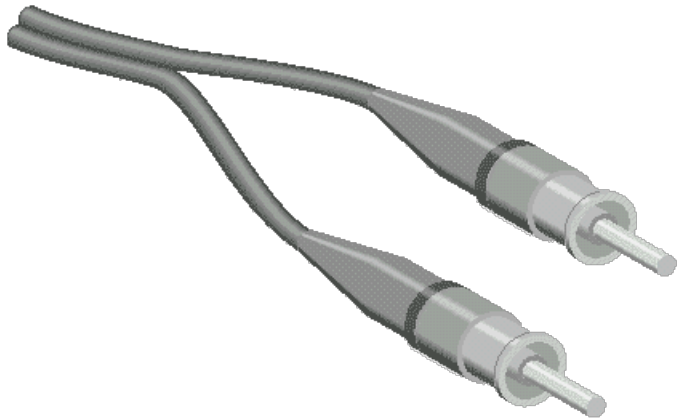
Common Communication Standards
Ethernet (802.3 10/100Base-T)

- 10Base-T: twisted pair cable, allows 10Mb/s (still found in older networks)
- 500m max segment length
- 100Base-TX (fast Ethernet): two twisted pair cables (CAT5); full tuplex
  - Most common cabling in office LANs today (allows 100Mb/s)
  - 100m max segment length
- There is also 1000Base and 10GBase



Common Communication Standards
Fibre Optics (10/100/1000/10G Base)

- Between 550m and 40km max segment length
- Commonly used for:
  - Backbones
  - High speed networks
  - Environments with high electrical noise
  - Networks with better security (taps hard to make)



- IEEE 802.11, 802.11a, 802.11b, 802.11g, 802.11n, ...
- 2.4 GHz (b, g, n) and 5 GHz (a, n, ac) - frequency band not restricted
- 1Mbit/s - 54Mbit/s (and more)
- 2.4 GHz band is divided into 14 channels (3 non-overlapping: 1, 6, 11)
- 500m range (at 1Mbit/s in open)
- Affected by walls, microwave ovens (2.4 GHz), ...

- Bluetooth (version 1 to 5)
  - 2.4 GHz frequency band
  - Typically up to 10m
  - Data rate: kbit/s to few Mbit/s
- Asymmetric digital subscriber line (ADSL[4])
  - Data rate: from a few Mbit/s to 20+ Mbit/s
  - Slower sending than receiving
- Mobile Phones (2G, 2.5G, 3G, 4G)

[4] ADSL, ADSL2, ADSL2+