BSc (Hons) Computer Science

University of Portsmouth

Third Year

Advanced Networks

M21279

Semester 1

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Contents

Lecture - Introduction

11:00	30/09/24	Asim Ali

Admin

- Lectures given by Dr Asim Ali
- Office - BK 2.20
  - Monday 1300-1400
  - Thursday 1100-1200
- 2 hour lecture every week (PK 2.01)
- 1 hour seminar every week (AG 1.03)

The module information is available at the URL below:
https://course-module-catalog.port.ac.uk/#/moduleDetail/M21279/2024%2F25

Assessments

This module is assessed by one exam and one piece of coursework as below

- 60%, 90 minute Exam covering LO1,2,3&4 - TB1 assessment period (January)
- 40%, Group coursework covering LO5 - 2-4 members *or* individual (but not recommended)
  - 5 pages maximum
  - Template provided
  - Previous samples provided

Lecture - Signal Encoding

11:30 30/09/24 Asim Ali

Signals

(In this context) Signals are typically electromagnetic waves that carry information using some method of encoding. This means that the 'shape' of the signal is changed to represent information. There are three main types of signal–

- Analogue Signals, which vary continuously and smoothly over time
- Digital Signals, which have only 2 levels and change near instantly
- Discrete Signals, which have 2 or more levels and change near instantly

When information is transmitted, it is often converted between many different signals before it reaches the destination. For example, if you have ADSL internet, your computer sends the data as a digital signal to the modem, which is then converted to an analogue signal before it is transmitted across a POTS network (Plain Old Telephone System), then the receiver's modem converts it back to a digital signal before it is sent on to the receiver.

Digital Signal Encoding

There are many methods of encoding a digital signal, but some of the most common are–

- Non-return to Zero Level (NRZ-L)
  - 0 – High voltage level
  - 1 – Low voltage level
- Non-return to Zero Inverted (NRZ-I)
  - 0 – No transition (high-low or low-high voltage level) on clock pulse
  - 1 – Transition on clock pulse
- Bipolar-AMI
  - 0 – Zero voltage
  - 1 – Alternating positive or negative voltage level
- MLT-3 (Multi-Level Transmit 3)
  - 0 – Remain at the same voltage level
  - 1 – Transition to the next voltage level
  - Uses 3 voltage levels, named $+1$,0&-1 but can be any arbitrary voltages
- Manchester
  - 0 – Transition from high-low voltage level in the middle of the clock interval
  - 1 – Transition from low-high voltage level
- Differential Manchester

- 0 – Transition (high-low or low-high voltage level) on clock pulse
- 1 – No transition on clock pulse
- Always transitions in the middle of the clock interval

In this context, the high and low voltage levels can be whatever you like, but are typically either a positive and negative voltage of the same magnitude, or are a positive voltage and zero. The most common voltages used for signalling are 3.3, 5 and 12 volts. In the case of Bipolar-AMI, the 3 voltage levels can be arbitrary, and don't have to be, for example $+5$, 0 and -5 volts.

Diagrams

Below is the binary string 01100110 encoded using all of the above encoding schemes. This assumes that the previous state before the transmission starts is always low, and that each vertical dotted line represents a clock pulse.

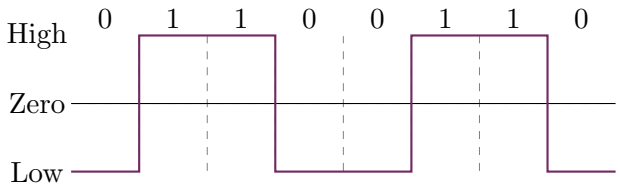


Figure 2.1: Non-return to Zero Level (NRZ-L)

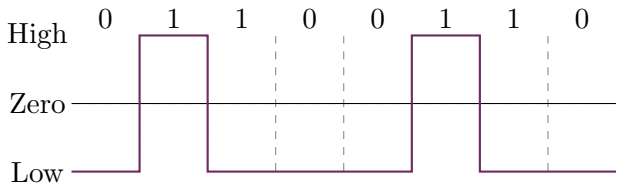


Figure 2.2: Non-return to Zero Inverted (NRZ-I)

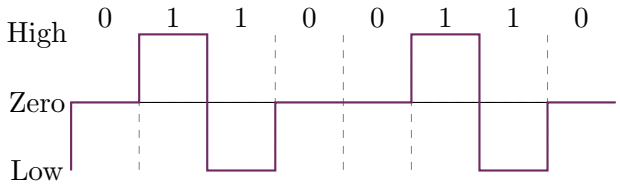


Figure 2.3: Bipolar-AMI

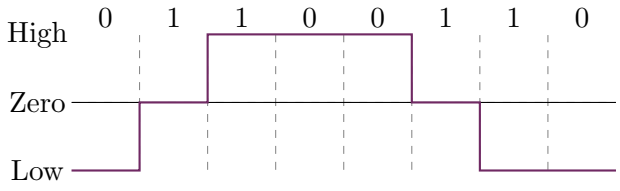


Figure 2.4: Multi-Level Transmit 3 (MLT-3)

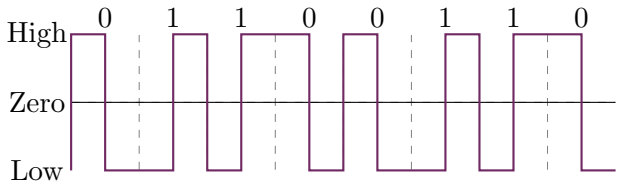


Figure 2.5: Manchester

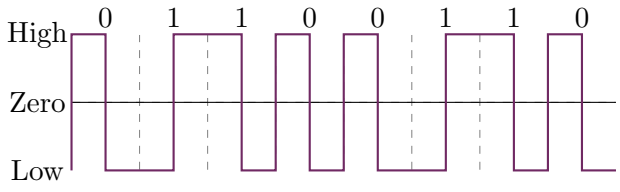


Figure 2.6: Differential Manchester

Carrier Waves and Modulation

A carrier wave is a continuous waveform that, on it's own, carries no information. This carrier wave is then modified by another signal to convey information. This modification can be of it's amplitude, frequency, phase, or a combination of all 3. This is known as modulation, hence the names AM (Amplitude Modulation) and FM (Frequency Modulation) for the two types of analogue radio.

Digital-to-Analogue Encoding

There are several methods of encoding a digital signal on an analogue transmission medium. In the case of sending digital data over a POTS network, the signal is encoded onto a carrier wave in the range of 300-3400Hz using a MoDem (Modulator-Demodulator). The main methods of encoding are–

- Amplitude-Shift keying (ASK)
- Frequency-Shift keying (FSK)
  - Binary FSK (BFSK)
  - Multiple FSK (MFSK)
- Phase-Shift keying (PSK)
  - Binary PSK – 1 = A sine wave, 0 = The same sine wave shifted by $180°$
  - Differential PSK (DPSK) – 1 = The previous sine wave shifted by $180°$, 0 = The previous sine wave
  - Multiple-level PSK
- Quadratic AM (Combination of ASK and PSK)

The sender and receiver may use different frequencies as to allow full-duplex data transmission on the same physical medium or radio channel. Full-duplex meaning full-speed transmission in both directions simultaneously.

Diagrams

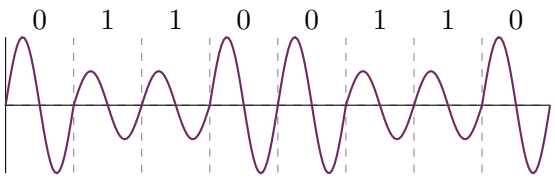


Figure 2.7: Amplitude-Shift Keying

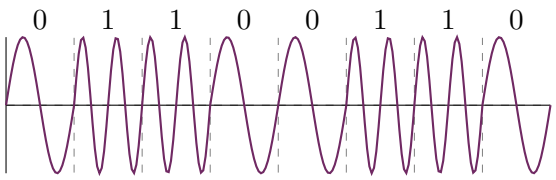


Figure 2.8: Binary Frequency-Shift Keying

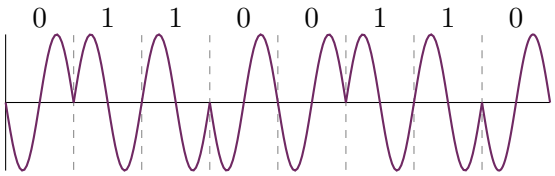


Figure 2.9: Binary Phase-Shift Keying

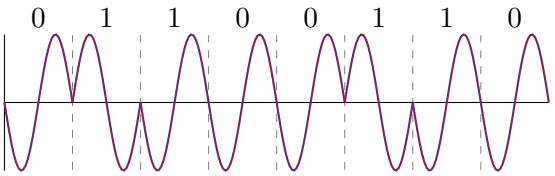


Figure 2.10: Differential Phase-Shift Keying

Seminar - Encoding Exercises

12:00 03/10/24 Asim Ali

Figure 3.1: Encode the binary data 11000011 with the MLT-3 encoding scheme

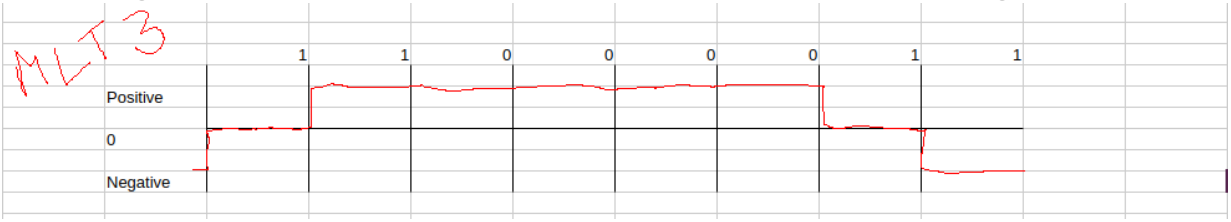


Figure 3.2: Encode the binary data 11000011 with the Non-Differential Manchester encoding scheme

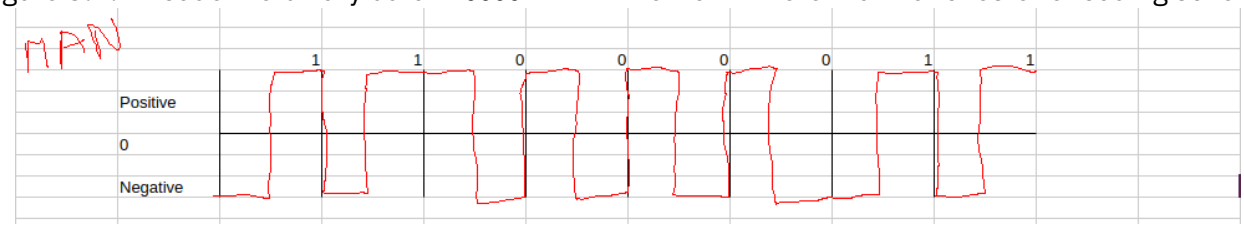
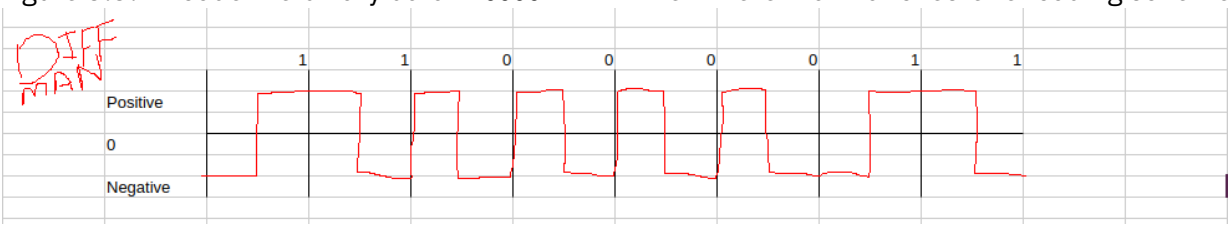


Figure 3.3: Encode the binary data 11000011 with the Differential Manchester encoding scheme



Lecture - Signal Encoding II

11:00 07/10/24 Asim Ali

Transmission Media

There are many different mediums which can be used to transmit information. In the case of networks, there are two main types, guided and unguided media.

- Guided Media
  - The signal is contained within a medium, such as
  - Copper cable (twisted pair, coaxial, etc)
  - Fibre optics
- Unguided Media
  - The signal is sent out without containment, through the air
  - This does not mean that the signal is not directional, microwave networks are often highly directional to reduce signal drop-off and interference
  - Microwave, Radio, Cellular and Satellite

Signal Properties

- **Data Rate** – The speed in bits per second (bps or b/s) at which data can be communicated
- **Error** – The reception of a 1 when 0 was transmitted, or vice versa
- **Error Rate** – The rate at which errors occur, usually as a ratio or percentage
- **Frequency Bandwidth** – The difference between the upper and lower frequency in a continuous frequency band
- **Channel Capacity** – The maximum rate at which data can be transmitted through a channel
- **Signal-to-Noise Ratio** – The ratio of the signal power to noise power in decibels (dB)

Interference and Noise

Definition

Interference is when two signals are added together. There are two main types of interference – constructive and destructive. When two signals combine to create a signal with a higher amplitude, this is constructive interference. If the amplitude is reduced, this is destructive interference.

Definition

Noise is any other signal which interferes with the desired signal along the medium of transmission. Typically, any noise in a signal will make it more difficult to decode, since the signal may be reduced in amplitude or shifted in phase.

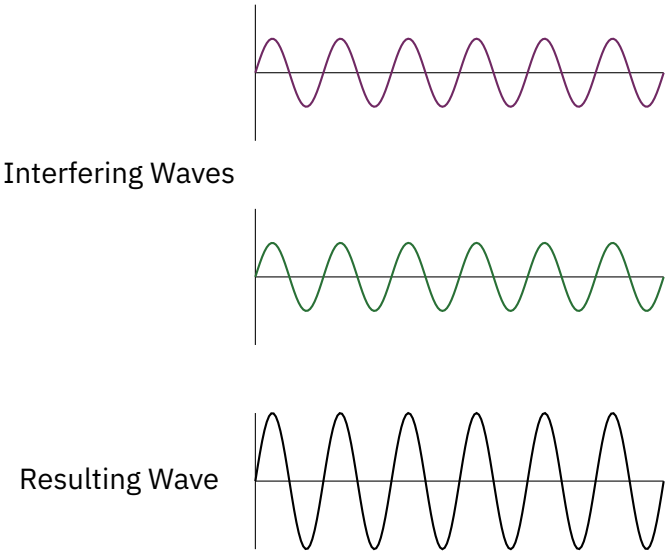


Figure 4.1: Constructive interference

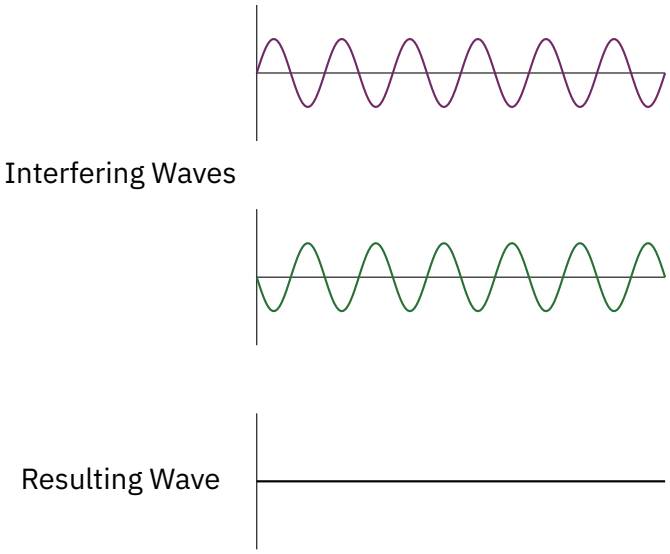


Figure 4.2: Destructive interference

Securing a Signal

When a signal is sent through any media, if a third party has access to the same media, they can intercept, block and even fake signals. This is because there is no inherent security in an electromagnetic wave, so we need to find ways of securing it.

Spread Spectrum

If we were to transmit a signal using a wide range of the spectrum, rather than a single frequency, it makes it harder for a third party to entirely block the signal. This method is often used in military applications, as well as wired and wireless networks. Three common techniques are–

- Frequency Hopping Spread Spectrum (FHSS)
  - Data is sent using one of the previously discussed analogue transmission techniques, but the carrier frequency is changed rapidly across a wide spectrum, using a code or pattern known by both the transmitter and receiver
  - This makes it harder to intercept or block transmissions, as long as the pattern of frequency hopping is not known
  - It is also very resilient to narrowband interference (interference over a small band of frequencies)
- Direct Sequence Spread Spectrum (DSSS)
  - Each bit of the data is represented by multiple bits of the transmitted signal, using a spreading code
  - The bits in the PN sequence are known as chips, and the sequence of them the chip sequence
  - One technique is to combine the data with the spreading code bit stream using an exclusive-or
- Code Division Multiple Access (CDMA)

Multiplexing

Definition

Multiplexing is sending multiple data streams or signals over a single transmission medium.

Frequency Division

With frequency division multiplexing, you have a transmission medium which can send data over a wide spectrum of frequencies, and multiple signals you need to send at the same time. If you modulate the different signals using a different carrier frequency for each, and leave a suitable gap between them, you can then combine the waves together to create a single composite wave which encodes the data of all the streams. The receiver then needs to know only the frequency of the signal they need to receive, and pass the composite wave through a filter for that specific frequency to recover the signal intended for them.

Time Division

With time division multiplexing, each of the signals gets a certain share of time in which it can be transmitted. This often means that the data needs to be buffered on both ends, so may be more costly to implement. This also greatly limits the bandwidth available to each signal, as it would be split between all of the signals on the same channel.

Code Division Multiple Access (CDMA)

CDMA is a multiplexing technique which can be used with a spread-spectrum signal. Given a data stream of bit rate R, we assign each bit a unique user code of n according to a Walsh matrix. If a user, k, sends a 1, the transmitter sends the chip code ck, and if they send a 0, the transmitter sends the inverse of that chip code, $c'k$. The chip codes of all users will add up to a bipolar signal, D. The receiver decodes the signal for a specific user with a function, by taking the cartesian product of D and the specific chip code ck, $D \times ck$. If $D \times ck = n$ then a 1 is received, and if $D \times ck = -n$ then a 0 is received.

Example

We have 4 users, with chip codes as follows

- A: $(-1, -1, -1, -1)$
- B: $(-1, +1, -1, +1)$
- C: $(-1, -1, +1, +1)$
- D: $(-1, +1, +1, -1)$

If the users were to send $1, 1, 1, 0$ respectively, then we would add up the signals such that $A + B + C + D' = (-1, -1, -1, -1) + (-1, +1, -1, +1) + (-1, -1, +1, +1) + (+1, -1, -1, +1) = (-2, -2, -2, +2)$

Then, the receivers filter out each individual signal by multiplying the received signal by the chip code of the signal they're interested in. To get back the signal for A, you would do the following $(-2, -2, -2, +2) \times (-1, -1, -1, -1) = (-2 \times -1) + (-2 \times -1) + (-2 \times -1) + (+2 \times -1) = 2 + 2 + 2 - 2 = 4$, which shows that A was sending a 1.

Seminar - Encoding Exercises II

12:00 10/10/24 Asim Ali

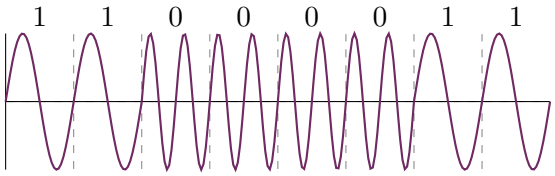


Figure 5.1: BFSK representation of the binary number 11000011

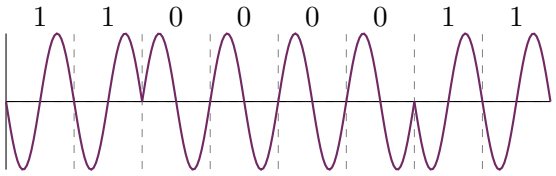


Figure 5.2: BPSK representation of the binary number 11000011

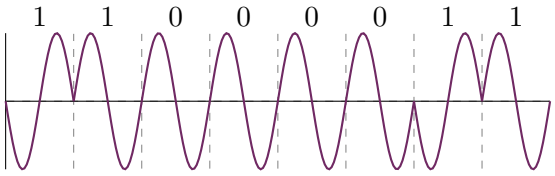


Figure 5.3: DPSK representation of the binary number 11000011

INPUT	1				0				1				1			
PN Stream	0	1	1	0	1	0	0	1	0	1	1	0	1	0	1	1
Transmitted	1	0	0	1	1	0	0	1	1	0	0	1	0	1	0	0
Received	1	0	0	1	1	0	0	1	1	0	0	1	0	1	0	0
PN Stream	0	1	1	0	1	0	0	1	0	1	1	0	1	0	1	1
OUTPUT	1				0				1				1			

Figure 5.4: DSSS encoding and decoding of the binary number 1001

Lecture - Security

11:00 14/10/24 Asim Ali

Security Factors

There are three main security factors we need to consider–

- Confidentiality
  - Only authorised parties should be able to read the information
- Integrity
  - Only authorised parties should be able to modify, create and delete information
- Availability
  - Authorised parties should always have access to the information

Types of Attackers

- Passive Attackers
  - The attacker only listens to the messages, so they can only read the information
- Active Attackers
  - The attacker listens, modifies and sends messages, so they can read the information, modify it or fabricate it entirely

To overcome both of these types of attacker, you can encrypt the data, meaning that it is unreadable by any third parties, and if someone attempts to modify or spoof a message, it will not be encrypted with the same key and so the receiver will know it was not sent by the correct person.

Symmetric (Shared Key) Encryption

Symmetric key encryption requires the sender and receiver to already have a shared key, which will then be used to both encrypt and decrypt the messages.

DES (Data Encryption Standard)

Plaintext is split into 64-bit blocks. The key is 56-bits long and 16 subkeys are generated for 16 rounds of cryptography. The subkeys are then used in reverse order to decrypt the data. Because this quickly became insecure, Triple-DES was created as a new standard, which is as literal as the name suggests. You simply encrypt the data three times with three different keys, then decrypt 3 times in reverse order.

AES (Advanced Encryption Standard)

Plaintext is split into 128-bit blocks. The key is 128,192 or 256-bits long, giving the algorithm the name AES-128/192/256. AES is a much more advanced algorithm than DES, and it was created with the express purpose of replacing DES

Confidentiality

Because the messages are encrypted, they cannot be read or examined by a third party. This does rely upon the keys being shared ahead of time, in a secure way such that no third parties know what the key is.

Asymmetric (Public Key) Encryption

In asymmetric encryption, the sender and receiver have two different but related keys. The sender uses the public key of the receiver to encrypt the message, and the receiver uses their own private key to decrypt the message.

RSA (Rivest-Shamir-Adleman)

1. Select two large primes p and q (the larger the better)
2. $n = pq$ and $z = (p-1)(q-1)$
3. Select a number relatively prime (such that they have no common divisors) to z and call it d
4. Find e such that $e * d = 1 \mod z$
5. The public key is then (e, n) and the private key (d, n)
6. To encrypt a message, convert the plaintext M into an integer m such that $0 \leq m < n$, using a known and reversible padding scheme. Then compute the ciphertext c such as $c = m^e(\mod n)$
7. To then decrypt the message, you use the private key d by computing $c^d = (m^e)^d = m(\mod n)$. Then given m, you recover the message M by reversing the padding scheme

Figure 6.1: Encrypt then decrypt the string 'PORT' with the public key $(3, 33)$ and the private key $(7, 33)$

Char	Numeric	P^3	P^3 Mod 33		C^7	C^7 mod 33	Char
P	16	4096	4		16384	16	P
O	15	3375	9		4782969	15	O
R	18	5832	24		4586471424	18	R
T	20	8000	14		105413504	20	T
Sender					Receiver		

Confidentiality

Because the messages are encrypted, they cannot be read or examined by a third party. Since the public key can only be used to encrypt messages (theoretically it can be used to determine the private key but this is effectively impossible with current computational power), it can be sent out on the internet for anyone to use to encrypt messages for the receiver. As long as the private key is kept secret by the receiver, the messages are perfectly confidential.

Ensuring Integrity

To make sure that a message was sent by the correct person, and without being modified we can use either signatures, message digests or both.

Digital Signatures

When making a digital signature, the inverse of public-key cryptography is done. This means that only the owner of the signature knows the private key, but everyone knows the public key. The private key is used to cryptographically sign a file or message, which anyone can use the public key to verify, but only the owner of the keypair can use their key to sign. This means that if a message is signed, it must've come from the correct person.

Message Digests

A message digest (or hash function) takes a message M and produces a small 'fingerprint' known as the message digest $H(M)$. A secure hash function H encrypts a small block of the message which is produced as a function of the message, known as the authenticator. The properties of H are such that $H(M) \neq H(M')$ and given $H(M)$ is is computationally impossible to find M. The message digest is encrypted with the sender's private key, and serves as a signature that verifies the content and order of the message. Two popular digest functions are MD5 and SHA-1.

Authentication

Authentication verifies that a message has come from a verified source. This can be achieved using conventional encryption techniques as discussed previously. This does not protect against so-called playback attacks however. If a third party records an encrypted message, they can re-send it again at a later time, and since the message is correctly encrypted, the receiver will still believe it to be a valid message.

This can be avoided by adding a number to the cipher that relates to the time the message was sent, either directly or by using it as the seed for a random number generator. When the message is received, if the time is too far in the past, the message will either be ignored, or requested for re-sending to ensure the correct message was sent.

Lecture - Local Area Networks

11:00 04/11/24 Asim Ali

Data Link Layer

Within the Data Link layer of the OSI reference model, there are two control systems– the Logical Link Control and Media Access Control. The logical link control is responsible for interfacing with the layers above it, and performing flow and error control.

Media Access Control is responsible for more of the addressing and actual communications, and handles assembling and disassembling the transmission frame, which consists of

- Receiver's address
- Error detection data, e.g. checksum or crc

Media Access Protocol

The original ethernet protocol was designed for use in bus or star networks, and so includes error and collision handling. Since only one station is able to transmit at a time in a bus or (hub) star network, there needs to be a way to determine if a collision has occurred and how it should be resolved. This is made up of a set of rules–

- If there is already a station transmitting, do not transmit.
- If another station transmits while you are transmitting, jam the medium and wait for a random length of time, using the back-off algorithm. (Select a random length of time from 0 to $2^n - 1$ slots, where n is the number of collisions).
- If there have been an excessive number of collisions, cancel the transmission and send an error up through the layers.
- After waiting, attempt to transmit again.

The length of one transmission slot depends upon the speed of the medium, and the minimum size of packets. If the slot size is 512bits, then at 10Mbps, the slot time is $\frac{512}{10000000}$ or 0.0000512 seconds (or 51.2 µsec)

To determine if a collision has occurred, each station is connected to the medium with two wires, one for transmitting and one for receiving. During transmission, if the signal sent out on the transmission line is not the same as what is received, then another station is interfering with the transmission, and a collision has occurred.

Switching

Store-and-Forward

When the switch receives a packet, it waits for the entire packet to arrive and stores it in memory before forwarding it to the intended recipient. This mode of operation works for both half and full-duplex transmission.

The latency in this mode can be calculated by sender-switch transmission time (packet size / transmission speed) + switch latency + switch-recipient transmission time + propagation delay of the medium (how long the data takes to get from one end of the medium to the other).

Virtual-cut Through

When the switch receives a packet, it only buffers enough of the packet to allow it time to process the MAC header, and determine where the packet should be sent. It then just forwards the buffer and the data as it flows into the switch.

The latency here can be calculated by sender-switch transmission time + switch latency + propagation delay of the medium.

Ethernet Frame Format

Each frame sent on an ethernet network contains

- Preamble– A series of 56 1s and 0s, used to sync the clock of the receiver (56 bits)
- Frame Delimiter– A byte which signals the start of the frame, specifically 10101011 (8 bits)
- Source– Address of the sending station (48 bits)
- Destination– Address of the recipient station (48 bits)
- Length– The length of the data in bytes (16 bits)
- Data– Up to 12000 bits (1500 bytes) of data ($0 - 12000$ bits)
- Pad– Padding added to ensure the data is at least 46 bytes long ($0 - 368$ bits)
- CRC– Cyclic Redundancy Check information, used to detect errors in the frame, so it can be re-sent on error (32 bits)

This gives us a minimum frame length of $48 + 48 + 16 + 0 + 368 + 32 = 512$ bits

Lecture - Wireless Local Area Networks

11:00 11/11/24 Asim Ali

A single cell network is one which has a single Access Point (or Control Module), using a single frequency, but may have any number of clients (User Modules). A multiple-cell network may have multiple access points using different frequencies, each with multiple clients, but they must be connected to the same wired network for back-haul.

Each cell acts like a star network, since client can only communicate with the access point, and not directly with any of the other clients on the same network. In a multiple-cell network, they also cannot communicate directly between cells without a wired back-haul, which is usually part of an existing wired network.

Before a client can communicate in a cell, it needs to associate with the access point. In a single cell network, this is simple since there is only ever a single access point that needs to be associated with. In a multi-cell network, the client must disassociate from one access point, and associate to the new one. This may be done manually, if each access point is broadcasting a different SSID, or it may be done automatically if it's a cohesive network where the access points communicate to hand-off clients.

There are also ad-hoc WLAN networks, in which the devices are all simultaneously clients and access points, and communicate directly with each other.

IEEE 802.11

Terms

- Associated Stations– Devices connected to a WLAN
- Access Point– Provides access to the network for associated devices
- Basic Service Set (BSS)– A set of stations controlled by one coordinator
- Extended Service Set (ESS)– A set of one or more connected BSSs
- Distribution System (DS)– A system used to connect a set of BSSs and LANs to create an ESS
- Frame– A unit of data in the MAC protocol

Services

The MAC Service Data Unit is effectively the mechanism by which packets are prepared and sent over the medium.

Service	Provider	Used for
Association	Distribution System	MSDU
Authentication	Stations	Access & Security
De-authentication	Stations	Access & Security
Disassociation	Distribution System	MSDU
Distribution	Distribution System	MSDU
Integration	Distribution System	MSDU
MAC Service Data Unit (MSDU)	Stations	
Privacy	Stations	Access & Security
Re-association	Distribution System	MSDU

Access Control (CSMA/CA)

A very similar protocol to CSMA/CD, but designed specifically for wireless networks rather than wired bus networks. The difference is that the nodes might not know that they are causing a collision, since they may be in range of the access point, but not the other transmitting node.

There is an optional centralised controller known as the Point Coordination Function (PCF), which provides collision avoidance by providing permission to each node before it is allowed to send a message. There is also a distributed version known as the distributed coordination function (DCF), which is used in ad-hoc networks or in networks where throughput is more important than latency.

Point Coordination Function

The controller (usually the access point) offers a transmission slot to each known client, which the client then replies to, saying that it either does or does not wish to transmit. If the client does not wish to transmit, the slot is offered to the next client, and so on. It uses a round-robin method to give each client an opportunity to transmit, and guarantees there are no collisions. This does however waste a lot of capacity, since nodes often do not wish to transmit, and if there are some devices with lots of data, and some with no data, they are still given the same share of the throughput.

The access point also sends out a 'beacon frame' $10 - 100$ times per second, which advertises the network to any stations within the coverage area. The frame also contains information such as hopping frequencies, dwell times, clock synchronisation and more.

Distributed Coordination Function

DCF uses CSMA/CA to provide collision avoidance, as well as various levels of Inter-Frame Spacing (IFS). There are two methods which a network can use to confirm that a packet has been received correctly.

- Frame Exchange Protocol
  - Sender transmits frame immediately
  - Receiver response with an acknowledgement
  - If sender doesn't receive acknowledgement, it retransmits the frame
- Four Frame Exchange
  - Sender sends request-to-send (RTS)
  - Receiver responds with a clear-to-send (CTS)
  - Sender transmits frame
  - Receiver responds with an acknowledgement

If any station receives an RTS or CTS message not addressed to them, they immediately put themselves into a Non-Active Mode (NAV) until the medium is again idle. That way, even if the station is not in range of the requesting station, it should always be in range of the clearing station, as it will most likely be the access point. If the sending station does not receive an acknowledgement within a short time, the transmission is cancelled and it must send a new RTS before it can transmit.

The Distributed Inter-Frame Spacing (DIFS) is the length of time that a node must wait between transmissions, and the length of time that is multiplied to get the exponential back-off delays.

Priority Traffic

Some traffic needs to be given priority over others, such as acknowledgements, CTS messages and poll responses. These types of traffic use the Short Inter-Frame Spacing (SIFS) so they are more likely to transmit immediately. The access point also has priority over all other stations, and uses the Point-Coordinator

Inter-Frame Spacing (PIFS), which is shorter than the DIFS, but longer than the SIFS.

Super Frames

The bandwidth of the frequency is split into so-called **Super Frames**, which are a certain length of time.

Each 'Super Frame' has two sections. The first part of the frame uses PCF to poll each station for time-sensitive frames which need to be sent before anything else. For the second part, the point-coordinator goes idle and allows time for DCF frames to be sent asynchronously. This allows both time-sensitive and throughput-sensitive traffic on the same network.

If the end of one transmission overlaps the start of a super frame, the length of the super frame is reduced and the PCF section is delayed as to not collide with the previous transmission. This typically means that the DCF time in this super frame is reduced.

Lecture - Bluetooth Networks

11:00 18/11/24 Asim Ali

The original purpose was to create a universal interface for using small, local ad-hoc networks. It was also intended as a replacement for irDA– an infrared communication protocol.

The design specifications required a maximum range of $10 - 100m$, low power consumption, and a license free frequency to keep costs low. The specific frequency it uses is roughly 2.45GHz, which is within the license free frequency band also occupied by 2.4GHz Wi-Fi.

Bluetooth Protocols

Ordered from lowest to highest in the protocol stack, these are some of the main protocols used to control and communicate between bluetooth devices.

Radio

Responsible for frequency hopping, modulation and demodulation, and managing transmission power.

Baseband

Responsible for establishing connections, addressing different devices, formatting packets, timing messages and controlling transmission power.

Link Manager Protocol

The Link Manager Protocol (LMP) is responsible for initiating and maintaining connections between devices, authentication and encryption, and is in the lower layers of the bluetooth protocol.

Logical Link Control and Adaption

Adapts existing protocols to work over a baseband network, such as TCP/IP and telephony. It offers connectionless and connection-oriented services, similar to TCP and UDP.

Service Discovery Protocol

Provides device information and service advertisement, which can be queried by other devices to initiate establishing a connection.

Piconet

A **Piconet** is a collection of bluetooth devices connected in an ad-hoc manner. They form a star network with one device acting as the master, and up to 255 devices connected to it as clients. All devices in a piconet are synchronised to the same hopping sequence, and each piconet has it's own hopping pattern to avoid interfering with each other. Before a device is able to join a network, it has to synchronise with the hopping pattern.

While up to 255 devices can be in a piconet, only 7 devices can be actively communicating with the master at any time. All other devices are placed into a parked state, where they master is still aware they exist and may want to connect, but they cannot actively communicate.

Active clients can be in one of three states– Active (Transmits and receives), Sniffing (Reduced number of slots at a reduced power) or Holding (Further reduced power, only supporting SCO links).

There is also a standby state, in which the device is in range of the piconet, but is not participating.

Radio Specifications

Include table from slide 9

Baseband Specification

Bluetooth baseband uses Frequency Hopping Spread Spectrum (FHSS) to make it less likely for interference to occur, and to make it harder to eavesdrop on communications. The hopping frequency for baseband is 1600 hops/sec, with a dwell time of 625 µsec, which is also the slot time. There are 79 carrier frequencies within the band, each of which is hopped to in a pre-determined but pseudorandom sequence, which further minimises both the likelihood and impact of interference.

Bluetooth devices use Time Division Duplex, where the same frequency is used for sending and receiving data, but not at the same time. Each slot is labelled from 0 to $2^{27} - 1$, and loops. The master uses even slots, and clients share the odd slots using Time Division Multiple Access (TDMA). In general, Piconets use FH-TDD-TDMA (Frequency Hopping Time Division Duplex Time Division Multiple Access).

Scatternet

Multiple piconets may exist in one area, and may form a scatternet. A bridge device connects two piconets together, and may be a client in both networks, or a master in one and client in another. The bridge acts as a relay between the two networks, and forwards messages between them. Clients transmit only with the permission of the master, using Time Division Multiplexing to access the medium.

Links Between Master and Clients

Bluetooth Packet Format

- Access Code– 72 bits used for timing synchronisation, offset compensation, paging and inquiry
- Header– 54 bits used to identify packet type and contain protocol control information
- Payload– $0 - 2745$ bits of actual data

Synchronous Connection Oriented (SCO)

A fixed number of slots are assigned between point-to-point and master-client communication. The master maintains connections with all devices using reserved slots at a regular interval. Slots must be reserved, and the smallest unit of reservation is 2 consecutive slots– one in each direction. The payload of each slot may be 80, 160 or 240 bits. The most reliable variant is 80 bits, at 800 slots/sec as the packets are replicated 3 times. The master can support three simultaneous links, if each of them uses the 80 bit variant. SCO communications are never re-transmitted, and error correction techniques are used at each end instead. This is typically used for realtime data, video and audio.

Asynchronous Connectionless (ACL)

There can be only a single ACL link at a time, and transmits in slots not already reserved for SCO communications. ACL links use 1, 3 or 5 slot packets, which are assigned by the master, depending upon the requirements of devices on the network. The first 259 µsec of the slot are used as settling time, then 126

bits of header, and finally 240, 1490 or 2740 bits of data, depending on the number of slots used. There is no bandwidth guaranteed, and retransmission may be required. A client may only reply to the master with an ACL slot, and may never initiate communication without the master having assigned slots. After every ACL slot, a single SCO slot is reserved for the client to reply to the master.