Contents

[Lecture on 1.2]

1 Introduction

Dr. Declan Delaney

1.1 Motivation and Introduction

1. Signals travel without wires
   (a) In this module, signals travel as radio waves
   (optical and acoustic systems ignored)
2. Applications are mostly in communications
   (a) Signals modulated to carry information
   (b) Many familiar applications such as radar, navigation, etc.

Example: Modern smart phone has approximately 9 distinct wireless systems. Try identifying them?

- NFC
- Cellulars
  - 2G

- 3G
- 4G
- 5G

- GPS
- Bluetooth
- WiFi
- UWB
- Lidar

Advantages of Wireless

- Mobility
- Good for one-to-many transmissions
- Cheap

Increasingly used for high capacity point-to-point links (cheaper than wired) (e.g. to serve remote areas)

Advantages of Wired

- Very little leakage
- No interference
- Multiple systems can operate adjacently without issue

but considerably more overheads. Suitable for super high capacity lines (eg. fibre-optic transatlantic cables)

1.2 The Wireless Spectrum

The EM spectrum is a shared and limited resource.
Mostly regulated by government agencies.

Frequencies must be carefully given out, but can be reused at different locations as we will see.

Overview of a wireless system:

- Start with raw data
- Source coding (compression)
- Channel coding (error detection & error correction)
- Modulation

- TX
- RX
- Demodulation
- Channel decoding
- Source decoding

This module is mainly about modulation and TX/RX, the rest is information theory.

1.3 Assessment & Delivery

Component	Timing	Weight
Lab Assignments	Varied (3 labs)	25%
Online BS quizzes	?	25%
Final Exam		50%

- Lab 1: Receiver architectures
- Lab 2: Phase-Locked Loops
- Lab 3: Amplifiers

Open book final with emphasis on design and problem solving

1.4 Module Outline

- (1) Radio Link Design
  - Link budget?
  - How far? How much power?
- (2) Non-Linear System
- (3) Frequency Generation and Synthesis
- (4) Transmitter Design
  - Requirements and specifications
  - Transmitter architecture choices
- (5) Noise
  - Sources of noise
  - Noise analysis, low-noise design
- (6) Receiver Design
  - Requirements and specifications
  - Receiver architecture choices
- (7) Transceiver Design

  - Transmitter and receiver combined!
- (8) Antennas and Propagation
  - Review of antenna theory
  - Practical antennas and propagation of radio waves
- (9) System-Level Issues and Examples

1.5 Textbooks

Purely optional, module notes should be sufficient.

- "Microwave and RF Design of Wireless Systems"
  by David M. Pozar
- "Antennas"
  by John D. Kraus

[Lecture on 1.3]

1.6 Basics of Wireless Communication

Amplifier to increase signal power enough to drive the antenna

Multiple Access

- CSMA: Listen to the channel, send if it's clear
- FDMA: Frequency divided MA
- TDMA: Time divided MA

You require a 'guard band' between frequency bands where no data is sent to avoid interference

CDMA is a good way to overcome this waste, ODMA is an even better approach

1.6.1 Main components of a transmitter

- Signal is 'mixed' (modulated) with an oscillator at the frequency of the channel being used
  - The frequency has to be adjustable to allow for different channels
- A power amp is required to power an antenna

Amp goes first because high-frequency amplification is a fucking nightmare

1.6.2 Main components of a receiver

Signal arrives on an antenna (which collects EM waves in the vicinity, sometimes in a preferred direction, and puts them on a cable, waveguide, or circuit board track)

RX:

- Receive at very low power
- Select and amplify the desired signal
- Estimate the original signal

The signal is too weak to demodulate, so you need a high-frequency amplifier before the demodulator.

For most of this module, we will look at block-level circuits and not worry about precise circuit design.

Channel capacity (Shannon-Hartley): $C = B \times \log_2(1 + \frac{S}{N})$

- C is channel capacity (eg. bits per second)
- B is bandwidth (Hz)
- $\frac{S}{N}$ is the signal-to-noise ratio

Cellular:

- 2G operated at 800-900 MHz and 64 kHz channels
- 3G operated at 1-2 GHz and got 8 MHz channels
- 4G operates at up to 5 GHz and 50-100 MHz channels
- 5G has channels up to 10 GHz

The increase in speed is partially due to better MA schemes, but mainly due to the bigger bandwidth.

Other options to increase capacity:

- Increase SNR
  - Increase power (limited by regulations)
  - or reduce noise (choose a frequency with less background?)

2 Basic Antenna & Propagation

Radio link design

- What will be the power at the receiver (or SNR)?
- How far away can the antennae be?
- How much power is needed?

Answers culminate in a *link budget* calculation

Antennae

- Circuitry generates the signal and amplifies to high power
- High power signal goes along a 'feed track'
  - Very little losses here
- Then into the antenna
  - Can be directed, but not guided, so loses power quickly
  - Not all power is radiated, some is lost

[Lecture on 1.5]

Antenna Power

Ignoring free space losses

- Assume total power remains constant as it propagates
- but spreads over a larger area (inverse square law)
- Consider *power density* in W/m^2

With space losses

- Model with a 'propagation constant' $\gamma \geq 2$
- $\frac{\text{Power density at distance } r_2}{\text{Power density at distance } r_1} = \frac{r_1}{r_2}\gamma$

Isotropic Reference Antenna

- Assume a point source
- Radiates in all directions uniformly
- 100% of input power is radiated

Not possible but useful for comparison purposes

Omni-directional Antenna

- Similar model but losses are allowable
- I npractice only possible in one plane

Antenna Gain

- Antennae are not amps - they don't actually have gain.

- However, a focused antenna delivers more power to the receiver than an isotropic tradiator, so there is a 'focusing gain'

$$\text{Gain in a particular direction} := \frac{\text{Power density observed in that direction}}{\text{Power density expected from an isotropic radiator}}$$

- Obviously normally measured in the direction of transmission

2.1 Receiver Antennae

- Collects electromagnetic waves
- May be directional - sensitive to waves from a certain direction
- Measure the aperture / collection area
  - Some antennae have an obvious physical aperture (eg. parabolic dish)
  - Others have an 'effective aperture' A, such that $P_{RX} = D_{RX}A$ where P_{RX} is the collected power and D_{RX} is the power density of the incoming wave
- Aperture efficiency
  - Even those with a physical aperture have an 'effective aperture', which is lower due to losses on the dish
    Aperture efficiency $:= \frac{\text{Effective aperture } A}{\text{Physical aperture}} < 1$
- Always use 'effective aperture', which accounts for dish losses

Reciprocity

- Antennae can TX and RX
  - Same beam and shape each way
- RX gain is equal to TX gain
- One expression for gain based on the aperture is
  $G = \frac{4\pi A}{\lambda^2}$ where λ is wavelength.