Part II: Communication Technologies

Historical Perspective

A brief history of telecommunications

- **1838** William F. Cooke and Sir Charles Wheatstone build the telegraph (Morse code communications).
  - It is interesting that communications started with digital technology.
- **1844** Samuel F. B. Morse demonstrates the Baltimore, MD, and Washington, DC, telegraph line.
- **1858** First transatlantic cable is laid and failed after 26 days.
- **1864** James C. Maxwell predicts electromagnetic radiation.
- **1876** Alexander G. Bell develops and patents the telephone.
  - Analog technology.

A brief history of telecommunications

- **1894** Oliver Lodge demonstrates wireless communication over a distance of 150 yards (~137m).
- **1900** Gulielmo Marconi transmits the first transatlantic wireless signal.
- **1905** R. Fessenden transmits speech and music by radio.
- **1915** Bell System completes a US transcontinental telephone line.
- **1920** KDKA, Pittsburgh, PA, begins the first scheduled radio broadcasts.

A brief history of telecommunications

- **1926** RJ.L. Baird (England) and C.F. Jenkins (US) demonstrate television.
- **1933** Edwin H. Armstrong invents FM.
- **1935** R.A. Watson-Watt develops the first practical radar.
- **1936** The BBC begins first television broadcasts.
- **1953** NTSC color television is introduced in the US.
- **1953** The first transatlantic telephone cable (36 voice channels) is laid.
- **1957** The 1st Earth satellite, *Sputnik I*, is launched by USSR.

A brief history of telecommunications

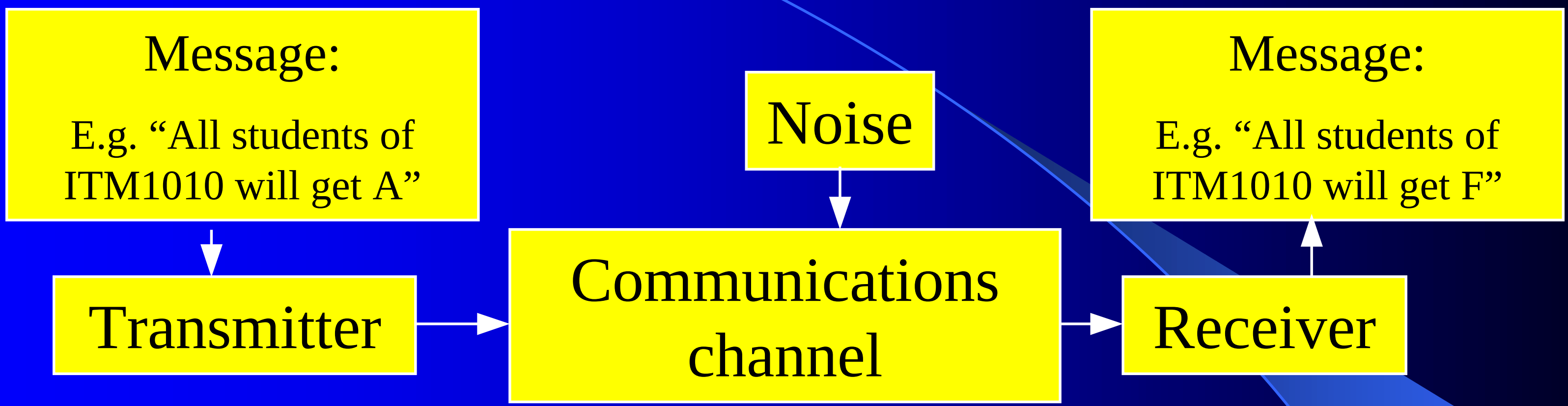
- **1964** The electronic telephone switching system starts.
- **1968** Cable television systems are developed.
- **1972** Motorola demonstrates the cellular telephone to FCC.
- **1980** Bell System FT3 fiber-optic communication is developed.
- **1985** Fax machines become popular.
- **1989** GPS using satellite is developed.
- **1995** The Internet and WWW become popular.
- **2000-** Era of digital signal processing with microprocessors, megaflop PCs, digital satellite systems, DTV, and PCS.

ITM1010
Computer and Communication Technologies

Part II: Introduction to Communication Technologies

Information Measure

Communications System



- Message transmitted in a communications system is only one of a finite set of messages.
- Message may be corrupted by noise in the channel, transmitter or receiver
- Communications engineers' basic objective is to design a system which faithfully reproduces the message sent at the receiver in the most efficient (e.g.. least time, cost) way possible.

Measurement of information

- More information is contained in an unexpected message than one which is expected. E.g., a message such as “ next week’s lottery will draw 2,11,12,17,30,41” has more information content than a message saying “This sentence is written in English.”

Measurement of information

- If a message m_j has probability P_j of being sent, the information content of the message I_j is defined by:

$$I_j = \log_2 \frac{1}{P_j}$$

  – If log to base 2 is used then the unit of information is the bit

Refresher on logarithms

- By definition, if $a^x=y$ then $\log_a y = x$
- Some basic properties of logarithms include
  - $\log(xy)=\log x + \log y$
  - $\log(x/y)=\log x - \log y$
  - $\log x^r = r \log x$

Refresher on logarithms

- How to change the base e.g. what is $\log_b y$ in terms of $\log_a y$?

$$\text{Let } z = \log_b y$$

$$b^z = y$$

Taking, log to base *a* on both sides

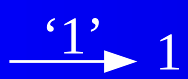
$$z \log_a b = \log_a y$$

$$z = \frac{\log_a y}{\log_a b} = \log_b y$$

Hence $\log_2 y = \log_{10} y / \log_{10} 2$

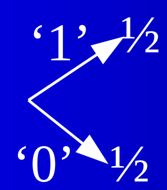
Probability and information

Message is always ‘1’



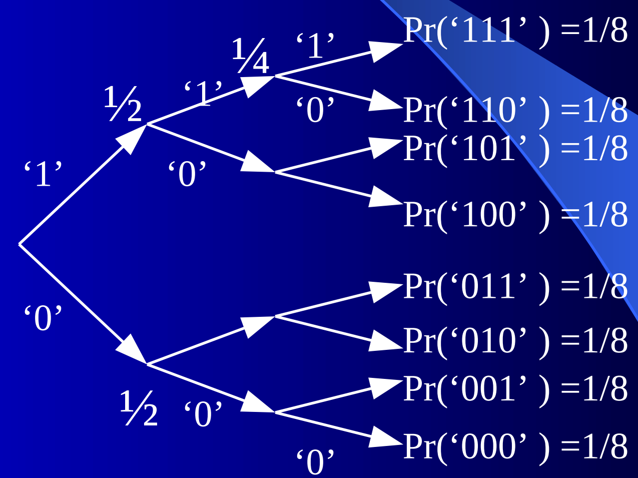
Information content of message is
$I_1 = \log_2 1 = 0$

Message is equally likely to be either ‘1’ or ‘0’



Information content of a message is
$I_1 = \log_2 2 = 1$
$I_0 = \log_2 2 = 1$

Message is equally likely to be any of 000, 001, 010, 011, 100, 101, 110, 111



Information content of a message is
$I_{111} = \log_2 8 = 3$

Binary digits and bits

- If the probability of sending a binary digit (1 or 0) are equal to 1/2 then the information content of a binary digit is

$$I_1 = I_0 = \log_2 \frac{1}{0.5} = \log_2 2 = 1$$

  - Most engineers use the same word (bit) for a binary digit and the unit of information. However information content of a binary digit is not necessarily equal to 1 bit (e.g. if the probability of a 1 is not equal to ½).
  - If log to base 10 is used the unit of information is the hartley (named after R.V.Hartley who first suggested the use of logs to measure information in 1928).

Average Information Content and Entropy

- The average information content H of all possible messages in a communications system which has a total of N different messages (each having information Ij $=\log_2 1/P_j = -\log_2 P_j$) is:

$$\mathrm{H} = p_1 \mathrm{I}_1 + p_2 \mathrm{I}_2 + \ldots + p_N \mathrm{I}_N$$

$$\mathrm{H} = -\sum_{j=1}^{N} p_j \log_2 p_j$$

- Since the form of this equation is identical to the definition for entropy in statistical mechanics, H is also called entropy.
- Entropy may be thought of as a measure of the average uncertainty or randomness of the system and will have a maximum when all possible messages are equally likely.
- Unit of entropy is bits per message.

Example: entropy coding of information

- Suppose a language uses an alphabet of 4 symbols, which we denote by A,B,C and D, and that the probability of each symbol occurring in the language are 0.5, 0.25, 0.125 and 0.125 respectively.
  - The most obvious code is not the most efficient. E.g. if the binary numbers 00,01,10,11 are used for A,B,C and D, we need 2 bits for each symbol. For a long message of n symbols using this code, $2n$ bits must be sent.
  - But the entropy in this example is

$$H=0.5 \log_2 2+0.25 \log_2 4+0.125 \log_2 8+0.125 \log_2 8 = 1.75$$

  - Only need 1.75 n bits to send n symbols

An example of Entropy Coding

- An entropy code for the previous example language is :

  0=A 10=B 110=C 111=D

- The average number of binary digits needed to encode a sequence of n symbols using this code is

  n (0.5 x 1+ 0.25x2 + 0.125 x 3 + 0.125 x 3) = 1.75 n

- The encoded message can be readily recovered by using illegal bit sequences (e.g.. 01) to identify the boundary between symbols.
- We have used knowledge of the statistics of a message source to reduce the number of binary digits needed on average to send a message from that source.

Example: Entropy of English

- The entropy of English may be defined as the average information content of each letter in the alphabet
- 26 letters in the English alphabet: If each letter occurs with equal probability the information content of each letter is $\log_2(26)=4.7$ bits. However not all letters have equal probability (E.g.. “E” occurs more frequently in English than the letter “Q”)
- In 1950, Claude Shannon calculated the entropy of English to be 2.3 bits per letter when statistical effects extending up to 8 letters were considered. When long range effects (up to 100 letters) were included the entropy was further reduced to only 1 bit per letter.

Summary

- Message sent by a communications system is only one of a finite set of possible message
- Information content of a message can be precisely defined mathematically as

$$I_j = \log_2 \frac{1}{P_j}$$

- Unit of information is bit
- The average information content of all possible messages in a system is called entropy (unit: bits per message)

$$H = -\sum_{j=1}^{N} p_j \log_2 p_j$$

- One binary digit may not necessarily carry one bit of information.
- Possible to design efficient codes which achieve the minimum number of binary digits per message as specified by entropy