E445 Spring 2014
Lecture 1

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Lecture 1 EE445 - Outcomes

- In this lecture you:
  - will be introduced to the course grading elements
  - should be able to define the process of communications and the elements in a communication system
  - determine the tower height required on a perfect earth for LOS (line of sight) wireless communications communications

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Course Mechanics

- Prerequisites: EE308- Signal and Systems Analysis or equivalent or consent of the instructor
- Text: **Digital and Analog Communications Systems, Prentice Hall, Leon W. Couch, 2013, ISBN 0-13-291538-3**
- Other References:
  - Modern Digital and Analog Communication Systems, B. P. Lathi
  - Communication Systems, A. Bruce Carlson
  - Fundamentals of Communications Systems, J. G. Proakis

The Course Syllabus is available on the Class Website

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Course TOPICS

- **Review of Signals and Spectra**
- **Analysis and Transmission of Signals**
- **Sampling and pulse code modulation**
- **Principles of Digital Baseband Signals**
- **Bandpass Signaling Principles and Circuits**
- **Bandpass Modulated Systems**
- **Introduction to the theory of probability**
- **Behavior of digital systems in the presence of noise**
- **Error correcting codes (time permitting)**
- **Example systems**

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$$$$$$$$

Projections for the Wi-Fi market are among the rosiest in IT. At the 802.11 Planet Conference & Expo this week, an industry group said the **$2 billion Wi-Fi industry** should expand at an compounded growth rate of 30 percent to nearly a **$6 billion industry**, putting it on par with household name brands like Budweiser and in line with growth in the mobile PC industry.

Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update, 2012–2017

http://www.cisco.com/en/US/solutions/collateral/ns341/ns525/ns537/ns705/ns827/white_paper_c11-520862.html

The Mobile Network in 2012:

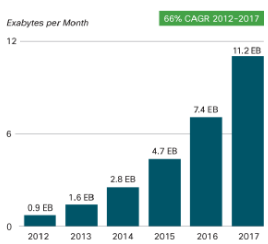
- **Global mobile data traffic grew 70 percent in 2012**. Global mobile data traffic reached 885 petabytes per month at the end of 2012, up from 520 petabytes per month at the end of 2011.
- **Last year's mobile data traffic was nearly twelve times the size of the entire global Internet in 2000**. Global mobile data traffic in 2012 (885 petabytes per month) was nearly twelve times greater than the total global Internet traffic in 2000 (75 petabytes per month).
- **Mobile video traffic exceeded 50 percent for the first time in 2012**. Mobile video traffic was 51 percent of traffic by the end of 2012.
- **Mobile network connection speeds more than doubled in 2012**. Globally, the average mobile network downstream speed in 2012 was 526 kilobits per second (kbps), up from 248 kbps in 2011. The average mobile network connection speed for smart phones in 2012 was 2,064 kbps, up from 1,211 kbps in 2011. The average mobile network connection speed for tablets in 2012 was 3,683 kbps, up from 2,030 kbps in 2011.

Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update, 2012–2017

Global Mobile Data Traffic, 2012 to 2017

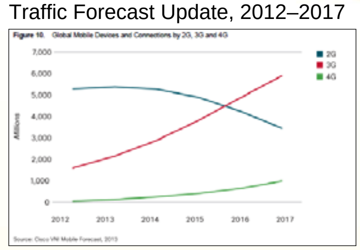
Overall mobile data traffic is expected to grow to 11.2 exabytes per month by 2017, a 13-fold increase over 2012. Mobile data traffic will grow at a CAGR of 66 percent from 2012 to 2017 (Figure 1).

Figure 1. Cisco Forecasts 11.2 Exabytes per Month of Mobile Data Traffic by 2017



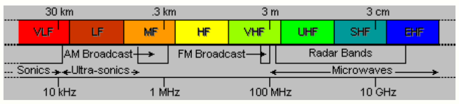
Source: Cisco VNI Mobile Forecast, 2013

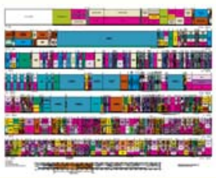
Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update, 2012–2017



Although 4G connections represent only 0.9 percent of mobile connections today, they already account for 14 percent of mobile data traffic. By 2017, 4G will represent 10 percent of connections, but 45 percent of total traffic.

Spectrum is a limited resource

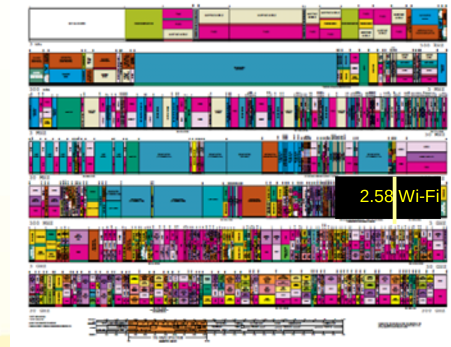




Given spectrum is a limited resource – we desire to pass the most information we can in the least bandwidth.

What is the limiting factor for how much information we may transmit/Hz?

Spectrum is a limited resource



What is Communications?

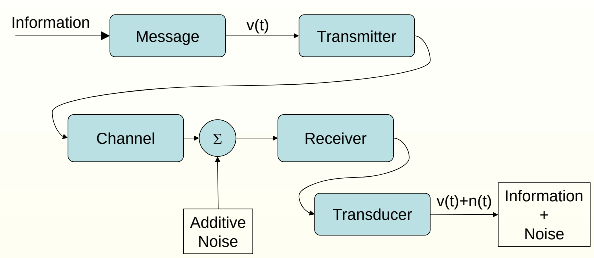
INFORMATION SOURCE

Communications is the Process of <u>Transmitting</u> <u>Information</u> from a Source to a Destination

- Telephone –wired (electrons)
- FM/AM Radio – wireless (EM)
- Fiber Optics – light (photons)
- Speech – acoustic
- Astronomy- light (photons)

INFORMATION DESTINATION

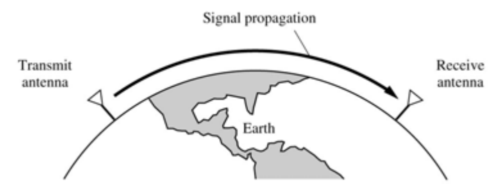
A Communication System



The Wireless Channel

- Signal Propagation
- Channel Model is statistical, dependent on:
  - the carrier frequency
  - the signal bandwidth
  - the terrain along and around the propagation path between the transmitter and receiver

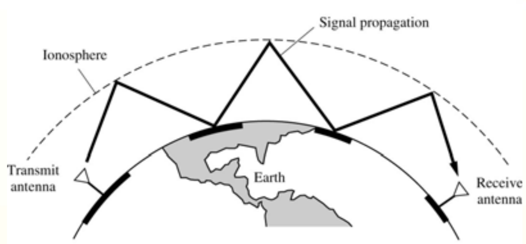
Figure 1–2 Propagation of radio frequencies.



(a) Ground–Wave Propagation (Below 2 MHz)

Signals follow the curvature of the earth

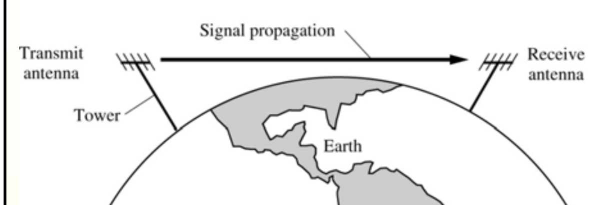
Figure 1–2 Propagation of radio frequencies.



(b) Sky–Wave Propagation (2 to 30 MHz)

Signals bounce between the earth and the Ionosphere

Figure 1–2 Propagation of radio frequencies.



(c) Line-of-Sight (LOS) Propagation (Above 30 MHz)

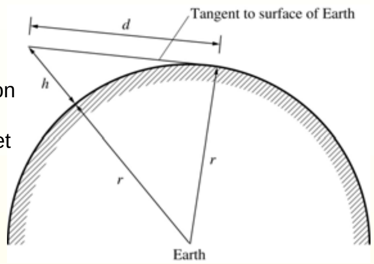
Line Of Sight - Tower Height to Clear a Spherical Earth

$$d = \sqrt{2h}$$

d= distance to horizon in miles

h= tower height in feet

Note: the total path distance between equal height towers is 2d



Couch, *Digital and Analog Communication Systems*, Seventh Edition

Earth Bulge

Earth Bulge

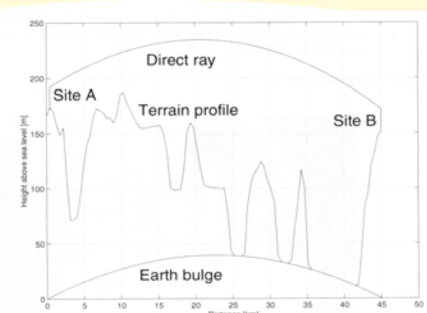
When planning for paths longer than seven miles, the curvature of the earth might become a factor in path planning and require that the antenna be located higher off the ground. The additional antenna height needed can be calculated using:

$$H = \frac{D^2}{8}$$

where

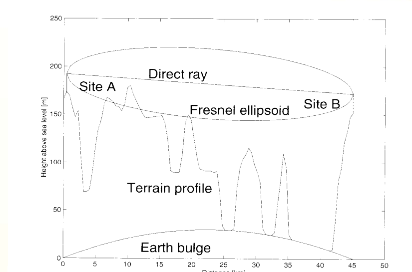
H = Height of earth bulge (in feet)

D = Distance between antennas (in miles)



- When the wave interacts with the ground or some other obstruction we no longer have free space propagation to the receiver

Plane Earth Loss- Fresnel Diffraction



Path profile as Figure 6.2 but with Earth radius corrected to account for atmospheric refractive index gradient. The Fresnel ellipsoid represents 0.6 × the first Fresnel zone at 900 MHz

Non-LOS communication involves an additional loss due to Diffraction

Earth Bulge with Fresnel Diffraction

http://www.cisco.com/univercd/cc/td/doc/product/wireless/bbfw/ptop/p2pspg02/spg02ch2.htm#xtocid19

Minimum Antenna Height

The minimum antenna height at each end of the link for paths longer than seven miles (for smooth terrain without obstructions) is the height of the First Fresnel Zone plus the additional height required to clear the earth bulge. The formula would be:

$$H = 43.3\sqrt{\frac{D}{4F}} + \frac{D^2}{8}$$

where

H = Height of the antenna (in feet)

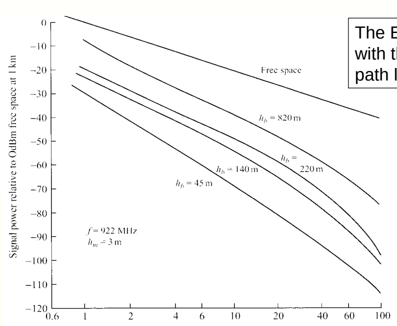
D = Distance between antennas (in miles)

F = Frequency in GHz

Tower Height

Line of Sight Distance Between Antenna Towers	Height of Tower to Avoid Flat Earth Curvature	Tower Height Required Over Tallest Obstacle In Line-of-Sight to Provide 60% Fresnel Zone Clearance	
		2.4GHz 802.11b/g (Fresnel Zone Radius = 39 Feet)	5.8 GHz 802.11a (Fresnel Zone Radius = 25 Feet)
8 Miles	10 feet	33	25
10 Miles	15 feet	38	30
12 Miles	20 feet	43	35
14 Miles	25 feet	48	40
16 Miles	30 feet	53	45
18 Miles	40 feet	63	55
20 Miles	50 feet	73	65
22 Miles	60 feet	83	75
24 Miles	70 feet	93	85
26 Miles	80 feet	103	95
28 Miles	100 feet	123	115
32 Miles	125 feet	148	140

Free Space vs Ground effects



The EM wave interacting with the ground affects path loss

EELE445-14

Lecture 2

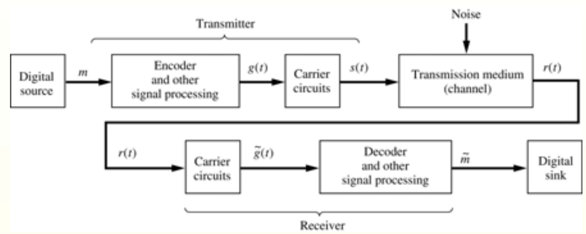
Information, Power, rms, dB

Lecture 2 EE445 - Outcomes

- In this lecture you:
  - be able to sketch the block diagram of a communications system and describe it
  - define the function of a communications engineer
  - define Information and Shannon's Law
  - will be able to work with dB, dBm, dBW, dBv, dBuV,….

Figure 1–4 General digital communication system.

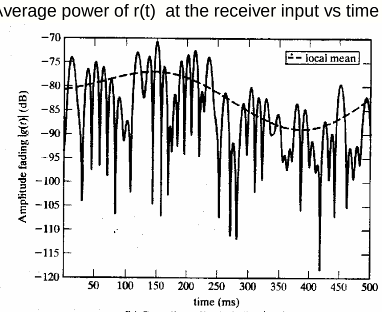
$$S(t) = R(t)\cos(\omega_c t + \theta(t))$$



Information is in R(t) and/or θ(t)

Example of Received signal Power vs time for a Wireless channel

Average power of r(t) at the receiver input vs time



(b) Overall amplitude fading $|g(t)|$ (dB)

Optimum digital communication system.

•The Communication Engineers Job is to maximize the amount of information transmitted though the channel using the least amount of spectrum – i.e. using the smallest bandwidth possible.

•System noise limits the information capacity of a communications system for a given bandwidth. This is defined by <u>Shannon's Law for information channel capacity</u>

Information Measure - I

Definition. The *information* sent from a digital source when the jth message is transmitted is given by

$$I_j = \log_2\left(\frac{1}{P_j}\right) \text{ bits} \qquad (1\text{–}7a)$$

where P_j is the probability of transmitting the jth message.††

Example 8-bit word: $possible\ outcomes: O_j\ ,\ m = 2^8\ ,\ j = 1..m$

$$O_1 = [0,0,0,0,0,0,0,0]$$

$$O_{256} = [1,1,1,1,1,1,1,1]$$

$$P(O_1) = \frac{1}{2^8} = 1/256 = 0.00391 = 2^{-8}$$

$$I_1 = \log_2\left(\frac{1}{2^{-8}}\right) = 8\ bits$$

see appendix B-3 for review

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Average Information Measure- Entropy

$$I_j = -\frac{1}{\log_{10} 2}\log_{10} P_j = -\frac{1}{\ln 2}\ln P_j \qquad (1\text{–}7b)$$

In general, the information content will vary from message to message because the P_j's will not be equal. Consequently, we need an average information measure for the source, considering all the possible messages we can send.

Definition. The *average information* measure of a digital source is

Entropy: $$H = \sum_{j=1}^{m} P_j I_j = \sum_{j=1}^{m} P_j \log_2\left(\frac{1}{P_j}\right) \text{ bits} \qquad (1\text{–}8)$$

where m is the number of possible different source messages and P_j is the probability of sending the jth message (m is finite because a digital source is assumed). The average information is called *entropy*.

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Shannon's Law for additive white noise

Information Source Rate, R and channel Capacity, C:

$$Bit\ Rate:\quad R = \frac{H}{T}\quad bits/s$$

$$Channel\ Capacity:\quad C = B \bullet \log_2\left(1 + \frac{S}{N}\right)\quad bits/s$$

H = Entropy or average information
T = time duration of transmission
B = Bandwidth in Hz
S = Signal power in watts
N = Noise power in watts

For low BER: $R \le C$

Shannon's Law is the upper limit for channel capacity. Research into new modulation and coding techniques to approach this limit is very active

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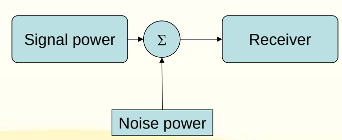
Shannon's Capacity Example

A communication system has a bandwidth of 1 MHz. The signal power is 1 picowatt. The noise power is 4 femtowatts.

What is the channel capacity in Bits/sec?



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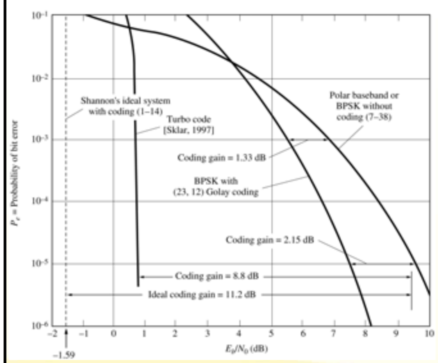
Shannon's Capacity Example

$$C = B \bullet \log_2\left(1+\frac{S}{N}\right)\ bits/s$$

$N := 4\cdot 10^{-15}$ $S := 10\cdot 10^{-12}$ $B := 10^{6}$

$C := \frac{1}{\ln(2)}\cdot B\cdot \ln\left(1+\frac{S}{N}\right)$ $C = 1.129\times 10^{7}$ Bits per second

Figure 1–8 Performance of digital systems—with and without coding.



How does coding reduce the BER?

Couch, Digital and Analog Communication Systems, Seventh Edition

dB and Units

- dB are used because of the extremely wide dynamic range of signals we encounter in communications.
  10^6 Watts to 10^{-13} Watts

$$dB \equiv 10\log\left[\frac{P_1}{P_2}\right] \quad P_1 = \frac{V_1^2}{R_1} \quad P_2 = \frac{V_2^2}{R_2}$$

$$dB = 10\log\left[\frac{V_1^2}{V_2^2}\frac{R_2}{R_1}\right] = 20\log\left[\frac{V_1}{V_2}\right] + 10\log\left[\frac{R_2}{R_1}\right]$$

dB and Units

So when $R_1 = R_2$:

$$dB = 10\log\left[\frac{P_1}{P_2}\right] = 20\log\left[\frac{V_1}{V_2}\right] = 20\log\left[\frac{I_1}{I_2}\right]$$

We often set P_2 to some reference power (or voltage)

dBm = dB relative to 1mW

$$dBm = 10\log\left[\frac{P_1\ in\ mW}{P_2 = 1\ mW}\right]$$

dB and Units

$dBW \equiv dB\ relative\ to\ 1\ Watt$

$dBW = 10\log[P_1\ in\ Watts],\ P_2 = 1\ Watt$

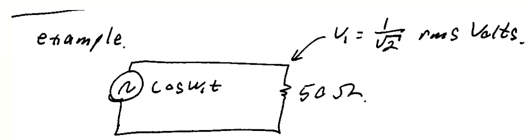
$dBV \equiv dB\ relative\ to\ 1\ Volt$

$dBV = 20\log[V_1\ in\ rms\ Volts], V_2 = 1\ Volt\ rms$

$dBuV \equiv dB\ relative\ to\ 1\ \mu Volt$

$dBV = 20\log[V_1\ in\ rms\ \mu Volts], V_2 = 1\ \mu Volt\ rms$

dB and Units- Example



$$P = \left(\frac{1}{\sqrt{2}}\right)^2 \bullet \frac{1}{50} = 0.01\ Watts = 10mW$$

in dBm: $P_{dBm} = 10\log\left[\frac{10\ mW}{1\ mW}\right] = 10\ dBm$