Deep Space Telecom

Prof. Dean Johnson
Electrical and Computer Engineering
Western Michigan University
Oral Communication

The Encode-Decode Model of Communication
http://www.sltinfo.com
Data Communication

http://www.englishexercises.org/makeagame
The Thin Atmosphere to Communicate

https://fettss.arc.nasa.gov/collection/details/earth-atmosphere/
Telecommunication is – according to Article 1.3 of the International Telecommunication Union's (ITU) Radio Regulations (RR) – defined as "Any transmission, emission or reception of signs, signals, writings, images and sounds or intelligence of any nature by wire, radio, optical or other electromagnetic systems."

http://www.bro.lsu.edu/radio/Classroom
Lecture: Rm. C-229 @10:30 am MWF
Instructor: Dr. Dean Johnson homepages.wmich.edu/~johnson
    Office: Rm. B-228 West Parkview
    Email: johnson@wmich.edu
    Hours: MWF 9:30 to 10:30 a.m. or some afternoons after 1:30 p.m.

Course Objective
The course will examine the means by which telemetry, command and
tracking are done between spacecraft and earth-borne antennas through
a systems approach. The telecom hardware of several current and
past planetary observational platforms will be examined. In addition,
basic remote sensing concepts will be presented to help understand the
science objectives and visualization constructs of these missions. The
Mars Exploration Rovers telecom and imaging systems will be examined
in detail. This course will satisfy Concentration Area#2 in the ECE
graduate program or a 4000 ECE Elective in the ECE UG program.
Syllabus

Materials Used in Class:

1. Connect 2.0 & Exam system: Go to http://connect.mcgraw-hill.com/class/ece-5950-22443 & press REGISTER NOW. Type the email address and password to create an account. The online access costs $70 (free for 14 days) unless used in another course.

2. On-line course materials:
      i. Principle Textbook: Deep Space Telecommunications System Design (see), by Joseph Yuen (5th item from top)
      ii. Descanso Book Series
      iii. Design and Performance Summary Series
   b. Remote Sensing Area:
      Notes by van Zyl at http://www.its.caltech.edu/~ee157/
   c. Visualization Area:
      i. Solar System 3D models: http://solarsystem.nasa.gov/eyes/
      ii. Google Earth View->Explore->Mars
      v. New Horizons leaving Pluto: http://pluto.jhuapl.edu/
      vii. Curiosity (MSL) Rover:
   viii. NYT Mars Rover Tracker:
   ix. iPhone/Android Apps: Earth-Now, Spacecraft 3D

3. Science Objectives and Background:
   a. Ustream video: http://www.ustream.tv/nasajpl
   b. Travelers Guide to the Planets Video:
3. Additional References:
   a. WolframAlpha Online computational engine by Wolfram Research
   d. Camera Lenses, from Box Camera to Digital by Gregory Smith (SPIE Press, 2006)

Grading: View on Elearning
The following preliminary grade scale shall be used.

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(Items may be adjusted)

WMU Honesty Policy: Attempting to obtain credit for work (lab, hw, reports, exams) done by somebody else is illegal and punishable in this class. You are responsible for making yourself aware of and understanding the policies and procedures in the Undergraduate/Graduate Catalog that pertain to Academic Honesty. These policies include cheating, fabrication, falsification and forgery, multiple submission, plagiarism, complicity and computer misuse.
[http://catalog.wmich.edu/content.php?catoid=24&navoid=974]
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Please enter the URL below.

https:// descanso.jpl.nasa.gov/

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Please enter the URL below.

https://eyes.nasa.gov/index.html

Note: Many popular websites allow secure access. Please click on the preview button to ensure the web page is accessible.
EonSS Demo

- Demo on next slide of how to use Eyes on the Solar System to see
  - Voyager (about Jupiter, 1980)
  - Juno (about Jupiter now)
EonSS Demo

- The next slide shows how to use Eyes on the Solar System to see
  - Cassini (about Saturn now)
Three Functions of a TeleCom System

- Telemetry (SC to Ground)
- Command (Ground to SC)
- Tracking (Ground to SC to Ground)
Three Functions of a Telecom System

Fig. 1-1. A typical deep space telecommunications system
Atmospheric Transmission Windows

Transparency of the Earth's atmosphere versus radiation wavelength

- **S-band**: 2.3 GHz, 1.13 m
- **X-band**: 8.4 GHz, 40 mm
- **Ka-band**: 32 GHz, 9.4 mm
The Electromagnetic Spectrum

In vacuum, wavelength $\lambda$ and frequency $f$ are related by the speed of light:

$$c = \lambda f$$

$$c = 2.998 \times 10^8 \text{ meters/second}$$
EM Power from a Space Craft

\[ P_t \text{ transmitted} \]
\[ 21 \text{ W} \leq L \text{ dBm} \]

\[ \rho = \text{power flux density} \]
\[ = \frac{P_t G_t}{4\pi r^2} \left[ \frac{\text{W}}{\text{m}^2} \right] \]

Receiver area:
\[ A_r = \pi R^2 \]
\[ D = \text{cm} \]

\[ P_r = \text{received power} \]
\[ = \rho A_r \]
Example: Voyager

\[ r_3 = 6.8 \times 10^9 \text{ m} \]
\[ P_T = 21.3 \text{ W} \]
\[ a_T = 6.5 \times 10^4 \]
\[ P = \frac{P_T \cdot r_T}{4\pi r^2} = 2.383 \times 10^{-19} \frac{\text{W}}{\text{m}^2} \]
\[ P_R = P \cdot A_T = 3.22 \times 10^{16} \text{ W} \]

In 1970: D = 6.4m → 20m
Calculate \( P_R \)
for \( D = 70 \text{ m} \)
Introduction to Thermal Noise
Computing Noise Power in a R

\[ V_n = \sqrt{4kTR} \quad (B=1) \]

\[ V_L = \frac{1}{2} V_n \quad (R_L = R) \]
\[ = \frac{1}{2} \sqrt{4kTR} \]

\[ P_n = \text{noise power density} (= N_0) \]
\[ = \frac{V_n^2}{R} = \frac{1}{2} \frac{kTR}{R} \]
\[ = kT = N_0 \]
The noise spectral density is,

\[ N_0 = kT \]  \hspace{1cm} (1.1.5)

where \( k \) is Boltzmann's constant = \( 1.38 \times 10^{-20} \) mW/K Hz, and \( T \) is the system equivalent noise temperature = 28.5 K. Thus,

\[ N_0 = 3.933 \times 10^{-22} \text{ W/Hz} \]  \hspace{1cm} (1.1.6)

There are also other losses in the entire link such as circuit losses and antenna pointing losses, etc., other than that due to distance. For the Voyager telemetry link under consideration, the total loss is \( L = 0.7 \) (unitless). Therefore, the received signal-power-to-noise-spectral-density ratio, when this loss \( L \) is taken into account, is

\[ \frac{S}{N_0} = \frac{P_R L}{N_0} = 5.428 \times 10^5 \text{ Hz for Voyager} \]  \hspace{1cm} (1.1.7)
Introduction to Signal to Noise Ratio
For Voyager imaging data, the acceptable telemetry data quality has a bit error probability of $5 \times 10^{-3}$ [1, 2]. Voyager uses PCM/PSK/PM modulation and convolutional code with Viterbi decoding, which requires a received signal-power-to-noise-spectral-density ratio of $2.05 \times 10^5$ Hz for a data rate of 115.2 kilobits per second.

$$\frac{S/N_0}{R} = \frac{2.05 \times 10^5 \text{ Hz}}{115.2 \times 10^3 \text{ Hz}}$$

$$= 17.28$$

$$= \frac{E_b}{N_0}$$

$$10 \log_2(17.28) = 12.37 \text{ dB}$$