Goal of Short Course

Provide a common understanding of the current system, providing a baseline from which we can start

This is not meant to teach you how to design, build, and operate ground systems

We will describe the important (relevant to this study) aspects common to such systems today

After this, you can forget everything and tell me how these systems should be built in the future
The deep space communications system

This is a JPL-centric example – all JPL facilities
What are the Earth elements of the system?

A bunch of very large antennas
   Perhaps, some smaller ones that we can array
Geographic locations to “see” the user spacecraft as needed
High power transmitters to provide uplink
Sensitive receivers to detect downlink
Frequency assignments so we don’t interfere with others
“Extra” signal processing to allow detection of very weak signals
   Error-correcting codes
   Data compression
Data repositories that scientists can use to find the bits
A “scheduling system” that puts the various elements together into “links” as needed – and allows them to be reused
People: operators, maintenance, schedulers, managers …
The Deep Space Network
NASA’s Connection to the Moon, Planets, & Beyond

Large antennas at three global sites: California, Madrid, Canberra
Captures all information from our spacecraft
  Most sensitive receivers
Sends all instructions to them
  Most powerful transmitters
Provides most of the navigation
  Most stable clocks and best algorithms
Enabling more than 30 spacecraft in flight today
The DSN is not alone
Here is ESA’s ESTRACK network
There are others …
Constraints – it’s different in deep space

On Earth, communications is usually limited by

- Bandwidth – simply getting a big enough pipe, or
- Cost – competing with others to buy the pipe we want

The connection between Earth and deep space is limited by power – or something related to power

Since uplink is typically low-rate for deep space, I will concentrate on discussing downlink in this talk
All of these things determine the received power
Why is Deep Space Comm Difficult?

Communications performance decreases as the square of the distance. Jupiter is nearly 1 billion km away, while a GEO Earth communications satellite is only about 40 thousand km away.

- It’s about 87 dB (~1/2 billion times) harder from deep space!

<table>
<thead>
<tr>
<th>Place</th>
<th>Distance</th>
<th>Difficulty</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geo</td>
<td>$4 \times 10^4$ km</td>
<td>Baseline</td>
</tr>
<tr>
<td>Moon</td>
<td>$4 \times 10^5$ km</td>
<td>100</td>
</tr>
<tr>
<td>Mars</td>
<td>$3 \times 10^8$ km</td>
<td>$5.6 \times 10^7$</td>
</tr>
<tr>
<td>Jupiter</td>
<td>$8 \times 10^8$ km</td>
<td>$4.0 \times 10^8$</td>
</tr>
<tr>
<td>Pluto</td>
<td>$5 \times 10^9$ km</td>
<td>$1.6 \times 10^{10}$</td>
</tr>
</tbody>
</table>
Inverse Square Loss

Sphere area: $4\pi r^2$
source power: $P$

intensity at surface of sphere: $\frac{P}{4\pi r^2} = E$

The energy twice as far from the source is spread over four times the area, hence one-fourth the intensity

$E = \frac{P}{4\pi r^2} = \frac{E}{4}$
But other things count too:
Why Ka-Band is not an 11.6 dB improvement

We would expect an 11.6 dB advantage over X-band based on the square of the ratio of frequencies.

Various degradations result in less

This old “thermometer” was a guide to technology investment.

Example of an error budget

Final result turned out to be 5 to 7 dB advantage, depending on scenario.
DSN Scheduling

Every link using the DSN is scheduled in advance
This is a hard problem because

- There are only a ~dozen DSN antennas and ~35 operating spacecraft
- Spacecraft tend to clump in the sky – the DSN is driven by astrology
- Some links have special importance – e.g. launches, landing, and trajectory changes
- Also critical science encounters, including occultations (more astrology?)
- Deep space missions typically require things to stay unchanged for months at a time because of their own sequenced operations – hence schedules are set far in advance
- Changes in schedule (e.g. launch slips) play havoc with this
Service Scheduling Software (SSS)

SSS is a tool that helps the scheduling process.

It does not do this autonomously.
People work the schedules – representing each user mission.
In fact, every bit is scheduled
And its even worse than that …

Missions use the DSN schedule to assign data to each link to return from space

The more DSN time they can get, the more data they can return

Because the DSN time and data are both precious, missions will add “margin” to the power to ensure a high probability (say 98%) of getting all those bits back correctly

Note: This extra power is also precious and using more of it works exactly against maximizing data return
NASA’s Planetary Data System: The last mile to the scientists

The repository for data from planetary missions

Serves as a model for other mission types

Consists of “nodes” of like-data

- Atmospheres (ATM)
- Geosciences (GEO)
- Cartography and Imaging Sciences (IMG)
- Navigational & Ancillary Information (NAIF)
- Planetary Plasma Interactions (PPI)
- Ring-Moon Systems (RMS)
- Small Bodies (SBN)

• Data ontology is well-defined and tools exist to help missions enter their data
Flexibility and Scalability

• The DSN is inherently flexible
  – All sites use same architecture and processes
  – All antennas can provide all services – mostly
  – Using CCSDS standards for communications

• DSN is inherently scalable
  – Can easily add or subtract antennas
  – Array antennas for more downlink performance
    • Have demonstrated uplink too – but not yet operational

• We work with our customer community to determine the needed scale and flexibility
  – We perform market research for 25 years in the future
  – We have user groups and publish our plans
Challenge: Future Missions Generate More Data

We expect data rates from deep space missions to increase 10-fold each decade for 50 years.
Some things do not scale well

The scheduling process we use today is not inherently scalable

It can break down with large number of missions or large numbers of links

It has also been suggested (by Vint Cerf among others) that the idea of scheduling each downlinked spacecraft bit also will not scale

It can break down as above

And also as the data volume in each mission grows
Technology that can help

Disruption Tolerant Networking
  - Can automate scheduling of bits within links
  - Can reduce wasted “margin”

Automated link scheduling
  - Can help scale up to future mission set

Demand-Access protocols
  - Can bridge to onboard autonomy to reduce required communications links

Data science techniques
  - Can help scientists find the data they need in the system

Others you will hear about or maybe invent in this study
Conclusion

• Today’s deep space communications system works well getting data between space and scientists
• However, it may be using more power than needed
• And it may not scale as needed in the future