Bradley Davis

The communication to/from the satellite with the ground is organized into OSI layers. This document explains each layer in detail.

CougSatNet

CougSat and Ground Communication Protocol

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# Introduction

These are topics that should be fully comprehended to understand how CougSatNet works.

## Open Systems Interconnection (OSI) Model

The OSI model[[1]](#footnote-1) is a conceptual model that can be applied to any communication system. It has eight layers, see Table 1; each layer serves the layer above it and is served by the layer below it. This document will progress through each layer explaining its contents and how the layers interface with their neighbors.

Table : OSI Model Layers

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Layer | | | Protocol Data Unit | Function |
| Host layers | 7 | Application | Data | High-level APIs |
| 6 | Presentation | Translation of data between a networking service and an application |
| 5 | Session | Managing communication sessions |
| 4 | Transport | Segment | Reliable transmission of data segments between points on a network |
| Media layers | 3 | Network | Packet | Structuring and managing a multi-node network |
| 2 | Data link | Frame | Reliable transmission of data frames between two nodes connected by a physical layer |
| 1 | Physical | Symbol | Transmission and reception of raw bit streams over a physical medium |
| 0 | Medium | Electrons, Photons | The physical medium: copper, fiber, wireless |

## Radio Frequency Wireless Transmission

The modulation of electromagnetic waves is used to carry information. When the carrier frequency is between and , it is classified as radio frequency[[2]](#footnote-2).

### Antenna

An AC current applied to a length of conductors will radiate energy outwards as electromagnetic waves with the same frequency and phase as the current. The output pattern depends on the shape of the conductors. This pattern is described generally by three parameters: bandwidth, gain, and polarization. There are many more parameters to characterize an antenna[[3]](#footnote-3) but these are the important ones to understand a radio system.

The bandwidth specifies the range of frequencies that the antenna can effectively radiate. When a carrier signal is modulated to encode information, the frequency can spread out from the center and the antenna needs to be able to operate in this spectrum.

The gain specifies the directivity of the radiation pattern. Thanks to the conservation of energy, a passive antenna cannot amplify the signal so this parameter is better known as directivity. An antenna with an isotropic radiation pattern has a gain of . Any angle outward from an isotropic antenna will have the same output energy. A higher gain antenna will have a higher directivity, that is more of its radiated energy is emitted in the same direction. This does mean that other off angles to a high gain antenna will not transmit as much energy therefore it needs to be aimed at the target better. The same property works in the reverse direction: a low gain antenna does not need to aimed very well but is not sensitive, a high gain antenna is more sensitive but needs to be aimed well.

The polarization specifies the direction of the electromagnetic wave that is transmitted or received by the antenna. A linear polarization will radiate waves in a plane. This plane needs to be aligned between the transmitter and receiver to reduce the cross-polarization loss. A circular polarization, will radiate waves that spin around the velocity of propagation. The angle between the transmitter and receiver does not matter but ensuring that both antennae are polarized in the same direction, left or right-handed, to reduce cross-polarization loss. A linear and circular-polarization antenna can communicate to each other but will incur a fixed cross-polarization loss regardless of angle. Note that reflections, refractions, and other physics, will bend the polarization from these ideal shapes into a general elliptical polarization.

### Modulation and Demodulation

An electromagnetic wave can be described by its frequency, amplitude, and phase. Each of these parameters can be varied with time, or modified, to encode information which is called modulation[[4]](#footnote-5). The modulation schemes used in CougSatNet are described here. The process of reversing the modulation is called demodulation.

#### In-Phase and Quadrature (I/Q) Components

Through math, these three parameters can be converted into the amplitude of the wave’s in-phase and quadrature components. The math is based on the summing of trigonometric functions, see the equations and . These two amplitudes can be varied to achieve any modulation of frequency, amplitude, and/or phase. Most often the carrier frequency is too fast to sample or synthesize directly so a baseband signal is used at an intermediate frequency. This is captured by multiplying the I/Q components by the carrier frequency, see equation .

#### Quadrature Phase-Shift Keying (QPSK)

This modulation scheme shifts the phase of the wave to indicate one of four symbols. The shifts are apart and usually aligned to . The phase is a step function which is represented by stepping the baseband in-phase and quadrature phase components between . This is convenient as electronics are very good at generating square waves rather than synthesizing a sine wave with phase shifts.

A constellation diagram, a plot of versus taken at the sampling points, reveals four dots at each of the angles described above. These points are , see Figure 1. A window around these points is used to identify the symbols during demodulation.

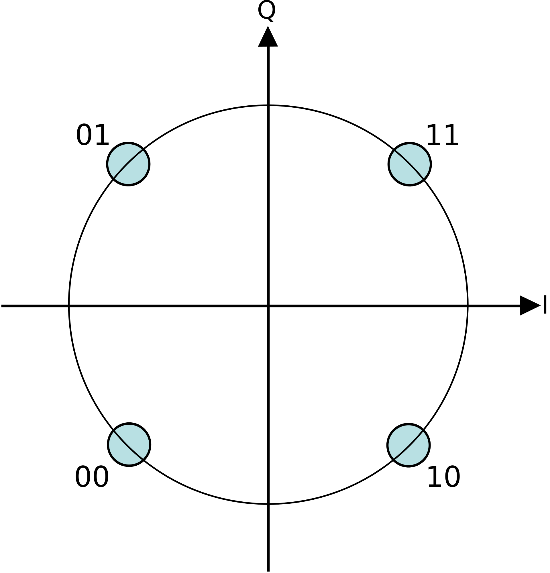


Figure : QPSK Modulation Constellation Diagram[[5]](#footnote-6)

#### Data Over Voice (DOV)

This modulation technique allows both voice (spoken words) and data to be simultaneously transmitted. The baseband signals are modulated with the sum of amplitude modulation for voice and frequency modulation for data.

Amplitude modulation takes both the in-phase and quadrature components and varies their amplitudes together. For voice, this is done according to the sound being encoded. On the constellation diagram, the dot moves along the diagonal, including negative amplitude.

Frequency modulation could be viewed as a continuous phase shift modulation. On the constellation diagram, the dot moves around in a circle with a fixed amplitude. The faster it moves around, the farther from the carrier frequency the result is. The baseband in-phase component gets a sine wave with a frequency of the modulation and the quadrature gets that wave shifted by . Most often the symbols are distinct tones.

Human speech operates in the range. For the data, the symbols should be outside of this range to not interfere. Furthermore, human hearing is which could result in an audible hum if the symbols are located within this range. Some radios will band-pass only the speech range to reduce noise from a tone for example.

Together data over voice will look on the constellation diagram as a weird mess. Think the voice is moving randomly along its line then the frequency modulation is a circle around that point. Luckily, a band-pass filter will separate these signals.

## Cyclic-Redundancy Check

### 16 bits

0xd175 -ham 4 up to 32kb

### 32 bits

0xc9d204f5 -ham 4 up to 2Gb

## Data Formatting

This document uses extensive use of byte and bit tables to present data. An example byte table can be found in Table 2. To read a byte table, the cell’s offset from the beginning of the data set is given by summing the byte offsets in its row and column. In the example, *A* is found at 0x0003, *B* is at 0x0009, *C* is at 0x000D, and *D* is at 0x0016. Note that some values may span more than one byte with which its cells will be merged together, see *D.* Note that when a bit table is presented, the first cell’s offset is zero and it is the most significant bit. This is reverse of the bit’s value (the most significant bit has the highest position and value).

Table : Byte Table Example

| Byte Offset | 0x00 | 0x01 | 0x02 | 0x03 | 0x04 | 0x05 | 0x06 | 0x07 |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 0x0000 |  |  |  | *A* |  |  |  |  |
| 0x0008 |  | *B* |  |  |  | *C* |  |  |
| 0x0010 |  |  |  |  |  |  | *D* | |

# Layer Description

This describes how the OSI model applies to CougSatNet. As a club we aim to develop more than CougSat-1 ergo this interface is designed for future expandability.

## Layer 7: Application

This layer is the closest to the user. It is the thing shown to the end user. The Ground’s end user is a ground station operator. The end user on the satellite side are the sensors and end effectors in the various subsystems.

### Ground Side

The Ground software shall present the information in a graphical user interface (GUI). With relative ease and speed, a ground station operator will understand the status of the satellite on the other end of the CougSatNet.

The real value numbers (degrees Celsius, amperes, etc.) will be visible as plain text. Graphical elements will enhance the experience with graphs, maps, etc. that include a color scale or acceptable ranges. These ranges are unique to each parameter being measured.

### Satellite Side

Each subsystem has a plethora of sensors and end effectors that either measure or control real life parameters of the satellite. This includes, but not limited to:

* Temperature sensors
* Gyroscopes
* Voltmeters
* Ammeters
* Magnetometer
* Illuminance sensors
* Radionavigation-satellite service receivers
* Cameras
* Gas sensors
* Thermal heaters and knifes
* LEDs
* Magnetorquers
* Radio transmitters and receivers

## Layer 6: Presentation

This layer is the data syntax layer. It transforms raw bits into presentable information. File types, such as PNG, are found on this layer. Files exchanged between the Ground and the satellite include, but not limited to:

* Telemetry containing files, see CougSatTelem (CST)
* Images, see CougSatGraphics (CSG)
* Binary images for processors, see CougSatBin (CSB)
* Command instructions, see CougSatCommand (CSC)
* Payload configuration files
* Log files

Both the Ground and Satellite, upon receiving one of these files, knows what GUI element or end effector to update. They are also knowledgeable on how to construct these files.

## Layer 5: Session

This layer handles organizing a communication link. This layer also includes methods for securing a communication link to prevent unauthorized access. On the satellite, the C&DH transfers session messages to and from the Comms.

### Session Message Format

Each session message begins with a header, then a file, and finished with a CRC, see Table 3.

Table : Session Message Format

| Byte Offset | 0x00 | 0x01 | 0x02 | 0x03 | 0x04 | 0x05 | 0x06 | 0x07 |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 0x0000 | Session Flags | | Password [63:16] | | | | | |
| 0x0008 | Password [15:0] | | File Length | | | File Name… | | |
| 0x0010 | File… | | | | | | | |
| … |
| End-4 | CRC | | | |  |  |  |  |

#### Session Flags

The most significant bit is the secure flag, a password is included when secure flag is set. When the secure flag is unset, the password is all zeros. The remaining is the session ID number that is incremented each time a new session is created.

#### Password

Note this is only included if the secure flag is set in the Session Flags. If the flag is unset, this field is all zeros. The password is a number that is generated using the SHA-256 algorithm[[6]](#footnote-7). A passphrase is hashed using SHA-256 then the lowest are used as the password to validate the session. If the received password does not match the stored password, the session is aborted. If there is no password when the attached file requires authentication to process, the session is aborted.

Only the first file transferred in a session may require a password. Once a session is authenticated, all messages belonging to that session are authenticated, this is to reduce the number of transmissions of the secret password. The authentication for that session ID is lost once the session ends.

#### File Length

A number represent the number of bytes the attached file contains. This leads to a maximum file size of . This is around the limit for a link window running at . If a larger file needs to transferred, then it should be broken into chunks.

#### File Name

The name of the attached file is a null-terminated string with UTF-8 encoding[[7]](#footnote-8). The file name is limited to ; if this limit is reached before a null character, the file name is invalid, and the session is aborted.

#### File

The attached file is appended to the session header without any modifications or transformations.

#### CRC

A Cyclic-Redundancy Check is performed on the session header and data. Its checksum is appended to the session data. If the given checksum does not match the computed checksum, the session is aborted.

### Control Files

There are certain file names that are used to control the session. The attached file has details on the control

#### REQUEST

This requests a file (or files) to be sent from the other end. The attached file contains a list of file paths, separated by newlines, to be sent if present. The example below requests for the newest payload file then the EPS’s status report.

payload/newest

eps/status

#### CLOSE

This closes a session by invalidating the session ID’s password, if provided, and incrementing the session ID counter. An explicit close should be given but the session will automatically close if a new one is started or after a reasonable timeout.

## Layer 4: Transport

This layer coordinates data transfer between the Ground and the satellite with quality of service functions.

### Segmentation

Large session messages need to be broken into smaller segments to reduce the segment error rate. A bit error rate of , the target rate of the hardware, results in out of chunks, will have zero errors. chucks, just 8 times longer, are error free. Smaller chucks reduce the number of chunks that need to be retransmitted. The drawbacks is more byte overhead from the more headers which also requires more time to process.

CougSatNet’s transport protocol segments session messages into chunks. Each segment is given an ID that is used to reassembly the segments in the correct order.

### Acknowledgement

When the sender wants to validate the receiver read a valid segment, it will send a segment with A set. The receiver then returns a list of segment IDs it successfully received as a Receipt Segment.

#### Acknowledge Timing

It is impractical to ask for acknowledgement on every segment as there is delay in switching from transmit to receive in the hardware. The throughput would be severely inhibited. Instead, CougSatNet utilizes selective acknowledgement on a block of segments.

The destination keeps a list of IDs of the most recent segments successfully received. Every so often, up to segments, the source will set the ACK flag in the next segment being transmitted. The destination, upon reading this flag, replies with a Receipt Segment containing that list of IDs. The source receives that receipt and figures which segments it needs to resend during Retransmission.

If the source does not receive a receipt within , it transmits the same segment with acknowledge flag set again. After ten failed attempts at receiving a receipt, the source indicates the link has been lost.

Note that the source may decide to change its chunk length during transmission up to the limit of segments to test the link quality before operating at full-length. A session message may also only be a single or couple segments long and not require a full-length chuck at all.

#### Receipt Segment

A Receipt is a segment with the Receipt flag set whose Session Data Payload contains a list of segment IDs that have been successfully received. The list is a concatenation of the most recent Segment IDs. Since the IDs are , they have of padding prepended such that each is a new ID.

### Retransmission

When retransmitting the lost segments, the source will set the acknowledge flag in the last one and repeat the Acknowledgement process until all segments in the block have successfully been received. It then begins sending the next block.

### Segment Data Format

Table : Transport Data Format

| Bit Offset | 0x00 | 0x01 | 0x02 | 0x03 | 0x04 | 0x05 | 0x06 | 0x07 |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 0x0000 | Segment ID [13:6] | | | | | | | |
| 0x0008 | Segment ID [5:0] | | | | | | Segment Length [9:8] | |
| 0x0010 | Segment Length [7:0] | | | | | | | |
| 0x0018 | Session Message ID | | | | Keep Alive | Last | ACK | Receipt |
| 0x0020 | Session Data Payload… | | | | | | | |

#### Segment ID

This is a number indicating which segment it is in the segmented session message. The first segment has an ID of . Each following segment increments this number for a total of segments per session message.

#### Segment Length

This is a number of how long the payload is in bytes. Which means a maximum length of . Combined with the segment ID allows a session message to be

#### Session Message ID

This is a indicating which session message it belongs to. It begins at zero and increments each session message. If a session message is not fully transferred before the link is lost and Keep Alive is set, both sides will reserve the current session message ID to resume later and skip over it when incrementing for session messages transferred in between.

#### Keep Alive

This flag indicates, when set, that both sides should reserve the session message ID in case the link terminates before the session message is fully transferred. When link is re-established, the sender can resume sending with the same reserved session message ID to resume transfer. The session message ID can be reserved, and thus resumed, for up to or until the satellite reboots for some reason.

#### Last

This flag indicates, when set, that the segment is the last segment for the session message ID being assembled. Upon processing this segment, the session message is completely transferred and assembled.

#### ACK

This flag indicates, when set, that the destination needs to acknowledge its received segments as described in Acknowledgement.

#### Receipt

This flag indicates, when set, that the segment data payload contains a receipt as described in Receipt Segment.

#### Session Data Payload

This is the data of the segment, appended to the header, without any modifications or transformations.

## Layer 3: Network

Packet addressing- ground, cougsat 1-7 sender recipient, transport type, finally payload

## Layer 2: Data Link

Frame

Preamble, 8/10b encoding and EOF with crc16

## Layer 1: Physical

The symbols differ depending on the mode of transmission. The high gain antenna will always use QPSK modulation. The low gain antenna will use DOV for beacon transmission, with integrated telemetry, and QPSK for command and control messages.

## Layer 0: Medium

Since the satellite is into space and moving very fast, copper wires don’t work well. The information is a radio frequency electromagnetic wave. The carrier frequency is for the low gain antenna and for the high gain antenna. The low gain antenna is linearly polarized for simplicity. The high gain antenna is circularly polarized for low cross-polarization loss.

# Example Broadcast Communication

# Example Reliable Communication

1. For more information, read [Wikipedia’s article](https://en.wikipedia.org/wiki/OSI_model) on the OSI model [↑](#footnote-ref-1)
2. For more information, read [Wikipedia’s article](https://en.wikipedia.org/wiki/Radio) on radio [↑](#footnote-ref-2)
3. For more information, see [Wikipedia’s article](https://en.wikipedia.org/wiki/Antenna_(radio)) on radio antennae [↑](#footnote-ref-3)
4. For more information, see [Wikipedia’s article](https://en.wikipedia.org/wiki/Modulation) on modulation [↑](#footnote-ref-5)
5. Source: <https://commons.wikimedia.org/wiki/File:QPSK_Gray_Coded.svg> [↑](#footnote-ref-6)
6. For more information, see [Wikipedia’s article](https://en.wikipedia.org/wiki/SHA-2) on SHA-2 [↑](#footnote-ref-7)
7. For more information, see [Wikipedia’s article](https://en.wikipedia.org/wiki/UTF-8) on UTF-8 [↑](#footnote-ref-8)