# Replacing the CCSDS Telecommand Protocol with Next Generation Uplink

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# Overview

- The Problem – the aging CCSDS Telecommand Standard is technologically outdated and today's technology would provide superior forward link performance

- The Consultative Committee for Space Data Standards (CCSDS) is considering replacing Telecommand (TC) with the Next Generation Uplink Protocol

- Next Generation Uplink Trade-offs
  - Selection of the Data Link layer protocol
  - Forward Error Correction Coding
  - Synchronization and Termination Method
  - Retransmission Technique

- Results & Conclusions

# The Changing Command Environment

- In the 1980s when the TC protocol was standardized:
  - Digital technology was first emerging and digital flight hardware was heavy and required lots of power thus limiting the complexity of the transceiver and command decoders
    - Simple uplink coding was employed primarily to detect transmission errors
      - Flight receivers only output hard symbols and simple error checking code decoder was provided
    - Short commands for emergencies situations with a minimum access window
      - For communications short fall events (RF or pointing anomalies), short commands provided access
    - Flight Controllers were simple with little or no memory thus few commands were required
- Today:
  - Digital technology has matured and some flight equipment can be even be formulated in Flight Programmable Gate Arrays (FPGAs).
    - Next generation S/C will require extensive commanding including large files uploads
    - Emerging communications protocols (e.g. DTN) require substantial handshaking
    - New software transponders can operate at much lower SNRs and output quantized bits
    - Newer codes have emerged that provide significant performance gain and can now be easily implementable with current technology
  - S/C have greater autonomy and provide a better communications environment so that short commands may no longer be necessary for most deep space missions.
  - Need for added uplink security adds considerable bits to minimum command size

# What are your basic requirements for commanding?

1. What is the anticipated emergency commanding environment?

2. Are there latency requirements for your mission? Are they different during normal operations from off normal operations?

3. Are there specific limitations that need to be considered?
   - Can the same protocol and forward error correcting coding be used for emergency and nominal commanding circumstances?
     - Can a single forward error correction (FEC) command code satisfy the totality of a mission's needs (latency, EIRP) ?
     - Can a single mission utilize two FEC codes without adding excessive implementation complexity ?

4. Is Security required to protect your missions thus adding substantial uplink bandwidth ?

# Next Generation Uplink Trades

1. Should the next generation uplink protocol follow the TC protocol or the AOS protocol ?
   - The requirement for short emergency commands when data rates are limited favors the TC protocol
2. Selection of Low Density Parity Check (LDPC) code
   - Rate ½ or other
   - Code word sizes for TC 64,128,256 or greater
     - A set of sizes that are tied to different operational modes could be implemented with added complexity over just one code word size.
   - Code word size for AOS 1k, 4k, or 16k
3. Selection of Synchronization Word size
   - Depends on selected code and symbol SNR and if idle allowed between frames
   - Need very high probability of discovery in 1 "word" especially for TC protocol
4. Code block termination method for TC protocol
   - Use an erred code word as the code block terminator (current approach)
   - Use a byte in each code word that identifies the last code word in the code block
   - Limit content of code block to 1 frame, allows use of frame length

*Note: The LDPC upgrade is required primarily for deep space missions but the proposed approach can benefit near earth and manned missions as well.*

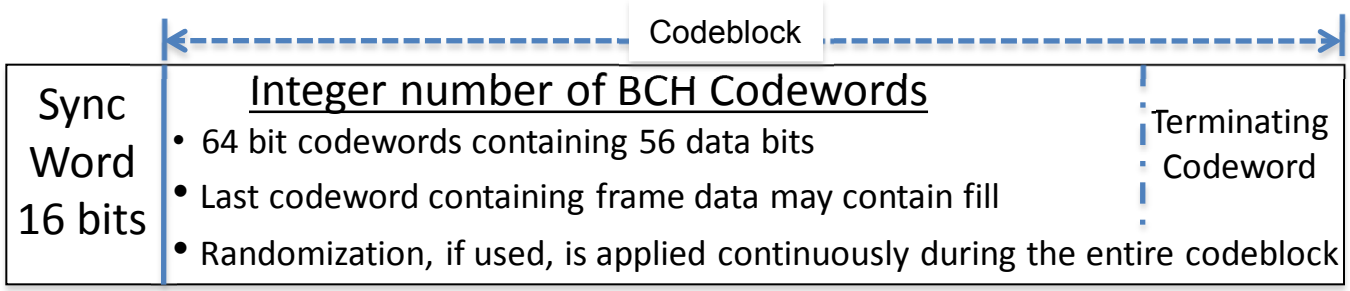
# Current Direct from Earth Uplink Protocols

- Unmanned missions use the CCSDS TC protocol that uses variable length data frames and relies on a (64,56) BCH code.
  - Minimum size command is a 56 bit data frame requiring at least 134 bits plus the bits required for symbol acquisition
    - 16 bits for a frame sync
    - 64 bits for code word carrying 56 data bits
    - 64 bits for code word used to terminate code block
  - The BCH Code FEC requires about 9 dB bit SNR

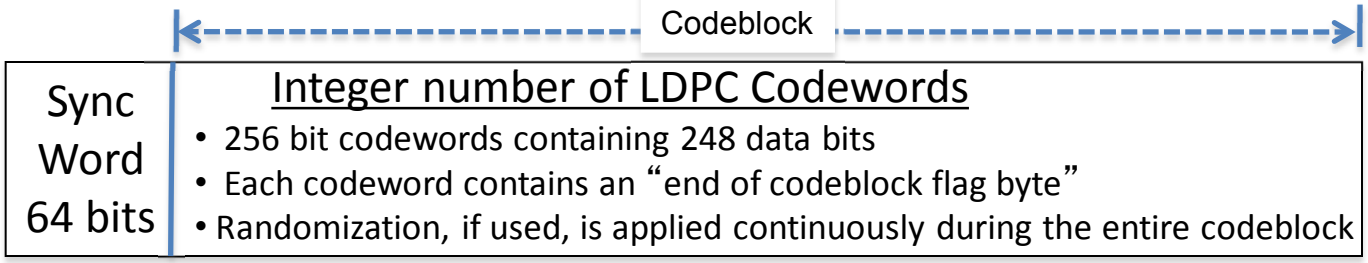
- The manned missions use the AOS protocol and the Reed-Solomon Code
  - Assuming the interleave 5 Reed-Solomon (R-S) command the minimum command requires an error free frame that is about 10,000 bits
  - The R-S Code FEC requires about 6 dB bit SNR

# Telecommand Protocol

- The Basic Protocol
  - Sync word (ASM) search (optional idle followed by sync word)
  - Series of codewords (herein called a Codeblock) containing 1 or more frames
  - A codeblock terminator
- Using BCH




- Using LDPC (This example uses a rate ½, 256 bit LDPC code)



# AOS Uplink using LDPC

- The Basic Protocol
  - Sync word (ASM) search is used to determine the location of the start of a frame and coincident codeblock. Once the ASM is detected the search is halted until the codeblock is received. The next ASM is required to start on the first bit following the codeblock.
  - The fixed length codeblock containing a single fixed length command frame is processed and the contained data are extracted and delivered.

*Note: No idle bits are allowed within the repeating series of codeblocks and ASMs*

| Sync Word 64 bits | An LDPC Codeword containing 1 command frame<br>• Most probably a codeword of 1k to 16 k bits |
|---|---|

# Link Layer Protocol Trade

| | Telecommand (TC) | AOS |
|---|---|---|
| Mission Usage | Unmanned Missions | Manned Missions |
| Synchronous/Asynchronous | Asynchronous – Idle allowed | Synchronous – No Idle uses Fill Frames when no data |
| Payload | One message per frame | Packet based data transfer |
| Short Commands | Advantage – latency & small code word size | |
| Long Commands | | Advantage – use larger size code word |
| DSN CLTU Service | No changes required to add LDPC capability | Change to synchronous uplink (fill frames) required |

# Forward Error Correction
# Better Performance at a Price

- For future missions the CCSDS is currently defining a next generation uplink protocol that uses high performance forward error correction codes to provide a coding gain between 3 to 9 dB.
- **Performance:** This is a factor of 2 to 8 times better performance than the current BCH code in the CCSDS Telecommand Standard.
- **Price:** This requires a new radio that is able to output soft symbols to the LDPC decoder and operate at Eb/No = 2.7 dB or Es/No = -0.3 dB for LDPC (256,128).
  - NASA/JPL Universal Space Transponder (UST) currently under development

# Coding Trade

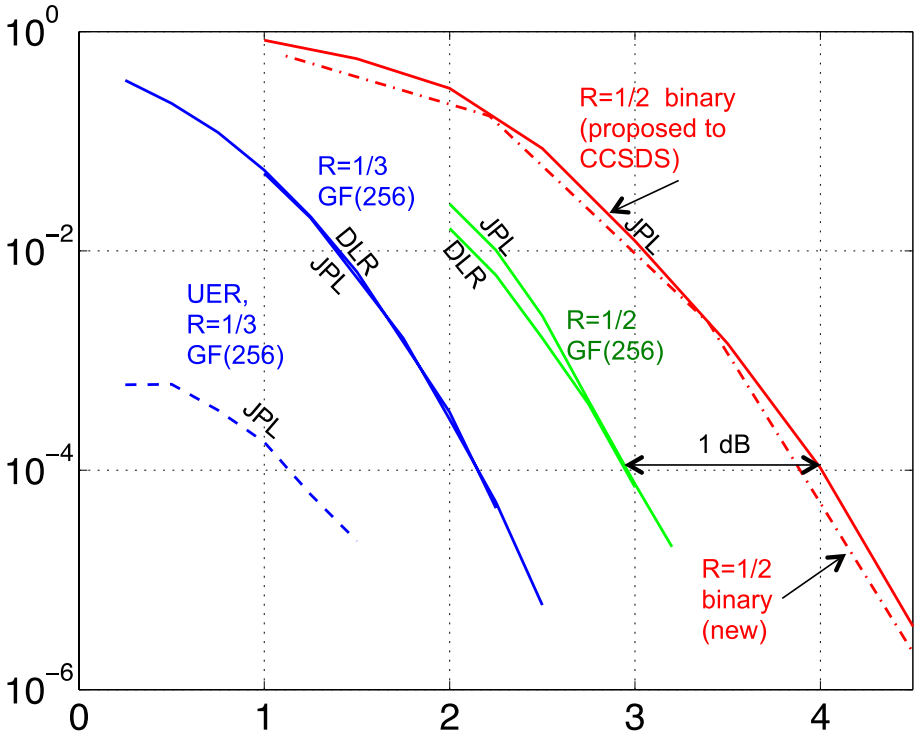
(binary LDPC codes unless otherwise stated)

| | Code SNR operating point | Performance Impact |
|---|---|---|
| BCH (56,64) | ~9 dB (TC) | Current Baseline |
| LDPC ½, (128,64) | ~5 dB (TC) | ~4 dB better than BCH |
| LDPC ½, (256,128) | ~4 dB (TC) | ~5 dB better than BCH |
| LDPC ½, (512,256) | ~3 dB (TC) | ~6 dB better than BCH<br>Send (64,56) code 4x faster<br>But same latency as current TC |
| Non-binary LDPC ½, (512,256) | ~2 dB | ~7 dB improvement<br>~60x complex implementation |
| LDPC ½, (2048,1024) | ~1.5 dB (AOS) | ~7.5 dB better than BCH<br>data rate 5x faster but larger code word needs 3x latency |
| LDPC ½, (8192,4096) | ~1.2 dB (AOS) | ~7.8 dB better than BCH |
| LDPC ½, (16384,8192) | ~1.0 dB (AOS) | ~8 dB better than BCH |

Notes:

MINIMUM BIT ERROR RATE = $1 * 10^{-5}$
MINIMUM UNDETECTED BIT ERROR RATE = $1 * 10^{-9}$

# What are the candidate non-binary Forward Error Correction Codes (FEC)




Work done by Ken Andrews and Bruce Moision – NASA/JPL

# Codeblock termination method for TC

- Current BCH approach
  - Uses uncorrectable codeword to terminate the codeblock.

- Optional LDPC approaches
  1. Use a byte in a fixed position within each codeword as a flag to signal the last codeword in the codeblock.
     - Example using 256 bit code (fixed 3.2% overhead for codeblock termination)
       - » A 248 bit command only requires a single codeword (8 bits)
       - » A 992 bit command will require 4 codewords thus contains 32 bits for flags
       - » A 7,940 bit command will require 256 bits for flags
  2. Uses uncorrectable codeword to terminate the codeblock.
     - Requires a 256 bit codeword to signal the end of the codeblock independent of the size of the data frame.
       - » A 256 bit command require 100% overhead
       - » A 8196 bit command required 3.02% overhead

# Code block Termination Trade

| Command Size | Signaling Byte per Code word Overhead | Erred Code word Overhead |
|---|---|---|
| 256 bits | 8/248 ~ 3.2% | 256/256 = 100% |
| 1024 bits | 32/994 ~ 3.2% | 256/1024 = 25% |
| 8192 bits | 256/7940 ~ 3.2% | 256/8192 ~ 3% |

# Licklider Transmission Protocol (LTP)

- COP-1 in TC limits the effective data rate, because any data loss will suspend data delivery for at least one round trip while go-back-N procedure is executed.
- LTP selective NAK provides the same reliability but more efficiently: only the data that are known to have been lost are retransmitted.
- LTP concurrent transmission enables delivery of received data to continue during retransmission of lost data, so effective data rate is higher.
- LTP is more efficient for high-rate uplink than COP-1.

# Conclusions/Results

- Better performing Forward Error Correction on the forward link along with adequate power in the data open an uplink operations trade space that enable missions to:
  - Command to greater distances in deep space (increased uplink margin)
  - Increase the size of the payload data (latency may be a factor)
  - Provides space for the security header/trailer of the CCSDS Space Data Link Security Protocol
  - Note: These higher rates could be used for relief of emergency communication margins/rates and not limited to improving top-end rate performance.
- A higher performance uplink could also reduce the requirements on flight emergency antenna size and/or the performance required from ground stations.
- Use of a selective repeat ARQ protocol may increase the uplink design requirements but the resultant development is deemed acceptable, due the factor of 4 to 8 potential increase in uplink data rate.

# Acknowledgements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