The Consultative Committee for Space Data Systems

Concept Paper Concerning Lunar S-Band Proximity Links

SPECTRALLY EFFICIENT WAVEFORMS, CODING AND THE TRANSFER FRAME

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1 INTRODUCTION

1.1 Purpose

The purpose of this document is to provide information and justification to the Consultative Committee for Space Data Systems (CCSDS) for evaluation and development activities resulting in a Revised Proximity-1 Protocol (RPP).

1.2 Scope

- Purpose of RPP
- Background
- What is being proposed and why
- Benefits of RPP
- Low data rate systems
- Slicing
- Data Scrambling
- Frequency Assignment and Channelization
- Relationship to existing standards
- Interoperability
- Applicability to other frequency bands
- Summary and Conclusion
- Acronym List

1.3 References

[1] CCSDS 211.1-B-4, PROXIMITY-1 SPACE LINK PROTOCOL— PHYSICAL LAYER, December 2013

[2] CCSDS 211.0-B-6, PROXIMITY-1 SPACE LINK PROTOCOL— DATA LINK LAYER, July 2020.

[3] CCSDS 211.2-B-3, PROXIMITY-1 SPACE LINK PROTOCOL—CODING AND SYNCHRONIZATION SUBLAYER, Blue Book, October 2019.

[4] CCSDS 401.0-B-32, RADIO FREQUENCY AND MODULATION SYSTEMS— PART 1, EARTH STATIONS AND SPACECRAFT, October 2021

[5] CCSDS 413.0-G-3, BANDWIDTH-EFFICIENT MODULATIONS— SUMMARY OF DEFINITION, IMPLEMENTATION, AND PERFORMANCE, Green Book, February 2018.

[6] CCSDS 130.1-G-3, TM SYNCHRONIZATION AND CHANNEL CODING— SUMMARY OF CONCEPT AND RATIONALE, Green Book, June 2020

[7] S. Dolinar1 and K. Andrews, "Performance and Decoder Complexity Estimates for Families of Low-Density Parity-Check Codes," available at https://ipnpr.jpl.nasa.gov/progress_report/42-168/168C.pdf.

[8] CCSDS 732.1-B-2, UNIFIED SPACE DATA LINK PROTOCOL, Blue Book, October 2018.

2 DETAILED DESCRIPTIONS

2.1 Purpose of the RPP concept paper

The purpose of the RPP concept paper is to request an extension to the existing Proximity-1 protocol by summarizing for CCSDS management the needs and benefits for bandwidth efficient modulation and coding and the use of the V4 frame format (also known as USLP) to provide a suitable protocol for lunar S-band proximity links.

2.2 Background

CCSDS already provides the Proximity-1 Space Link Protocol consisting of a set of recommendations for proximity links at UHF [1-3]. This recommended set of protocols has been used by Mars missions to communicate to Earth via a Mars orbiting relay satellite. With the recent surge of interest in going back to the Moon, which will include extensive human and robotic presence on the surface of the Moon, the need for a communication infrastructure on and near the Moon is pressing. The current users of UHF Proximity-1 employ a bandwidth-inefficient waveform format (PCM/PM/bi-phase-L) and a low code rate of 0.5 (LDPC or convolutional). Moreover, they use transfer frame Version 3 format which is less flexible and less amenable to high-rate communications than the newer Version 4 transfer frame format.

2.3 What is being proposed and why

To protect radio astronomy sites from radio interference, limitations are imposed on UHF transmissions at the far side of the Moon. However, missions are allowed to use S-band frequencies, which provide more bandwidth than UHF, everywhere on the Moon. Therefore, it is foreseen that many missions will use the S-band [2025-2110 MHz forward, 2200-2290 MHz return] at the Moon instead of UHF for their proximity communications. Because activities at the Moon are deemed to be much more intense than Mars and also because the same spectrum has to be shared among surface-to-relay, surface-to-Earth and orbit-to-Earth users, the 90-MHz S-band allocated bandwidth is anticipated to become oversubscribed quickly, making it difficult for missions to use the spectrum without frequent coordination with each other. Hence, there is a need for providing a proximity Space Link Protocol recommendation at S-band with the following attributes:

1. Use S-Band frequencies of 2025-2110 MHz, forward communications, and 2200-2290 MHz, return communications

2. Use spectrally efficient waveforms to conserve bandwidth

3. Consider higher coding rates than 0.5 to further conserve bandwidth

4. Use Version 4 transfer frame format for added flexibility

2.4 Statement of expected benefits from what is being proposed

CCSDS recommends two constant-envelope waveforms that are spectrally efficient. These waveforms are GMSK and filtered OQPSK using a linear phase modulator [4]. Both these techniques offer great spectral efficiencies, are reasonably simple to implement and are resilient to amplifier nonlinearities because of their constant envelope nature. Therefore, either of these two schemes would provide for adequate spectral efficiency. As a side note, GMSK has an added advantage that a method for simultaneously performing ranging and telemetry is already provided by CCSDS. This feature of the GMSK potentially can be employed by some users to conduct range measurements while performing telemetry.

Table 1 compares power and bandwidth requirements of three modulation types, unfiltered BPSK, OQPSK/PM and GMSK. The data in the table have been obtained from Reference 5. GMSK and OQPSK have similar performances with a much better spectral efficiency than unfiltered BPSK. For example, whereas GMSK is 24 times more bandwidth efficient than unfiltered BPSK, its power performance is only 0.2 dB worse than unfiltered BPSK.

Table 1. Simulated Uncoded BER Performance of Three Types of Modulation Waveforms after Spectral Regrowth due to Saturated SSPA
&
Occupied Bandwidth of the Waveforms normalized to the Symbol Rate

Credit: CCSDS 413.0-G-3

Modulation Type	**Receiver Type**	**Eb/No for 10^{-3} BER**	**Occupied Bandwidth**
Unfiltered BPSK (for reference only)	Integrate and Dump	6.8 dB	20.56 R_s
Baseband Filtered OQPSK/PM Butterworth 6th order BTs=0.5	Integrate and Dump	7.6 dB	0.88 R_s
Precoded GMSK BTs=0.25	Viterbi Receiver	7.0 dB	0.86 Rs

Similarly, CCSDS provides recommendations for the Coding and Synchronization Sublayer of the existing Proximity-1 protocol. These codes are the rate 1/2 convolutional code (constraint length 7) and rate 1/2 LDPC (k=1024) [6]. The recommended LDPC code outperforms the recommended convolutional code by about 4 dB at a bit error rate of 10^{-6}. Therefore, the LDPC code is clearly a better choice. Furthermore, the rate 2/3 LDPC code can provide about the same performance as rate 1/2 if the code information block length is increased from 1024 to 4096 bits [6]. Hence the rate 2/3 LDPC code with k=4096 improves bandwidth efficiency by 25% with negligible performance loss with respect to the rate 1/2, k=1024. It is also noted that the decoding complexity of LDPC (r=2/3, k=4096) is similar to (r=1/2, k=1024) code [7].

2.5 Low Data Rate systems

Because low-data-rate systems may require a residual carrier to aid with receiver carrier tracking, the legacy modulation waveform used at UHF (PCM/PM/bi-phase-L) can optionally be available for data rates below 64 kbps (or another suitable rate). Therefore, GMSK and OQPSK could be recommended for all rates, but rates below 64 kbps would have the option of using GMSK or OQPSK or PCM/PM/bi-phase-L modulation. It is also noted that low-data-rate links may want to begin the communication session with a short period of pure carrier tone transmission, immediately followed by modulated

PCM/PM/bi-phase-L signal to further assist receiver initial synchronization. This feature can particularly be helpful in high Doppler channels. Furthermore, it could be useful for the hailing channel because usually low data rates are used while hailing.

2.6 Slicing

As the Proximity-1 protocol already includes it, Slicing should be implemented whenever the transfer frame length is not the same as the message size of the codeword, k. A stream of transfer frames with attached synch markers (ASMs) is generated and presented to the slicer. The slicer cuts the stream into pieces of length k and sends them to the encoder. The receiver reassembles the original stream and presents it to the high data layer.

2.7 Data Scrambling

In order for the receiver system to work properly, every data capture system at the receiving end requires that the incoming signal have sufficient bit transition density. The current version of Proximity-1 protocol does not require data scrambling (or randomizing) because the PCM/PM/bi-phase-L modulation guarantees transitions at every bit. However, GMSK and OQPK modulations do not make such guarantees, hence, data should be scrambled before being encoded. Therefore, a standard bit randomizer needs to be specified in the revised Proximity-1 protocol.

2.8 Frequency Assignment and Channelization

Currently, Proximity-1 protocol divides the UHF band into 16 channels. If deemed necessary, a new channeling system needs to be defined for the S-band.

2.9 Relationship to existing standards

The proposed modulation and coding options are among the recommended CCSDS modulation and coding techniques [5, 6]. The proposed transfer frame format is also a CCSDS recommendation [8].

3 INTEROPERABILITY

Because there is no substantial lunar relay communication activity yet, interoperability is not foreseen to be a concern. However, by implementing recommendations provided in this concept paper, future missions will be able to be interoperable.

4 APPLICABILITY TO OTHER FREQUENCY BANDS

The discussion in this concept paper can also apply to K-band frequencies. Proximity links at K-band can benefit from spectral efficiency gained by the use of efficient modulation and coding. Furthermore, they will also benefit by the use of CCSDS Version 4 transfer frame (USLP) rather than Version 3 for added flexibility. Likewise, the existing UHF Proximity-1 standard can be modified, per the discussions in this paper, to improve spectral efficiency and performance.

Moreover, since there is no standard defined for K-band proximity (forward: 23.15-23.55, return: 27.0-27.5 GHz) yet, this is an opportune moment to further extend Proximity-1 to include K-band frequencies by taking advantage of the recommendations made in this concept paper. We note that the need for a K-band proximity standard, in general, and for the Moon, in particular, is pressing because many of the future missions to the Moon are expected to require wideband communications. Wideband proximity communication is not practical at UHF or S-band frequencies because of their limited bandwidth. However, because of K-band's generous bandwidth allocation, it is ideally suitable for high data rate communications.

It is also noted that the recommendations in this concept paper do not have to be limited to the Moon. They can also be adopted at other regions, such as Mars.

5 SUMMARY AND CONCLUSION

The following table summarizes the recommendations proposed in this concept paper to extend the existing Proximity-1 protocol to S-band communications:

#	Protocol	Recommendation	Comment
1	Modulation	GMSK or Filtered OQPSK/PM	All data rates
		PCM/Bi-Phase-L	Optional for low data rates (≤64 kbps)
2	Coding*	LDPC, r=2/3, k=4096	All data rates
		LDPC, r=1/2, k=1024	Optional for low data rates (≤64 kbps)
3	Transfer Frame	USLP	

*Note: In addition to the proposed coding options in the above table, other LDPC code rates and block lengths may be considered, if deemed appropriate by CCSDS.

6 ACRONYM LIST

ASM	Attached Synch Marker
CCSDS	Consultative Committee for Space Data Systems
GMSK	Gaussian minimum shift keying
ICSIS	International Communication System Interoperability Standards
LDPC	Low-Density Parity-Check
OQPSK	Offset quadrature phase shift keying
RPP	Revised Proximity Recommendation
SCaN	Space Communications and Navigation
USLP	Unified Space Data Link Protocol