SCaN Network Ground Station Receiver Performance for Future Service Support

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Overview

- Background
- Objectives
- Future NASA Ground Station Support for Low Density Parity Check (LDPC) Coding Scheme
- Current DSN and SN Ground Station Receiver Parameters
- Prototype New SN Ground Receiver
- Receiver Performance Comparison

Background

- **In 2008, NASA's three Communication and Navigation networks – the Space Network (SN), the Near Earth Network (NEN) and the Deep Space Network (DSN) - were gathered under one NASA Program Office, Space Communication and Navigation (SCaN), with the goal of:**
  - providing integrated services to NASA and external organization missons, and
  - ensuring that the networks could meet the evolving and diverse needs of future flight missions with as low an infrastructure cost as possible
- **Over the past few years, the SCaN Program has defined new data, navigation and science services to be offered by the integrated network and sought to understand how the current ground station hardware can be modified to support these new services or if new ground station equipment will be needed**
- **The ground stations for each of the three networks were designed and developed to support the needs and meet the constraints of different mission types**
  - different signal formats for telemetry and navigation are supported
  - distinct requirements are supported by each network's ground station receivers

Objectives

- **Examine the impact of providing the newly standardized CCSDS Low Density Parity Check (LDPC) codes[1] to the SCaN return data service on the SCaN SN and DSN ground stations receivers:**
  - SN Current Receiver: Integrated Receiver (IR)
  - DSN Current Receiver: Downlink Telemetry and Tracking (DTT) Receiver
  - Early Commercial-Off-The-Shelf (COTS) prototype of the SN User Service Subsystem Component Replacement (USS CR) Narrow Band Receiver
- **Motivate discussion of general issues of ground station hardware design to enable simple and cheap modifications for support of future services**

Note 1: Consultative Committee for Space Data Systems, "TM Synchronization and Channel Coding," Blue Book: Recommended Standards, Issue 2, CCSDS 131.0-B-2, August, 2011.

Benefit of LDPC Codes

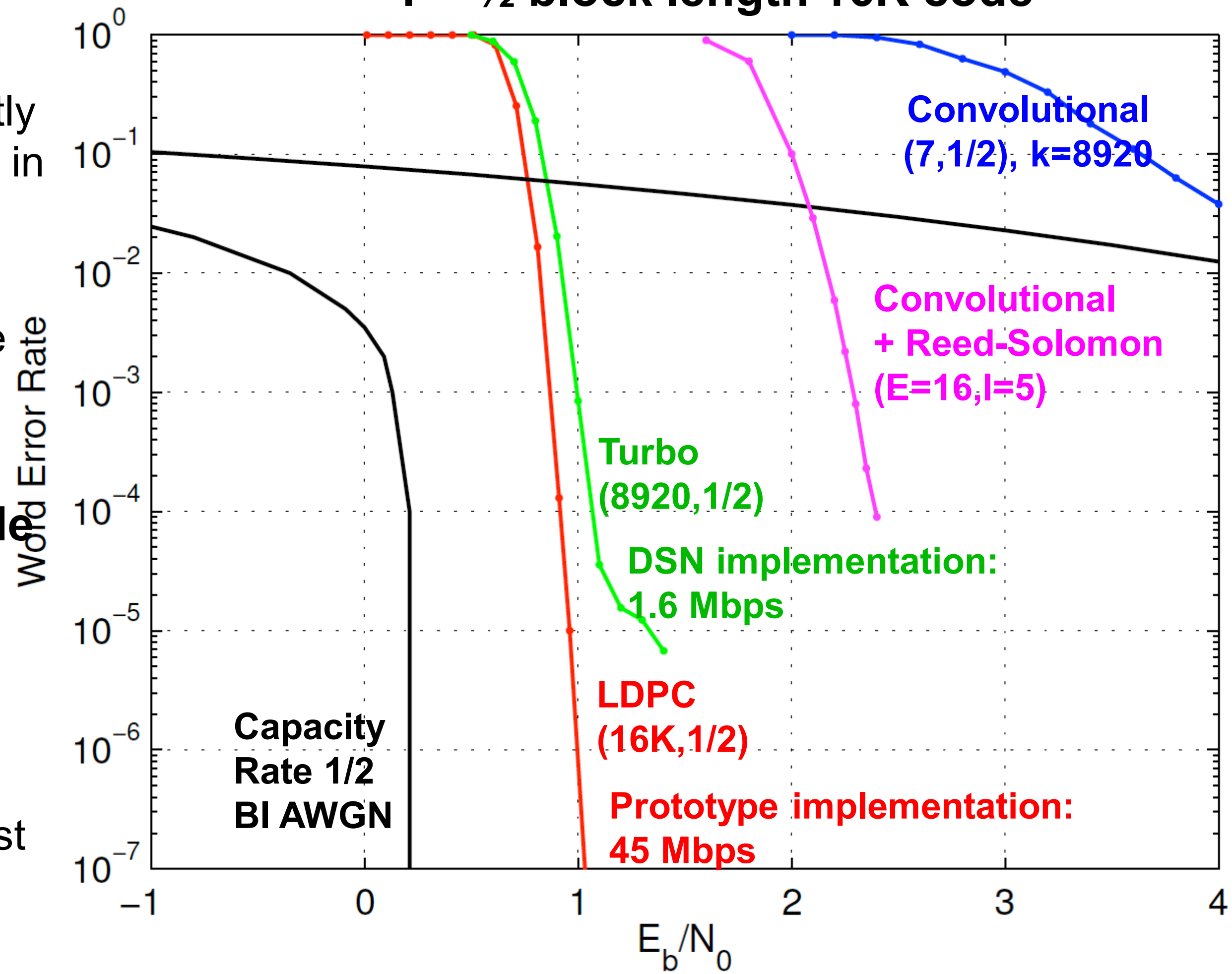
LDPC codes have:

- Near-capacity performance
- Are less prone to error floors than turbo codes, the currently used high performance code in DSN
- Have fast hardware implementations (and can be used onboard spacecraft)

CCSDS LDPC codes vary from rate ½ to 7/8 with code lengths from 1K to 16K

- Low rate, high block length codes have the best power performance
- High rate codes have the best spectral efficiency

Performance of some rate ½ codes currently in use in the DSN and the new CCSDS r = ½ block length 16K code



LDPC Codes Planned for SN Support

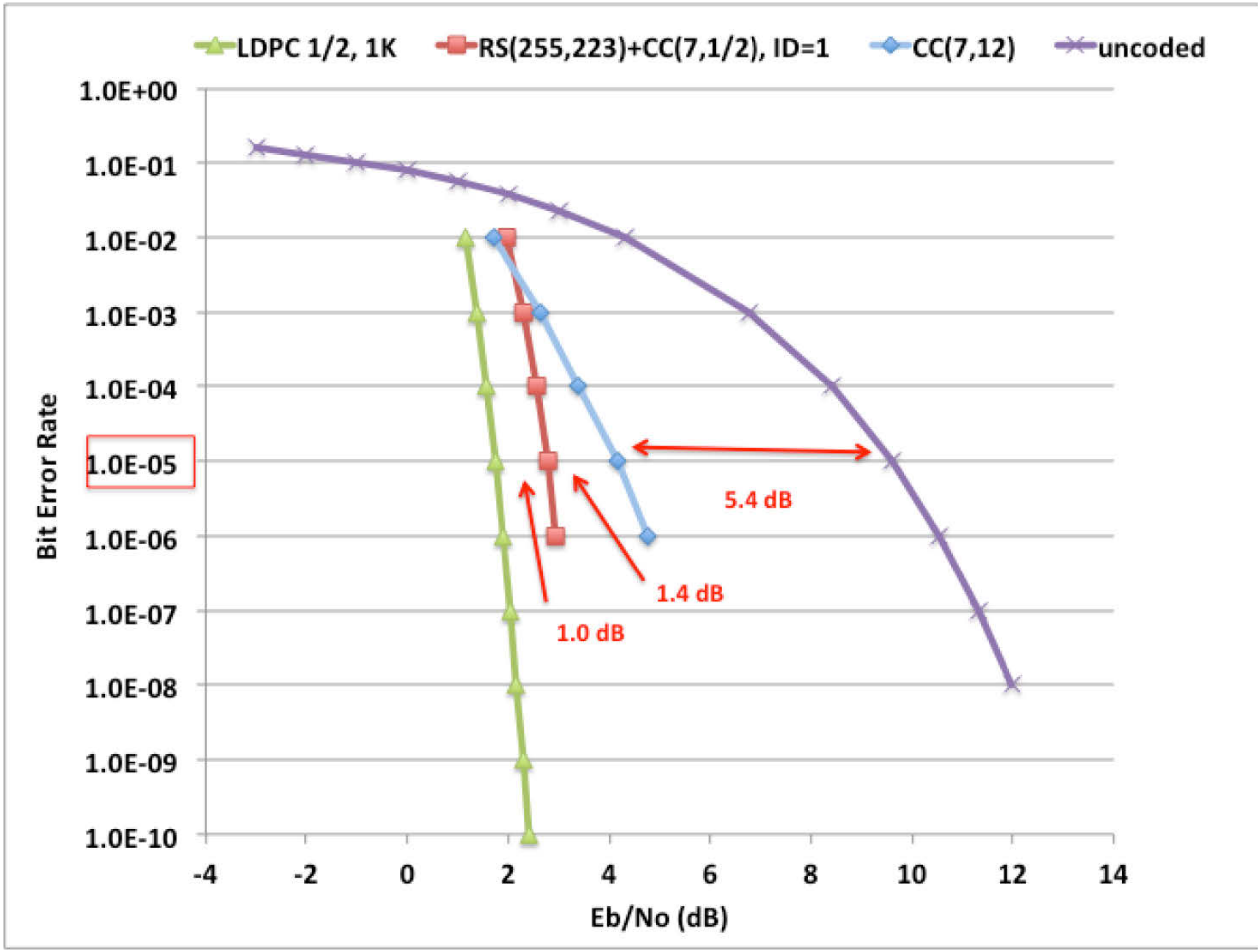
SN is planning support for LDPC r = ½, 1K code for power constrained applications and r = 7/8 for bandwidth constrained applications

LDPC r = ½, 1K code will reduce required signal power at BER 10^{-5} by:

- 7.8 dB over uncoded links
- 2.4 dB over conv code (7, ½) links
- 1.0 dB over concatenated RS and CC codes

Use of LDPC rate ½ codes require SN ground receivers to operate at Es/No ~ - 1 dB

BPSK Performance of Selected SN Codes



Current SCaN Ground Station Receivers:

High Level Description DSN DTT

- **DTT designed in ~ 1985 and became operational in ~1990s**
- **Design drivers: weak signal acquisition & tracking, performance with long CC and external decoders**
- **Performance set by original design, although boards have been replaced with higher speed electronics**
- **Receiver configured by mission ops team for minimum telemetry implementation loss**

Parameter	S-, X-, and Ka-band Characteristics
Receiver Type	Digital
Carrier Loop Bandwidth	0.5 Hz – 200 Hz
Carrier Tracking	Residual Carrier or Suppressed Carrier
Modulation Types	BPSK, QPSK, OQPSK
Acquisition and Tracking Aid	Spacecraft frequency predicts
Subcarrier Frequencies	500 Hz – 2.0 MHz
Subcarrier Data Rate (Typical)	10 - 100 Kbps
Direct Modulation (Typical)	100 Kbps - 6 Mbps
Symbol Loop Bandwidth (Typ.)	0.01 Hz – 25 Hz
Available Decoding	Short and long Constraint Convolutional, Reed- Solomon, Concatenated Convolutional and Reed-Solomon, Turbo
Receiver SNR Threshold (Es/No)	~ - 8 dB (set by long constraint CC)
Soft output symbols	8 bit soft decision outputs (used as input to Telemetry Processor board)
Ranging	Sequential Tone Ranging

Current SCaN Ground Station Receivers:

High Level Description SN IR

- **IR designed in 1990's**
- **Provides spread spectrum modulation (DG1) modes with PN ranging and direct data modulation on carrier**
- **Receiver can be configured for specific mission rqmts**

TDRS S-band Single Access Return Link Receiver Parameters

	Data Group 1						Data Group 2
	Mode 1		Mode 2		Mode 3		
Modulation Type	BPSK	SQPN	BPSK	SQPN	QPSK, SQPSK		QPSK, SQPSK
I/Q Data:	PN long code		PN short code		I: PN long code; Q:unspread		I & Q data unspread
Data Rates: I channel	0.2 - 300 kbps		2 - 300 kbps		0.2 - 300 kbps		2 kbps - 6 Mbps
Data Rates: Q channel	N/A	0.2 - 300 kbps	N/A	2 - 300 kbps	2 kbps - 6 Mbps		2 kbps - 6 Mbps
Coherent Turn-around	Yes	Yes	No	No	Yes		Yes
Acquisition and Tracking Aid	Operates with and w/o spacecraft frequency predicts						Same as DG1
Symbol Loop Bandwidth (Typ.)	Symbol Rate; "0.01%", "0.1%" and "2%" ~0.014 % (2% is no longer operational)						Same as DG1
Available Decoding	Rate 1/2 & 1/3 convolutional code						Same as DG1
Receiver SNR Threshold (Es/No)	~ 1dB						Same as DG1
Soft output symbols	5 bits (from SSA Combining Output port)						Same as DG1
Ranging	PN long code						Not supported

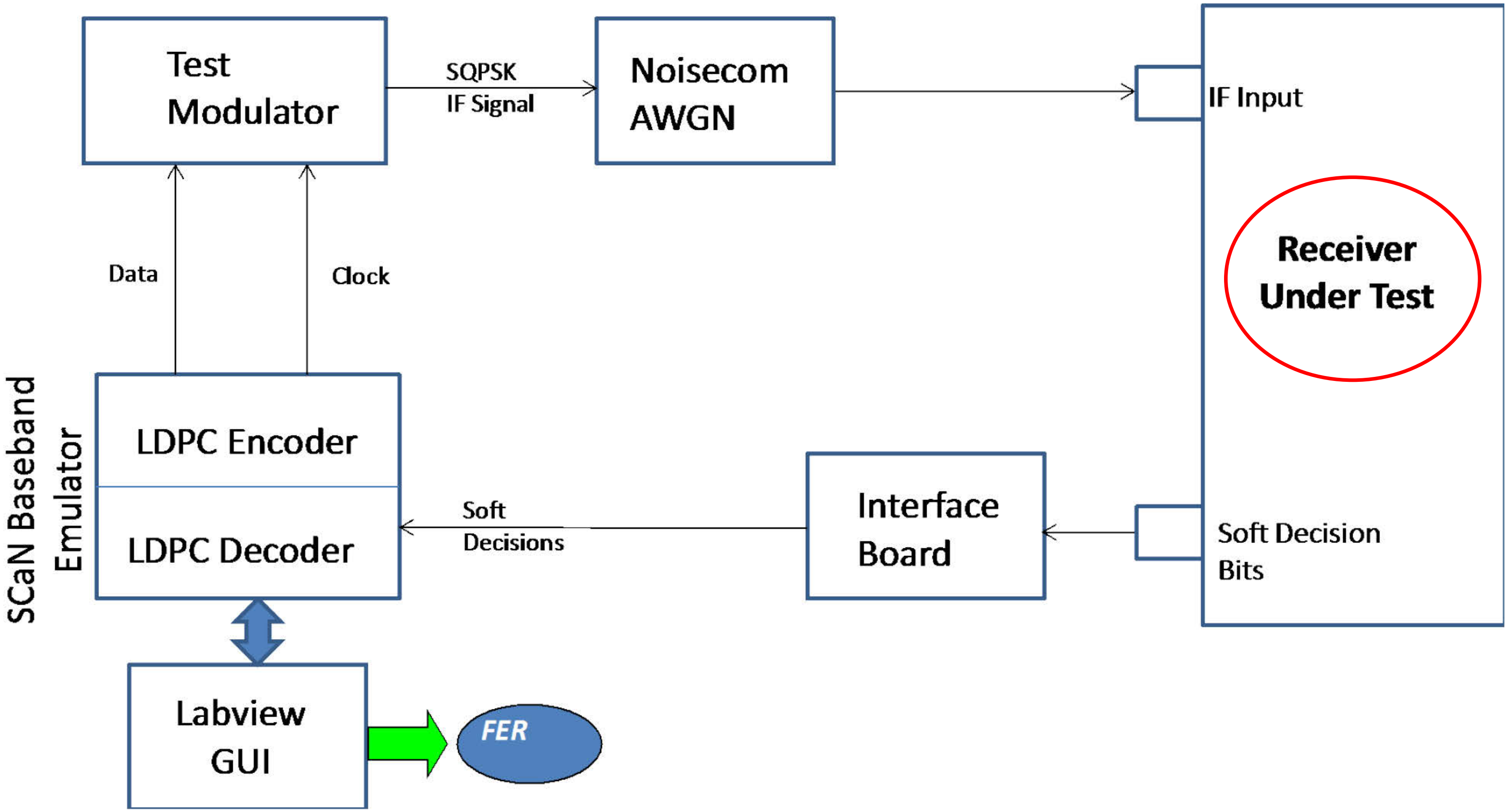
Current SCaN Ground Station Receivers:

High Level Description Prototype SN USS CR

- **During NASA's Constellation program, a Commercial-Off-The-Shelf (COTS) modem, RT Logic T400, had been procured as part of the SCaN Emulator.**
- **This unit is a software-defined modulator, receiver, and digital processing unit with signal processing performed in software and Field-Programmable Gate Array (FPGA) firmware. It is capable of producing and receiving all TDRS DG1 and DG2 S-band Single Access waveforms**
- **The unit was modified to provide:**
  - Carrier lock at SNR required for r = ½, 1K LDPC code, ie. Es/No ~ - 1.5 dB for both DG1 and DG2 modes in the presence of +/- 230 KHz Doppler and +/- 1.5 KHz/sec Doppler rate
  - Soft symbol outputs quantized to 7 bits in DG2 mode and to 3 bits (max permitted due to hardware limitations) in DG1 mode
  - Ability to modify symbol acquisition and tracking loop bandwidths from ~100 Hz to 100 KHz
- **Subsequently, the USS CR Project selected RT Logic as their modem manufacturer with similar requirements wrt LDPC decoding**
- **The modified COTS modem is referred to now as a prototype for the USS CR project**

Block Diagram: Receiver Performance Tests with LDPC

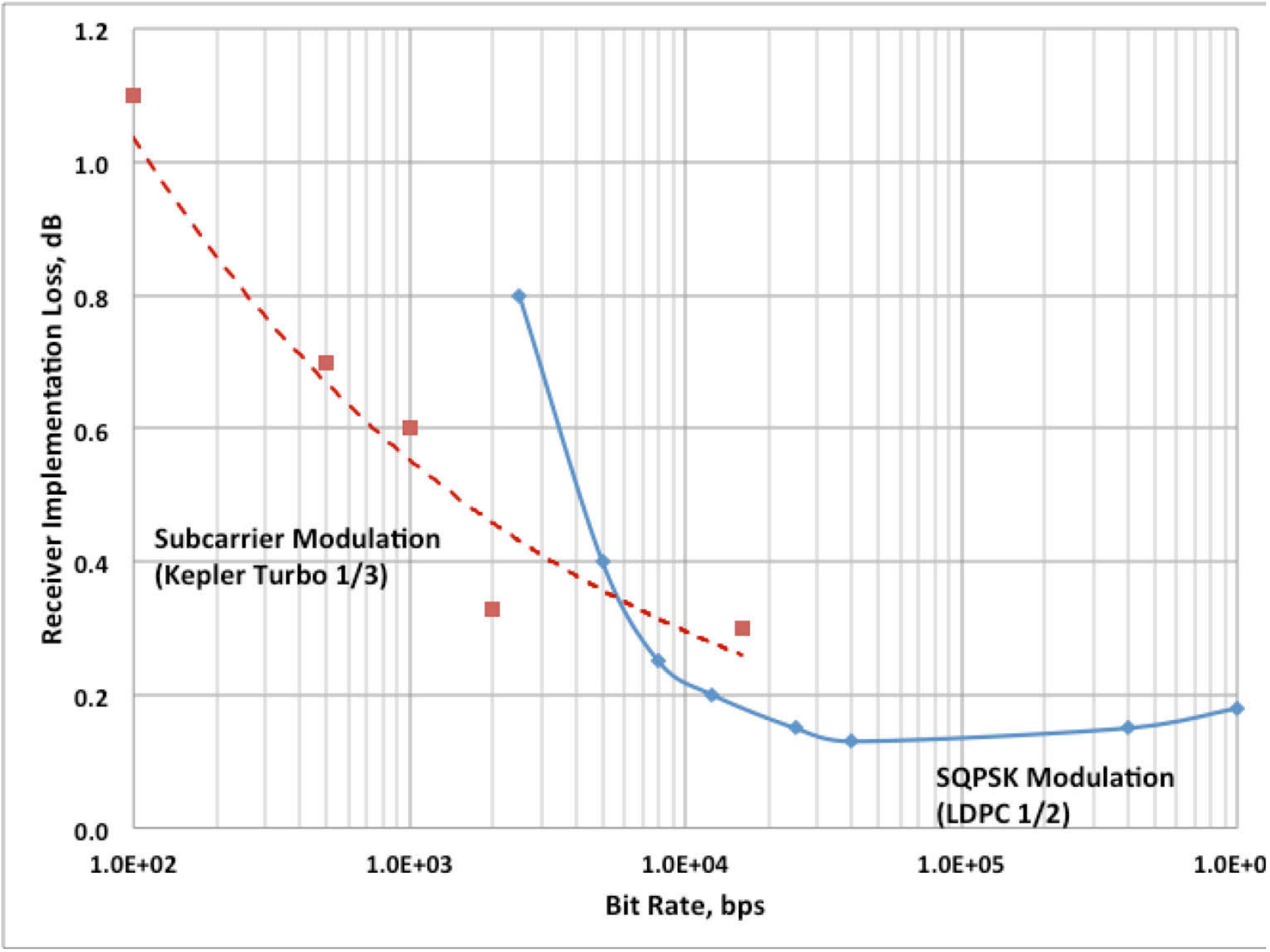
Test set up used to measure Frame Error Rate for LDPC coded signal using SCaN's current DSN and SN receivers and the prototype for the USS CR receiver. External LDPC codec used for all receivers.



SCaN Baseband Emulator: LDPC Codec

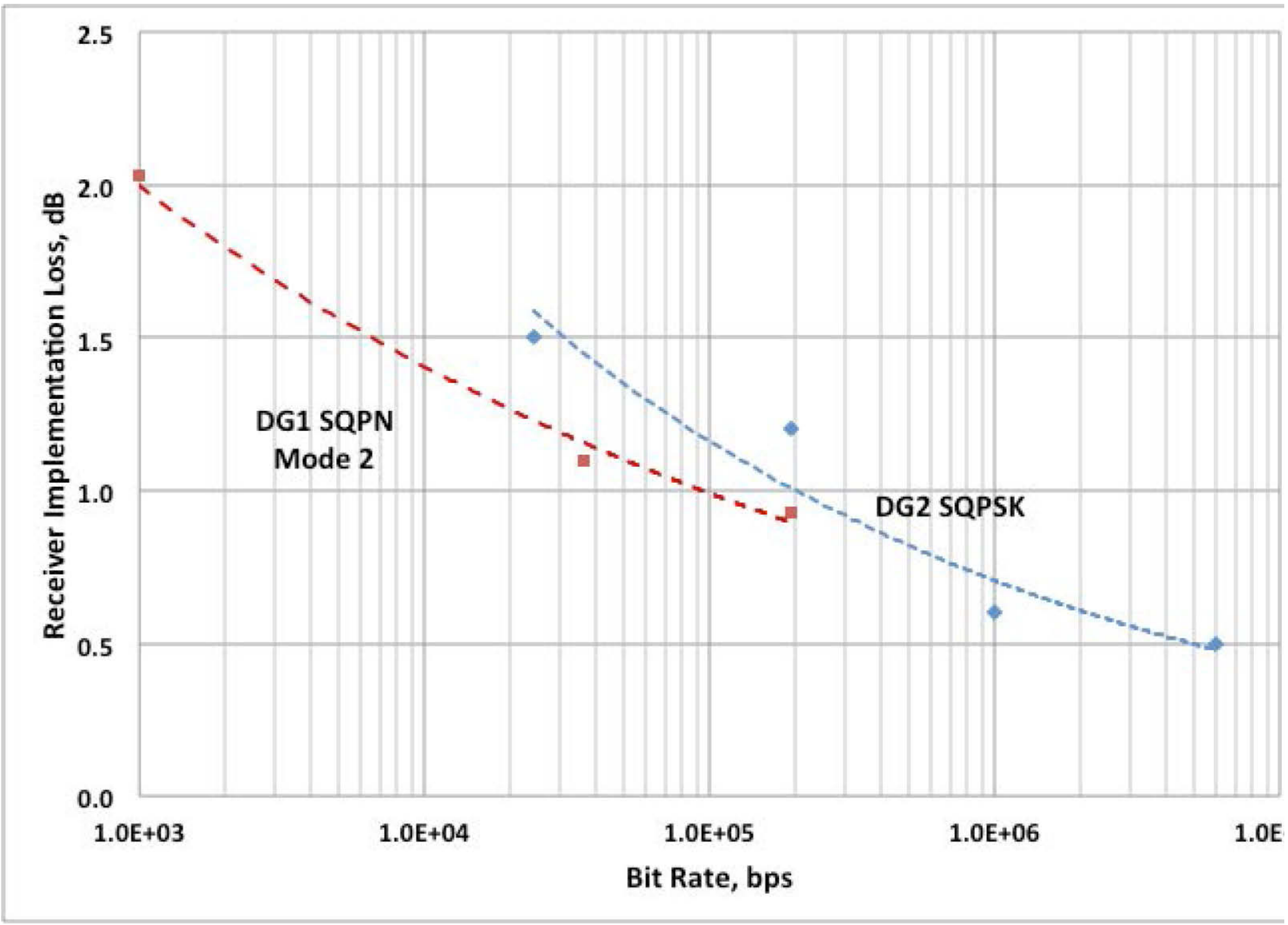
- SCaN Baseband Emulator includes LDPC codec functionality
- CCSDS NASA LDPC code supported
- Scaling factor for the soft decision bits was controlled by built-in receiver symbol SNR estimator or set manually

DSN DTT Performance with r = ½ 1K LDPC at 10^{-4} FER



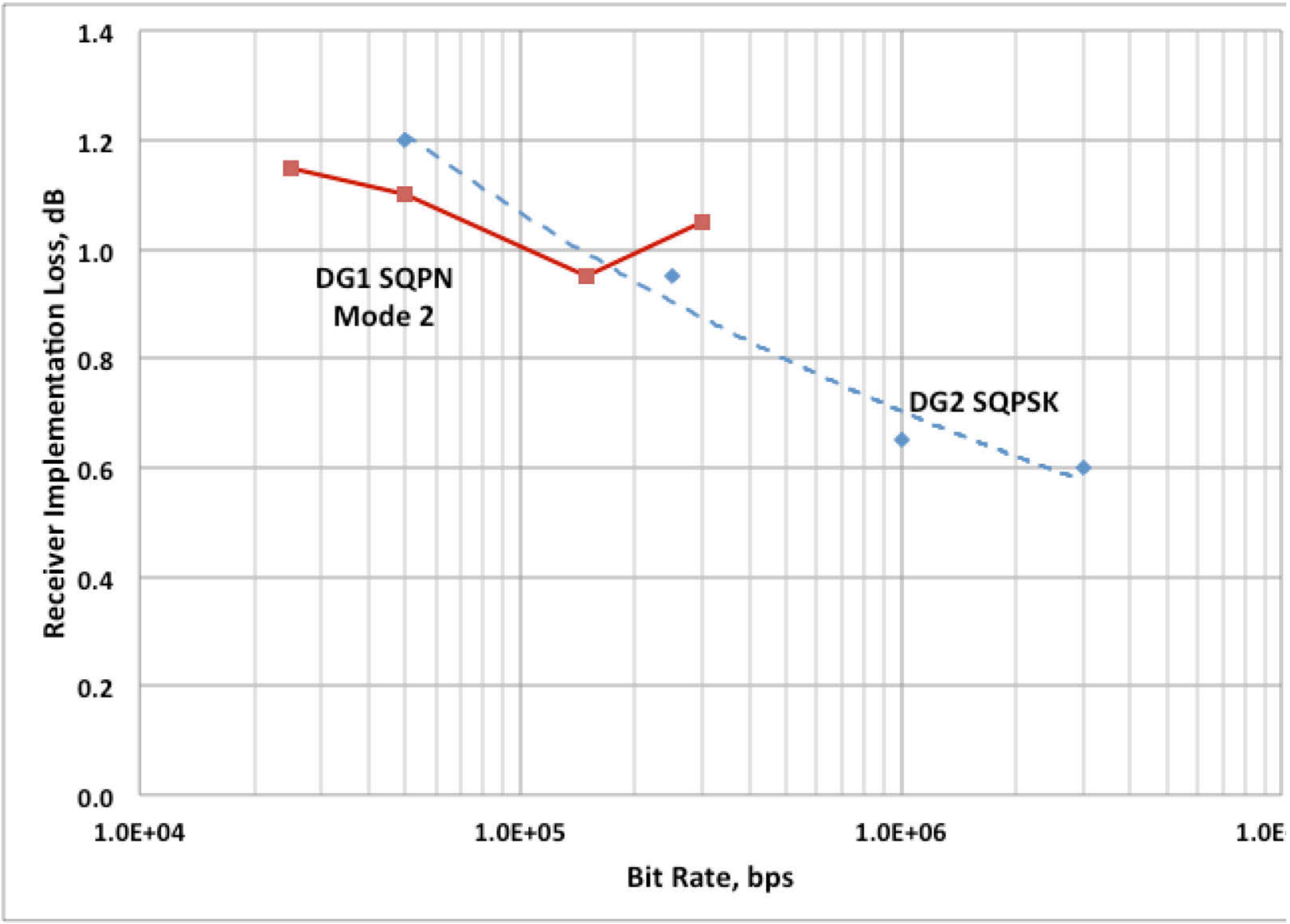
- Receiver & decoder implementation loss (I_L) measured over bit rates typical for DSN missions: 100bps to 1 Mbps
- DSN recommends suppressed carrier operation at > 20 Kbps
- SQPSK with LDPC and BPSK subcarrier with Turbo 1/3 code shown:
  - Residual carrier tracking enables low I_L at low data rates
  - DTT symbol loop BW varied from 0.1% to 0.00005% data rate

SN IR Performance with r = ½ 1K LDPC at 10^{-4} FER



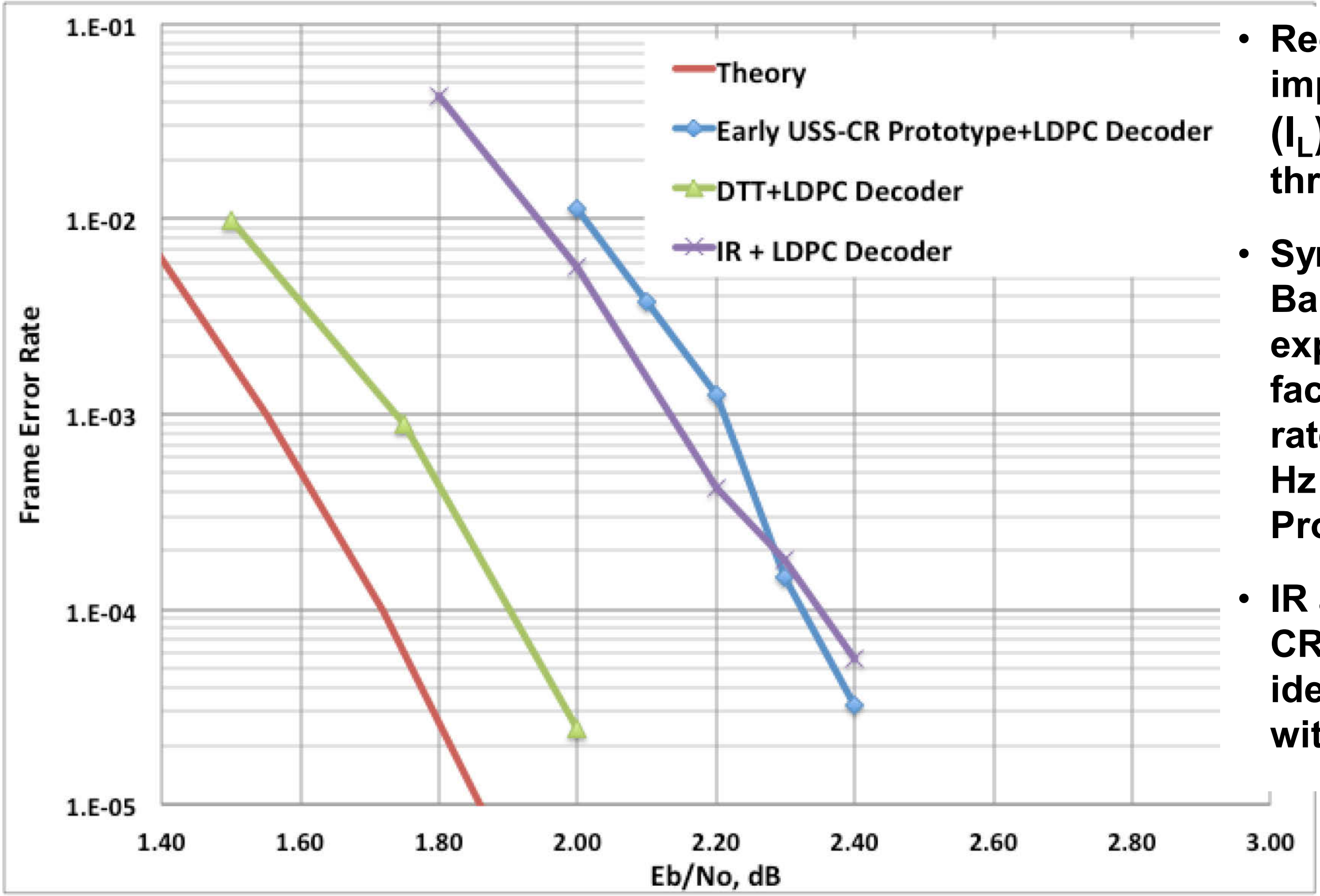
- IR set to narrowest symbol loop BW ('2% Jitter' setting) corresponding to 0.014% symbol rate
- Receiver & decoder implementation loss (I_L) measured over bit rates typical for SN missions: 1 Kbps to 6 Mbps
- DG1 SQPN and DG2 SQPSK shown:
  - I_L increases as data rates decrease
  - SQPN slightly higher I_L than SQPSK

Prototype USS CR Modem Performance with r = ½ 1K LDPC at 10^{-4} FER



- Receiver & decoder implementation loss (I_L) measured over bit rates: 25 Kbps to 3 Mbps
- Carrier and Symbol Loop Bandwidth set to 0.001% of symbol rate
- Decoder loss likely higher for DG1 mode due to use of 3 soft bits vs. 7 for DG2 mode. Scaling factor = ¼.
- DG1 SQPN and DG2 SQPSK shown I_L increases at low data rates

Receiver Performance Comparison for SQPSK modulation, 1 Mbps with r = ½, 1K LDPC



- **Receiver & decoder implementation loss (I_L) < 0.6 dB for all three receivers**
- **Symbol Loop Bandwidth not expected to be strong factor at high data rates (1 Hz DTT; 280 Hz IR; 20 Hz Prototype)**
- **IR and Prototype USS CR modem have identical performance within test accuracy**