NASA DATA STANDARDS PROGRAM OFFICE

NASA Data Standards Working Group

CCSDS Fall Meeting - Heppenheim - Oct. 2-5, 2007

Uplink Coding

Ken Andrews, Dariush Divsalar, Sam Dolinar, Bruce Moision, Jon Hamkins, Fabrizio Pollara

JPL, Communications Architectures and Research section

Fabrizio.Pollara@jpl.nasa.gov

OVERVIEW

- Objectives
  - Develop and recommend error correcting codes for improving high rate and emergency uplink
- Meeting goals
  - Present status and progress in uplink coding; discuss current proposals
  - Involve all agencies in firming up requirements
- NASA goals
  - Present a NASA recommendation, and request the start of a White or Orange Book on uplink coding

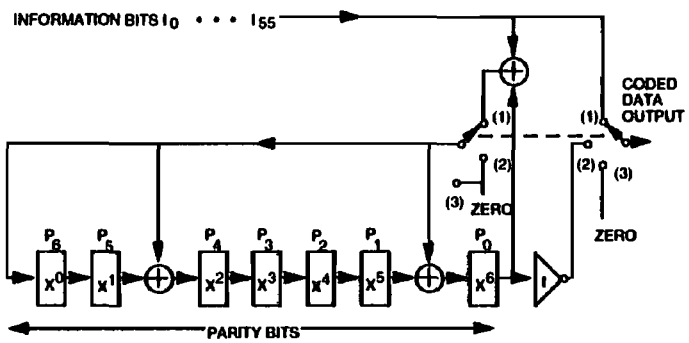
STATUS

- WG History (Jan. 2007)
  - JPL presented results on undetected error rate of LDPC codes for uplink
  - JPL presented and led the discussion on requirements for four types of uplink
  - Activity of other Agencies in uplink coding is low

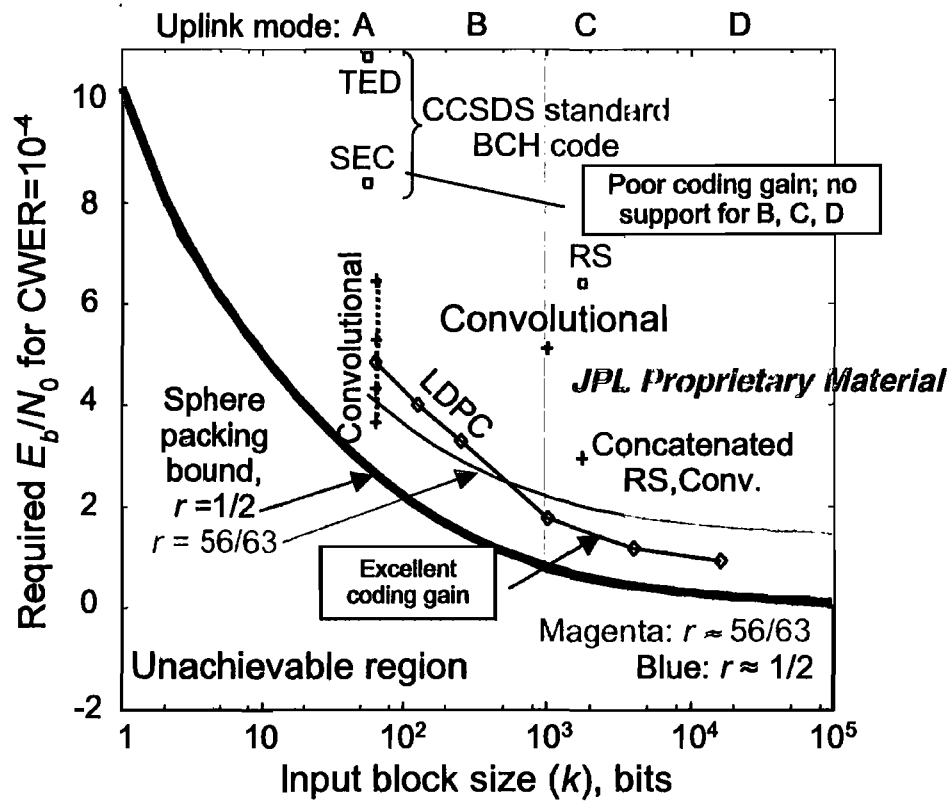
TECHNICAL PROGRESS

Background

- Current CCSDS Uplink Coding standard:
  - (n,k)=(63,56) expurgated Hamming code (a BCH code)
  - Low latency, low complexity encoding/decoding:



  - Operable in two modes:
    - Triple-error-detect (TED)
    - Single-error-correct, double-error detect (SEC)
  - Poor coding gain: 1.9 dB (SEC), -0.5 dB (TED), while up to 6.3 dB gain available at r=56/63 (WER=10^{-3})!



- Uplink telecommand will have an expanded role:

Mode	Purpose	Blocklength (Kbits)	Throughput(Kbps)
A	Emergency	0.1	0.01
B	Command/ARQ	0.1 - 1	1 - 4
C	File upload	1-4	1,000
D	Human support	>4	20,000

- Goal is to select coding schemes for 4 principal operation modes (at left).
- Challenge: design new codes where significant gains over existing solutions are achievable

TECHNICAL PROGRESS

- Defined uplink coding performance metrics & constraints:
  - Undetected Error Rate (UER)
  - Word Error Rate (WER)
  - Required E_b / N_0
  - Complexity
  - High E_s / N_0 required by receiver
  - Receiver constrained to output hard decisions
- Identified target performance, consistent with past and planned missions (Needs validation from other Agencies)
- Developed method to select codes based on multiple criteria
  - Plots of UER, WER, E_b/N_0 allows quick comparison of multiple factor tradespace
- Filled trade space for different modes with candidate codes

- Designed new LDPC codes for modes A,B (short blocklength codes)

  [See details in back-up slides]
  - Short blocklengths require novel protographs
  - Codes demonstrate <u>excellent performance</u>: Low undetected error rate at all SNRs; very low at low SNR

- Will recommend short LDPC codes for modes A, B, and the same LDPC codes developed for downlink for modes C, D

Short LDPC Codes for Uplink

- Documented recent results on short LDPC codes for uplink (submitted to the IEEE Military Communications Conference, 2007)
  - Rate ½ codes with input block size 64, 128, and 256 bits were designed
  - To simplify the encoder and decoder implementations the structure of the codes is based on protographs and circulants
  - These codes are designed for short block sizes based on maximizing the minimum distance and stopping set size subject to a constraint on the maximum variable node degree. In particular, we considered codes with variable node degrees between 3 and 5
  - Increasing the node degree leads to larger minimum distances, at the expense of smaller girth
  - Therefore there is a trade-off between undetected error rate performance (improved by increasing minimum distance) and the degree of suboptimality of the iterative decoders typically used (which are adversely affected by graph loops)

Short LDPC Codes for Uplink

Fig. 1

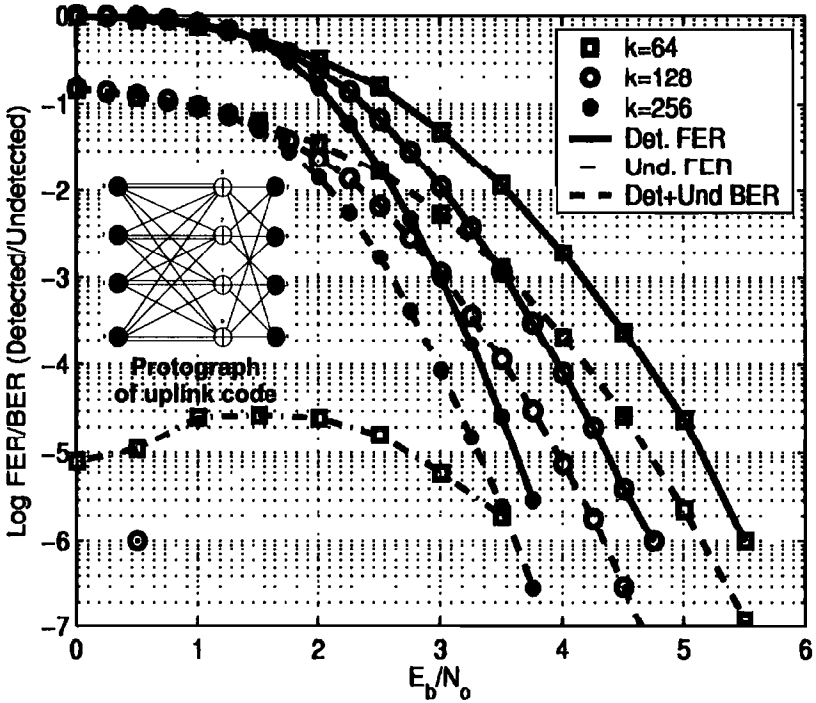
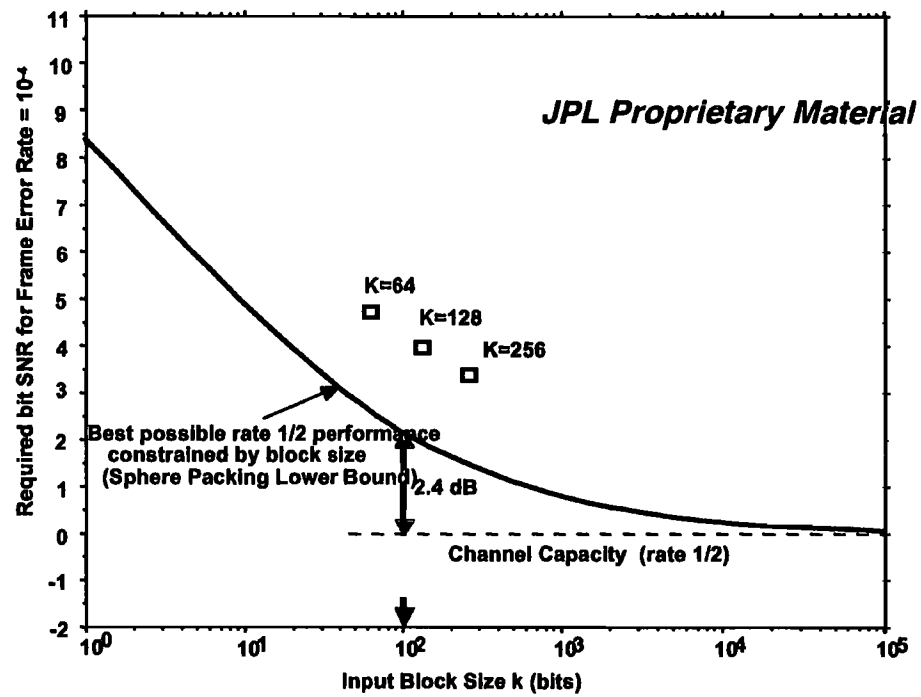


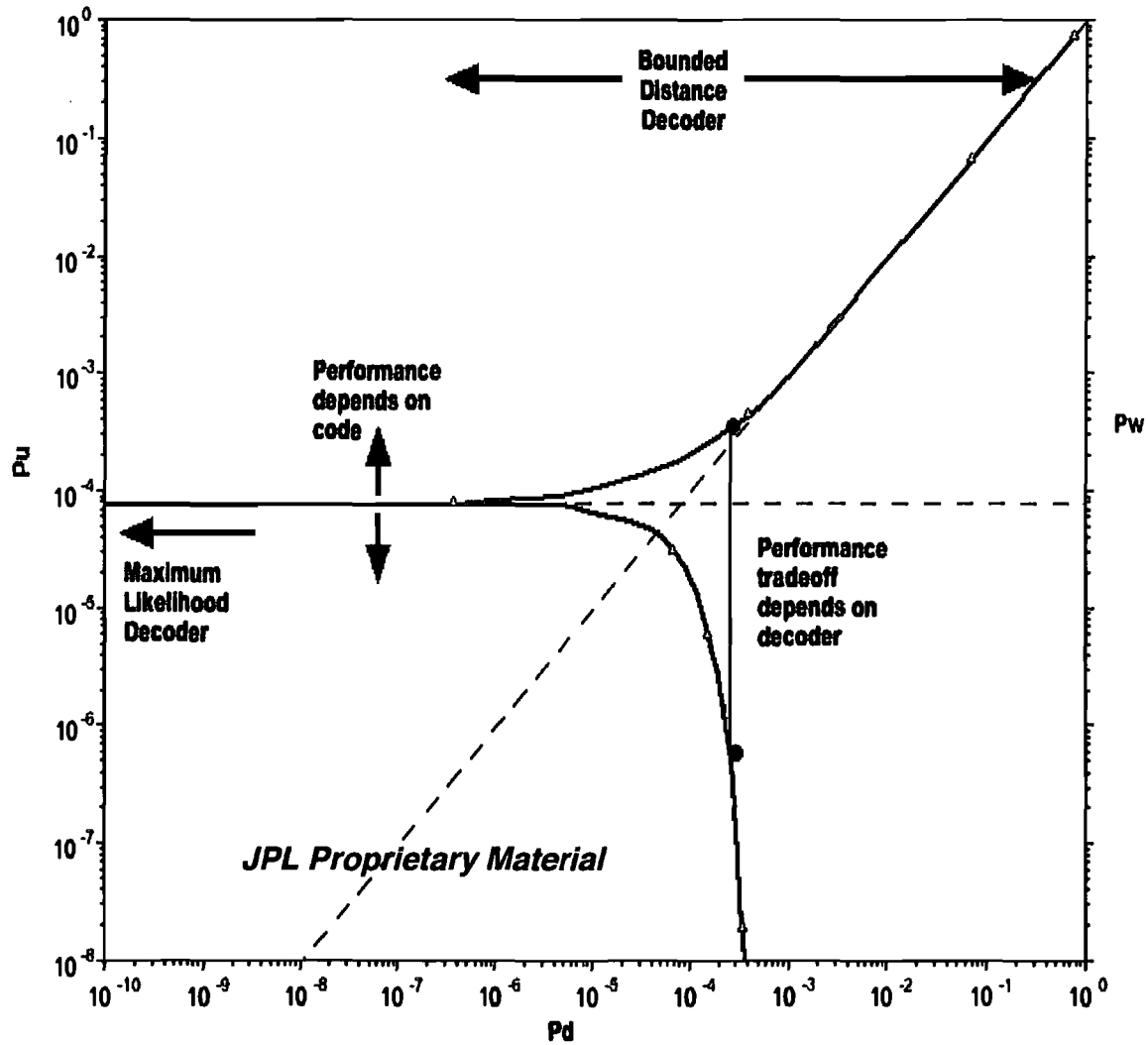
Fig. 2



- The uplink code protograph in the Figure 1 was lifted by factor 16 using progressive edge growth and ACE algorithm to find phases associated with circulants of size 16. The minimum distance of this rate 1/2 (128,64) code is 14.
- Simulation results for this uplink code shows that the bit and frame error rates below 10^{-7} can be achieved. No error floor was observed
- Maximum undetected error rate for k=64 bit code is 2×10^{-5}. This maximum occurs between 1 and 2 dB bit signal to noise ratio. The undetected error rate is lower below and above this SNR. At higher SNR the undetected error rate sharply decreases. This is useful for a spacecraft if it tumbles and loses its antenna pointing. Higher block sizes shows much lower undetected error rates.
- Performance of these codes compared with sphere packing lower bound in Figure 2. The results show that the performance of uplink codes for various block sizes are uniformly close to the theoretical lower bound.

General Results on Pu-Pw Tradeoff

- Found new results on the limits of coding with joint constraints on detected and undetected error rates
  - These results are based on an extension of Shannon theory on random coding bounds, with bounded distance decoding
  - Results apply to any (n,k) code
- A small sacrifice in Pw gives huge improvements in Pu



Uplink Coding: Candidates for Mode A

Code	(n,k)	Ops per bit	Latency (bits)	Eb/No at CWER = 10^-4	Eb/No at UER = 10^-9
Uncoded	**(63,63)**	**0**	**63**	**10.3**	**13.4**
Expurgated Hamming (SEC)	**(63,56)**	**1**	**63**	**8.4**	**9.6**
Expurgated hamming (TED)	**(63,56)**	**2**	**63**	**10.9**	**7.7**
Convolutional (3,1/2)	**(64,32)***	**12**	**10**	**6.5**	**9.4**
Convolutional (7,1/2)	**(64,32)***	**192**	**30**	**4.3**	**6.9**
Convolutional (9,1/2)	**(64,32)***	**768**	**40**	**3.7**	**6.1**
SEC+(3,1/2)	**(126,56)**	**14**	**71**	**6.5**	**8.8**
TED+(7,1/2)	**(126,56)**	**216**	**89**	**4.8**	**6.3**
TED+convolutional interleaver+(3,1/2)	**(126,56)**	**15**	**71**	**7.0**	**7.5**
TED+convolutional interleaver+(7,1/2)	**(126,64)**	**216**	**206**	**5.0**	**5.9**
LDPC	**(128,64)**	**248****	**96**	**5.0**	**5.5**
SCCC (3,1/2)+acc.	**(128,64)**	**290**	**96**	**4.4**	**6.5**

Legacy codes

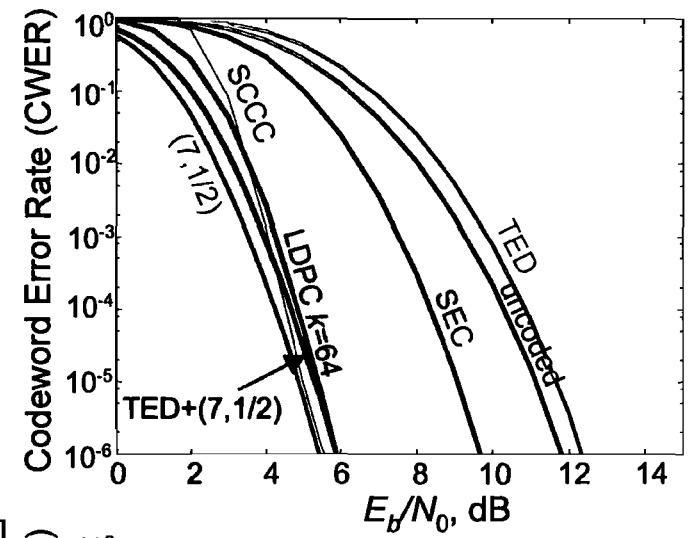
Simple, conventional codes alone or in combination

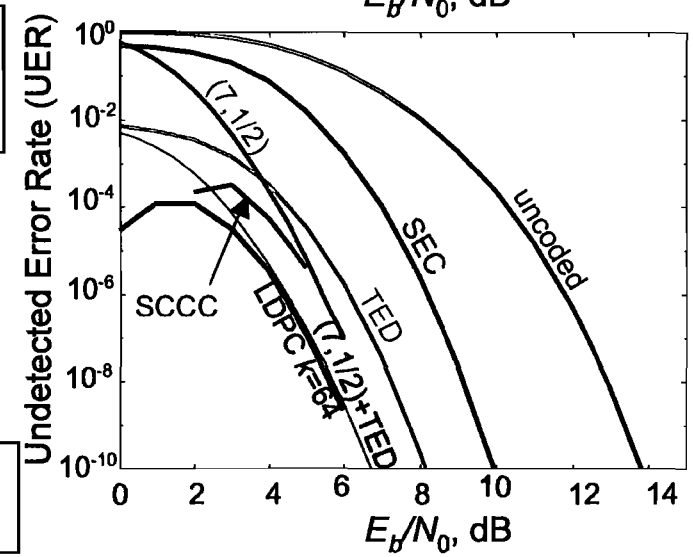
New codes

Performance improved by 3 to 4 dB

* Excludes termination bits (every 1024 bits)
** Average, at CWR=10^{-4}

The maximum of two values (in bold) is the E_b/N_0 requirement driver

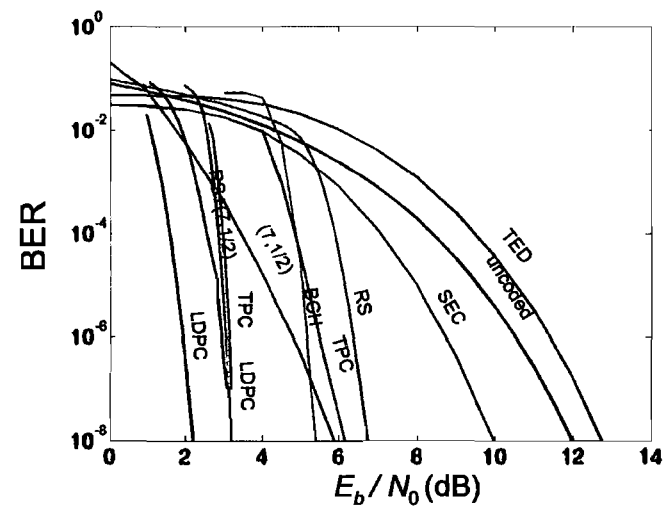




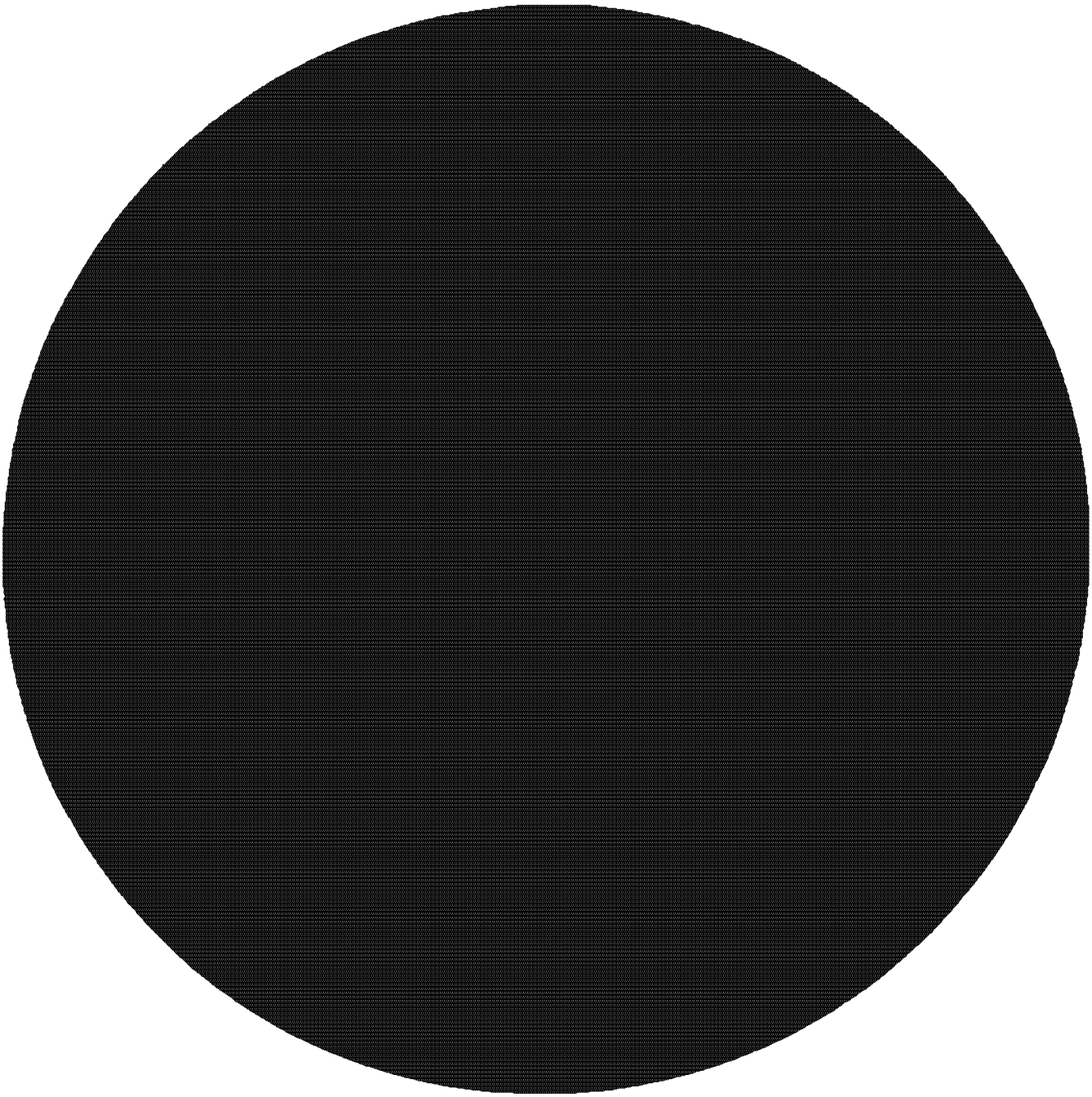
Uplink Coding: Candidates for Modes C and D

Code	n	k	E_b/N_0 @BER<10^{-7}	E_b/N_0 @BER <10^{-7}, E_s/N_0>0	Input	
Uncoded	1	1	11.2	11.2	hard	
BCH, SEC	63	56	9.5	9.5	hard	X
BCH, TED	63	56	11.7	11.7		
RS(255,223)	2040	1784	6.6	6.6	hard	
TPC(hard decision)	4096	3249	5.6	5.6	hard	✓✓
BCH	2047	1024	5.3	5.3	hard	
(7,1/2)	2048	1018	5.4	5.4	soft	
TPC	4096	3249	3.2	3.2	soft	
RS(255,223)+(7,1/2)	4080	1784	3.1	3.6	soft	
LDPC	5120	4096	3.1	3.1	soft	✓✓✓
LDPC	2048	1024	2.1	3.0	soft	✓

UER not explicitly considered since sufficiently low undetected error rates may be achieved efficiently for long blocklength codes by adding a CRC. E.g., a 16-bit CRC yields UER = WER x 1.3×10^{-5} with an overhead of 0.06 dB for a code with k = 1024.



Uplink may be constrained to operate with hard-inputs or at high Es/No, such that full coding gain is not realizable, e.g., Electra currently supports Es/No>0 dB

X *current standard*
✓ *most power efficient solution*
✓✓ *best hard-input constrained solution*
✓✓✓ *best E_s/N_0 constrained solution*

End of File