LDPC in NanoCom Link S

ESD7 Project with GOMspace

Project Report - Group

Aalborg University
Electronics and System Design.

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AALBORG UNIVERSITY
STUDENT REPORT

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Preface

Thank to Jesper Larsen and Henrik Kalstrup at GOMspace for their time, guidance, and materials.

This report is confidential and should be treated as such.

Aalborg University, February 23, 2026

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1 Introduction

Since the invention of the computer during the second world war, data transmission and by extension data coding have been hot topics of research as society needs and expects faster and more reliable data transfer. In today's world people expect to be able to transfer up to 400 Mbps pretty much anywhere on earth directly from low earth orbit (LEO) satellites [7]. Or even to recieve a usable 4G cell network, directly from space[8].

1.1 GOMspace

GOMspace is a satellite company founded in 2007, with its headquarters based in Aalborg, Denmark. They have more than 75 satellites in orbit, more than 2000 space proven product a year, and serve customers in more than 60 countries, [3]. In 2025 they were credited to be one of the largest facilities in Northern Europe enabling them to build and integrate up to one satellite per day, [6]. They are particular known for their CubeSat's and smaller satellite solutions and have a wide variety of products and solutions based on customers wishes, to make space more accessible and affordable.

1.2 Initial Problem Statment

Three problems have been posed by GOMspace for students projects. All of which include som kind of signal processing and the use of hardware design through FPGA.

1. **Introduction of Low Density Parity Check LDPC in NanoCom Link S, for added performance and compatibility towards ground stations:** This project would have focus on developing an encoder and decoder. The current system should be taken into account to ensure system compatibility and coherence, in the design and throughout the development.

2. **Introduction of channelization and potentially other DSP blocks in NanoSig Probe, for increasing the possibility of signal detection and processing in various COMINT and ELINT scenarios:** This would involve data intelligence, and signal interception. This project is relatively open to interpretation. The project would involve channelizing the input data for the Nanosig Probe, to perform better signal detection and potentially save buffer space. Other than that the project leaves it up to the students to think of other DSP enchancments that could be made to increase signal detection.

3. **Pop-Up S-Band Earth station with ZedBoard:** This would involve developing a mobile Earth station, to track and find satellites in orbit and work with modules

and parts that are already in development. Here a large focus would also be on coherence with existing modules, along with developing the track and point, and associated hard- and software.

While all three project are intriguing, the first project "Introduction of LDPC in NanoCom link S" was chosen. This project was chosen as it aligned well with the groups wishes and interests, as well as being a well defined and well scoped project. From the project description, an initial problem statement was created.

What is the NanoCom Link S, how is it currently used and what are the systems constrains? What are LDPC codes, what are their advantages and limitations and how can they be utilized in the NanoCom Link S, to improve their current throughput?

2 Problem Analysis

2.1 What is the NanoCom Link-S

NanoCom link-s is GOMspace's satellite communications solutions for S-band communication. It consist of 2 physical modules:

1. An exterior CCSDS compliant S-band antenna, meant for the outside of a 1U satellite rack.

2. An internal SDR Radio / transciever, also build to fit inside a 1U rack. This module also includes a 120GB downlink data buffer.

The antenna supports ~~transmitting at a frequency of~~ a Tx-band at 2200-2290 MHz and ~~receiving at~~ a Rx-band at 2025-2110 MHz. Internally, the second module supports spacewire[1], canbus and RS-422 for sending and receiving data over CSP or TCP/IP. The system supports BPSK and QPSK encoding for up to 7.5MBps transfer speed. The system needs between 8-18V of supply voltage and draws at most 15W[5].

?

what is this ?

t,t draws current
consumes power

Jes hader todo at
heeeele mit gamle hyste

[1]spacewire is a physical interface and network protocol develop by ESA for space applications

3 | Technical Analysis

3.1 Error Detection and Correcting Codes

The field of error detection and error correction is wide and has excited for many years in binary communication since its usage and both utilizes adding extra data, for the purpose of processing the data afterwards.

Error detection comes in very forms, such as a single parity bit, but becomes unstable, with larger data sets or high possibility of bit flip. CRC more commonly used, as larger data sets can be sent, but a larger amount of redundancy. In both cases, neither can correct the error, but just determinate that one occurred.

Error correction on the other hand is able to detect the error, and with a high possibility, guess back to the original message, correcting the error that has happened in transmission. Mostly known is Hamming codes, which was introduced in 1947, and since then the field has expanded. In 1963, Robert G. Gallager wrote "Low-Density Parity-Check Codes" and was mostly forgotten, as large amounts of data needs to be transmitted to be beneficial. As technology has advanced better error correction has been needed and now Low-Density Parity-Check (LDPC) has become the standard and preferred method in satellite communication.

3.2 Low Density Parity Check

As the name suggest, LDPC has a significantly low density of "1" compared to "0" in the parity check matrix. This however does have the problem of having a much more complicated generator matrix.

3.2.1 Construction of LDCP code

3.3 Progressive edge growth

https://uzum.github.io/ldpc-peg/

3.4 Noisy-channel Coding Theorem (Shannon's Limit)

Der er ikke tilføjet kilder til denne del endnu

The noisy channel theorem (or Shannon's limit Theorem) is a foundational theorem in information theory. It states that any communication channel has a capacity 'C' that

Sendes data eller sendes dataraten ?

describes the maximum data rate 'R' that can be sent through it without loss. Or in other words a data rate R can be reached without loss through 'coding' as long as $R < C$.

3.4.1 Time Continuos Channels

<meta>

Addetive White Gausian Noise Channel, (AWGN)

no way to start a paragraph.

model (emulates)

Sometimes also known as the Shannon-Hartley theorem. This channel simulates any time continuous signal with normally distributed noise. Because of this it is the most widely used time continuous channel, as this describes most real world time continuos systems. The channel capacity C of this channel can be described with the Shannon-Hartley theorem:

$$C = B \cdot log_2(1 + \frac{S}{N}) \tag{3.1}$$

where:

1. C is channel capacity $[bps]$
2. B is the bandwidth of the channel $[Hz]$
3. $\frac{S}{N}$ is the linear signal to noise ratio, (SNR) of the signal $[*]$

nonlinear alternative ?

3.4.2 Time Discrete Channels

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Binary Symmetric Channel, (BSC)

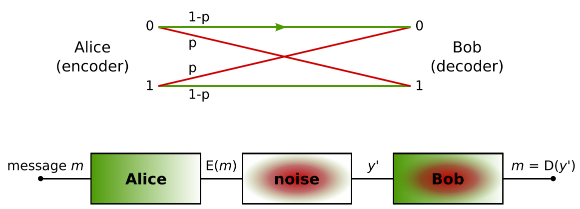

Figure 3.1: Graph showing the input and output of a binary symmetric channel [2].

Binary symmetric channels are the most common form of time discrete channel. It models any time discrete binary medium where the only error that can occur is a bit-flip. The channel capacity of a BSC can be found using equation 3.2.

$$\begin{aligned} C &= 1 - f(p) \\ f(p) &= pLOG_2(p) + (1-p)LOG_2(1-p) + 1 \end{aligned} \tag{3.2}$$

Where p is the chance of a bit-flip.

Notice while C is still the channel capacity, due to it now being time discrete, the unit changes from $[bps]$ bits per second to $[bpcu]$, bits per channel use.

Binary Erasure Channel, (BEC)

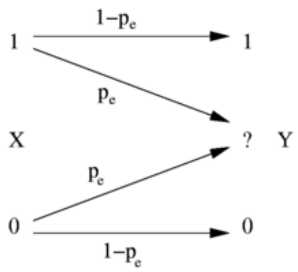

Figure 3.2: Graph showing a binary erasure channel [1].

discrete

A binary erasure channel models a time discrete binary channel where an error can occur such that the bit of information is completely erased. This is less common as most binary systems work by implementing a threshold on a voltage. The channel capacity of a Binary Erasure Channel can be described with the following equation:

$$C = 1 - p \tag{3.3}$$

where p is the chance that an erasure happens.

Additive White Gaussian Noise (Time discrete)

The AWGN channel can also be described in a time discrete setting. This results in an equation that does not depend on bandwidth as it is already "band limited" due to the fact that it has been sampled. The equation for the capacity of a time discrete AWGN channel can be seen in equation 3.4.

$$C = \frac{1}{2} LOG_2(1 + \frac{P}{N}) \tag{3.4}$$

Where P is the is the channel power and N is the noise power. This is mostly a syntactical change as this still represents SNR.

The time continuos equation 3.1 can actually be derived from this equation using Shannon-Nyquist sampling theorem see 3.5.

?

$B = \frac{1}{2}$

$$\begin{aligned} C &= \frac{1}{2} LOG_2(1 + \frac{P}{N}) \\ &\Updownarrow \\ C &= 2B(\frac{1}{2} LOG_2(1 + \frac{P}{N})) \\ &= B \cdot LOG_2(1 + \frac{P}{N}) \end{aligned} \tag{3.5}$$

Zero crossings

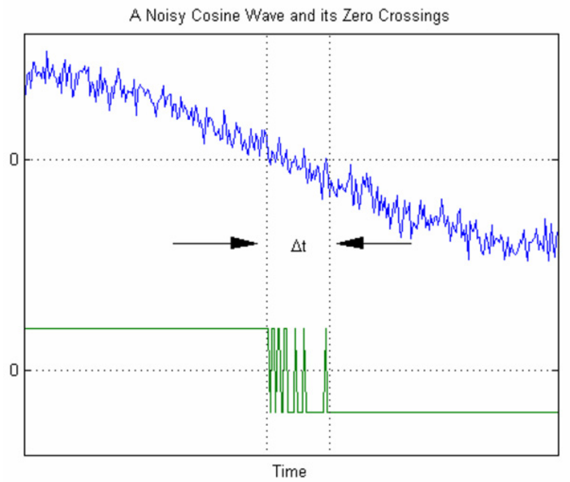

Figure 3.3: Figure showing the raw signal (with gaussian noise) in blue and the sampled/filtered signal in green,[4]

Additionally the number of zero crossings pr second of a AWGN channel can also be desribed using equation 3.6

$$f_0 \sqrt{\frac{1 + SNR + \frac{B^2}{12 f_0^2}}{SNR + 1}} \tag{3.6}$$

where f_0 is the sampling frequency and B is the bandwidth of the signal.

Hvordan vil I stille formler op? Som her? Eller som Eq. (3.1)?

Jeg foretrækker som her, men vigtigst af alt, så skal I beslutte jer !!!

4 | Specifications

5 | System Design

6 Integration Test

7 Acceptance Test

8 | Discussion

9 | Conclusion

Glossary

AWGN Addetive White Gaussian Noise. 6–8

BEC Binary Erasure Channel. 7

BSC Binary Symmetric Channel. 6

CCSDS Consulate Committee for Space Data System . 4

ESA European Space Agency. 4

LDPC Low Density Parity Check. 2, 3

LEO Low Earth Orbit. 2

SNR Signal to noise ratio. 6, 7

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A | Vocabulary

Parity bit	A bit reserved to make a set of bits always have an even amount of ones
Parity check set	a set of bits which under no error should have an even amount of ones
Erasure rate (error rate)	the percentage of bits that fail during transmission
Density / sparsity	how big is the overlap in parity check sets (this is also representented in the amount of 1s in the parity check matrix H)
Tanner graph	a graph like **??** that shows all the parity check sets and how they are connected to the data
Error floor	
Progressive edge growth	
BER	Bit error rate (se erasure rate)
FER	Frame error rate (the error rate for a whole frame instead of a singular frame)
Galios Field or finite field GF(n)	a set of numbers that contain a finite number of elements. It only has the + and * operator, which both work as expected with an added %n operator behind them.
Shannon limit	the theoretical absolute best / fastest transmission rate

Table A.1: Caption