BEP: Advanced Hard-Decision FEC for 400G Optical Fibre Communications

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1 Introduction/Motivation

More and more data centers are being built to support high-capacity data networks. These centers are interconnected using 100 Gbit/s links but will soon migrate to 400 Gbit/s to increase capacity. Optical fibre links are a clear example of such complex but data-rich systems. This is due to the physical complexity of the fibre propagation which is mathematically described by a nonlinear differential equation with no known closed-form solution: the nonlinear Schrödinger equation (NLSE) [**?**, Ch. 2]. At the same time, numerical routines can be used to generate large amounts of data for the optical systems under consideration.

An optical fibre behaves as a nonlinear medium as the optical signal power at their input is increased. As no closed-form solutions are available for the NLSE, the design of good enough transmitter/receiver pairs is usually based on crucial simplifications. This often leads to solutions that are far from the optimal one. On the other hand, optical fibre transmission systems are today under a huge pressure to deliver ever-higher data rates over longer transmission distances (thousands of kilometers!), and thus, efficient and low complexity Forward error correction (FEC, also known as error control coding) appears as a potential tool to help researchers to improve next-generation optical fibre transceivers. This is a key difference over the 100GE (100 Gbit/s Ethernet) objectives, where FEC was optional. FEC codes that can boost the coding gains are of key importance.

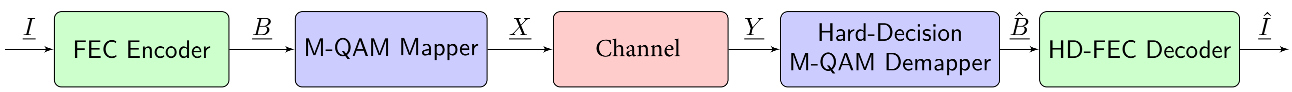

Figure 1: Schematic diagram of coded modulation system.

Staircase codes, which is are a family of powerful hard-decision FEC codes, have has been approved in the 400 ZR Implementation Agreement by the Optical Internet working Forum [1]. Recently, we have developed a new decoding algorithm (the SABM algorithm) of SCCs to further improve the performance [2]. Although the results are promising, it is still unclear how to design an efficient algorithm for the 400 ZR standard.

2 The Plan

Suggested work plan for the project.

1. Read up on FEC in general, and on SCCs in particular. Understand how FEC works, as well as SCCs and BCH codes (which are at the core of SCCs).

   (a) [1] - The whole paper (a good start to know about SCC, please read carefully)

   (b) [2] - The whole paper (please read carefully).

   (c) [3] - Section 1, 2 and 3

   (d) [4] - The whole paper (Read the details of SABM algorithm)

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In this project, you will implement FEC algorithms for in the 400 ZR Implementation Agreement, which use SCCs as outer codes and Hamming codes as inner codes. The tasks include numerical simulations to:

2. Implement a miss-correction algorithm.
3. Read and reproduce Yi's results [4] to familiarize yourself with GPUs.
4. Improve the performance of SABM by considering the soft information of Hamming codes
5. Combine the SABM algorithm with high order modulation formats, i.e. 16QAM/64QAM.

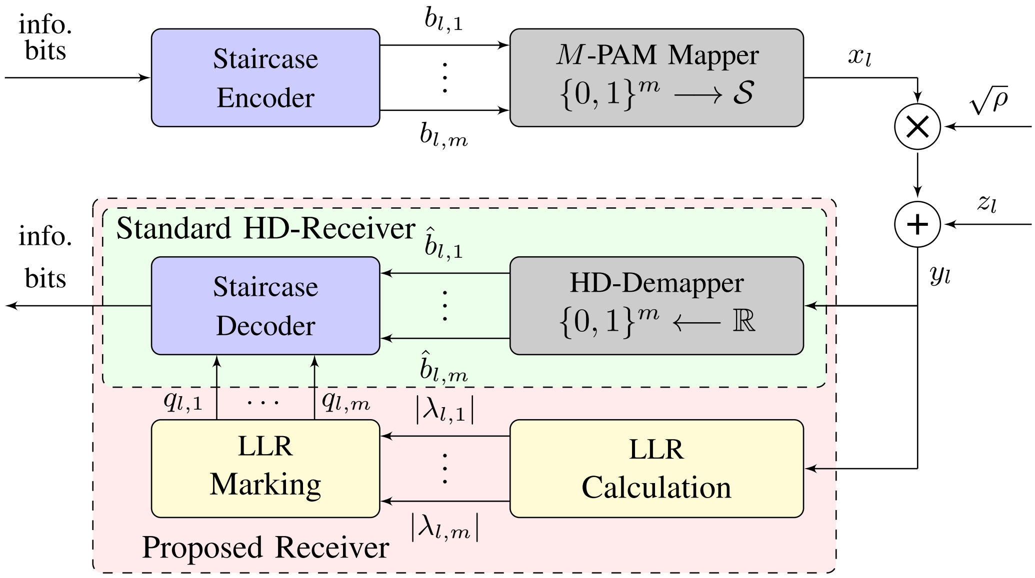

Figure 2: Sytem model for SABM.

There are other things that (if time allows), could be interesting to look at. For example:

- Investigate the efficiency of the SABM algorithm, i.e., coding gain, error floor, and complexity.
- Apply the SABM for product codes with high order modulation formats
- Implement a simple SCCs simulator using GPUs. Hopefully the GPU-based SCC decoder will be faster than using a CPU. Run comparisons for different constellations and code rate.

3 Duties and Timeline

Bin and Gabriele will be the day-to-day supervisor. At least one meeting per week with the daily supervisors is required. The student should join every second week the meeting with the group meeting. A desktop on floor 7 can be allocated to the student if required.

A draft of the timeline for this project is as follows:

- Submit planning: February 20, 2018
- Submit intermediate paper: April 28, 2018
- Submit revised planning: April 28, 2018
- Submit paper (+code of conduct): June 12, 2018
- Submit reflection report: June 12, 2018
- Final presentations: June 18-22, 2018

4 Students Tasks (Stage 1, Months 1-2)

The aim of this project is to study the applicability of SABM techniques for 400G optical communications. The student tasks are:

1. Learn basic principles of FEC.
2. Get familiar with programming for coding and encoding.
3. Implement simple M-QAM with SCCs.
4. Implement M-QAM with SCCs and Hamming codes.

5 Students Tasks (Stage 2, Months 3-5)

In the second phase of this project, the students will try to solve one of the following projects:

- Apply SABM for coded modulation system with SCCs and Hamming codes
- Apply SABM for coded modulation system with product codes

A detailed description of these subprojects with the corresponding tasks will be made available in due course.

6 Expected Outcomes

- Thorough reading of suggested literature
- Regular meetings with supervisors
- A well-commented Matlab code
- A 6-10 pages IEEE-type paper/report. A template with structure will be provided in due course.

References

[1] B. P. Smith, A. Farhood, A. Hunt, F. R. Kschischang, and J. Lodge, "Staircase codes: FEC for 100 Gb/s OTN," *Journal of Lightwave Technology*, vol. 30, no. 1, pp. 110–117, Jan. 2012.

[2] L. M. Zhang and F. R. Kschischang, "Staircase codes with 6% to 33% overhead," *Journal of Lightwave Technology*, vol. 32, no. 10, pp. 1999–2002, May 2014.

[3] C. Häger and H. D. Pfister, "Miscorrection-free decoding of staircase codes," in *European Conference on Optical Communciation (ECOC)*, Gothenburg, Sweden, Sep. 2017.

[4] Y. Lei, A. Alvarado, B. Chen, X. Deng, Z. Cao, J. Li, and K. Xu, "Decoding staircase codes with marked bits," in *2018 IEEE 10th International Symposium on Turbo Codes & Iterative Information Processing (ISTC)*, Hong Kong, China, Dec. 2018.