TECHNION - ISRAEL INSTITUTE OF TECHNOLOGY

Department of Electrical Engineering

Handout 1 | **Codes on Graphs and Iterative Decoding**

General Information | Lecturer: Dr. Igal Sason

Advanced Topics in Communication and Information 1 (048703):
Codes on Graphs and Iterative Decoding Algorithms

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Time and location: Sunday, 16:30–18:30, Meyer 351.

Reception hours: For those who arrive to Technion once per week, it is possible to schedule a meeting with me immediately after the lecture. Otherwise, please contact me in my official reception hours which are on Mondays 16:30–17:30 and Tuesdays 11:30–12:30.

Web page: `http://www.ee.technion.ac.il/people/sason/codes_on_graphs.html`.

Pre-requisites: 'Information Theory' (048733)
'Introduction to Digital Communications' (046206).

1. Introduction

The channel coding theorem of Shannon assures the existence of codes which in principle can be decoded reliably at all rates below the channel capacity, and on the other hand, it states that reliable communication is not possible at rates above the channel capacity. For more than 50 years, a central challenge of coding theory has been to devise coding schemes which come close to achieving the channel capacity with practical decoding complexity and tolerable delay. Following the breakthrough introduction of turbo codes and the rediscovery of low-density parity-check codes, it was realized that these codes and lots of other variants of capacity-approaching error correcting codes can all be understood as codes defined on graphs. Graphs not only describe the codes, but more importantly, they structure the operation of efficient iterative decoding algorithms which are used to decode these codes, having the potential to approach channel capacity while maintaining reasonable decoding complexity. The exciting developments in coding theory during the last decade did not only revolutionize the field of channel coding, but had also a great impact in other areas, such as channel equalization, lossless and lossy data compression, interference cancellation, multi-user detection etc., where the "turbo-principle" can be applied efficiently. In this course, we focus on codes defined on graphs, derive practical and efficient iterative decoding algorithms, and provide analytic tools to analyze their performance and complexity.

2. Course Outline

- Introduction: communication channels and channel capacity, block and convolutional codes, and motivating the study of codes on graphs and iterative decoding algorithms (2 lectures).

- Low-density parity-check (LDPC) codes and repeat-accumulate (RA) codes: setting and notations (1 lecture).

- Asymptotic analysis of LDPC codes on the binary erasure channel: iterative decoding, simplifications, concentration, asymptotic analysis under iterative message-passing decoding, stability, capacity-achieving degree distributions, EXIT charts (3 lectures).

- Parity-check density versus performance of binary linear block codes over memoryless symmetric channels, the connection between parity-check density and complexity for codes defined by standard Tanner graphs, and capacity-achieving ensembles of RA codes for the binary erasure channel with bounded complexity (1 lecture).

- Asymptotic analysis of LDPC codes on binary, memoryless, symmetric channels: iterative message-passing decoders, density evolution, monotonicity, thresholds, stability, concentration, EXIT charts, the Gaussian approximation for density evolution and approximated threshold transformations (4 lectures).

- Factor graphs: graphical representation of factorization, recursive determination of marginal functions, belief-propagation decoding of codes on graphs (1 lecture).

- The BCJR algorithm, and iterative decoding of turbo codes and interleaved serially concatenated convolutional codes (2 lectures).

3. Course Policy

- The purpose of the homework assignments is to enable a deeper understanding of the course. At least four homework assignments should be submitted by every student; their weight on the final grade is 40% (based on the best four homework assignments).

- The course policy will be determined at the beginning of the semester; there will be either a final exam or a critical summary report followed by a discussion in my office.

References

[1] R. G. Gallager, *Low-Density Parity-Check Codes*, M.I.T. Press, 1963.

[2] C. Berrou, A. Glavieux and P. Thitimajshima, “Near Shannon limit error-correcting coding and decoding: turbo codes,” *Proceedings 1993 IEEE International Conference on Communications*, pp. 1064–1070, Geneva, Switzerland, May 1993.

[3] Special issue on *Codes on Graphs and Iterative Algorithms*, *IEEE Trans. on Information Theory*, vol. 47, no. 2, February 2001.

[4] Special issues on *The Turbo Principle: From Theory to Practice* (Parts I, II), *IEEE Journal on Selected Areas in Communications*, vol. 19, no. 5 & 9, May & Sept. 2001.

[5] Tutorial papers on capacity-approaching codes, iterative decoding algorithms, and iterative soft signal processing for digital communications. See *IEEE Communications Magazine*, vol. 41, August 2003, and *IEEE Signal Processing Magazine*, vol. 21, January 2004.

[6] T. Richardson and R. Urbanke, *Iterative Coding Systems*, in preparation. [Online]. Available: http://lthcwww.epfl.ch/papers/ics.ps.

[7] S. B. Wicker and S. Kim, *Fundamentals of Codes, Graphs, and Iterative Decoding*, Kluwer Academic Publishers, 2003. ISBN 1-4020-7264-3.