2021-11th International Symposium on Topics in Coding

Montréal, Canada

Aug. 30 - Sep. 3, 2021

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Welcome to the 11th International Symposium on Topics in Coding.

Nowadays, coding is almost everywhere and touches many fields that were not expected to be computerized only a few years ago, which therefore increases the amount of research done. Through all this research, we witnessed a revolution in communications, using, for example, microelectronics, artificial intelligence or machine learning to innovate and improve, among other things, communication efficiency. Coding and all its collateral fields brought communications to a new level and the ISTC symposium is the perfect platform to discuss it.

After the highly successful symposium in Hong Kong in 2018, ISTC was meant to continue its tour of the continents by stopping in Montreal. Unfortunately, the ISTC’s travel plans were disrupted by the worldwide pandemic and as a result, the conference will be held exclusively in virtual format. This year again, the program has a lot to offer with 19 special session presentations, 33 oral presentations in regular sessions, 12 poster presentations and 8 keynote talks by distinguished speakers.

Past attendees of the International Symposium on Turbo Codes and Iterative Information Processing may have noticed the change in the conference name this year. It became the International Symposium on Topics in Coding. The conference keeps the same acronym “ISTC.” It was widely agreed among the members of the organizing committee that the old name no longer reflected the content of the conference: ISTC has long since become a renowned conference in the area of channel coding and the change intends to match the name with the actual content, hopefully making it more visible to newcomers to the field.

We wish you a wonderful symposium and we hope that you will take advantage of this event not only to listen to great presentations, but also to reconnect with your colleagues from the coding community.

François Gagnon and Catherine Douillard
General Chairs
Symposium Organizing Committee

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The International Symposium on Topics in Coding is grateful to all its sponsors for supporting the dissemination of high quality scientific contributions in coding theory and its applications. Thanks to our sponsors, and in particular our Platinum sponsors Huawei and our Gold sponsor Qualcomm, ISTC has been able to offer free early-bird registration and heavily discounted regular registration to all participants.

**Platinum Sponsor: Huawei**

Huawei is a leading global provider of information and communications technology (ICT) infrastructure and smart devices. With integrated solutions across four key domains – telecom networks, IT, smart devices, and cloud services – we are committed to bringing the benefits of digital innovation to every person, home, and organization for a fully connected, intelligent world.

Huawei’s end-to-end portfolio of products, solutions and services are competitive and secure. Through open collaboration with ecosystem partners, we create lasting value for our customers, working to empower people, enrich home life, and inspire innovation in organizations of all shapes and sizes.

At Huawei, innovation focuses on customer needs. We invest heavily in basic research, concentrating on technological breakthroughs that drive the world forward. We have more than 194,000 employees and operate in more than 170 countries and regions. Founded in 1987, Huawei is a private company wholly owned by its employees.

Established in 2008, Huawei Canada ranks amongst the top corporate R&D investors in the country and is committed to connecting Canadians for a better, brighter future. In 2021, Huawei Canada ranked among Canada’s Top 100 Most Attractive Employers, as voted on by engineering and IT students at universities across the country.

**Gold Sponsor: Qualcomm**

Qualcomm is the world’s leading wireless technology innovator and the driving force behind the development, launch, and expansion of 5G. When we connected the phone to the internet, the mobile revolution was born. Today, our foundational technologies enable the mobile ecosystem and are found in every 3G, 4G and 5G smartphone. We bring the benefits of mobile to new industries, including automotive, the internet of things, and computing, and are leading the way to a world where everything and everyone can communicate and interact seamlessly.

Qualcomm Incorporated includes our licensing business, QTL, and the vast majority of our patent portfolio. Qualcomm Technologies, Inc., a subsidiary of Qualcomm Incorporated, oper-
ates, along with its subsidiaries, substantially all of our engineering, research and development functions, and substantially all of our products and services businesses, including our QCT semiconductor business.

**Event Host: École de technologie supérieure (ÉTS)**

As one of the biggest schools of engineering in Canada that trains 25% of all Quebec engineers and ranks second in Canada for the number of undergraduate degrees granted in engineering, ÉTS is pleased to host the 2021 ISTC symposium. Research is the key for innovation and this is why we created, for instance, the communications and microelectronics integration laboratory (LACIME), and the resilient machine learning institute (ReMI), which intend to accelerate progress in terms of coding, communications and in many other technological areas.

**Academic Sponsors**

ISTC would like to thank all its academic sponsors École de technologie supérieure, École Polytechnique de Montréal, and McGill University, for their monetary contributions as well as for the many resources they provided to help with the organization of the conference.

**Technical Sponsors**

The conference also thanks the IEEE and the IEEE Information Theory Society for their support, and for publishing the accepted papers in IEEEXplore.
Overview

(All times are Montreal local times, UTC-4.)

Monday, August 30th, 2021

9:00 - 9:20  Welcome speech
9:20 - 10:20 Regular Session 1 & Regular Session 2
10:20 - 10:40 Coffee break
10:40 - 11:40 Keynote 1
11:40 - 13:00 Special Session 1
13:00 - 13:40 Break
13:40 - 14:40 Keynote 2

Tuesday, August 31st, 2021

9:00 - 9:20  Day 2 Introduction
9:20 - 10:20 Regular Session 3 & Regular Session 4
10:20 - 10:40 Coffee break
10:40 - 11:40 Keynote 3
11:40 - 13:00 Special Session 2
13:00 - 13:40 Break
13:40 - 14:40 Regular Session 5

Wednesday, September 1st, 2021

9:00 - 9:20  Day 3 Introduction
9:20 - 10:20 Regular Session 6 & Regular Session 7
10:20 - 10:40 Coffee break
10:40 - 12:00 Special Session 3
12:00 - 13:00 Keynote 4
13:00 - 13:40 Break
13:40 - 14:40 Regular Session 8
14:40 - 15:40 Poster Session
Thursday, September 2nd, 2021

9:00 - 9:20  Day 4 Introduction
9:20 - 10:20  Regular Session 9 & Regular Session 10
10:20 - 10:40  Coffee break
10:40 - 11:40  Keynote 5
11:40 - 13:00  Special Session 4
13:00 - 13:40  Break
13:40 - 14:40  Keynote 6

Friday, September 3rd, 2021

9:00 - 9:20  Day 5 Introduction
9:20 - 10:20  Regular Session 11
10:20 - 10:40  Coffee break
10:40 - 11:40  Keynote 7
11:40 - 12:40  Special Session 5
12:40 - 13:20  Break
13:20 - 14:20  Keynote 8
14:20 - 14:40  Closing remarks

Keynotes

Monday, August 30th, 2021

Keynote 1 : Yury Polyanskiy, LIDS, MIT, USA

Talk Title: Coding problems in the unsourced MAC model
Abstract: Any digital communication process starts with the “Initial Access” phase, in which the presence and identity (a short 100 bit message) of the communicating node needs to be made known to the base station. Due to the large number of nodes, modern systems need to enable simultaneous discovery of multiple nodes leading to the issue of random access. Exactly the same problem is faced by the LP-WAN networks servicing many low-rate, low duty-cycle uncoordinated sensors. Unsourced MAC (UMAC) is a simplified mathematical abstraction of these problems. In this talk we will review information-theoretic benchmarks on UMAC and then proceed to challenges in applying iterative coding methods for UMAC. Despite more than 50 years of work on random access, no production wireless networks employ any coded solutions and rely on the simplistic ALOHA. To dethrone ALOHA our community needs to invent UMAC codes with acceptable complexity.

Yury Polyanskiy is an Associate Professor of Electrical Engineering and Computer Science and a member of LIDS at MIT. Yury received M.S. degree in applied mathematics and physics from the Moscow Institute of Physics and Technology, Moscow, Russia in 2005 and Ph.D. degree in electrical engineering from Princeton University, Princeton, NJ in 2010. His research interests span information theory, statistical learning, error-correcting codes, wireless communication and fault tolerance. Dr. Polyanskiy won the 2013 NSF CAREER award and 2011 IEEE Information Theory Society Paper Award.
**Keynote 2: Olgica Milenkovic, University of Illinois, Urbana-Champaign (UIUC), USA**

**Talk Title:** Reducing the Latency and Cost of DNA-Based Data Storage Systems  
**Abstract:** DNA-based data storage is an emerging archival repository and computational paradigm that exploits unique properties of the DNA molecules to ensure ultra-high densities, extreme robustness/durability and ease of information copying/replication. The main issues that stand in the way of practical deployment of DNA-based storage platforms are the high cost of information recording and the large latency of both the read and write systems. We present an overview of our recently proposed approaches for addressing these issues based on multidimensional information recording and retrieval. In particular, we describe how to increase the size of the DNA alphabet to improve the cycle efficiency of recorders and how to use readily available native DNA and the topological dimension of the molecule to accommodate rewritable metadata. We also introduce new machine learning and computer vision methods the aim to reduce the overhead in the cost of the system design by eliminating the need for expensive worst-case error-control redundancy. Whenever the learning approaches prove to be inadequate, we provide descriptions of new coding approaches needed and the means to implement them.

Olgica Milenkovic is a professor of Electrical and Computer Engineering at the University of Illinois, Urbana-Champaign (UIUC), and Research Professor at the Coordinated Science Laboratory. She obtained her Masters Degree in Mathematics in 2001 and PhD in Electrical Engineering in 2002, both from the University of Michigan, Ann Arbor. Her scholarly contributions have been recognized by multiple awards, including the NSF Faculty Early Career Development (CAREER) Award, the DARPA Young Faculty Award, the Dean’s Excellence in Research Award, and several best paper awards. In 2013, she was elected a UIUC Center for Advanced Study Associate and Willett Scholar while in 2015 she was elected Distinguished Lecturer of the Information Theory Society. In 2018 she became an IEEE Fellow. She has served as Associate Editor of the IEEE Transactions of Communications, the IEEE Transactions on Signal Processing, the IEEE Transactions on Information Theory and the IEEE Transactions on Molecular, Biological and Multi-Scale Communications. In 2009, she was the Guest Editor in Chief of a special issue of the IEEE Transactions on Information Theory on Molecular Biology and Neuroscience.

**Tuesday, August 31st, 2021**

**Keynote 3: Henry D. Pfister, Duke University, USA**

**Talk Title:** Symmetry in Communications and Machine Learning  
**Abstract:** This talk considers the evolution of decoding methods that exploit symmetry to improve the performance of communication systems. Many of these methods were developed to improve the performance of iterative decoding algorithms for error correcting codes. These include random redundant decoding, multiple bases belief propagation, and using all minimum weight parity checks. Recently, automorphism ensemble decoding was shown to achieve surprisingly good decoding performance for Reed-Muller with relatively low complexity. Since this approach boils down to applying multiple bases belief propagation with a well-chosen parity-check matrix, we will also discuss why it outperforms previous approaches. Finally, we conclude by pointing out some connections with recent work in machine learning that also focuses on exploiting symmetry to improve performance.
**Wednesday, September 1st, 2021**

**Keynote 4: Eitan Yaakobi, Technion – Israel Institute of Technology, Israel**

**Talk Title:** The Sequence Reconstruction Problem and Its Connection to DNA Storage

**Abstract:** Reconstruction of sequences refers to a large class of problems in which there are several noisy copies of the information and the goal is to decode the information, either with small or zero error probability. The problem of using a set of erroneous sequences in order to recover the correct one falls under the framework of Levenshtein’s reconstruction problem and the trace reconstruction problem. One of the dominant motivating applications of the sequence reconstruction problems is DNA storage, where every DNA strand has several noisy copies. In the reconstruction problem, the sequence is a codeword and the goal is to determine the minimum number of noisy copies that guarantees unique decoding in the worst case. This number must be larger than the largest intersection of two balls of any two codewords in the code, where the ball is the set of all noisy copies that can be received. Even though the minimum number of copies which guarantees unique decoding has been solved in many cases, in practice, and in particular for the DNA storage channel, we do not necessarily have control on the size of each cluster, and it is very likely that this size is significantly smaller than the required minimum size. In this case, the goal is to minimize the distance between the original sequence and the decoder’s estimation or to output a small list of words which contain the correct sequence. This talk will review the recent advances in several problems that fall under the general framework of the sequence reconstruction problem and their applicability for DNA storage.

**Eitan Yaakobi** is an Associate Professor at the Computer Science Department at the Technion – Israel Institute of Technology. Between 2011-2013, he was a postdoctoral researcher in the department of Electrical Engineering at the California Institute of Technology. His research interests include information and coding theory with applications to non-volatile memories, associative memories, data storage and retrieval, and voting theory. He received the Marconi Society Young Scholar Award in 2009 and the Intel Ph.D. Fellowship in 2010-2011.

**Thursday, September 2nd, 2021**

**Keynote 5: Amin Shokrollahi, EPFL and Kandou Bus, Switzerland**

**Talk Title:** Chordal Codes for Chip-to-Chip Communication

**Abstract:** Modern electronic devices consist of a multitude of IC components: the processor,
the memory, the RF modem and the baseband chip (in wireless devices), and the graphics processor, are only some examples of components scattered throughout a device. The increase of the volume of digital data that needs to be accessed and processed by such devices calls for ever faster communication between these IC’s. Faster communication, however, often translates to higher susceptibility to various types of noise, and inevitably to a higher power consumption in order to combat the noise. This increase in power consumption is, for the most part, far from linear, and cannot be easily compensated for by Moore’s Law. In this talk I will give a short overview of problems encountered in chip-to-chip communication, and will advocate the use of novel coding techniques to solve those problems. I will also briefly talk about Kandou Bus, and some of the approaches the company is taking to design, implement, and market such solutions.

Amin Shokrollahi finished his PhD at the University of Bonn in 1991 where he was an assistant professor until 1995. From 1995 to 1998 he was at the International Computer Science Institute in Berkeley. In 1998 he joined the Bell Laboratories as a Member of the Technical Staff. From 2000 to 2009 he was the Chief Scientist of Digital Fountain. In 2003 he joined EPFL as a full professor of Mathematics and Computer Science. In 2011 he founded the company Kandou Bus which designs fast and energy efficient chip-to-chip links. Dr. Shokrollahi’s research covers a wide range of topics from pure mathematics to electronics. He has 200+ publications, and 150+ pending and granted patent applications. An IEEE Fellow, Dr. Shokrollahi’s honors include several IEEE Paper Awards, the IEEE Eric E. Sumner Award, the Advanced Research Grant of the ERC, the IEEE Hamming Medal, the Mustafa Prize, and the ISSCC Jan van Vessem Award for outstanding European paper.

Keynote 6: Warren J. Gross, McGill University, Canada

Talk Title: Practical Near-Maximum-Likelihood Decoding for 5G/6G
Abstract: New applications envisioned for networks in 5G and beyond place emphasis on ultra-reliable and low-latency communications. To simultaneously support the seemingly contradictory requirements placed on the error-correcting systems in future networks, near-maximum likelihood decoding of short block-length codes has become a focus of recent research. In this talk we will present recent results on several different near-maximum likelihood decoding techniques for short block-length codes, including techniques for decoding short Reed-Muller and Polar Codes, AI-assisted decoding, and GRAND decoding. An emphasis will be placed on reducing the complexity of near-ML decoding algorithms towards practical hardware implementations.

Warren J. Gross received the B.A.Sc. degree in electrical engineering from the University of Waterloo, Waterloo, ON, Canada, in 1996, and the M.A.Sc. and Ph.D. degrees from the University of Toronto, Toronto, ON, Canada, in 1999 and 2003, respectively. He is currently a Professor, the Louis-Ho Faculty Scholar in Technological Innovation, and the Chair of the Department of Electrical and Computer Engineering, McGill University, Montreal, QC, Canada. His research interests are in the design and implementation of signal processing systems and custom computer architectures. Dr. Gross is a licensed Professional Engineer in the Province of Ontario. He served as the Chair of the IEEE Signal Processing Society Technical Committee on Design and Implementation of Signal Processing Systems. He has
served as a General Co-Chair of IEEE Nanoarch 2020, IEEE GlobalSIP 2017, IEEE SiPS 2017, and as a Technical Program Co-Chair of SiPS 2012. He served as an Associate Editor for the IEEE TRANSACTIONS ON SIGNAL PROCESSING and as a Senior Area Editor.

Friday, September 3rd, 2021

Keynote 7: Hans-Andrea Loeliger, Swiss Federal Institute of Technology in Zürich (ETH), Switzerland

Talk Title: NUV Representations and Applications, Old and New

Abstract: NUV priors (normals with unknown variance) enormously increase the expressive power of otherwise linear Gaussian models. Such models are naturally associated with iterative algorithms that alternate between a descent step (or Gaussian message passing) with fixed variances, and independent scalar updates of the unknown variances. In a state space setting, the Gaussian step is naturally carried out by Kalman-type recursions, with complexity linear in “time”. NUV representations of \( \exp(-\kappa(x)) \) have been known, e.g., for \( \kappa(x) = |x|^p \) with \( p > 0 \), \( \kappa(x) = \nu \log |x| \) with \( \nu > 0 \), smoothed versions thereof, and vector versions where \( |x| \) is replaced by \( \|x\| \). Very recently, composite NUV priors have been devised that effectively binarize (i.e., constrain \( x \) to \{a, b\}) or enforce half-space constraints, which opens a wide range of new applications in control and communications.

Hans-Andrea Loeliger received the Diploma in electrical engineering and a PhD degree (1992) from ETH Zurich. From 1992 to 1995, he was with Linköping University, Sweden. From 1995 to 2000, he was a full-time technical consultant and co-owner of a consulting company. Since 2000, he has been a professor at the Department of Information Technology and Electrical Engineering of ETH Zurich. His research interests have been in the broad areas of signal processing, machine learning, information theory, quantum systems, error correcting codes, communications, electronic circuits, and neural computation.

Keynote 8: Pramod Viswanath, University of Illinois, Urbana-Champaign (UIUC), USA

Talk Title: KO Codes

Abstract: Landmark codes underpin reliable physical layer communication, e.g., Reed-Muller, BCH, Convolution, Turbo, LDPC and Polar codes: each is a linear code and represents a mathematical breakthrough. The impact on humanity is huge: each of these codes has been used in global wireless communication standards (satellite, WiFi, cellular). Reliability of communication over the classical additive white Gaussian noise (AWGN) channel enables benchmarking and ranking of the different codes. In this paper, we construct KO codes, a computationally efficient family of deep-learning driven (encoder, decoder) pairs that outperform the state-of-the-art reliability performance on the standardized AWGN channel. KO codes beat state-of-the-art Reed-Muller and Polar codes, under the low-complexity successive cancellation decoding, in the challenging short-to-medium block length regime on the AWGN channel. We show that the gains of KO codes are primarily due to the nonlinear mapping of information bits directly to transmit symbols (bypassing modulation) and yet possess an efficient, high performance decoder. The key technical innovation that renders this possible is the design of a novel family of neural architectures inspired by the computation tree of the Kronecker Operation (KO) central to Reed-Muller and Polar codes. These architectures pave the way for the discovery of a much richer class of hitherto unexplored nonlinear algebraic structures. The code is available
Pramod Viswanath received the Ph.D. degree in electrical engineering and computer science from University of California at Berkeley in 2000. From 2000 to 2001, he was a member of research staff at Flarion technologies, NJ. Since 2001, he is on the faculty at University of Illinois at Urbana Champaign in Electrical and Computer Engineering, where he currently is a professor. His current research interests are in first principles design of blockchains.

Regular and Special Sessions

Monday, August 30th, 2021

Regular Session 1: Turbo Coding

Chairperson: Catherine Douillard (IMT Atlantique, France)

09:20 Low Complexity Non-binary Turbo Decoding based on the Local-SOVA Algorithm

Hugo Le Blevec, Rami Klaimi (IMT Atlantique, France), Stefan Weithoffer (IMT Atlantique, France), Charbel Abdel Nour (IMT Atlantique, France), and Amer Baghdadi (Télécom Bretagne, France)

Non-binary Turbo codes have been shown to outperform their binary counterparts in terms of error correcting performance yet the decoding complexity of the commonly used Min-Log-MAP algorithm prohibits efficient hardware implementations. In this work, we apply for the first time the recently proposed Local SOVA algorithm for decoding non-binary Turbo codes. Moreover, we propose a low complexity variant dedicated to the direct association with high order constellations denoted by the nearest neighbor Local SOVA. It considers only a limited amount of nearest competing constellation symbols for the soft output computation. Simulation results show that this approach allows a complexity reduction of up to 52% in terms of add-compare-select operations while maintaining the same error correcting performance compared to the Min-Log-MAP algorithm. It can even reach up to 80% if high code rates or frame error rates higher than $10^{-4}$ are targeted. The achieved complexity reduction represents a significant step forward towards hardware implementation.

09:40 Simplified recursion units for Max-Log-MAP: New trade-offs through variants of Local-SOVA

Rami Klaimi, Stefan Weithoffer (IMT Atlantique, France), Charbel Abdel Nour (IMT Atlantique, France), and Catherine Douillard (IMT Atlantique, France)

The Log-domain BCJR algorithm is broadly used in iterative decoding processes. However, the serial nature of the recursive state metric calculations is a limiting factor for throughput increase. A possible solution resorts to high-radix decoding,
which involves decoding several successive symbols at once. Despite several studies aiming at reducing its complexity, high-radix processing remains the most computationally intensive part of the decoder when targeting very high throughput. In this work, we propose a reformulation specifically targeting the complexity reduction of the recursive calculation units by either limiting the required number of operations or by selectively removing unnecessary ones. We report a complexity reduction of the add-compare-select units in the order of 50% compared to the recently proposed local-SOVA algorithm. In addition, our results show that several performance/complexity trade-offs can be achieved thanks to the proposed simplified variants. This represents a promising step forward in order to implement efficient very high throughput convolutional decoders.

10:00 Shuffled Decoding of Serial Concatenated Convolutional Codes
Aomar Bourenane, Matthieu Arzel (IMT Atlantique, France), Frederic Guilloud (IMT Atlantique, France), and Alain Thomas (Safran Data Systems, France)

Shuffled decoding enables to accelerate the extrinsic information exchange during iterative decoding of concatenated codes. It has already been applied to parallel convolutional codes or low-density parity-check codes. In this article, we propose to apply shuffled decoding to serial concatenation convolutional codes. We take advantage of their systematic encoding to propose an efficient shuffled decoding scheme. Compared to a standard iterative decoding scheme, the convergence of our shuffled implementation is obtained within fewer iterations, each one requiring also less time to be completed. This convergence acceleration yields doubling the throughput. We finally show that doubling the throughput comes at a lower cost than doubling the hardware resources, making this shuffled scheme efficient in term of implementation. For instance, the memory usage is 29% more efficient thanks to our proposal than a baseline scheme, which significantly reduces the power consumption of hardware decoders.

Regular Session 2: Emerging Applications
Chairperson: Lele Wang (University of British Columbia, Canada)

09:20 Frame Codes For Distributed Coded Computation
Royee Yosibash, and Ram Zamir (Tel Aviv University, Israel)

In the last years, some algorithms have struggled with the run time of large scale and computationally complex tasks needing a many consecutive calculations. A common practice for decreasing run-time in such algorithms is using a large distributed system comprised of individual computational nodes. One of the more significant challenges in these large systems are the “stragglers” - computational nodes whom, unexpectedly, have a significantly higher response time than their non-straggling counterparts. Taking this uncertainty into account calls for a “back-up” scheme in order to ensure high-quality service. One such method is implementing a coding technique taken from the realm of information and code theory. In information theory’s terms, these straggler nodes are considered as “erasures” - a symbol in a stream that is lost and the receiver knows only through side information that the symbol’s real value is unknown. Some of the codes that have been looked into include general
maximum distance separable (MDS) codes, Reed-Solomon (RS) or Bose-Chaudhuri-Hocquenghem (BCH) codes and the general case polynomial codes. In order to evaluate which code is best suited for distributed computation, many research groups have chosen performance measures such as computational complexity of recovery, or average run-time, in order to show that a certain code is a good solution. But the above erasure correction codes - when applied to real-valued data - are sensitive to computational errors. In particular, the decoding process may highly amplify these errors due to it being numerically unstable. This amplification of the computational errors incited other codes to be created that try minimizing that amplification affect. In this paper we try to tackle this issue by introducing codes based on results taken from novel ideas from frame theory and random matrix theory. Specifically, we show how new variations of polynomial codes over the complex field could be constructed with these frame-centric design guidelines. The noise amplification of these codes follow the theoretical expectations, and one of the suggested type of codes has near identical amplification as the benchmark for optimum noise amplification.

**09:40 Irregular Invertible Bloom Look-Up Tables**  
*Francisco Lázaro, and Balazs Matuz (German Aerospace Center (DLR), Germany)*

We consider invertible Bloom lookup tables (IBLTs) which are probabilistic data structures that allow to store key-value pairs. An IBLT supports insertion and deletion of key-value pairs, as well as the recovery of all key-value pairs that have been inserted, as long as the number of key-value pairs stored in the IBLT does not exceed a certain number. The recovery operation on an IBLT can be represented as a peeling process on a bipartite graph. We present a density evolution analysis of IBLTs which allows to predict the maximum number of key-value pairs that can be inserted in the table so that recovery is still successful with high probability. This analysis holds for arbitrary irregular degree distributions and generalizes results in the literature. We complement our analysis by numerical simulations of our own IBLT design which allows to recover a larger number of key-value pairs as state-of-the-art IBLTs of same size.

**10:00 Variants on Block Design Based Gradient Codes for Adversarial Stragglers**  
*Animesh Sakorikar, and Lele Wang (University of British Columbia, Canada)*

Gradient coding is a coding theoretic framework to provide robustness against slow or unresponsive machines, known as stragglers, in distributed machine learning applications. Recently, Kadhe et al. proposed a gradient code based on a combinatorial design, called balanced incomplete block design (BIBD), which is shown to outperform many existing gradient codes in worst-case adversarial straggling scenarios. However, parameters for which such BIBD constructions exist are very limited. In this paper, we aim to overcome such limitations and construct gradient codes which exist for a wide range of parameters while retaining the superior performance of BIBD gradient codes. Two such constructions are proposed, one based on a probabilistic construction that relax the stringent BIBD gradient code constraints, and the other based on taking the Kronecker product of existing gradient codes. Theoretical error bounds for worst-case adversarial stragglng scenarios are derived. Simulations show that the proposed constructions can outperform existing gradient codes with similar redundancy per data piece.
Special Session 1: Distributed Computing

Chairperson: Stark Draper (University of Toronto, Canada)

11:40 Rateless Codes for Distributed Non-linear Computations

Ankur Mallick, Sophie Smith (Carnegie Mellon University, USA), and Gauri Joshi (Carnegie Mellon University, USA)

Machine learning today involves massive distributed computations running on cloud servers, which are highly susceptible to slowdown or straggling. Recent work has demonstrated the effectiveness of erasure codes in mitigating such slowdown for linear computations, by adding redundant computations such that the entire computation can be recovered as long as a subset of nodes finish their assigned tasks. However, most machine learning algorithms typically involve non-linear computations that cannot be directly handled by these coded computing approaches. In this work, we propose a coded computing strategy for mitigating the effect of stragglers on non-linear distributed computations. Our strategy relies on the observation that many expensive non-linear functions can be decomposed into sums of cheap non-linear functions. We show that erasure codes, specifically rateless codes can be used to generate and compute random linear combinations of these functions at the nodes such that the original function can be computed as long as a subset of nodes return their computations. Simulations and experiments on AWS Lambda demonstrate the superiority of our approach over various uncoded baselines.

12:00 Iteration Based Analysis of Straggling Channel Decoders for Network Function Virtualization

Yashar Naderzadeh, and Joerg Kliewer (New Jersey Institute of Technology, USA)

We consider the uplink of a cloud radio access network, in which baseband functionality is offloaded to the off-the-shelf servers in the cloud via network function virtualization (NFV). Specifically, we consider channel decoding of iteratively decodable channel codes as an important time-critical baseband operation. It has been shown that by reencoding the received channel codewords at the cloud by a linear NFV code, the impact of straggling decoders can be reduced. In previous work the channel decoding operation in each server after some probabilistic processing delay was assumed to have converged to a codeword with only negligible probability of error. In contrast, in this work we leverage the fact that for iterative decoding we can trade-off latency versus decoding error by considering intermediate decoding results, i.e., after each decoder iteration. We derive an analytical expression for the frame unavailability probability as a function of the decoding latency and thus of the minimum number of iterations at all decoders. We show that for LDPC codes the minimum latency is significantly reduced if we also combine intermediate results of the decoders at each iteration.

12:20 Exploitation of temporal structure in momentum-SGD for gradient compression

Tharindu Adikari, and Stark Draper (University of Toronto, Canada)

Distributed optimization has become the norm for training machine learning models on large datasets. Learning bigger models on such systems leads to the exchange
of large-volume updates. For this reason, limits on network communication in a distributed system can bottleneck learning progress. While compression techniques have been introduced to reduce bit-rates, no methods have yet leveraged the temporal structure that exist in consecutive vector updates. An important example is distributed momentum-SGD where temporal correlation is enhanced by the low-pass-filtering effect of applying momentum. In this paper we design methods that leverage temporal correlation to reduce bit-rates in systems employing momentum-SGD. We demonstrate that a significant reduction in the volume of communication can be realized. Experiments with the ImageNet dataset show that our proposed methods offers up to 40% bit savings compared to widely used methods such Scaled-sign and Top-K.

12:40 Codes for (Un)Expected Loads

Emina Soljanin (Rutgers University, USA)

Distributed computing systems strive to maximize the number of concurrent data access requests they can support with fixed resources. Replicating data objects according to their relative popularity and access volume helps achieve this goal. However, these quantities are often unpredictable. In emerging applications such as edge computing, not only the instantaneous but also the expected numbers of users and their data interests extensively fluctuate. Therefore, data storage schemes should support such dynamics. Erasure-coding is emerging as an efficient and robust form of redundant storage. This talk asks which data access rates erasure-coded systems can support. It introduces the notion of access service rate region and argues that it should be an essential consideration in designing efficient distributed systems that must remain stable for a wide range and multiple combinations of mean loads. We will explain the recently recognized connections with batch codes for load balancing and combinatorial optimization on graphs. We will discuss some systems issues as well.

Tuesday, August 31st, 2021

Regular Session 3: Physical Layer Communication

Chairperson: Karine Amis (IMT Atlantique, France)

09:20 PAM-6 Coded Modulation for IM/DD Channels with a Peak-Power Constraint

Tobias Prinz, Thomas Wiegart (Technical University of Munich, Germany), Daniel Plabst (Technische Universität München, Germany), Stefano Calabro (Huawei Technologies Duesseldorf GmbH, Germany), Georg Böcherer (Huawei Technologies, France), Nebojsa Stojanovic (Huawei Technologies Duesseldorf GmbH, Germany), and Talha Rahman (Huawei Technologies Duesseldorf GmbH, Germany)

Coded modulation with probabilistic amplitude shaping (PAS) is considered for intensity modulation/direct detection channels with a transmitter peak-power constraint. PAS is used to map bits to a uniform PAM-6 distribution and outperforms PAM-8 for rates up to around 2.3 bits per channel use. PAM-6 with PAS also
outperforms a cross-shaped QAM-32 constellation by up to 1 dB and 0.65 dB after bit-metric soft- and hard decoding, respectively. An alternative PAM-6 scheme based on a framed-cross-shaped QAM-32 constellation is proposed that shows similar gains.

09:40 Multiuser MIMO Detection With Composite NUV Priors

Gian Marti, Raphael Keusch (ETH Zurich, Switzerland), and Hans-Andrea Loeliger (ETH Zurich, Switzerland)

Normals with unknown variances (NUV) representations encompass both variational representations of sparsifying norms and priors for sparse Bayesian learning. Recently, a binarizing NUV prior has been proposed and shown to work very well on certain approximation problems. This paper elaborates on this new prior and begins to explore its use for recovery problems. Specifically, the method is applied to the multiuser multiple-input multiple-output (MIMO) detection problem and empirically compared with existing approaches. We find that it outperforms methods based on convex relaxations and that it is more robust than a method based on approximate message-passing.

10:00 Improved Dimming Scheme based on Non-DC Free RLL Codes for VLC

Elie Ngomseu Mambou, Thibaud Tonnellier (McGill University, Canada), and Warren Gross (McGill University, Canada)

The dimming control is crucial for visible light communication (VLC) channels to maintain data transmission at different levels of lighting brightness. However, ensuring the dimming control while keeping a flicker-free channel remains a challenging task in VLC. Conventional techniques use the interleaving of compensation symbols (CS) applied on balanced codewords, usually obtained via run-length limited (RLL) codes. However, CS increases the redundancy used and are just thrown away during the decoding. Moreover, the interleaving step may increase the latency of the system. In this letter, new families of non-DC free RLL codes with variable weights are proposed. The dimming control can therefore be achieved without CS. Simulations stipulate that the proposed 4B7B code in FEC-coded channels achieve dimming ratios of 29% and 71% while improving on redundancy and error correction performance. For a 29% and 71% dimming ratios, at a BER of 0.0001, gains in dB of 0.8 and 0.6 versus 3 and 2.6 are reported between the coded proposed RLL against the coded 1B2B and 4B6B with CS respectively.

Regular Session 4: Coded Modulation

Chairperson: Emmanuel Boutillon (Université de Bretagne Sud, France)

09:20 Symbol Message Passing Decoding of LDPC Codes for Orthogonal Modulations

Emna Ben Yacoub, and Balazs Matuz (German Aerospace Center (DLR), Germany)

A simple decoder for q-ary low-density parity-check codes is studied, termed symbol message passing. The decoder passes hard decisions from a q-ary alphabet. For orthogonal modulations over the additive white Gaussian channel for which the modulation order and the field order q are equal, it is shown that the extrinsic messages
can be modelled as observations of a q-ary symmetric channel, allowing to work out
density evolution equations. A stability analysis is provided which emphasizes the
influence of degree-3 variable nodes. Simulation results show performance gains for
increasing q w.r.t. binary low-density parity-check codes with bit-interleaved coded
modulation, and potential savings in decoding complexity.

09:40 Rate-adaptive Inner Code for Non-binary Decoders

Cédric Marchand, and Emmanuel Boutillon (Université de Bretagne Sud, France)

In most communication systems, the coding rate of the error control code adapts to
the channel condition. In this paper, we propose a new approach. A fixed coding rate
GF(q) Non-binary code is used as an outer code, and a cardinal q non-linear inner
code is truncated to match the channel condition. The inner code is a Truncated
Cyclic Code Shift Keying code. Simulation results for a payload of 120 bits show
state-of-the-art performances in a wide range of SNR from -13.5 to 7 dB.

10:00 Design of Iterative Demapping Schedules for Reduced-Complexity BICM-ID with Bi-

tary LDPC Codes and Orthogonal Modulations

Rémi Chauvat, Axel Garcia-Pena (ENAC, France), and Matteo Paonni
(Joint Research Centre, European Commission, Italy)

LDPC-coded modulations are attractive solutions for many communications links. BICM provides a very simple, flexible yet effective way of combining binary chan-
nel codes with non-binary modulations. However, iterative demapping is sometimes
necessary to increase the coding gains. This is especially the case for orthogonal
modulations where the “BICM capacity” falls far away from the coded modulation
capacity. Unfortunately, iterative demapping results in a significant computational
cost. A pragmatic solution to reduce this computational cost aims at restricting the
number of demapping activations. In this article, a strategy to compute the minimum
number of demapping activations necessary for a target estimated BER performance
is presented and results are introduced for BICM-ID with binary LDPC-coded or-
thogonal modulations. Iterative demapping schedules optimized for a limited number
of demapper activations are designed and evaluated in the finite code length regime.

Special Session 2: ML for Communications

Chairpersons: Yair Be’ery (Tel Aviv University, Israel) and Henry Pfister (Duke Uni-

versity, USA)

11:40 Serial vs. Parallel Turbo-Autoencoders and Accelerated Training for Learned Channel

Codes

Jannis A Clausius, Sebastian Dörner (University of Stuttgart, Ger-

many), Sebastian Cammerer (Nvidia, Germany), and Stephan ten
Brink (University of Stuttgart, Germany)

Attracted by its scalability towards practical codeword lengths, we revisit the idea
of Turbo-autoencoders for end-to-end learning of PHY-Layer communications. For
this, we study the existing concepts of Turbo-autoencoders from the literature and
compare the concept with state-of-the-art classical coding schemes. We propose a
new component-wise training algorithm based on the idea of Gaussian a priori dis-
tributions that reduces the overall training time by almost a magnitude. Further, we
propose a new serial architecture inspired by classical serially concatenated Turbo code structures and show that a carefully optimized interface between the two component autoencoders is required. To the best of our knowledge, these serial Turbo autoencoder structures are the best known neural network based learned sequences that can be trained from scratch without any required expert knowledge in the domain of channel codes.

**12:00 Symbol-Level Online Channel Tracking for Deep Learning-Aided Receivers**

Ron Aharon Finish and Yoav Cohen (Ben-Gurion University of the Negev, Israel) and Tomer Raviv (Tel-Aviv University, Israel) and Nir Shlezinger (Ben-Gurion University of the Negev, Israel)

N/A

**12:20 CSI-aided Robust Neural-based Decoders**

Meryem Benammar, Eduardo Dadalto Camara Gomes (Centrale-Supélec CNRS Université Paris Saclay, France), and Pablo Piantanida (CentraleSupélec CNRS Université Paris Saclay, France)

In this work, we investigate the design of neural based channel decoders for the Binary Asymmetric Channel (BAC), which exhibits robustness issues related to training/testing channel parameters mismatch. Rather than enforcing the independence of the trained model to the channel parameter as in our previous work, we show that providing even a coarse (possibly imperfect) quantized CSI to the decoder, allows to build a single robust neural decoder for all values of channel parameters.

**12:40 Deep Waveform Learning for the Next Generation of Communication Systems**

Mathieu Goutay (Nokia Bell Labs and Université de Lyon, France), Fayçal Ait Aoudia (Nokia Bell Labs), Jakob Hoydis (NVIDIA Research), and Jean-Marie Gorce (Université de Lyon, France)

Orthogonal frequency division multiplexing (OFDM) is a key component of current radio systems, thanks to its very efficient implementation and easy single tap equalization at the receiver. However, it suffers from high peak-to-average power ratio (PAPR) and poor spectral containment. In this work, we investigate the use of neural networks to reduce these drawbacks and achieve a better tradeoff between rate and PAPR under controled adjacent channel leakage ratios (ACLRs). Our approach relies on a neural network (NN)-based high-dimensional modulation scheme and a NN-based receiver, both operating on top of OFDM. Simulations results show that our approach achieves higher rates than a pilot reduction tone (PRT) scheme, while enabling similar PAPR reductions.

**Regular Session 5: Reed-Muller Codes**

Chairperson: Warren Gross (McGill University, Canada)

**13:40 Iterative Reed-Muller Decoding**

Marvin Geiselhart, Ahmed Elkelesh (University of Stuttgart, Germany), Moustafa Ebada (University of Stuttgart, Germany), Sebastian Cammerer (Nvidia, Germany), and Stephan ten Brink (University of Stuttgart, Germany)
Reed-Muller (RM) codes are known for their good maximum likelihood (ML) performance in the short block-length regime. Despite being one of the oldest classes of channel codes, finding a low complexity soft-input decoding scheme is still an open problem. In this work, we present a belief propagation (BP) decoding architecture for RM codes based on their rich automorphism group. The decoding algorithm can be seen as a generalization of multiple-bases belief propagation (MBBP) using polar BP as constituent decoders. We provide extensive error-rate performance simulations and compare our results to existing decoding schemes. We report a near-ML performance for the RM(3,7)-code (e.g., 0.05 dB away from the ML bound at BLER of $10^{-4}$) at a competitive computational cost. To the best of our knowledge, our proposed decoder achieves the best performance of all iterative RM decoders presented thus far.

14:00 Reduced Complexity RPA Decoder for Reed-Muller Codes

Jiajie Li, Syed Mohsin Abbas (McGill University, Canada), Thibaud Tonnellier (McGill University, Canada), and Warren Gross (McGill University, Canada)

The recursive projection-aggregation (RPA) decoder is a recently proposed near maximum likelihood (ML) decoder for Reed-Muller (RM) codes with low rates and short code lengths. However, the high computational complexity of RPA decoding is a major bottleneck for using RPA in applications that have a limited resource and energy budget. In this work, syndrome-based early stopping techniques as well as a scheduling scheme is proposed for the RPA decoder, which help in reducing the computational complexity while keeping similar decoding performance. Comparing to the baseline RPA decoder, the proposed techniques result in a 69 - 98% reduction in average computational complexity for a target frame error rate (FER) of $1e^{-5}$. Additionally, this work introduces hardware-friendly approximation functions to replace the RPA’s computationally expensive transcendental projection function.

14:20 Improved hybrid RM-polar codes and decoding on stable permuted factor graphs

Wei Wu, Zhen Zhai (University of California San Diego, USA), and Paul H. Siegel (University of California, San Diego, USA)

A new family of modified polar codes and a new permutation selection scheme for belief propagation list (BPL) decoding are presented. We first propose a new code construction methodology to interpolate between Reed-Muller (RM) codes and polar codes. By taking advantage of an existing partial order on bit-channels whose corresponding indices share the same Hamming weight, we analyze the complexity of the new construction method. It is shown that we need to compute the reliability of roughly a fraction $1/\log_3 N$ of all the bit-channels contained in the subset. Then, we explore a special family of factor-graph layer permutations called stable permutations (SPs) that preserve a specified information set when the corresponding bit permutations are applied to message bit indices. Simulation results show that the error-rate performance of the new family of codes is better than that of 5G polar codes under successive cancellation list (SCL) decoding. In addition, the SP selection scheme stands out as a preferred one for BPL decoding in terms of error-rate performance, while the average number of iterations per belief propagation (BP) decoder on the permuted factor graph is close to that of the original BP decoder when an early stopping condition is applied.
Wednesday, September 1\textsuperscript{st}, 2021

Regular Session 6: New Applications

Chairperson: Elsa Dupraz (IMT Atlantique, France)

09:20 An Improved Sliding Window BATS Code

Sachini Jayasooriya, Jinhong Yuan (University of New South Wales, Australia), and Yixuan Xie (University of New South Wales, Australia)

Batched sparse (BATS) codes, a class of random linear network coding, are proposed to transmit a collection of packets through erasure networks. BATS codes generalize the fountain codes and preserve properties such as ratelessness and low encoding/decoding complexity. In BATS codes, the destination node starts decoding information packets only after receiving a sufficient number of coded packets. This induces a latency. The larger the size of information block is, the longer the latency. In this paper, we apply sliding window framework over BATS codes, that divides the information block into smaller sub-blocks, thus helping to reduce the latency. In the proposed sliding window BATS coding scheme, multiple degree distributions are designed based on the overlapping pattern of input packets in a window, and coded packets are generated accordingly. Based on asymptotic performance analysis, we formulate a heuristic optimization problem to jointly optimize the degree distribution and the window selection probability for each sub-window. Simulation results show that the proposed sliding window BATS code outperforms the standard BATS codes and existing sliding window BATS codes in terms of overhead and latency.

09:40 Joint Source-Channel Codes Based on a Single Protograph

Francis C.M. Lau, and Jia Zhan (The Hong Kong Polytechnic University, Hong Kong)

In this paper, we propose using a single protograph to design joint source-channel codes (JSCCs). We present a generalized algorithm, called protograph extrinsic information transfer for JSCC algorithm (PEXIT-JSCC algorithm), for analyzing the channel threshold of the proposed JSCC. Using the classic AR3A and AR4JA protographs, we construct AR3A-JSCC and AR4JA-JSCC codes. We analyze their decoding thresholds and compare their performance with JSCC systems using optimized double protograph low-density-party-check codes.

10:00 Channel Model with Memory for DNA Data Storage with Nanopore Sequencing

Belaid Hamoum, Elsa Dupraz (IMT Atlantique, France), Laura Conde-Canencia (Université de Bretagne Sud, France), and Dominique Lavenier (Cnrs-Irisa, France)

This paper is dedicated to channel modeling and error-correction coding for DNA data storage with nanopore sequencing. We first propose a novel statistical model for DNA storage, which takes into account the memory within DNA storage error events, and follows the way nanopore sequencing works. Compared to existing channel models, the proposed model represents more accurate experimental datasets. We also propose a full error-correction scheme for DNA storage, based on a consensus algorithm and non-binary LDPC codes. Especially, we introduce a novel synchronization
method which allows to eliminate remaining deletion errors after the consensus, before applying a belief-propagation LDPC decoding algorithm to correct substitution errors. This method exploits the LDPC code structure to correct deletions, and does not require adding any extra redundancy.

Regular Session 7: Polar Decoding

Chairperson: Charbel Abdel Nour (IMT Atlantique, France)

09:20 Reduced Complexity of a Successive Cancellation Based Decoder for NB-Polar Codes

Franklin Cochachin Henestroza, Laura Luzzi (ENSEA & CNRS, Université de Cergy-Pontoise, France), and Fakhreddine Ghaifafi (ETIS University of Paris Seine ENSEA CNRS, France)

This paper proposes a simplified version of the Successive Cancellation (SC) decoder for Non-Binary Polar (NB-Polar) codes. The proposed decoder, named Successive Cancellation Min-Sum (SC-MS), is exclusively formulated in the Log-Likelihood Ratio (LLR) domain to reduce the decoding complexity of the SC decoder. The NB-Polar codes are associated with Cyclic Code-Shift Keying (CCSK) modulation to obtain a new coded modulation scheme for ultra-low signal-to-noise ratios (SNRs). The quantized version of the SC-MS decoder is investigated using quantized LLRs on optimized size of bits. Our simulation results show that the SC-MS decoder presents a negligible performance degradation with respect to the SC decoder for code length $N < 2048$. Additionally, the 2-bit SC-MS and 3-bit SC-MS offer a good trade-off between decoding performance and complexity.

09:40 List decoding for concatenated codes based on the Plotkin construction with BCH component codes

Daniel Nicolas Bailon, and Juergen Freudenberger (University of Applied Sciences, Konstanz & Institute for System Dynamics (ISD), Germany)

Reed-Muller codes are a popular code family based on the Plotkin construction. Recently, these codes have regained some interest due to their close relation to polar codes and their low-complexity decoding. We consider a similar code family, i.e., the Plotkin concatenation with binary BCH component codes. This construction leads to increased flexibility regarding the attainable code parameters. Moreover, these codes have better code parameters and error correction performance than comparable RM codes. In this work, we consider a list-based decoding algorithm for the Plotkin concatenation with BCH component codes. The proposed list decoding leads to a significant coding gain with only a small increase in computational complexity. Simulation results demonstrate that the Plotkin concatenation with the proposed decoding achieves near maximum likelihood decoding performance. This coding scheme can outperform polar codes for moderate code lengths.

10:00 Input-distribution-aware parallel decoding of block codes

Carlo Condo, and Alex Nicolescu (Infinera, Canada)

Many channel decoders rely on parallel decoding attempts to achieve good performance with acceptable latency. However, most of the time fewer attempts than the
foreseen maximum are sufficient for successful decoding. Input-distribution-aware (IDA) decoding allows to determine the parallelism of polar code list decoders by observing the distribution of channel information. In this work, IDA decoding is proven to be effective with different codes and decoding algorithms as well. Two techniques, M-IDA and MD-IDA, are proposed: they exploit the sampling of the input distribution inherent to particular decoding algorithms to perform low-cost IDA decoding. Simulation results on the decoding of BCH codes via the Chase and ORBGRAND algorithms show that they perform at least as well as the original IDA decoding, allowing to reduce run-time complexity down to 17% and 67% with minimal error correction degradation.

**Special Session 3: High-Throughput Coding**

**Chairperson:** Alexandre Graell i Amat *(Chalmers University of Technology, Sweden)*

**10:40** Design of Spatially Coupled Turbo Product Codes for Optical Communications

**Guido Montorsi, and Sergio Benedetto** *(Politecnico di Torino, Italy)*

A new design is proposed for spatially coupled turbo product codes matching the challenging constraints of forward error correcting codes for optical communication applications. The design includes a simple encoding algorithm that matches the reduced rate of the code w.r.t. the block turbo product codes and keeps the frame structure of the original block product code by replacing part of the information bits with properly designed check on checks. Moreover, conditions are shown on the spatially coupling matrix on the code that allows to increase the minimum distance of the code, thus coping with the very low bit error probability required in optical communications.

**11:00** FAID Diversity via Neural Networks

**Xin Xiao, Nithin Raveendran** *(University of Arizona, USA)*, **Bane Vasic** *(University of Arizona, USA)*, **Shu Lin** *(University of California, Davis, USA)*, and **Ravi Tandon** *(University of Arizona, USA)*

Decoder diversity is a powerful error correction framework in which a collection of decoders collaboratively correct a set of error patterns otherwise uncorrectable by any individual decoder. In this paper, we propose a new approach to design the decoder diversity of finite alphabet iterative decoders (FAIDs) for Low-Density Parity Check (LDPC) codes over the binary symmetric channel (BSC), for the purpose of lowering the error floor while guaranteeing the waterfall performance. The proposed decoder diversity is achieved by training a recurrent quantized neural network (RQNN) to learn/design FAIDs. We demonstrated for the first time that a machine-learned decoder can surpass in performance a man-made decoder of the same complexity. As RQNNs can model a broad class of FAIDs, they are capable of learning an arbitrary FAID. To provide sufficient knowledge of the error floor to the RQNN, the training sets are constructed by sampling from the set of most problematic error patterns - trapping sets. In contrast to the existing methods that use the cross-entropy function as the loss function, we introduce a frame-error-rate (FER) based loss function to train the RQNN with the objective of correcting specific error patterns rather than reducing the bit error rate (BER). The examples and simulation results show that
the RQNN-aided decoder diversity increases the error correction capability of LDPC codes and lowers the error floor.

11:20 Quaternary Message Passing Decoding of LDPC Codes: Density Evolution Analysis and Error Floor

Emna Ben Yacoub, Balazs Matuz (German Aerospace Center (DLR), Germany), Alexandre Graell i Amat (Chalmers University of Technology, Sweden), and Gianluigi Liva (German Aerospace Center (DLR), Germany)

We revisit a coarsely quantized message passing decoding algorithm for low-density parity-check (LDPC) code ensembles, named quaternary message passing (QMP). Particularly, we analyze the performance of unstructured LDPC codes under QMP decoding by means of density evolution. The impact of degree-2 and degree-3 variable nodes on the error floor performance is also discussed. We design a code for QMP that performs within 0.55 dB of the 5G LDPC code at a block error rate of $10^{-4}$.

11:40 On Parameter Optimization and Reach Enhancement for the Improved Soft-Aided Staircase Decoder

Yi Lei, Bin Chen (Hefei University of Technology, China), Gabriele Liga (Eindhoven University of Technology, The Netherlands), and Alex Alvarado (Eindhoven University of Technology (TU/e), The Netherlands)

The so-called improved soft-aided bit-marking algorithm was recently proposed for staircase codes (SCCs) in the context of fiber optical communications. This algorithm is known as iSABM-SCC. With the help of channel soft information, the iSABM-SCC decoder marks bits via thresholds to deal with both miscorrections and failures of hard-decision (HD) decoding. In this paper, we study iSABM-SCC focusing on the parameter optimization of the algorithm and its performance analysis, in terms of the gap to the achievable information rates (AIRs) of HD codes and the fiber reach enhancement. We show in this paper that the marking thresholds and the number of modified component decodings heavily affect the performance of iSABM-SCC, and thus, they need to be carefully optimized. By replacing standard decoding with the optimized iSABM-SCC decoding, the gap to the AIRs of HD codes can be reduced to 0.26–1.02 dB for code rates of 0.74–0.87 in the additive white Gaussian noise channel with 8-ary pulse amplitude modulation. The obtained reach increase is up to 22% for data rates between 401 Gbps and 468 Gbps in an optical fiber channel.

Regular Session 8: Spatial Coupling

Chairperson: Daniel J. Costello (University of Notre Dame, USA)

13:40 Spatially-Coupled Serially Concatenated Codes with Periodic Convolutional Permutors

Muhammad Farooq, Alexandre Graell i Amat (Chalmers University of Technology, Sweden), and Michael Lentmaier (Lund University, Sweden)
Spatially-coupled serially concatenated codes (SCSCCs) are a class of turbo-like codes constructed by interconnecting a sequence of SCCs using a set of block permutors. At short block lengths, however, the bit-error-rate (BER) performance of SC-SCCs constructed by independent block permutors exhibits a high error floor. In this paper, we propose an alternative method for constructing SC-SCCs to mitigate this problem. Particularly, we use a family of periodically time-varying blockwise convolutional permutors with flexible block length. We derive these convolutional permutors from a block permutor of an optimized spread by applying an unwrapping procedure. We prove that for any chosen block length, the unwrapping procedure preserves the spread of the original block permutor. We further present an efficient implementation method for the blockwise convolutional permutor that derives the permutation indices directly from those of the underlying block permutor. Considering both random permutors and quadratic permutation polynomial (QPP) permutors, we perform BER simulations for SC-SCCs with decoding latencies 4096 and 16384. Numerical results show that SC-SCCs based on the proposed convolutional permutors have no visible error floor, which is especially notable at short block lengths.

14:00 Towards Fully Pipelined Decoding of Spatially Coupled Serially Concatenated Codes

Mojtaba Mahdavi, Liang Liu (Lund University, Sweden), Ove Edfors (Lund University, Sweden), Michael Lentmaier (Lund University, Sweden), Norbert Wehn (University of Kaiserslautern, Germany), and Stefan Weithoffer (IMT Atlantique, France)

Having close-to-capacity performance and low error floor, even for small block lengths, make spatially coupled serially concatenated codes (SC-SCCs) a very promising class of codes. However, classical window decoding of SC-SCCs either limits the minimum block length or requires a large number of iterations, which increases the complexity and constrains the degree to which an SC-SCC decoder architecture can be parallelized. In this paper we propose jumping window decoding (JWD), an algorithmic modification to the scheduling of decoding such that it enables pipelined implementation of SC-SCCs decoder. Also, it provides flexibility in terms of block length and number of iterations and makes them independent of each other. Simulation results show that our scheme outperforms classical window decoding of both SC-SCCs and uncoupled SCCs, in terms of performance. Furthermore, we present a fully pipelined hardware architecture to realize JWD of SC-SCCs along with area estimates in 12nm technology for the respective case study.

14:20 Iterative Threshold Decoding of Spatially Coupled, Parallel-Concatenated Codes

Andrew D. Cummins, David G. M. Mitchell (New Mexico State University, USA), and Daniel J. Costello, Jr. (University of Notre Dame, USA)

Spatially coupled, parallel concatenated codes (SC-PCCs) have been shown to approach channel capacity when decoded using optimal iterative methods. However, under complexity constraints such decoding strategies can result in unacceptable power and latency costs. In this work, we employ convolutional self-orthogonal component codes along with low-complexity, suboptimal a posteriori probability (APP) threshold decoders with SC-PCCs to reduce decoding complexity. The proposed code design is faster, more energy efficient, and easier to implement than optimal
methods, while offering significant coding gain over existing threshold decodable, turbo-like constructions of similar complexity. The design also serves to further illustrate the advantages spatial coupling can provide to existing code constructions and decoder implementations.

Thursday, September 2nd, 2021

Regular Session 9: Coding Theory

Chairperson: David Mitchell (New Mexico State University, USA)

09:20 Polar Coding for Information Regular Processes

Stephen Timmel, and Gretchen Matthews (Virginia Tech, USA)

Polar codes use an explicit channel model, so the precise nature of the communication channel determines if and when polarization occurs. In practice, communication channels typically have memory which affects the probability of error in nearby symbols. In this paper, we extend existing results to show polarization for the more general family of information regular processes and define a growth rate for promptness. We then show that information regular processes with linear promptness polarize and provide an example with practical applications for which the rate of polarization is very slow.

09:40 Joint Source-Channel Polar Coding for Biased Bernoulli Sources at Short Blocklengths

Mengfan Zheng, Jiaqi Gu (Huawei Technologies Co., Ltd, China), Mengyao Ma (Huawei Technologies Co., Ltd., China), and Cong Ling (Imperial College London, United Kingdom (Great Britain))

We study the design of joint source-channel polar coding for biased Bernoulli sources in this paper, focusing on short blocklengths. We first introduce the CRC-aided successive cancellation decoding scheme into source polar coding and demonstrate its superior performance at short blocklengths. Then we design a joint decoding scheme for concatenated source-channel polar codes, using soft information from the source decoder and source CRC bits to aid channel decoding. Simulations show that the proposed scheme outperforms separate source-channel polar coding and can even break through the finite blocklength bound of separate source-channel coding in some cases.

10:00 Necessary and Sufficient Girth Conditions for LDPC Tanner Graphs with Denser Protographs

Anthony Gómez-Fonseca, Roxana Smarandache (University of Notre Dame, USA), and David G. M. Mitchell (New Mexico State University, USA)

This paper gives necessary and sufficient conditions for the Tanner graph of a quasi-cyclic (QC) low-density parity-check (LDPC) code based on the all-one protograph to have girth 6, 8, 10, and 12, respectively, in the case of parity-check matrices with column weight 4. These results are a natural extension of the girth results of the already-studied cases of column weight 2 and 3, and it is based on the connection between the girth of a Tanner graph given by a parity-check matrix and the properties
of powers of the product between the matrix and its transpose. The girth conditions can be easily incorporated into fast algorithms that construct codes of desired girth between 6 and 12; our own algorithms are presented for each girth, together with constructions obtained from them and corresponding computer simulations. More importantly, this paper emphasizes how the girth conditions of the Tanner graph corresponding to a parity-check matrix composed of circulants relate to the matrix obtained by adding (over the integers) the circulant columns of the parity-check matrix. In particular, we show that imposing girth conditions on a parity-check matrix is equivalent to imposing conditions on a square circulant submatrix of size 4 obtained from it.

Regular Session 10: Neural-aided Decoding and Implementation

Chairperson: Valentin Savin (CEA LETI, France)

09:20 Using Deep Neural Networks to Predict and Improve the Performance of Polar Codes

Mathieu Léonardon, and Vincent Gripon (IMT Atlantique, France)

Polar codes can theoretically achieve very competitive Frame Error Rates. In practice, the performance may depend on the chosen decoding procedure, as well as other parameters of the communication system on which it is deployed. In general, designing efficient polar codes for a specific context can quickly become challenging. In this paper, we introduce a methodology that consists in training deep neural networks to predict the frame error rate of polar codes based on their frozen bit construction sequence. We introduce an algorithm based on Projected Gradient Descent that leverages the gradient of the neural network function to generate promising frozen bit sequences. We showcase on generated datasets the ability of the proposed methodology to produce codes more efficient than those used to train the neural networks, even when the latter are selected among the most efficient ones.

09:40 Error Structure Aware Parallel BP-RNN Decoders for Short LDPC Codes

Joachim Rosseel, Valérian Mannoni (CEA, France), Valentin Savin (CEA LETI, France), and Inbar Fijalkow (ETIS / CY Cergy Paris University, ENSEA, CNRS, France)

This article deals with the decoding of short block length Low Density Parity Check (LDPC) codes. It has already been demonstrated that Belief Propagation (BP) can be adjusted to the short coding length, thanks to its modeling by a Recurrent Neural Network (BP-RNN). To strengthen this adaptation, we introduce a new training method for the BP-RNN. Its aim is to specialize the BP-RNN on error events sharing the same structural properties. This approach is then associated with a new decoder composed of several parallel specialized BP-RNN decoders, each trained on correcting a different type of error events. Our results show that the proposed specialized BP-RNNs working in parallel effectively enhance the decoding capacity for short block length LDPC codes.

10:00 A Flexible and Portable Real-time DVB-S2 Transceiver using Multicore and SIMD CPUs

Adrien Cassagne, Mathieu Léonardon (IMT Atlantique, France), Romain Tajan (Bordeaux INP & IMS Laboratory, France), Camille
Software implementation of digital communication systems is more and more used in different contexts. In the case of satellite communication standards, they are an appealing alternative in ground stations. The challenge is to push the performance of these digital communication systems to meet the real time constraints. In this paper, we propose an open source digital communication transceiver that enables to exploit the parallelism of general purpose processors (multicore, SIMD). It is also flexible, supporting several modulation and coding schemes. Finally, it is portable, being able to adapt to the level of parallelism of different CPU architectures (x86 and ARM).

Special Session 4: Energy-Efficient Codes

Chairpersons: Francois Leduc-Primeau (Polytechnique Montréal, Canada) and Elsa Dupraz (IMT Atlantique, France)

11:40 Gradient Descent Bit-Flip Decoding with Momentum

Valentin Savin

In this paper, we propose a Gradient Descent Bit-Flipping (GDBF) decoding with momentum, which considers past updates to provide inertia to the decoding process. We show that GDBF or randomized GDBF decoders with momentum may closely approach the floating-point Belief-Propagation decoding performance, and even outperform it in the error-floor region, especially for graphs with high connectivity degree.

12:00 Energy Efficient FEC Decoders

Matthias Herrmann, Claus Kestel (University of Kaiserslautern, Germany), and Norbert Wehn (University of Kaiserslautern, Germany)

Channel coding, or Forward Error Correction (FEC), is a crucial technology component in any digital baseband processing. Decoder IPs for advanced coding schemes like Turbo, LDPC, and Polar codes are major sources of power consumption and silicon area in baseband SOCs and largely contribute to the baseband latency and throughput limitations. Although we observe a continuous increase in throughput and lower latency requirements in emerging communication standards, the available power and energy budget does not increase due to, e.g., thermal design power constraints. If we look on the silicon technology progress, the transistor density still follows Moore’s law, but the power improvement largely slows down, that exacerbates the power density problem. Hence, for use cases with high throughput requirements like 5G, power, power density and energy efficiency become a major bottleneck for the successful application of advanced channel coding from a silicon implementation perspective. In this paper we focus especially on LDPC and Polar codes since they are part of many communication standards. Challenges, power and energy optimizations on the different design levels for decoders targeting throughput towards 1Tb/s and various trade-offs are presented.
Towards an Accurate High-Level Energy Model for LDPC Decoders

Jeremy Nadal, Simon Brown (Polytechnique Montréal, Canada), Elsa Dupraz (IMT Atlantique, France), and François Leduc-Primeau (Polytechnique Montréal, Canada & IMT Atlantique, France)

Estimating the energy consumption of LDPC decoders is a long and difficult task due to the large number of factors involved. Modern circuit synthesis tools can provide a satisfactory estimation of the power consumption, but this requires that the circuit be already implemented and it can take hours to provide the estimate. Currently, no accurate models are available to evaluate the decoding energy early in the design process. We propose a high-level energy model for flip-flop memory elements in LDPC architectures. The originality of the model is that it can analytically evaluate the variation of the energy due to the switching activity of the circuit gates, depending on the probability mass function (PMF) of the circuit inputs. Such PMFs are obtained through an adapted density evolution method that we propose. Therefore, the energy can be profiled for each decoding iteration and SNR value while considering several architecture choices. We illustrate the validity of the model by comparing the obtained energy estimates with measurements based on circuit simulations.

Coding Schemes for Crossbar Resistive Memory with High Line Resistance in SCM Applications

Zehui Chen, and Lara Dolecek (UCLA, USA)

Crossbar resistive memory with 1 Selector 1 Resistor (1S1R) structure is attractive for low-cost, power efficient, and high-density storage class memory (SCM) applications. As technology scales down to the single-nm regime, the increasing resistivity of wordline/bitline becomes a limiting factor to device reliability. Due to the line resistance, reliability of memory cells in an array is spatially non-uniform. In this paper, by mitigating and leveraging this spatial non-uniformity, we propose two simple yet effective coding schemes, one that utilizes interleaving and one that utilizes multiple codes based on a proposed location dependent code allocation (LDCA) framework, to reduce the undetected bit-error rate (UBER) or to allow for lower write voltage for power efficiency in the studied crossbar resistive memories.

Friday, September 3rd, 2021

Regular Session 11: Spatially-Coupled LDPC Codes

Chairperson: Yuval Cassuto (Technion, Israel)

Connecting Spatially Coupled LDPC Code Chains for Bit-Interleaved Coded Modulation

Yihuan Liao, Min Qiu (University of New South Wales, Australia), and Jinhong Yuan (University of New South Wales, Australia)

This paper investigates the design of spatially coupled low-density parity-check (SC-LDPC) codes constructed from connected-chain ensembles for bit-interleaved coded modulation (BICM) schemes. For short coupling lengths, connecting multiple SC-LDPC chains can improve decoding performance over single-chains and impose structured unequal error protection (UEP). A joint design of connected-chain ensembles
and bit mapping to further exploit the UEP from codes and high-order modulations is proposed. Numerical results demonstrate the superiority of the proposed design over existing connected-chain ensembles and over single-chain ensembles with existing bit mapping design.

09:40 A Class of Hybrid Coupled Serially Concatenated Codes

Chaojie Yang, Shancheng Zhao (Jinan University, China), and Xiao Ma (Sun Yat-sen University, China)

Spatially coupled serially concatenated codes (SC-SCCs) outperform the spatially coupled parallel concatenated codes (SC-PCCs) both in the waterfall region and the error-floor region. Although the SC-SCCs with a weak outer convolutional code (CC) and a strong inner CC reveal good waterfall performance, their error-floors are still too high. This paper introduces the recursive encoding structure into SC-SCCs to reduce the error-floor. We introduce the hybrid coupled serially concatenated codes (HC-SCCs), in which spatial coupling is achieved by taking a portion of the encoding outputs of both the outer and the inner encoders as the input of the current inner encoder. As a result, the proposed HC-SCCs are recursive in nature. The exact density evolution equations of the HC-SCCs are derived. Numerical results are provided to show the performance advantages of the proposed HC-SCCs. Particularly, simulation results show that, compared to the original SC-SCCs, about two orders of magnitude error-floor performance improvement are obtained with the proposed HC-SCCs.

10:00 On the Decoding Performance of Spatially Coupled LDPC Codes with Sub-block Access

Eshed Ram, and Yuval Cassuto (Technion, Israel)

We study spatially coupled LDPC codes that allow access to sub-blocks much smaller than the full code block. Sub-block access is realized by a semi-global decoder that decodes a chosen target sub-block by only accessing the target, plus a prescribed number of helper sub-blocks adjacent in the code chain. This paper analyzes the semi-global decoding performance of spatially coupled LDPC codes constructed from protographs. The main result shows that semi-global decoding thresholds can be derived from certain thresholds we define for the single-sub-block graph. These characterizing thresholds are also used for deriving lower bounds on the decoder’s performance over channels with variability and memory across sub-blocks, which are motivated by applications in data-storage.

Special Session 5: Industry Applications

Chairperson: Ingmar Land (Huawei, France)

11:40 Forward-Error-Correction for Beyond-5G Ultra-high Throughput Communications

Norbert Wehn, Onur Sahin (InterDigital, Inc., USA), and Matthias Herrmann (TU Kaiserslautern, Germany)

Forward-error-control (FEC) constitutes a dominant power consuming and throughput limiting component in the end-to-end digital baseband chain for wireless systems. With the progress in THz and Tb/s link-level technologies towards practical solutions and deployments arguably in beyond-5G and 6G era, the performance and implementation bottleneck due to FEC in these systems becomes increasingly clear. In
this paper, we explore FEC performance requirements for various beyond-5G wireless use-cases from a practical implementation perspective. We then provide some recent designs in LDPC and Polar Codes, and their decoder architectures that demonstrate significant potential towards achieving throughputs approaching 1 Tb/s.

12:10 Self-Decodability of HARQ Retransmissions for 5G NR LDPC Codes

Gabi Sarkis, Joseph B. Soriaga (Qualcomm, Inc., USA), and Thomas Richardson (Qualcomm Flarion Inc., USA)

Hybrid automatic retransmission request (HARQ) in modern wireless communication systems such as 4G and 5G is designed to allowing efficient combining of multiple (re)transmissions so as to to achieve coding gain. The coding performance for each retransmission in isolation may, however, not be consistent, potentially lacking self-decodability of individual retransmissions. This can require the UE to receive multiple additional retransmissions when the initial transmission is missed, undermining the intended efficiency of the HARQ system. In this paper, we discuss the self-decodability of HARQ retransmissions and show it can be improved, providing a balance between coding gain and self-decodability, by modifying the rate-matching operation without changing the channel code construction. We present results illustrating the gains in self-decodability using the proposed scheme.

Poster Session

Chairperson: Pascal Giard (École de technologie supérieure, Canada)

P 1 The Best, The Requested and The Default Non-Binary LDPC Decoding Algorithm

Joseph Jabour, Cédric Marchand (Lab-STICC Université de Bretagne Sud, France), and Emmanuel Boutillon (Université de Bretagne Sud, France)

This paper presents a different vision of the Non-Binary LDPC decoding algorithm. So far, state-of-the-art decoders are mainly focused on the reduction of the check node processing complexity, with a potential side effect on the size of the messages that are exchanged in the iterative decoder. However, it is possible to take a different approach and consider the reduction of the message size as the main objective. The paper presents “the Best, the Requested and the Default (BRD)” algorithm that shrinks dramatically the communication load between the variable nodes and check nodes. This reduction is independent of check node or variable node architectures. For GF(64)-LDPC decoders, the communication load becomes even lower than for a classical binary decoder, without noticeable decoding performance degradation. The BRD algorithm impacts directly the decoder hardware architecture in terms of memory and permutation resource and should trigger new investigations on check node and variable node architectures.

P 2 A Two-stage Decoding Algorithm for SpatiallyCoupled Algebraic LDPC Codes

Juewei Wang, and Xiao Ma (Sun Yat-sen University, China)

In this paper, we propose a two-stage decoding algorithm for spatially-coupled algebraic low-density parity-check (LDPC) codes with linear computational complexity, which consists of a sliding-window belief propagation (BP) decoding algorithm and a majority logic decoding
algorithm. Simulation results are presented, showing that the error floor of SC-LDPC codes can be lowered from $10^{-8}$ down to $10^{-9}$.

**P 3** Balanced Incomplete Block Designs, Partial Geometries, and Their Associated QC-LDPC Codes

Juane Li, Yi Gong (Guangdong University of Technology, China), Shu Lin (University of California, Davis, USA), and Khaled Abdel-Ghaffar (University of California, USA)

This paper presents two classes of partial geometries which are derived from balanced incomplete block designs of a special type. Based on these two classes of partial geometries, quasi-cyclic LDPC codes can be constructed. These codes not only perform well over AWGN channels decoded with the min-sum algorithm based on belief propagation but also can correct bursts of erasures over binary erasure channels (BECs) effectively.

**P 4** Neural-Network-Optimized Degree-Specific Weights for LDPC MinSum Decoding

Linfang Wang, Sean Chen (UCLA, USA), Jonathan V Nguyen (University of California, Los Angeles, USA), Richard Wesel (University of California, Los Angeles, USA), and Dariush Divsalar (Jet Propulsion Laboratory, USA)

Neural Normalized MinSum (N-NMS) decoding delivers better frame error rate (FER) performance on linear block codes than conventional normalized MinSum (NMS) by assigning dynamic multiplicative weights to each check-to-variable message in each iteration. Previous N-NMS efforts have primarily investigated short-length block codes ($N < 1000$), because the number of N-NMS parameters to be trained is proportional to the number of edges in the parity check matrix and the number of iterations, which imposes an impractical memory requirement when Pytorch or Tensorflow is used for training. This paper provides efficient approaches to training parameters of N-NMS that support N-NMS for longer block lengths. Specifically, this paper introduces a family of neural 2-dimensional normalized (N-2D-NMS) decoders with with various reduced parameter sets and shows how performance varies with the parameter set selected. The N-2D-NMS decoders share weights with respect to check node and/or variable node degree. Simulation results justify this approach, showing that the trained weights of N-NMS have a strong correlation to the check node degree, variable node degree, and iteration number. Further simulation results on the (3096,1032) protograph-based raptor-like (PBRL) code show that N-2D-NMS decoder can achieve the same FER as N-NMS with significantly fewer parameters required. The N-2D-NMS decoder for a (16200,7200) DVBS-2 standard LDPC code shows a lower error floor than belief propagation. Finally, a hybrid decoding structure combining a feedforward structure with a recurrent structure is proposed in this paper. The hybrid structure shows similar decoding performance to full feedforward structure, but requires significantly fewer parameters.

**P 6** Revisiting augmented decoding techniques for LTE Turbo Codes

Titouan Gendron, Emmanuel Boutillon (Université de Bretagne Sud, France), Charbel Abdel Nour (IMT Atlantique, France), and David Gnaedig (Turbo-Concept, France)

This paper revisits several methods used in iterative decoders to improve the performance of the LTE TurboCode for small information blocks. By considering the iterative decoder as a chaotic
system, some explanations are given on the unexpected behavior of several post-processing algorithms. A “dither-inspired” algorithm, called blind candidate decoding, is proposed. This algorithm improves error correction by performing several decoding attempts from a set of perturbed input. Combined with the use of the CRC as an outer code, a performance improvement of up to 1 dB in signal to noise ratio can be obtained for a frame error rate of $10^{-3}$. Moreover, a stopping criterion based on the Euclidean distance between the output and the input is proposed to mitigate the critical problem of undetected errors.

P 7 On the Equivalence between Pre-transformed and Parity-check Monomial Codes
Yuanxin Guo, Zihan Tang (Huawei Technologies, China), and Bin Li (Huawei Technologies, China)

Polar codes and Reed-Muller codes belong to a family of codes called monomial codes. In this work, we study pretransformed monomial codes, which cover several constructions including parity-check (PC) codes and PAC codes. We show that any pre-transformed monomial code can be transformed into a parity-check monomial code with the same codewords, and give an explicit algorithm for this transformation. We further prove that for certain monomial codes, the minimum weight is invariant under pre-transformation, but specific pretransformation matrices can be constructed to reduce the number of minimum-weight codewords. These results offer theoretical support for the success of various heuristics, e.g., PAC codes attain dispersion bound, and provide guidance for designing short codes.

P 8 Fast-SCAN Decoding of Polar Codes
Charles Pillet, Carlo Condo (Infinera, Canada), and Valerio Bioglio (France Research Center, Huawei Technologies Co. Ltd., Italy)

Polar codes are able to achieve the capacity of memoryless channels under successive cancellation (SC) decoding. Soft Cancellation (SCAN) is a soft-output decoder based on the SC schedule, useful in iterative decoding and concatenation of polar codes. However, the sequential nature of this decoder leads to high decoding latency compared to state-of-the-art codes. To reduce the latency of SCAN, in this paper we identify special nodes in the decoding tree, corresponding to specific frozen-bit sequences, and propose dedicated low-latency decoding approaches for each of them. The resulting fast-SCAN decoder does not alter the soft-output compared to the standard SCAN while dramatically reducing the decoding latency and yielding the same error correction performance.

P 9 Non-Binary Polar Codes for Spread-Spectrum Modulations
Valentin Savin (CEA LETI, France)

This paper proposes a new coded modulation scheme for reliable transmission of short data packets at very low signal-to-noise ratio, combining cyclic code shift keying modulation and non-binary polar coding. We consider non-binary polar codes defined over Galois fields, and propose a new design methodology, aimed at optimizing the choice of the kernel coefficients. Numerical results show that the system performance is close to the achievable limits in the finite blocklength regime.

P 10 Tailored List Decoding of Polar Codes
Malek Ellouze, Camille Leroux (IMS Lab - Institut Polytechnique de Bordeaux, France), Romain Tajan (Bordeaux INP & IMS Laboratory, France), Charly Poulliat (INP - ENSEEIHT Toulouse, France), and Christophe Jego (IMS CNRS Laboratory & Bordeaux INP / ENSEIRB-MATMECA, France)

In this paper, we provide some experimental evidence that a significant number of metric updates and sorting can be avoided during list decoding of polar codes. Starting from the observation that a non-negligible part of the reliable bit channels are located at the tail of the decoding sequence, it is possible to decode the end of the sequence without updating the metrics of list decoding. This tailored CRC-Aided successive cancellation list (T-CA-SCL) decoder can be seen as a simplification of SCL decoding. Moreover, a heuristic is proposed to determine the parameters required by the tailored-CA-SCL decoder. Experimental results show that the proposed tailored list decoding approach reduces the number of metric updates by 45% without significantly altering the error performance. Finally some leads are provided for further research to improve and extend the proposed approach.

P 11 Rate-adaptive Concatenated Multilevel Coding with Fixed Decoding Complexity
Tayyab Mehmood, Metodi Yankov (Technical University of Denmark, Denmark), and Soren Forchhammer (Technical University of Denmark, Denmark)

In this work, a low-complexity multilevel coding (MLC) based coded modulation approach having rate flexibility with two degrees of freedom is proposed. It consists of an inner soft-decision (SD) polar code serially concatenated with an outer hard-decision (HD) code. For a given HD outer code, a method is developed to optimize a multi-stage decoding based MLC scheme so that it will require a fixed amount of inner decoding operations and thereby having constant complexity while changing the transmission rate with near-continuous granularity. Over the range of studied transmission rates, the proposed MLC scheme with outer staircase code and zipper code utilizes 75%, and 73% fewer inner SD decodings, respectively, compared to BICM.

P 12 Multi Coding Rates Nested Recursive Convolutional Doubly-Orthogonal Codes
Eric Roy, Christian Cardinal (Ecole Polytechnique de Montréal, Canada), and David Haccoun (Ecole Polytechnique de Montréal, Canada)

This article presents a class of multi-coding rates time-invariant Recursive Convolutional Doubly-Orthogonal codes (RCDO). The Nested-RCDO (N-RCDO) codes are generated from their RCDO mother code which has a Tanner graph with a girth equal to 10 due to the doubly-orthogonal conditions imposed onto the connections positions of the mother recursive convolutional encoder. This implies that the girths of the N-RCDO codes are also equals to 10. Moreover, results are showing that regular \((3, d_p)\) N-RCDO codes nearly achieve their asymptotic decoding limits for all the desired coding rates obtained from the regular mother RCDO code. These codes also offer a substantial additional coding gain as compared to the non-recursive multi coding rates CDO codes.
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