2015 International Symposium on Network Coding

(NetCod 2015)

Sydney, Australia
22-24 June 2015

IEEE Catalog Number: CFP1541D-POD
ISBN: 978-1-4799-1912-3

10:30 AM - 12:05 PM

S1: Session #1

On Minimizing the Average Packet Decoding Delay in Wireless Network Coded Broadcast ***1***

Mingchao Yu (The Australian National University, Australia); Alex Sprintson (Texas A&M University, USA); Parastoo Sadeghi (The Australian National University, Australia)

We consider a setting in which a sender wishes to broadcast a block of K data packets to a set of wireless receivers, where each of the receivers has a subset of the data packets already available to it (e.g., from prior transmissions) and wants the rest of the packets. Our goal is to find a linear network coding scheme that yields the minimum average packet decoding delay (APDD), i.e., the average time it takes for a receiver to decode a data packet. Our contributions can be summarized as follows. First, we prove that this problem is NP- hard by presenting a reduction from the hypergraph coloring problem. Next, we show that a random linear network coding (RLNC) provides an approximate solution to this problem with approximation ratio 2 with high probability. Next, we present a methodology for designing specialized approximation algorithms for this problem that outperform RLNC solutions while maintaining the same throughput. In a special case of practical interest with a small number of wanted packets our solution can achieve an approximation ratio (4−2/K)3. Finally, we conduct an experimental study that demonstrates the advantages of the presented methodology.

Delay Reduction in Multi-Hop Device-to-Device Communication Using Network Coding ***6***

Ahmed Douik (California Institute of Technology, USA); Sameh Sorour (King Fahd University of Petroleum and Minerals (KFUPM), Saudi Arabia); Tareq Y. Al-Naffouri (King Abdullah University of Science and Technology, USA); Hong-Chuan Yang (University of Victoria, Canada); Mohamed-Slim Alouini (King Abdullah University of Science and Technology (KAUST), Saudi Arabia)

In this paper, the problem of reducing the broadcast delay of wireless network using instantly decodable network coding (IDNC) based device-to-device (D2D) communication is considered. In a D2D configuration, devices in the network can help hasten the recovery of the lost packets of other devices in their transmission range by sending network coded packets. To solve the problem, the different events occurring at each device are identified in order to derive an expression for the probability distribution of the decoding delay. The joint optimization problem over the set of transmitting devices and the packet combinations of each is formulated. The optimal solution when no interference is allowed between the transmitting devices is expressed using a graph theory approach by introducing the cooperation graph. Through extensive simulations, we compare the decoding delay experienced by all devices in the Point to Multi-Point (PMP) configuration, the fully connected D2D (FC-D2D) configuration and the more practical partially connected D2D (PC-D2D) configuration. Numerical results show that the PC-D2D outperforms the FC-D2D in all situations and provides a huge gain when the network is poorly connected.

Short Break

In Order Packet Delivery in Instantly Decodable Network Coded Systems Over Wireless Broadcast ***11***

Mohammad S. Karim, Parastoo Sadeghi and Neda Aboutorab (The Australian National University, Australia); Sameh Sorour (King Fahd University of Petroleum and Minerals (KFUPM), Saudi Arabia)

In this paper, we study in-order packet delivery in instantly decodable network coded systems for wireless broadcast networks. We are interested in applications, in which the successful delivery of a packet depends on the correct reception of this packet and all its preceding packets. We formulate the problem of minimizing the number of undelivered packets to all receivers over all transmissions until completion as a stochastic shortest path (SSP) problem. Although finding the optimal packet selection policy using SSP is computationally complex, it allows us to systematically exploit the problem structure and draw guidelines for efficient packet selection policies. According to these guidelines, we design a simple heuristic packet selection algorithm. Simulation results illustrate that our proposed algorithm provides quicker packet delivery to the receivers compared to the existing algorithms in the literature.

Adaptive Suppression of Inter-packet Delay Variations in Coded Packet Networks ***16***

Martin Jobst (Technische Universität München, Germany); Stephan M. Günther (Technische Universität München & Chair for Network Architectures and Services,

Germany); Maximilian Riemensberger, Georg Carle and Wolfgang Utschick (Technische Universität München, Germany)

Network coding tends to increase not only the end-to-end delay due to unavoidable buffering of packets, but it also increases the inter-packet delay variations (jitter) due to batching. While an increase in delay does not necessarily adversely affect throughput, sudden delay spikes may interfere with TCP's congestion avoidance mechanism. Such spikes are a common phenomenon in coded packet networks since packet loss may prevent the receiver from decoding a whole generation until sufficient redundant packets have arrived. After successful decoding, a burst of packets is forwarded. In this paper, we propose an adaptive queueing-based approach to minimize the inter-packet delay variation by dynamically delaying decoded packets at the receiver side depending on the current suppression queue backlog, average delay, and packet loss rate. We evaluate our approach by measuring TCP throughput on top of an RLNC system over a lossy wireless link. The TCP throughput significantly improves when our proposed method is used for inter-packet delay variation suppression. The method is implemented as a lightweight library and will be made available for download under the GNU GPLv2.

1:15 PM - 2:15 PM

K2: Keynote Talk: On Implications and Applications of Network Coding

Michelle Effros (Caltech)

The tool of reduction draws new relationships between seemingly disparate problems. In this talk, we use reduction to explore the implications and applications of network coding beyond the traditional network coding domain.

2:30 PM - 3:10 PM

S2: Session #2

***Successive Omniscience* 21**

Chung Chan (The Chinese University of Hong Kong, Hong Kong); Ali Al-Bashabsheh (Institute of Network Coding & The Chinese University of Hong Kong, Hong Kong); Javad B. Ebrahimi (The Chinese University of Hong Kong & Institute of Network Coding (INC), Hong Kong); Tarik Kaced (The Chinese University of Hong Kong & Institute of Network Coding, Hong Kong); Swanand Kadhe, Tie Liu, Alex Sprintson and Muxi Yan (Texas A&M University, USA); Qiaoqiao Zhou (The Chinese University of Hong Kong & Institute of Network Coding, Hong Kong)

The problem of successive omniscience is formulated for the study of a recently proposed multivariate mutual information measure. In this problem, a set of users want to achieve omniscience, i.e., recover the private sources of each other by exchanging messages. However, the omniscience is achieved in a successive manner such that local subgroups of users can first achieve local omniscience, i.e., recover the private sources of other users in the same subgroups. Global omniscience among all users is achieved by an additional exchange of messages. This formulation can be motivated by a distributed storage system that enables file sharing among groups of users. It is shown that the multivariate mutual information can be used to characterize the minimum storage required as well as the conditions under which local omniscience can be achieved for free without increasing the total communication rate required for global omniscience. Our results provide new interpretations of the multivariate mutual information.

***A Graph Model for Opportunistic Network Coding* 26**

Sameh Sorour (King Fahd University of Petroleum and Minerals (KFUPM), Saudi Arabia); Neda Aboutorab (The Australian National University, Australia); Tareq Y. Al-Naffouri (King Abdullah University of Science and Technology, USA); Mohamed-Slim Alouini (King Abdullah University of Science and Technology (KAUST), Saudi Arabia)

Recent advancements in graph-based analysis and solutions of instantly decodable network coding (IDNC) trigger the interest to extend them to more complicated opportunistic network coding (ONC) scenarios, with limited increase in complexity. In this paper, we design a simple IDNC-like graph model for a specific subclass of ONC, by introducing a more generalized definition of its vertices and the notion of vertex aggregation in order to represent the storage of non-instantly-decodable packets in ONC. Based on this representation, we determine the set of pairwise vertex adjacency conditions that can populate this graph with edges so as to guarantee decodability or aggregation for the vertices of each clique in this graph. We then develop the algorithmic procedures that can be applied on the designed graph model to optimize any performance metric for this ONC subclass. A case study on reducing the completion time shows that the proposed framework improves on the performance of IDNC and gets very close to the optimal performance.

3:40 PM - 4:40 PM

S3: Session #3

Content-type Coding ***31***

Linqi Song (University of California, Los Angeles, USA); Christina Fragouli (UCLA, USA)

This paper is motivated by the observation that, in many cases, we do not need to serve specific messages, but rather, any message within a content-type. Content-type traffic pervades a host of applications today, ranging from search engines and recommender networks to newsfeeds and advertisement networks. The paper asks a novel question: if there are benefits in designing network and channel codes specifically tailored to content-type requests. It provides three examples of content-type formulations to argue that, indeed in some cases we can have significant such benefits.

Index Coding Over Correlated Sources ***36***

Shigeki Miyake (NTT, Japan); Jun Muramatsu (NTT Corporation, Japan)

For the next generation content distribution network one of the promising architecture is ``cache network" at each node of which is equipped with cache or local storage. We consider the data compression problem called the index coding problem when a central content server disseminate multiple content data to each client that can recover target data using cached data as a side information. In this paper a coding scheme is proposed when multiple transmitted data have some correlation, and the scheme is shown to be optimal in the case that the number of data is less than or equal to three. By constructing the proposed code using sparse matrices, we can expect the efficient code that can be implemented by sum-product method or linear programming.

Iterative Merging Algorithm for Cooperative Data Exchange ***41***

Ni Ding, Rodney Andrew Kennedy and Parastoo Sadeghi (The Australian National University, Australia)

This paper considers the problem of finding the minimum sum-rate strategy in cooperative data exchange (CDE) systems. In a CDE system, there are a number of geographically close cooperative clients who send packets to help the others recover a packet set. A minimum sum-rate strategy is the strategy that achieves universal recovery (the situation when all the clients recover the whole packet set) with the the minimal sum-rate (the total number of transmissions). We propose an iterative merging (IM) algorithm that recursively merges client sets based on an estimate of the minimum sum-rate and achieves local recovery until the universal recovery is achieved. We prove that the minimum sum-rate and a corresponding strategy can be found by starting the IM algorithm with an initial lower estimate of the minimum sum-rate. We run an experiment to show that the complexity of IM algorithm is lower than the complexity of existing deterministic algorithms.

4:40 PM - 5:30 PM

P: Panel Discussion

7:00 PM - 10:00 PM

B: Banquet

Tuesday, June 23

9:00 AM - 10:00 AM

K3: Keynote Talk: Putting Physical-Layer Network Coding in Practice

Soung Liew (The Chinese University of Hong Kong)

This talk focuses on the practical aspects of putting physical-layer network coding (PNC) into practice in our prototyping efforts of PNC. PNC was first proposed in 2006 and has been attracting a wide following. PNC is founded on the idea that the electromagnetic waves received simultaneously from different sources are an additive superposition of signals. A form of network coding operation is performed automatically by nature during the reception process when multiple sources transmit simultaneously.Most work on PNC is theoretical in nature, focusing on various mathematical properties and models related to PNC systems. There has been relatively little implementation effort to examine whether the theoretical advantages of PNC can be realized in real systems when various practical challenges need to be surmounted. In this talk, I will relate our experience in prototyping PNC on the software-defined radio (SDR) platform. In particular, I will focus on how we address the various practical challenges. I will show a video clip of our most recent prototype of a PNC two-way relay network. The significant achievement of this prototype is that we now have a complete TCP/IP compatible system that can support standard TCP/IP applications (e.g., web browsing, video delivery) in real-time. I will also present a second prototype that realizes network-coded multiple access (NCMA). While the first prototype demonstrates the use of PNC on a relay network, the second prototype shows that PNC decoding can also find use in non-relay networks where the receiver aims to decode the individual messages simultaneously transmitted by a number of transmitters rather than a network-coded message. Lastly, I will talk about the potential prototyping of "real XOR in the air" systems where the network coding operations are performed by a node in the air (e.g., satellites), where the node can be moving. It has been nearly 10 years since PNC was first proposed. I will end this talk by reflecting on where we should go from here.

10:30 AM - 12:05 PM

S4: Session #4

On Adaptive (Functional MSR Code Based) Distributed Storage Systems ***46***

Brijesh Kumar Rai (IIT Guwahati, India)

Suppose that a data storage service provider implements functional MSR code based distributed storage system (DSS). Consider a scenario where the service provider has implemented an (n_1,k_1,B,d_1,t_1) functional MSR code based DSS, where B is the file that is stored. At a later point of time, due to certain considerations (such as storage cost, download bandwidth to repair failed nodes etc.), the service provider wants to convert this (n_1,k_1,B,d_1,t_1) functional MSR code based DSS to an (n_2,k_2,B,d_2,t_2) functional MSR code based DSS. The service provider wants to perform this conversion at the lowest possible cost, i.e., by downloading minimum amount of data. The question is: How should one design an (n_1,k_1,B,d_1,t_1) functional MSR code based DSS so that it requires minimum download to convert the DSS to an (n_2,k_2,B,d_2,t_2) functional MSR code based DSS?

In this paper, we propose a coding scheme which requires minimum download while converting an (n_1,k_1,B,d_1,t_1) functional MSR code based DSS to an (n_2,k_2,B,d_2,t_2) functional MSR code based DSS.

Network Coding for Data-Retrieving in Cloud Storage Systems ***51***

Yanbo Lu (Tsinghua University, P.R. China)

As the rapid growth of data, many storage systems have used erasure codes instead of replication to reduce the storage cost under the same level of reliability. Maximum-Distance-Separable (MDS) codes have been the most widely adopted, due to their optimal storage efficiency. It is well understood that the application of codes in storage systems, where the data is less frequently accessed. As in storage systems with the data that is frequently accessed (e.g. cloud storage systems), the performance of data-retrieving is the key metric. To the best of our knowledge, there has been only a little work on the performance of data-retrieving in cloud storage systems with erasure codes. They combined queuing theory with coding theory for storage systems. They focused on analysis and optimizing the effect of MDS codes in the performance of data-retrieving. And these studies were based on MDS codes and proposed their optimization methods. In this paper, we transfer the perspective of study of based on MDS codes to that of optimizing MDS codes in order to improve the performance of data-retrieving, that is, from optimizing the system retrieving strategies to optimizing the coding schemes. Final, we propose a new family of codes with MDS property, which reach optimal performance of data-retrieving in theory.

Short Break

On the Fundamental Limits of Coded Caching and Exact-Repair Regenerating Codes ***56***

Chao Tian (The University of Tennessee Knoxville, USA)

The fundamental limits are investigated for (i) the problem of coded caching with N=3 files and K=3 users, and (ii) the problem of (5,4,4) exact-repair regenerating codes, i.e., there are n=5 storage nodes where any k=4 nodes can be used to recover the data, and any failed node can be repaired with d=4 other nodes. A computational approach is adopted in this investigation which was developed by the author in an earlier work. For the first problem, an improved outer bound to the memory-delivery-rate tradeoff is obtained. For the second problem, a complete characterization of the storage-repair-bandwidth is provided. These results are part of the online collection of ``Solutions of Computed Information Theoretic Limits (SCITL)''.

Benchmarking the Performance of Hadoop Triple Replication and Erasure Coding on a Nation-Wide Distributed Cloud ***61***

Lakshmi Mohan and Renji Luke Harold (University of Melbourne, Australia); Udaya Parampalli (The University of Melbourne, Australia); Aaron Harwood and Pablo Serrano (University of Melbourne, Australia)

Large Scale distributed storage systems play a vital role in maintaining data across storage locations globally. These systems use replication as the default mechanism for providing fault-tolerance. Recently, erasure codes are being used as a viable alternative to replication, since they provide the same fault-tolerance for reduced storage overhead. However, their performance is unclear in a geographically diverse distributed storage system. This paper compares the performance of triple replication with the erasure coding (Reed-Solomon codes) used in Apache Hadoop's implementation of a distributed file system, on a cluster distributed across Australia that runs on the NeCTAR research cloud. Our results show that using erasure coding does not degrade the read performance in such a setting. We also compare the Hadoop's code with a local reconstruction code, implemented in the XORBAS version of Hadoop. These codes perform well in our clusters, but not as expected. We need new codes that perform better, addressing the geographical diversity issue. We believe that our framework is readily usable to test a range of novel erasure codes that are being introduced in the literature.

1:15 PM - 2:15 PM

K4: Keynote Talk: Fundamental Limits in Distributed Storage Networks

Terence Chan (University of South Australia)

The era of Big Data has presented both opportunities and challenges. Currently, about 2.5 quintillion bytes of data are generated each day. Internet of things, file sharing, large-scale scientific projects, and social networking are all fuelling the explosive growth in demands for data storage in our modern information technological infrastructure. In the past few years, we have seen network coding being actively studied to improve the data storage systems in order to reduce the data storage cost and at the same time also improve the reliability against any faults and failures (e.g., fire or power outage). In this talk, we will study the fundamental limits for data storage systems, especially under various constraint (e.g., privacy constraint and heterogeneous constraint).

2:30 PM - 3:10 PM

S5: Session #5

Towards Unconditional Tor-Like Anonymity ***66***

Iris Safaka (EPFL, Switzerland); László Czap (Ecole Polytechinque Fédérale de Lausanne, EPFL, Switzerland); Katerina Argyraki (EPFL, Switzerland); Christina Fragouli (UCLA, USA)

We design and evaluate a traffic anonymization protocol for wireless networks, aiming to protect against computationally powerful adversaries. Our protocol builds on recent key-generation techniques, that leverage intrinsic properties of the wireless together with standard coding techniques. We show how to exploit the security properties of such keys to design a Tor-like anonymity network, without making any assumptions about the computational capabilities of an adversary. Our analysis and evaluation on simulated ad-hoc wireless networks, shows that our protocol achieves a level of anonymity comparable to the level of the Tor network.

On Base Field of Linear Network Coding ***71***

Qifu T Sun (University of Science and Technology Beijing, P.R. China); Shuo-Yen Robert Li (University of Electronic Science and Technology of China, Hong Kong); Zongpeng Li (University of Calgary, Canada)

A few (single-source) multicast networks were recently discovered with the special property of linearly solvable over a finite field GF(q) but not over a larger GF(q'). In this paper, these networks are extended to a general class $\mathcal{N}$ of multicast networks. We obtain a concise condition, in terms of multiplicative subgroup orders in GF(q), for networks in $\mathcal{N}$ to be linearly solvable over GF(q). This full characterization facilitates us to design infinitely many new multicast networks linearly solvable over GF(q) but not over GF(q') with $q < q'$, based on a subgroup order criterion. As an interesting instance among them, a network linearly solvable over GF(2^{2k}) but not over GF(2^{2k+1}), can be constructed for every $k\geq 2$. Our findings suggest that the suitability of a field for a given network depends on not only the size and the characteristic of the field, but also the matching between the algebraic structure of the field and the topological structure of the network.

3:40 PM - 5:15 PM

S6: Session #6

Exploiting Symmetry in Computing Polyhedral Bounds on Network Coding Rate Regions ***76***

Jayant Apte and John M. Walsh (Drexel University, USA)

We propose an algorithm for computing polyhedral bounds on the rate regions of multi-source multi-sink network coding instances given the knowledge of symmetries of the instance as captured by the network symmetry group. We show how the network symmetry group can be interpreted as a group of symmetries of a polyhedron, which in turn enables the use techniques for exploiting symmetry in polyhedral computation to reduce the complexity of calculating the rate region. We apply these techniques to the polyhedral projection algorithm chm to list only those facets and extreme points of a polyhedral bound on rate region that are inequivalent under the action of the network symmetry group. Additionally, a generalization of this algorithm that can exploit richer super-groups of polyhedral symmetries, the restricted affine symmetry groups, is discussed.

Computer Aided Proofs for Rate Regions of Independent Distributed Source Coding Problems ***81***

Congduan Li, Steven Weber and John M. Walsh (Drexel University, USA)

The rate regions of independent distributed source coding (IDSC) problems, a sub-class of the broader family of multi-source multi-sink networks, are investigated. An IDSC problem consists of multiple sources, multiple encoders, and multiple decoders, where each encoder has access to all sources, and each decoder has access to a certain subset of the encoders while demanding a certain subset of the sources. Instead of manually deriving the rate region for a particular problem, computer tools are used to obtain the rate regions for thousands of non-isomorphic (symmetry-removed) IDSC instances. Enumeration of all non-isomorphic IDSC instances of a particular size is given. For each non-isomorphic IDSC instance, the Shannon outer bound, superposition coding inner bound, and several achievable inner bounds based on linear codes are considered. For the thousands of IDSC instances considered, vector binary inner bounds match the outer bound, and hence exact rate regions are proven. In addition, the achieving codes are known.

Short Break

Can Network Coding Bridge the Digital Divide in the Pacific? ***86***

Ulrich Speidel (University of Auckland, New Zealand); 'Etuate Cocker (The University of Auckland, New Zealand); Péter Vingelmann (Steinwurf ApS, Hungary); Janus Heide (Steinwurf ApS, Denmark); Muriel Médard (MIT, USA)

Conventional TCP performance is significantly impaired under long latency and/or constrained bandwidth. While small Pacific Island states on satellite links experience this in the extreme, small populations and remoteness often rule out submarine fibre connections and their communities struggle to reap the benefits of the Internet. Network-coded TCP (TCP/NC) can increase goodput under high latency and packet loss, but has not been used to tunnel conventional TCP and UDP across satellite links before. We report on a feasibility study aimed at determining expected goodput gain across such TCP/NC tunnels into island targets on geostationary and medium earth orbit satellite links.

A Hybrid EF/DF Protocol with Rateless Coded Network Code for Two-Way Relay Channel ***91***

Dai Jia (BeiJing Institute of Technology, P.R. China); Shuang Tian (Spreadtrum Communications, Inc., P.R. China); Jinhong Yuan (University of New South Wales, Australia); Zesong Fei and Jingming Kuang (Beijing Institute of Technology, P.R. China)

In this paper, we consider a rateless coded network coding design for a two-way relay channel (TWRC). Rateless codes are employed as it can operate over various channel conditions. Since the two users may use different code generator matrices, the relay may not directly recover the physical-layer network coded message. Therefore, we propose a hybrid estimate and forward (EF)/decode and forward (DF) protocol with rateless code for the TWRC. In the proposed scheme, the relay uses an iterative decoding process to decode the message of two users. The relay will generate network code, soft network code (SNC) or soft physical-layer network code (SPNC) and forward them to the users, depending on the relay recovers both users' message, only one user's message or no users' message, respectively. We design the degree distribution for the rateless code, which is suitable not only for decoding at users at high SNR, but also for decoding at the relay at low SNR. We show that the proposed hybrid EF/DF protocol with the designed rateless code outperforms other protocols significantly in terms of bit error rate (BER) performance.

5:15 PM - 5:25 PM

C: Closing