

# The Science of Network Coding

Michael Langberg (SUNY Buffalo)

and

Zongpeng Li (University of Calgary)

Sep. 20 2013 – Sep. 22 2013

Network coding is a relatively new concept that originated from information theory. In the recent past, a number of eye opening works have been conducted along the directions of applying this new tool for both (a) attacking classic computer science problems (e.g., Steiner trees, matrix rank computation) and (b) defining new fields of research (e.g., network error correction, optimal information network design). However, few opportunities exist for experts from the fields of information theory and computer science to meet in a common room, to involve in an in-depth dialog on the subject of profound interest to both of them — network coding. This workshop was intended to serve as such a unique venue.

During the workshop, several works from different areas of network coding were presented and discussed. The workshop had a total of 5 technical sessions. Each session included a number of talks on a similar topic and an open discussion on the major challenges and open problems in the topic at hand. The workshop also included a special session focusing on potential projects that may unify and lead the network coding community; such as special journal issues dedicated to Network Coding and the use of technology to create platforms that will promote collaboration in the form of broadcasted biweekly seminars and a data base of selected filmed lectures. Open problems were posed throughout the workshop and during special allocated time periods.

The workshop combined researchers from the fields of network information theory, coding theory, computer science and combinatorics. The discussions and interaction between the participants was intriguing and both ideas and perspectives were shared between the different communities. Several unknown connections between the works of different participants were unraveled. Examples include fundamental connections between the field size needed in communication networks and reductions between general and planar network topologies; and intriguing connections between coding techniques used in secure data exchange and those used in secure multiple source communication models.

Our workshop followed the schedule below. Several participants had the opportunity to share their problems, ideas, and perspectives, and we are certain that this workshop has set the foundations to future collaborations between new and veteran groups of researchers. We greatly thank BIRS for giving us this unique opportunity to gather.

## 1 Schedule

### Friday:

- 16:00** Check-in (front desk - Professional Development Centre - open 24 hours).
- 17:30-19:30** Dinner (at Vistas Main Dining Room on the 4th floor of Sally Borden Building).
- 19:30-21:00** Welcome gathering on 2nd floor, Corbett Hall.

Beverages and a small assortment of snacks are available in the lounge on a cash honor system.

### Saturday:

- 7:00-8:00** Early bird hike (sunrise 07:21) .
- 7:00-8:30** Breakfast.
- 8:30-10:15** Session 1: Index coding.
- Young-Han Kim (University of California at San Diego): On the capacity region for index coding.
  - Michelle Effros (California Institute of Technology): Edge removal and related problems.
  - Michael Langberg (SUNY Buffalo): On the connection between network coding and index coding.
  - Open discussion: Challenges and open problems related to index coding.
- 10:15-10:45** Coffee break (with BIRS BoD).
- 10:45-11:45** Session 2: Data exchange.
- Alex Sprintson (Texas A & M University): Distributed data exchange with weak security.
  - Salim El-Rouayheb (Illinois Institute of Technology): Network Coding for Data Exchange.
  - Open discussion: Challenges and open problems in data exchange.
- 11:45-13:15** Lunch.
- 13:15-14:45** Session 3: Network Coding fundamentals.
- Zongpeng Li (University of Calgary): Multiple-unicast network coding.
  - Xunrui Yin (University of Calgary): Network Coding and field size.
  - Aditya Ramamoorthy (Iowa State University): Achievability scheme for 3 unicast networks.
  - Open discussion: Challenges and open problems in NC fundamentals.
- 14:45-15:15** Coffee break.
- 15:15-17:00** Session 4: Error correction and secure communication.
- Tracey Ho (California Institute of Technology): Network error correction for distributed multi-source codes.
  - Sidharth Jaggi (Chinese University of Hong Kong): Reliable, deniable, and hidable network communication.
  - Joerg Kliewer (New Mexico State University): Polar coding for the operator channel.
  - Open discussion: Challenges and open problems in network error correction and secure communication.
- 17:00-18:30** Evening hike (sunset 19:36, full moon sunrise 20:27).
- 18:30-19:30** Dinner.
- 20:00-21:00** Open problems session.

### Sunday:

- 7:00-8:00** Early bird hike.
- 7:00-8:30** Breakfast.
- 8:30-10:15** Session 5: More on security and errors in network comm.
- Di Niu, Majid Khabbazian (University of Alberta) : Network Coding and Gossiping.
  - Christina Fragouli (EPFL / UCLA) : Secure network coding with erasures and feedback.
  - Mayank Bakshi (INC Hong Kong (CUNK)): On the capacity of Arbitrarily Varying Networks.
  - Open discussion.
- 10:15-10:45** Coffee break.
- 10:45-12:00** Open discussions (special journal issues, future BIRS workshops, and more ...).

## **2 Open questions and research directions discussed and arose from workshop**

A number of interesting open problems in the field of network coding were reviewed and discussed at the workshop. New problems and research directions also arose. Overall, the community felt that the workshop was very successful in advancing the state-of-the-art of network coding theory, and would like to express

their appreciation to BIRS for helping make the event possible! Below we list a few examples of the fruitful discussions.

## **2.1 The edge removal problem.**

In the recent few years, a group of researchers (including Effros, Langberg, Ho and others) have been studying the continuity of the network capacity (under network coding) with the removal of a single edge from the network. They proved that the edge removal problem has a few interesting equivalent formulations in the form of index coding and  $\epsilon$ -error edge capacities. This problem was discussed at the workshop and provoked abundant interest from the audience. The general agreement appeared to be that the problem is fundamental, and perhaps hard in its general form. However, potential approaches and partial results were exchanged among the audience.

## **2.2 The multiple-unicast network coding conjecture.**

A long-time standing open problem at the core of network coding theory is the multiple-unicast conjecture, which claims that network coding and routing are equivalent for multiple one-to-one information transmission sessions in an undirected network. Li, one of the researchers who originally proposed the conjecture in 2004, presented current status on the research that aims to settle the conjecture. The audience also expressed their views towards the validity and possible resolution of the conjecture, as well as the connection between the conjecture and other open problems in network coding.

## **2.3 Network coding and index coding.**

A couple of talks happened on the topic of examining the connection between network coding and index coding, another interesting problem at the intersection of computer science and information theory. A few researchers in the audience (e.g., Langberg, Springton, El Rougheb) have been conducting active research in this area, and provided overview of progress and future directions in this research field.

## **2.4 Network coding and field sizes.**

The problem of selecting the appropriate alphabet for performing encoding operations in network coding has been revisited during the workshop. First, very recent discoveries on the surprising result that a large field is not necessarily more powerful than a smaller one, even for single-source problems such as single multicast, was reported to the community for the first time, and generated substantial interest. Second, the possibility of designing efficient network coding solutions for special networks such as planar networks were discussed at the workshop, both through formal presentations and informal group discussions.

## **2.5 Network coding and networking.**

The fruitful field of applying network coding in computer networking has been another focus point in the workshop. Topics and research directions including (i) network coding for gossiping, (ii) network coding for network security and wireless communications, and (iii) network error correction are presented and discussed, bringing a number of the audience up to speed along these interesting research threads.

# **3 Conclusions and Acknowledgement to BIRS**

To conclude, the two day BIRS Workshop on The Science of Network Coding that happened during the weekend of September 20-22 2013 at BIRS, Banff, Alberta, Canada has been a very successful one, with both established scholars and young researchers attending from a number of different countries, with complementing backgrounds (information theory versus computer science). The dialogs that happened at the workshop have greatly helped the two communities to understand each other's research interests, latest progresses, and major focuses. A number of new and classic themes on network coding were discussed, leading to new thoughts on possible research methodology as well as new research problems and threads. It is not

over-estimating to state that the BIRS workshop on The Science of Network Coding has helped advance the research progress overall in the field of network coding, and for that, on behalf of the network coding research community, we hereby express our sincere gratitude to BIRS!