REPORT DOCUMENTATION PAGE

Form Approved OMB NO. 0704-0188

1. REPORT DATE (DD-MM-YYYY)	2. REPORT TYPE	3. DATES COVERED (From - To)
11-02-2018	Final Report	1-Jul-2014 - 30-Jun-2017

4. TITLE AND SUBTITLE

Final Report: Wireless Networks as Polymatroidal Graphs: Embedding, Multicommodity Flows, Cuts and Function Computation-Research Area 10-Network Science

5a. CONTRACT NUMBER
W911NF-14-1-0220

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER
611102

6. AUTHORS

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAMES AND ADDRESSES

University of Illinois - Urbana - Champaign
c/o Office of Sponsored Programs
1901 S. First Street, Suite A
Champaign, IL 61820 -7406

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS (ES)

U.S. Army Research Office
P.O. Box 12211
Research Triangle Park, NC 27709-2211

10. SPONSOR/MONITOR'S ACRONYM(S)
ARO

11. SPONSOR/MONITOR'S REPORT NUMBER(S)
65396-NS.8

12. DISTRIBUTION AVAILIBILITY STATEMENT

Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES

The views, opinions and/or findings contained in this report are those of the author(s) and should not contrued as an official Department of the Army position, policy or decision, unless so designated by other documentation.

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	15. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			Pramod Viswanath
UU	UU	UU	UU		19b. TELEPHONE NUMBER 217-244-8999

RPPR Final Report
as of 23-Mar-2018

Agency Code:

Proposal Number: 65396NS **Agreement Number: W911NF-14-1-0220**
INVESTIGATOR(S):

Name: Pramod Viswanath
Email: pramodv@illinois.edu
Phone Number: 2172448999
Principal: Y

Organization: **University of Illinois - Urbana - Champaign**
Address: c/o Office of Sponsored Programs, Champaign, IL 618207406
Country: USA
DUNS Number: 041544081 EIN: 376000511
Report Date: 30-Sep-2017 Date Received: 11-Feb-2018
Final Report for Period Beginning 01-Jul-2014 and Ending 30-Jun-2017
Title: Wireless Networks as Polymatroidal Graphs: Embedding, Multicommodity Flows, Cuts and Function Computation-Research Area 10-Network Science
Begin Performance Period: 01-Jul-2014 **End Performance Period:** 30-Jun-2017
Report Term: 0-Other
Submitted By: Pramod Viswanath Email: pramodv@illinois.edu
Phone: (217) 244-8999
Distribution Statement: 1-Approved for public release; distribution is unlimited.

STEM Degrees: **STEM Participants:**

Major Goals: The major goals of the project are discovery of new wireless interference management techniques, new techniques to prevent malware from spreading in distributed decentralized networks and new protocols for streaming data over purely distributed networks.

Accomplishments: See PDF document.

Training Opportunities: Nothing to Report

Results Dissemination: Journal papers:

Hiding the Rumor Source
Giulia Fanti, Peter Kairouz, Sewoong Oh, Kannan Ramchandran, and Pramod Viswanath
IEEE Transactions on Information Theory, Vol. 63(10), pp. 6679-6713, 2017.

Costly Circuits, Submodular Schedules and Approximate Caratheodory Theorems,
S. Venkatakrishnan, M. Alizadeh and P. Viswanath,
Queueing Systems, pp. 1-37, September 2017.

Honors and Awards: Lead Phd student on the project was Shaileshh Venkatakrishnan. He has graduated with his PhD and is now a postdoc at MIT.

Protocol Activity Status:

Technology Transfer: Collaboration with ARL researcher Dr. Hasan Cam has been successful and led to a technical paper, under review.

PARTICIPANTS:

Participant Type: PD/PI
Participant: Pramod Viswanath
Person Months Worked: 1.00 **Funding Support:**
Project Contribution:

RPPR Final Report
as of 23-Mar-2018

International Collaboration:
International Travel:
National Academy Member: N
Other Collaborators:

CONFERENCE PAPERS:

Publication Type: Conference Paper or Presentation **Publication Status:** 1-Published
Conference Name: ICML 2016
Date Received: 30-Aug-2016 Conference Date: 20-Jun-2016 Date Published: 01-Jul-2016
Conference Location: New York
Paper Title: Metadata Conscious Anonymous Messaging
Authors: Giulia Fanti, Peter Kairouz, Sewoong Oh, Kannan Ramchandran, Pramod Viswanath
Acknowledged Federal Support: **Y**

Publication Type: Conference Paper or Presentation **Publication Status:** 1-Published
Conference Name: ACM Sigmetrics
Date Received: 30-Aug-2016 Conference Date: 13-Jun-2016 Date Published: 01-Jul-2016
Conference Location: Antibes, France
Paper Title: Rumor Source Obfuscation on Irregular Trees
Authors: Giulia Fanti, Peter Kairouz, Sewoong Oh, Kannan Ramchandran, Pramod Viswanath
Acknowledged Federal Support: **Y**

Publication Type: Conference Paper or Presentation **Publication Status:** 1-Published
Conference Name: ACM Sigmetrics
Date Received: 30-Aug-2016 Conference Date: 13-Jun-2015 Date Published: 01-Jul-2016
Conference Location: Antibes, France
Paper Title: Costly Circuits, Submodular Schedules and Approximate Carathéodory Theorems
Authors: Shaileshh Venkatakrishnan, Mohammad Alizadeh, Pramod Viswanath
Acknowledged Federal Support: **Y**

Final Report

ARO Project: W911NF-14-1-0220; Title: Wireless Networks as Polymatroidal Graphs: Embeddings, Multicommodity Flows, Cuts and Function Computation.

The project has successfully led to new wireless interference management techniques, new techniques to prevent malware from spreading in distributed decentralized networks and new protocols for streaming data over purely distributed networks. This has included collaborations with ARL researcher Dr. Hasan Cam. Each of these works have been published in mainstream journals and conferences and the support from ARO acknowledged. We give a brief synopsis of the prominent outputs of this project below.

Interactive Interference Alignment.

Authors: Quan Geng, Sreeram Kannan, Pramod Viswanath

Abstract: We study interference channels (IFC) where interaction among sources and destinations is enabled, e.g., both sources and destinations can talk to each other using full-duplex radios. The interaction can come in two ways: 1) *In-band interaction:* sources and destinations can transmit and listen in the same channel simultaneously, enabling interaction. 2) *out-of-band interaction:* destinations talk back to the sources on an out-of-band channel, possible from white-space channels. The flexibility afforded by interaction among sources and destinations allows for the derivation of interference alignment (IA) strategies that have desirable "engineering properties": insensitivity to the rationality or irrationality of channel parameters, small block lengths and finite SNR operations. We show that for several classes of interference channels the interactive interference alignment scheme can achieve the optimal degrees of freedom. In particular, we show the *first simple scheme* (having finite block length, for channels having no diversity) for K=3,4 that can achieve the optimal degrees of freedom of K2 even after accounting for the cost of interaction. We also give simulation results on the finite SNR performance of interactive alignment under some settings. On the technical side, we show using a Gröbner basis argument that in a general network potentially utilizing cooperation and feedback, the optimal degrees of freedom under linear schemes of a fixed block length is the same for channel coefficients with probability 1. Furthermore, a numerical method to estimate this value is also presented. These tools have potentially wider utility in studying other wireless networks as well.

Publications: IEEE ISIT 2013 (conference) and IEEE Journal on Selected Areas in Communications, Vol. 32(9), pp. 1619-1706, June 2014 (journal).

Deterministic Near-Optimal P2P Streaming

Authors: Shaileshh Venkatakrishnan, Pramod Viswanath.

Abstract: We consider streaming over a peer-to-peer network with homogeneous nodes in which a single source broadcasts a data stream to all the users in the system. Peers are allowed to enter or leave the system (adversarially) arbitrarily. Previous approaches for streaming in this setting have either used randomized distribution graphs or structured trees with randomized maintenance algorithms. Randomized graphs handle peer churn well but have poor connectivity guarantees, while structured trees have good connectivity but have proven hard to maintain under peer churn. We improve upon both approaches by presenting a novel distribution structure with a deterministic and distributed algorithm for maintenance under peer churn; our result is inspired by a recent work proposing deterministic algorithms for rumor spreading in graphs. A key innovation in our approach is in having redundant links in the distribution structure. While this leads to a reduction in the maximum streaming rate possible, we show that for the amount of redundancy used, the delay guarantee of the proposed algorithm is near optimal. We introduce a tolerance parameter that captures the worst-case transient streaming rate received by the peers during churn events

and characterize the fundamental tradeoff between rate, delay and tolerance. A natural generalization of the deterministic algorithm achieves this tradeoff near optimally. Finally, the proposed deterministic algorithm is robust enough to handle various generalizations: ability to deal with heterogeneous node capacities of the peers and more complicated streaming patterns where multiple source transmissions are present.
Publication: ACM Sigmetrics, 2015.

Topological Immunization in Peer-to-Peer Networks.
Authors: Authors: Shaileshh Venkatakrishnan, Hasan Cam, Pramod Viswanath.
Abstract: Peer-to-Peer (p2p) networks, due to their popularity, vast user numbers and decentralized control, are experiencing a massive surge of malware attacks. Left unchecked, these malicious programs are capable of causing widespread damage to the network and financial loss. Traditional mitigation strategies at the application-level are impractical at this scale, and have led to network-based immunization strategies such as dynamically modifying connections based on peer interactions. In this paper, we propose an alternative approach of using the network?s topology to deter malware spread. Our approach proactively engineers the network in such a way that malware-resistant peers help shield the infection from spreading to the rest of the network. We propose a new metric called immunization-capacity to quantify and measure this spreading resistance. Using this metric the proposed algorithm is shown to be essentially optimal.
Publication: under review, 2018.