Guest Editorial Network Science

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OVER the past several years there has been increasing interest in studying the commonalities among multiple networks such as logistical networks, biological networks, financial and economic networks, transportation networks, cognitive networks, social networks, information networks and communications networks. Several possible cross-network commonalities have been identified and there is an emerging line of research that seeks to develop the theoretical underpinning to these commonalities. Collectively these efforts are known as network science. This JSAC special issue seeks to highlight fundamental advances in network science as well as its applications to communications networks and techno-social networks.

A key goal of network science research is to uncover universal laws that govern certain structural and functional aspects of multiple genres of networks. A useful side effect of such universal laws is that it may be possible to borrow key insights and design principles from different types of networks and apply them to communications networks problems, e.g., concepts from biological networks or social networks can be applied to communications networking.

Information propagation is one such fundamental problem in all networks, since the main function of every network is "transporting goods". Therefore, improving our understanding about the process by which influence/opinions/rumors/contagion spread in social networks could help use design better information dissemination protocols for communication networks.

A recent topic of research in the network science community is *combined* or *composite* networks – these are two or more interacting networks that must be characterized jointly rather than individually. For example, a social network and a communication network sharing some nodes (corresponding to users) may be modeled together as a composite network. This may be useful since the aggregate performance of a composite network may often depend on how the individual networks influence each other. Information may travel faster or slower through composite networks depending on how they are coupled.

The above vision was captured in the Call for Papers for this special issue in the IEEE Journal On Selected Areas In Communications, and it was published in June 2012. As a result of this solicitation, we received 62 submissions by the deadline of August 15, 2012. Papers were selected after two rigorous rounds of review[1]. The first round of notifications were sent out on December 17, 2012 to the authors whose papers passed the first round of review. Revised versions of the papers were submitted on January 31, 2013. Finally, after a second round of review, the Guest Editorial board decided on March 12, 2013 to accept 16 high quality papers for publication in this competitive special issue.

Papers appearing in this special issue belong to five broad themes, which are not necessarily mutually exclusive: (1) fundamental principles in network science, (2) information propagation models in networks, (3) bringing insights from other genres of networks, (4) economic and game theoretic models, and (5) application of network science principles to communications networking problems.

The first set of three papers develops algorithms, frameworks, and analysis techniques that are largely applicable to a broad class of network genres, while the fourth paper applies related analytical techniques to a specific problem domain.

In the paper, "Community Detection in Scale-Free Networks: Approximation Algorithms for Maximizing Modularity", community detection is formulated as modularity maximization for finding the partition with maximal associated modularity, a quality function introduced by Newman and Girvan in 2004. This is known to be an NP-hard problem, for which many heuristics have been proposed in the last decade. The proposed algorithm has the rare specificity that it has a guarantee of quality, in that it finds modularity within a bounded or logarithmic ratio of the optimal modularity of a network. It performs well, in terms of speed and maximization algorithms, compared to other algorithms.

In the paper "A Measurement Framework for Directed Networks", the authors propose an integrated sampling and estimation framework for nodal characteristics in directed networks. The paper proposes an algorithm which uses only local knowledge – the set of visited nodes – rather than prior global knowledge of the (latent) structure of the full network.

The paper "On Set Size Distribution Estimation and the Characterization of Large Networks via Sampling" studies a set size distribution estimation problem, where elements are randomly sampled from a collection of non-overlapping sets and the original set size distribution must be recovered from

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[1]Papers coauthored by Guest Editors and their mentors were handled independently by Senior Editors.

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the samples. Such sampling tools for large networks could be useful in characterizing in-degree distributions in large graphs and uncovering TCP/IP flow size distributions on the Internet.

The fourth paper, "On Credibility Estimation Tradeoffs in Assured Social Sensing" studies a topic related to sampling but purely in the context of social sensing. The authors deal with the problem of credibility estimation, and propose a method to derive confidence bounds to quantify the accuracy of claims coming from the social sensing applications. The paper formulates the trustworthiness of sources in social sensing as a maximum likelihood estimation problem and present sensitivity analysis of trade-offs.

The next set of five papers studies the important topic of the spreading of information through networks, where information could take the form of opinions, memes, rumors, influence, or just plain data without any semantics. These papers develop and use a plethora of mathematical tools that will be of interest to the network science community at large. The first two papers in this set use a recently proposed composite network framework to study the information diffusion problem.

In the paper "Conjoining Speeds up Information Diffusion in Overlaying Social-Physical Networks", the authors develop a theory of information diffusion in an overlaid social-physical network. They quantify the size and the critical percolation threshold of information epidemics in this *composite* social-physical network for the SIR model of information diffusion, and show that while there may be no percolation in the individual networks, percolation (i.e., information epidemics) could take place in the composite social-physical network.

In the paper "Competing Memes Propagation on Networks: A Network Science Perspective", the authors study the intertwined propagation of two competing memes (or data, rumors, etc.) in a composite network. Within the constraints of this scenario, they address two key questions: (a) which meme will prevail? and (b) can one influence the outcome of the propagations?

The paper "How Agreement and Disagreement Evolve over Random Dynamic Networks" studies a related topic. The authors develop a theoretical model based on attraction, repulsion, and neglect for representing a plethora of phenomena such as spreading of true and false information over a communication network, the propagation of faults in a large-scale control system, or the development of trust and mistrust in a society. They then establish a series of sufficient and/or necessary conditions for *agreement convergence* or *disagreement divergence* in dynamic networks.

In the paper "Consensus, Polarization and Clustering of Opinions in Social Networks", the authors study the problem of opinion dynamics in a social group. They analytically study a model where agents exchange their opinions with their neighbors and move their opinions closer to each other if they are like-minded (that is, the distance between opinions is smaller than a threshold). The main goal of the paper is to analyze the convergence properties of the opinion dynamics and explore the underlying characteristics that mark the phase transition from opinion polarization to consensus.

The paper "On Budgeted Influence Maximization in Social Networks" studies the budgeted influence maximization (BIM) problem which is concerned with selecting a set of seed nodes to disseminate some information that maximizes the total number of nodes influenced (termed as influence spread) in social networks at a total cost no more than a given budget. The authors give a guaranteed approximation algorithm for this optimization problem.

The next set of two papers brings insights from other genres of networks, such as neuronal networks and chemical reaction networks and show how these insights could be effective in designing networked systems, in general, and also have specific applications to communications networks problems.

In the paper, "The Wiring Economy Principle for Designing Inference Networks", the authors describe the wiring economy principle and its implications on the design of networked systems. They study the topology and placement of nodes in designing networks with optimal wiring cost properties. The authors restrict themselves to a non-malicious setting. The main theoretical result is the independence of optimizing placement and topology. A separation principle between logical topology design and node placement is demonstrated. Random networks were shown to present good performance.

The paper "Stability and Sensitivity Analysis of Traffic-Shaping Algorithms Inspired by Chemical Engineering" analyzes a chemical reactions metaphor for studying traffic shaping algorithms in communications networks. They show that the related fluid model, describing the emergent behavior of the overall system, can be derived from the corresponding reaction networks automatically. They also describe how to fine-tune these "chemical algorithms".

The next set of three papers proposes the use of economic and game theoretic models to understand characteristics of networks formed between independent agents who are driven by self-interest.

In the paper "Strategic Networks: Information Dissemination and Link Formation Among Self-Interested Agents", the authors study a class of network formation games. Here link formation is unilateral, but links, once created are bidirectional. Link formation incurs a cost and information dissemination yields a reward. This is analyzed as a non-cooperative game, and several analytical results on the ensuing equilibria are established. The paper establishes conditions under which core-periphery, sparse connectivity or scale-free properties arise at equilibrium. The strategic behavior of the agents with respect to information production is also characterized.

In the paper, "Selfish Mules: Social Profit Maximization in Sparse Sensornets using Rationally-Selfish Human Relays", the authors combine aspects of social networks and Lyapunov optimization techniques to develop a social-economic aware backpressure routing algorithm. The motivation of the work is to allow mobile devices carried by humans to assist in gathering data gathered by static sensors by acting as relays. The results show that such an algorithm outperforms those based purely on social-awareness or Lyapunov optimizations, illustrating the power of combining these techniques.

In the paper "Cooperation Dynamics on Collaborative Social Networks of Heterogeneous Population", the authors propose a two-phase Heterogeneous Public Goods Game (HPGG) model to study the cooperation dynamics in Collaborative Social Networks. Based on HPGG CSN model, the authors quantitatively investigate the relationship between cooperation rate and individuals heterogeneous behaviors from an evolutionary game perspective.

The final set of two papers apply network science concepts to specific communications networking problems of interest.

In the paper, "Characterizing Inter-domain Rerouting by Betweenness Centrality after Disruptive Events", the authors adapt the traditional network science metric of betweenness centrality to Internet ASes. Publicly available BGP data is used to calculate the value of AS Betweenness Centrality, and methods are developed to characterize several aspects of network re-routing. These include synchronization of rerouting, time between reroutes, and most impacted ASes. The authors then use these methods to characterize four real-word events that resulted in major disruptions.

The paper, "Integrated Multi-Network Modeling Environment for Spectrum Management", develops a multi-faceted model of cellular network usage that can be used for applications such as spectrum planning. The model combines many aspects of social, economic and network factors. Factors considered in the model include device ownership, usage patterns of different demographics, mobility and application demands. The models for these items are drawn from open source data sets and integrated so that urban areas can be accurately modeled for their spectrum use.

The guest editorial team expresses their deep appreciation to all the authors of the papers submitted to this special issue. We are grateful to all the reviewers involved in the review process, for delivering high-quality reviews for the papers in a timely manner. We would also like to express our gratitude to the JSAC team: the Editor-in-Chief Dr. Martha Steenstrup, the Senior Editors (for reviewing the small number of submissions that were co-authored by Guest Editors), the Executive Editor Laurel Greenidge, and the IEEE publications staff (Sue Lange, in particular) for their fantastic support and input, which made this issue possible. Last but not the least, the chair of Guest Editorial board would like to thank Dr. Craig Partridge and Prof. Don Towsley for their invaluable mentorship throughout the entire process.

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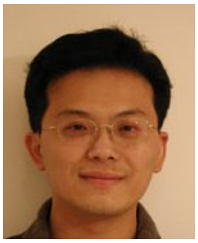
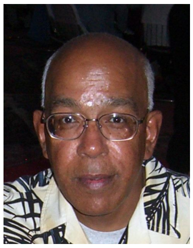


Ching-Yung Lin (Fellow, IEEE) received the B.S. and M.S. degrees in electrical engineering from National Taiwan University, Taipei, Taiwan, in 1991 and 1993, respectively, and the Ph.D. degree in electrical engineering from Columbia University, New York, NY, in 2000. He joined IBM T. J. Watson Research Center, Hawthorne, NY, in 2000, where he is the Lead and Principal Investigator of Social Network Analytics Research. He was an Affiliate Assistant/Associate Professor at the University of Washington, Seattle (2003-2009), and has been an Adjunct Associate/Full Professor at Columbia University, New York, NY, since 2005. His research interest mainly focuses on multimodality signal analysis, complex network analysis, and computational social and cognitive sciences. He leads several large research projects, including more than 35 Ph.D. researchers in IBM Research and ten U.S. universities, to advance fundamental research of network science and people analytics, as well as applied researches on collaboration, security, and commerce. The research goals are to 1) explore and investigate scientific challenges on large-scale network graph processing; 2) quantify value of networks; and 3) understand multichannel behaviors of people, from cognitive level to societal level. He is an author or coauthor of more than 150 research papers. He initiated the first large-scale video semantic annotation task including 23 global institutes and 111 researchers in 2003. His invention SmallBlue (IBMAtlas) has been featured in more than 120 press articles, including appearing four times in BusinessWeek magazine and being the Top Story of the Week in April 2009. Dr. Lin is a recipient of the 2011 Association of Information System ICIS Best Theme Paper Award, the 2003 IEEE CAS Society Young Author Award, the 2011 IBM Corporation Outstanding Innovation Award, the 2005 IBM Research Division Award, and the IBM Invention Achievement Award in 2001, 2003, 2007, 2010, and 2011. In 2010, IBM Exploratory Research Career Review selected him as one of the researchers Bmost likely to have greatest scientific impact for IBM and the world.[He was the Editor of the Interactive Magazines (EIM) of the IEEE Communications Society (2004-2006), and a Guest Editor of the PROCEEDINGS OF THE IEEE Special Issue on Digital Rights Management (2004), the EURASIP Journal on Applied Digital Signal Processing Special Issue on Visual Sensor Network (2006), the IEEE TRANSACTIONS ON MULTIMEDIA Special Issue on Communities and Media Computing (2009), the IEEE JOURNAL ON SELECTED AREA IN COMMUNICATIONS Special Issue on Network Science (2013), and the Journal of Multimedia Special Issue on Social Multimedia Computing (2013). He was the Chair of the IEEE International Conference on Multimedia and Expo 2009 and the Chair of Circuits and Systems Society Multimedia Technical Committee (2010-2011), and is the Chair of the Steering Committee of ACM SIG Health Informatics (IHI) (2009-2012). He is a member of the Academy of Management.



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