Introduction to the Issue on Signal Processing for Social Networks

NETWORKS are fundamental to our modern world: they appear throughout science and society, and continue to grow in size, complexity, and importance. Whenever we observe entities and relationships between them, we effectively define a network of some sort. As structural objects composed of nodes and links, networks play a strong and well-defined role across mathematics, science and engineering.

However, we require significant advances to be made in mathematical knowledge and understanding if we are to develop a holistic set of theory and methods for signal processing on graphs and networks—particularly social networks. In this realm, an important byproduct of the emergence of on-line social media is the phenomenon that most things we do online are recorded instantly, be it web-clicks, transactions, wall-posts on Facebook, tweets, or blogs. In the past year alone, we have generated 1.8 zettabytes (10^{21}) of data. The access to this massive amount of social data presents a unique opportunity to the signal processing community.

As networks grow in size and complexity, our ability to analyze them using existing signal processing methods is at severe risk of failing to keep pace. This special issue focuses on a core set of signal processing fundamentals for social networks, to provide both the necessary strong theoretical underpinnings and also the practical tools required to impact important practical applications.

Typical analyses are likely in part to involve multi-agent estimation, detection, and active decision-making where agents communicate over (a possibly random) graph. Such problems typically involve non-standard information patterns, since agents not only learn from their private observations but are also influenced by decisions of other agents. These together with the complex nature of the underlying graph can result in gossip propagation/data incest in estimation, and herding, where agents are overly influenced by the decisions of other agents. The recent literature in analysis of social networks involves multi-agent stochastic optimization and adaptive filtering, dynamics of random graphs, multi-agent Bayesian estimation, and social learning to understand how decision makers interact.

Another important challenge is handling, analyzing, and visualizing "big data" from social networks. Even though the data may be large in volume, each piece of data will typically only have a small amount of information relevant to the particular query or decision-making task. To make a difference, one really needs to aggregate information from heterogeneous sources of data simultaneously. The only way to do this is to develop a meaningful "informational" representation of the data, convert the data into such a representation, and then utilize it. Addressing this challenge requires developing novel statistical and machine learning tools based algorithmic approaches in the big data regime.

The objective of this special issue is to contribute to the progress and success of signal processing methods in social networks. We received a large number of submitted manuscripts, out of which seventeen papers were accepted for publication in this issue. These papers can be divided roughly into three categories: modeling of social network dynamics, inference in social networks, and applications. These categories are not disjoint, however, as papers often treat multiple aspects of social network analysis.

There are five papers in the first category, dynamic modeling of social networks. "Multi-Layer Graph Analysis for Dynamic Social Networks," by Oselio, Kulesza, and Hero, considers a unified model to capture multi-type social interactions. This work develops latent variable models and methods for mining multi-layer networks for connectivity patterns based on noisy data. In "Graphical Evolutionary Game for Information Diffusion over Social Networks," Jiang, Chen, and Liu, propose an evolutionary game theoretic framework to model the dynamic information diffusion process in social networks. The paper considers uniform degree and non-uniform degree networks and derives closed-form expressions for the evolutionary stable network states. "Diffusion in Social Networks as SIS Epidemics: Beyond Full Mixing and Complete Graphs," by Zhang and Moura also studies diffusion in social networks, but from a different perspective, deriving the equilibrium distribution corresponding to a scaled susceptible-infected-susceptible model for peer influence based on neighbor-to-neighbor interactions. This allows the authors to answer questions concerning how network topology affects the asymptotic behavior of diffusions on the network. The paper "Dynamic Stochastic Blockmodels for Time-Evolving Social Networks," by Xu and Hero, deals with fitting state space models to temporally dynamic networks. It is shown that combining a local search algorithm with the classical extended Kalman filter yields a computationally efficient algorithm that performs similarly to a state-of-the-art Markov chain Monte Carlo method. In related work, "Proximal-Gradient Algorithms for Tracking Cascades Over Social Networks," by Baingana, Mateos and Giannakis, develops dynamic structural equation models to infer slowly time-varying network topologies, which in turn enables tracking of cascades over social networks. Notably, this work shows how scalable gradient-based algorithms tailored for this context can lead to understandable trade-offs between convergence properties and computational complexity.

The last two papers in the prior category develop models designed to aid in making inferences about network behavior. These papers provide a segue into the largest grouping, with

Digital Object Identifier 10.1109/JSTSP.2014.2331002

seven papers, which fall within the category of inference in social networks. In "Bounded Confidence Opinion Dynamics in a Social Network of Bayesian Decision Makers," K. R. Varshney studies convergence of prior probabilities when agents are Bayesian decision makers that perform signal detection and the dynamics are applied to prior probabilities of hypotheses. The paper shows that the time to convergence changes with the signal-to-noise ratio in the detection task. "How to Identify an Infection Source with Limited Observations," by Luo, Tay, and Leng, treats the problem of tracing the source of a rumor in a network. While in general the source cannot be uniquely recovered, the authors show what is possible for the special case of trees, making a connection with the classical notion of Jordan centers, and then provide approximate source estimators for general networks. In "Convergence Analysis of Iterated Belief Revision in Complex Fusion Environments," Wickramarathne, Premaratne, Murthi and Chawla, study convergence of iterated belief revision in fusion environments comprising human and physical sensors, and conditions for consensus are analyzed. In "Graph-Theoretic Distributed Inference in Social Networks," by Doostmohammadian and Khan, the authors consider distributed inference in social digraph networks. Examples of social influence in political blogs and co-authorship graphs are presented. The paper "Provenance-assisted Classification in Social Networks" by D. Wang, *et al.*, investigates the use of source identities for enhancing the classification accuracy of social signals, where social signals comprise of microblog entries, geotags or uploaded images contributed by users in a social network. The paper "Distributed Online Learning in Social Recommender Systems" by Tekin, Zhang and van der Schaar, considers decentralized sequential decision making in distributed online recommender systems. The problem is formulated as a cooperative contextual bandit problem and the results illustrated on datasets from Amazon. Finally in this grouping, "Quickest Attack Detection in Multi-Agent Reputation Systems," by Li and X. Wang, considers the issue of security in reputation systems. To prevent the damage caused by the intentional injection of dishonest ratings, this paper aims to detect such attacks as soon as possible after their occurrence by sequentially observing the rating samples at a single or multiple agents. Both centralized and decentralized versions are proposed.

The final two papers in the previous category deal with major applications of social networks, namely recommender and reputation systems. The five papers in the final category deal with further particular applications arising in a social network setting. Crowdsourcing has been proven useful to collectively perform tasks in spite of some potentially unreliable workers. In the paper "Reliable Crowdsourcing for Multi-Class Labeling Using Coding Theory," Vempaty, L. R. Varshney and P. K. Varshney, innovatively apply error correcting codes and subsequent decoding algorithms to achieve reliable classification in crowdsourcing systems. Collaborative filtering plays a key role in recommender systems widely used in e-commerce. Hsiao, Kulesza, and Hero, remarkably extend the concept to the query context to combine recommendation and information retrieval as collaborative retrieval in the paper "Social Collaborative Retrieval." To further enhance spectral efficiency, small cells of complicated interaction are expected in the realization of future wireless networks. In "Optimal Subsidies for Shared Small Cell Networks—A Social Network Perspective," Yang and Quek supply an interesting approach to utilize information from social network analysis to form a Stackelberg game and thus to optimize small cell networks. "Asynchronous Gossip for Averaging and Spectral Ranking," by Borkar, Makhijani and Sundaresan, discusses variations of gossip algorithms, which are at the core of modern distributed computing architectures. In one of the variants, the paper discusses gossiping in asynchronous stochastic settings, where to overcome shortcomings of prior work, ideas from reinforcement learning are applied. And, finally, "Sharing in Networks of Strategic Agents," by Xu, Song and van der Schaar, considers the problem of incentivizing strategic agents to share information or goods, by designing distributed rating protocols that exploit the ongoing nature of the agents' interactions to assign ratings and through them, determine future rewards and punishments. The authors show that in many networks, the price of anarchy (PoA) obtained by adopting the proposed rating protocols is one, that is, the optimal social welfare is attained. In networks where the PoA is larger than one, it is shown that the proposed rating protocol significantly outperforms existing incentive mechanisms.

As is apparent from our description above, the papers that are collected here span a wide range of problems arising in the development and application of signal processing in social networks. We hope that this special issue will promote further research and inspire new approaches to address the interesting and important challenges in this field.

In closing, we would like to thank all the authors who submitted their manuscripts to this special issue, as well as the reviewers who provided valuable comments and suggestions. A special note of thanks goes to Dr. Fernando Pereira, the Editor-in-Chief of the IEEE JOURNAL OF SELECTED TOPICS IN SIGNAL PROCESSING, and Ms. Rebecca Wollman, the IEEE Publications Coordinator, for their active support.

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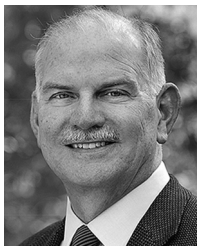

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