Technical Committee on Networks and Communication Systems

There has been an increasing volume of research on networks within the IEEE Control Systems Society (CSS) community. This research is not confined to work on traditional communication networks. It also extends to a broader set of networks, including other technological networks such as transportation and energy networks; social, economic, and financial networks; and biological networks. The CSS Technical Committee (TC) on Networks and Communications aims to promote communication among researchers active in the networks area. It provides a forum to discuss new research directions on the modeling, analysis, optimization, and control of emerging networks, both with social and technological aspects. It allows members to coordinate activities, including organization of new workshops and several invited sessions on networks at the American Control Conference and the IEEE Conference on Decision and Control (CDC). Another important objective is to increase CSS publications that could provide a visible outlet for high-quality research in this area. This TC currently has approximately 90 members, including about 20 students and postdocs. It is chaired by Giacomo Como and organized into eight working groups: Control of Network Systems (chaired by Paolo Frasca), Information Networks and Control (Serdar Yüksel), Networked Sensing and Sensor Networks (Venkatesh Saligrama), Optimization and Game Theoretic Methods in Networks (Francesca Parise), Cybersecurity and Privacy (Yilin Mo), Infrastructure Networks (Rahul Jain), Internet of Things (Rolf Findeisen), and Learning, Dynamics, and Behaviors in Social Systems (Chiara Ravazzi).

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THE WORKING GROUPS

CONTROL OF NETWORK SYSTEMS

This working group focuses on the analysis and design of networks of dynamical systems, taking a control systems perspective. In particular, analysis questions focus on control-theoretic properties of these network systems, along with collective and emergent properties of network systems such as synchronization. Design questions aim at developing centralized and distributed algorithms to achieve suitable collective goals at the network level. In distributed algorithms, each system comprising the network uses only local information obtained by sensing or communication to determine its role toward the global objective. The group activities encompass both theory and applications: in the last few years, transportation networks and social networks have attracted a lot of research interest. In the last two years, group members have also focused on the understanding and the mitigation of the COVID-19 pandemic by proposing optimal policies for social distancing, testing, and vaccinations.

INFORMATION NETWORKS AND CONTROL

Interaction of information and control has been evident since the 1960s in both control-theoretic and information-theoretic problems. However, the interaction has become indispensable in networked control systems, which entail decentralized stochastic systems connected through information channels. With the advances in the communications technology and the interconnectedness of the physical world, a rigorous understanding of such systems is essential for satisfactory system performance. The standard assumptions in either information and communication theory or control theory do not directly apply to such systems, and a truly interdisciplinary approach is required. Aspects of adaptation and learning from empirical data, lack of a centralized decision maker, and the presence of incomplete probability models add further challenges. The focus of the Working Group on Information Networks and Control is to facilitate interactions between researchers and engineers working on areas such as systems and control theory, information theory, dynamical systems, probability theory, and network science to address the challenges imposed by the applications, as well as address classical problems in each of the individual disciplines with an interdisciplinary approach. These include stochastic stability of control systems over networks; optimal networked control under information constraints; optimal zero-delay source and channel coding; capacity and error exponents of communication channels with and without feedback; finite-length information theory; optimal decentralized information exchange under information constraints; information structure design in networked control; robustness of networked systems to incomplete specifications and probability models; signaling and communication games in networked control; and interactions between dynamics, control theory, and information theory (as in the context of the operational usage of various forms of entropy in addressing fundamental problems). During the winter and summer of 2021, Massimo Franceschetti, Christoph Kawan, Alexey Matveev, and Serdar Yüksel organized a weekly online seminar on control and information. These weekly meetings hosted 15 seminars from both junior researchers and experts and entailed highly interactive discussions on the relations between control theory, information theory, and related areas such as dynamical systems, stochastic systems, optimization, and networked control under information constraints. The slides and video links of many of the sessions are available on the seminar website and a related YouTube channel via

The CSS Technical Committee on Networks and Communications aims to promote communication among researchers active in the networks area.

https://mast.queensu.ca/~yuksel/OnlineSeminaronControlandInformation.

OPTIMIZATION AND GAME THEORETIC METHODS IN NETWORKS

The vast majority of modern systems are highly complex, involving large numbers of strategic agents that interact and influence each other within a technological infrastructure. The electric grid, for example, is a large-scale engineering system that obeys physical laws. However, it is also fundamentally affected by the behavior of its human users and by the institutional effects of markets and regulators. In general, social networks, energy and financial systems, teams of robots, or transportation systems all involve the interaction of many different components, including both engineering aspects (for technology and communications) and human behavior and regulations (requiring concepts from sociology and economics).

Understanding the way in which such distributed systems of people and devices interact and work together and how to optimize those systems and interactions is the focus of the Working Group on Optimization and Game Theoretic Methods in Networks. To this end, the group leverages interdisciplinary techniques from optimization, control, game theory, network science, and network economics. Specific areas of research are decentralized and distributed control of multiagent and large-scale systems; resource allocation, network optimization and regulation; revenue maximization; real-time pricing decisions; rating and review systems; decision theory; learning dynamics; information design; distributed estimation and detection; and online learning and data-driven analysis of complex networks.

Yang Cai, Ozan Candogan, Nika Haghtalab, Francesca Parise, Muhammed O. Sayin, and Kaiqing Zhang recently organized the online seminar series "Games, Decisions, & Networks," which broadly focused on the foundations and applications of game theory, decision theory, and network theory. Speakers were from the intersection of economics, operations research, control, and computer science. All information is available at https://sites.google.com/view/gamesdecisionsnetworks.

CYBERSECURITY AND PRIVACY

Emerging networked control systems such as smart grids, intelligent transportation systems, and smart buildings will make extensive use of off-the-shelf networking and computing to make them smarter. However, widespread networking combined with unattended operation of myriad devices provides numerous potential entry points for malicious entities. Any successful attack on a safety-critical system, such as power grids, may significantly hamper the economy and even lead to the loss of human life. There recently has been increasing interest in analyzing the impact of malicious attacks against cyberphysical systems as well as designing more resilient systems with graceful performance degradation in the presence of adversaries. From a control theoretical point of view, an attack on a networked control system can be modeled as an unknown input to the system (integrity attacks), a sudden change of the system model (physically sabotage the system), packets dropping (denial of service attack), or an undesired disclosure of information (eavesdropping attack). Control system attacks can be characterized according to 1) the adversary's knowledge of the system model, 2) the adversary's disclosure resources (the knowledge of the real-time sensory and control data), and 3) the adversary's capability to disrupt the system's operation. Following this trend, the Working Group on Cybersecurity and Privacy has been organizing invited sessions on cyberphysical system security at the CDC for several years. The latest invited session was held at CDC 2020 and featured nine contributions, with topics ranging from data-driven attack detection to game theoretical analysis of the interaction between the defender and the adversary. It is clear that the control community has recognized that cybersecurity is a critical issue that needs to be addressed for future systems. The next objective of the working group would be to promote interdisciplinary research between the control and the security community and combine control theoretical countermeasures with cybersecurity-based ones to achieve defense in depth for cyberphysical systems.

LEARNING, DYNAMICS, AND BEHAVIORS IN SOCIAL SYSTEMS

New technologies for online interaction and personalized sensing and tracking devices are transforming the way individuals make decisions and gaining a critical role in society, including politics (campaigns, elections, and social unrests), consumer choices (adoption of new technologies and products), and user behaviors in critical infrastructure networks (transport, energy). As more data are collected and exchanged, detailing our behaviors, preferences, and relationships, there is an unprecedented interest from the social and economic sciences for quantitative analysis and mathematical modeling. The focus area of the Working Group on Learning, Dynamics, and Behaviors in Social Systems is on the development of sound mathematical foundations and computational tools from systems modeling, optimization, and control synthesis, game theory, and data processing for

social systems. Topics of interest to this working group include empirical and theoretical analysis of opinion dynamics, information flows, communication, influence, games, learning, and cascades in social systems; robustness analysis of social systems modeling; social systems identification and scalable algorithms for inference with social data; design of incentive mechanisms for steering social behaviors toward desired outcomes; and architectures for the exchange of information, social interaction, and crowdsourcing. Working group members have been involved in several activities, including the organization of a tutorial session and a virtual workshop. In particular, a tutorial session, "Control and Learning for Social Sciences: Dynamical Networks of Social Influence," was organized by Fabrizio Dabbene and Chiara Ravazzi at International Federation of Automatic Control (IFAC) World Congress 2020, held July 11–17, 2020 in Berlin, Germany. This tutorial provided an introduction to the dynamics of complex networks, agent-based modeling, and social systems and covered three "mature" directions: 1) formation of opinions and beliefs under social influence, 2) dynamics of interpersonal appraisals, and 3) identification and learning algorithms for analysis of networks' structural properties. A one-day virtual workshop, Learning Sparse Models: Theory and Applications From System Identification to Neural Networks, was organized by Sophie M. Fosson and Diego Regruto during September 2020, in collaboration with the CSS Italy Chapter and the CSS TC on System Identification and Adaptive Control. The workshop focused on sparse optimization techniques used to learn parsimonious models, with applications from engineering to social sciences. The article "Learning Hidden Influences in Large-Scale Dynamical Social Networks: A Data-Driven Sparsity-Based Approach," by Chiara Ravazzi, Fabrizio Dabbene, Constantino M. Lagoa, and Anton V. Proskurnikov, appeared in the October 2021 issue of *IEEE Control Systems* (see Figure 1). The survey provides a general overview of the main concepts, algorithmic tools, results, and open problems in the systematic study of learning interpersonal influence in networked systems. Finally, a new entry, "Dynamical Social Networks," by A. Proskurnikov and C. Ravazzi, appeared in *Encyclopedia of Systems and Control*. This new entry provides basic concepts and theoretical tools elaborated to study dynamical social networks, with a focus on structural properties of networks and dynamical processes over them.

RECENT ACTIVITIES

Several activities have been organized by TC members, many of which cut across the working groups' focus. On April 24, 2020, Fabrizio Dabbene organized the CSS Workshop on Modeling and Control of the COVID-19 Outbreak, in collaboration with the CSS Italy Chapter. The workshop collected very recent contributions of researchers in the systems and control field to the problem of modeling and predicting the dynamics of contagion evolution, presenting solution techniques specifically tailored to the specificities of the COVID-19 outbreak. In particular, it featured keynotes by Munther A. Dahleh ("Inching Back to Normal After COVID-19 Lockdown: Quantification of Measures") and Pietro Garibaldi ("Modeling Contacts and Transitions in the SIR Epidemics Model"). Recordings are available at http://www.ieeecss.it/events/covid.html. From December 12 to 13, 2020, a workshop on Dynamics in Social and Economic Networks at CDC 2020 was organized by Wenjun Mei, Francesca Parise, Giacomo Como, Ming Cao, and Bahman Gharesifad. This event brought together researchers using different approaches in this area, including game theory, complex network analysis, and multiagent systems, to give a general introduction to dynamics on socioeconomic systems, as well as present the latest results on various emerging topics such as social learning and opinion dynamics, network propagation models, coordination of competitive network systems, information design, and interventions under partial information. More information is available at https://www.meiwenjun.site/2020cdc-workshop-socialnetworks. A special section on mathematical modeling, analysis, and control of epidemics was organized in the Society for Industrial and Applied Mathematics *Journal of Control and Optimization* to bring together contributions at the intersection of systems and control theory and the mathematical study of epidemic spread processes. The section was edited by Carolyn Beck, Francesco Bullo, Giacomo Como, Kimon Drakopoulos, Dang H. Nguyen, Cameron Nowzari, Victor M. Preciado, and Shreyas Sundaram. A special issue on dynamics and behaviors in social networks, in *IEEE Transactions on Control of Network Systems*, was edited by Claudio Altafini, Giacomo Como, Julien M. Hendrickx, Alexander Olshevsky, and Alireza Tahbaz-Salehi. Finally, a special issue on advanced communications, control and computing for industrial Internet of Things appeared in *IEEE Internet of Things Journal* and was edited by Yonghui Li, Wanchun Liu, Daniel E. Quevedo, Vincent Lau, and Petar Popovski.

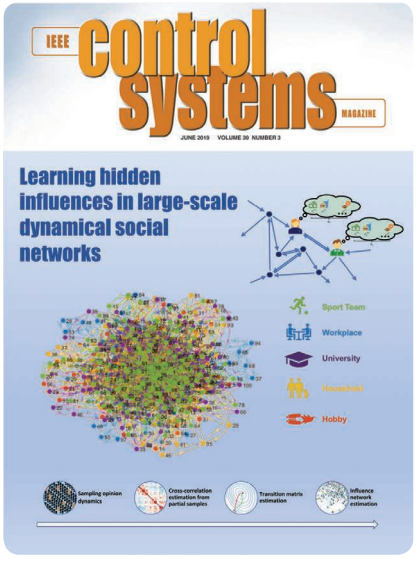

FIGURE 1 A proposed cover image of the October 2021 *IEEE Control Systems* (with the June masthead).

Giacomo Como, Paolo Frasca, Yilin Mo, Francesca Parise, Chiara Ravazzi, and Serdar Yüksel