Studies in Systems, Decision and Control 186

M. Hadi Amini
Kianoosh G. Boroojeni
S. S. Iyengar
Panos M. Pardalos
Frede Blaabjerg
Asad M. Madni *Editors*

Sustainable Interdependent Networks II

From Smart Power Grids to Intelligent Transportation Networks

Springer

Studies in Systems, Decision and Control

Volume 186

Series editor

Janusz Kacprzyk, Polish Academy of Sciences, Warsaw, Poland
e-mail: kacprzyk@ibspan.waw.pl

The series "Studies in Systems, Decision and Control" (SSDC) covers both new developments and advances, as well as the state of the art, in the various areas of broadly perceived systems, decision making and control- quickly, up to date and with a high quality. The intent is to cover the theory, applications, and perspectives on the state of the art and future developments relevant to systems, decision making, control, complex processes and related areas, as embedded in the fields of engineering, computer science, physics, economics, social and life sciences, as well as the paradigms and methodologies behind them. The series contains monographs, textbooks, lecture notes and edited volumes in systems, decision making and control spanning the areas of Cyber-Physical Systems, Autonomous Systems, Sensor Networks, Control Systems, Energy Systems, Automotive Systems, Biological Systems, Vehicular Networking and Connected Vehicles, Aerospace Systems, Automation, Manufacturing, Smart Grids, Nonlinear Systems, Power Systems, Robotics, Social Systems, Economic Systems and other. Of particular value to both the contributors and the readership are the short publication timeframe and the world-wide distribution and exposure which enable both a wide and rapid dissemination of research output.

More information about this series at http://www.springer.com/series/13304

M. Hadi Amini • Kianoosh G. Boroojeni
S. S. Iyengar • Panos M. Pardalos
Frede Blaabjerg • Asad M. Madni
Editors

Sustainable Interdependent Networks II

From Smart Power Grids to Intelligent Transportation Networks

Springer

Editors
M. Hadi Amini
Department of Electrical and Computer Engineering
Carnegie Mellon University
Pittsburgh, PA, USA

Kianoosh G. Boroojeni
School of Computing and Information Sciences
Florida International University
Miami, FL, USA

S. S. Iyengar
School of Computing and Information Sciences
Florida International University
Miami, FL, USA

Panos M. Pardalos
Department of Industrial & Systems Engineering
University of Florida
Gainesville, FL, USA

Frede Blaabjerg
Department of Energy Technology
Aalborg University
Aalborg, Denmark

Asad M. Madni
Department of Electrical & Computer Engineering
University of California Los Angeles
Los Angeles, CA, USA

ISSN 2198-4182 ISSN 2198-4190 (electronic)
Studies in Systems, Decision and Control
ISBN 978-3-319-98922-8 ISBN 978-3-319-98923-5 (eBook)
https://doi.org/10.1007/978-3-319-98923-5

Library of Congress Control Number: 2017963854

© Springer Nature Switzerland AG 2019
This work is subject to copyright. All rights are reserved by the Publisher, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, reuse of illustrations, recitation, broadcasting, reproduction on microfilms or in any other physical way, and transmission or information storage and retrieval, electronic adaptation, computer software, or by similar or dissimilar methodology now known or hereafter developed.
The use of general descriptive names, registered names, trademarks, service marks, etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant protective laws and regulations and therefore free for general use.
The publisher, the authors, and the editors are safe to assume that the advice and information in this book are believed to be true and accurate at the date of publication. Neither the publisher nor the authors or the editors give a warranty, express or implied, with respect to the material contained herein or for any errors or omissions that may have been made. The publisher remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

This Springer imprint is published by the registered company Springer Nature Switzerland AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

"This book presents an extremely valuable resource, the first of its kind, for scientists and engineers in addressing all critical aspects of interdependent power and transportation networks in a well-organized and strategic manner."

Prof. M. C. Frank Chang,
President of the National Chiao Tung University, Taiwan

"This book conducts an all-inclusive investigation of the interdependent power and transportation networks. I highly recommend this interesting book to those who are exploring futuristic but realistic ideas."

Prof. Oleg Prokopyev, Department of Industrial Engineering
University of Pittsburgh, USA;
Co-Editor-in-Chief, Optimization Letters

"The second volume of Sustainable Interdependent Networks depicts a thorough path towards developing sustainable smart cities, as well as introducing modern computational platforms to find the globally optimum operation point of the interdependent power and transportation networks."

Prof. Sumi Helal, School of Computing and Communications,
Lancaster University, UK; Editor-in-Chief, IEEE Computer

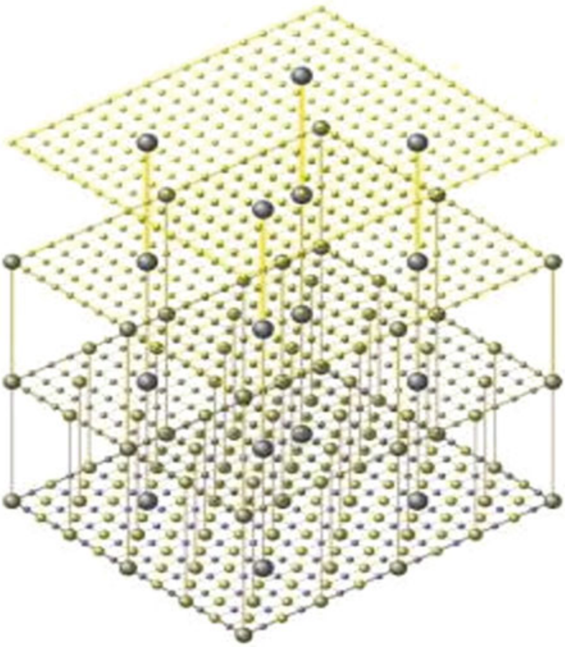
"Sustainable Interdependent Networks II succeeds to tackle the future challenges of smart cities with the emphasis on interdependent power and transportation networks. It is recommended to scholars from electrical engineering, computer science, civil engineering, and industrial engineering disciplines who seek to perform research in the state-of-the-art interdisciplinary research areas."

Prof. Jose C. Principe, Distinguished Professor,
Department of Electrical and Computer Engineering,
University of Florida, USA;
IEEE Fellow, AIMBE Fellow, IAMBE Fellow

"This book bridges the gap between theory and practice by providing a profound vision of interdependent networks. The second volume is specifically zooming into smart electric grids and intelligent transportation networks as subsets of smart cities. I would recommend this book for researchers who are eager to work on cutting-edge topics on the intersection of various disciplines, including system engineering, electrical engineering, computer science, and transportation engineering."

Prof. Sartaj Sahni, Distinguished Professor,
Computer and Information Sciences and Engineering,
University of Florida, USA; IEEE Fellow, ACM Fellow,
AAAS Fellow, Minnesota Supercomputer Institute Fellow

Preface



Since the concept of Internet of Things leading to smart cities, smart grids, and other technologies emerged, there has been a need to move towards a sustainable way of utilizing the technologies. Researchers have tried to answer this question on the emerging concern regarding the optimal operation of real-world large-scale complex networks. A smart city is a vision of the top brass of researchers to integrate multiple information and communication technologies in a secure fashion to manage a city's assets including transportation systems, power grids, distributed sensor networks, water supply networks, and other community services. Our reliance on these complex networks as global platforms for sustainable cities and societies as well as shortage of global nonrenewable energy sources has raised emerging concerns regarding the optimal and secure operation of these large-scale networks. Although the independent optimization of these networks leads to locally optimum operation points, there is an exigent need to move toward obtaining the globally optimum operation point of such networks while satisfying the constraints of each network properly.

There has been an emerging concern regarding the optimal operation of power and transportation networks. In the second volume of *Sustainable Interdependent Networks* book, we focus on the interdependencies of these two networks, optimization methods to deal with the computational complexity of them, and their role in future smart cities. We further investigate other networks, such as communication networks, that indirectly affect the operation of power and transportation networks. Our reliance on these networks as global platforms for sustainable development has led to the need for developing novel means to deal with arising issues. The considerable scale of such networks, due to the large number of buses in smart power grids and the increasing number of electric vehicles in transportation networks, brings a large variety of computational complexity and optimization challenges. Although the independent optimization of these networks leads to locally optimum operation points, there is an exigent need to move toward obtaining the globally optimum operation point of such networks while satisfying the constraints of each network properly.

The book series, including the first volume that has been published in early 2018, aims at covering wide areas from theoretical toward practical aspects of interdependent networks. Volumes I and II of this book cover different aspects of interdependent networks categorized in the following five categories:

1. Classic Optimization and Control Problems—consisting of research articles from outstanding researchers in the field that discusses and provides an insight into the classical and theoretical problems that exist in optimization and control.
2. Efficient Methods for Optimization Problems in Large-Scale Complex Networks: From Decentralized Methods Toward Fully Distributed Approaches—A more advanced outlook and possible methodologies that could be incorporated in large networks using various approaches are highlighted through manuscripts from leading researchers in this field.
3. Modeling the Interdependency of Power Systems, Communication Networks, Energy Systems (e.g., Gas, Renewables), Transportation Networks, Water Networks, and Societal Networks—The ways in which sustainable interdependence can be achieved across the various networks that span the horizons of smart cities are explained mathematically in terms of models that could be implemented. All the articles in this section deal with the interdependency of at least two networks that are an integral part of realizing a smart city.
4. Application of Power and Communication Networks: Co-simulation Platforms for Microgrids and Communication Networks, and Smart Grid Test Beds—The

various papers under this topic highlight the state-of-the-art technologies that are in place in the area of smart grids.

5. Application of Sustainable Interdependent Networks in Future Urban Development: The Tale of Smart Cities—This section constitutes papers that discuss the aspects to be pondered in the future and the direction in which the current school of researchers are heading toward realizing ideal sustained and interdependent networks in the future.

Pittsburgh, PA, USA — M. Hadi Amini
Miami, FL, USA — Kianoosh G. Boroojeni
Miami, FL, USA — S. S. Iyengar
Gainesville, FL, USA — Panos M. Pardalos
Aalborg, Denmark — Frede Blaabjerg
Los Angeles, CA, USA — Asad M. Madni

Acknowledgments

The editors express their deepest gratitude to the professional colleagues who have contributed to this book, the agencies that have funded the relevant research, and to their families for their continued support.

Contents

Contributors

Almoataz Y. Abdelaziz Electrical Power and Machines Department, Ain Shams University, Cairo, Egypt

Amir Abdollahi Department of Electrical Engineering, Shahid Bahonar University of Kerman, Kerman, Iran

Nadia Adnan Department of Management and Humanities, Universiti Teknologi PETRONAS, Seri Iskandar, Perak, Malaysia

M. Hadi Amini Department of Electrical and Computer Engineering, Carnegie Mellon University, Pittsburgh, PA, USA

Hamidreza Arasteh Department of Electrical Engineering, Shahid Beheshti University, Tehran, Iran

Niroo Research Institute, Tehran, Iran

Mohamad Ariff bin Bahruddin Economics Department, Indiana University Bloomington, Bloomington, IN, USA

Ramesh Baral School of Computing and Information Sciences, Florida International University, Miami, FL, USA

Vikram Bhattacharjee Department of Electrical and Computer Engineering, Carnegie Mellon University, Pittsburgh, PA, USA

Monalisa Biswal Department of Electrical Engineering, NIT Raipur, Chhattisgarh, India

João P. S. Catalão C-MAST, University of Beira Interior, Covilhã, Portugal

INESC TEC and the Faculty of Engineering of the University of Porto, Porto, Portugal

INESC-ID, Instituto Superior Técnico, University of Lisbon, Lisbon, Portugal

Juan Manuel Corchado BISITE Research Group, University of Salamanca, Salamanca, Spain

Osaka Institute of Technology, Asahi-ku Ohmiya, Osaka, Japan

Mahdi Fathi Industrial and System Engineering, University of Florida, Gainesville, FL, USA

Kenrick Fernande School of Computing and Information, Department of Computer Science, University of Pittsburgh, Pittsburgh, PA, USA

Desta Zahlay Fitiwi C-MAST, University of Beira Interior, Covilhã, Portugal

Amin Shokri Gazafroudi BISITE Research Group, University of Salamanca, Salamanca, Spain

Pedram Gharani School of Computing and Information, Department of Informatics and Networked Systems, University of Pittsburgh, Pittsburgh, PA, USA

Mohammed Hadi Department of Civil and Environmental Engineering, Florida International University, Miami, FL, USA

S. S. Iyengar School of Computing and Information Sciences, Florida International University, Miami, FL, USA

Amin Kargarian Department of Electrical and Computer Engineering, Louisiana State University, Baton Rouge, LA, USA

Mostafa Kazemi Faculty of Electrical Engineering, University of Shahreza, Shahreza, Iran

Hamidreza Keshavarz School of Electrical and Computer Engineering, Shiraz University, Shiraz, Iran

Marzieh Khakifirooz Industrial Engineering and Engineering Management, National Tsing Hua University, Hsinchu, Taiwan

Samaneh Khazraeian Department of Civil and Environmental Engineering, Florida International University, Miami, FL, USA

Intelligent Transportation Systems (ITS) Analyst, Stantec, Miami, FL, USA

Asad M. Madni Department of Electrical & Computer Engineering, University of California Los Angeles, Los Angeles, CA, USA

Nadali Mahmoudi School of ITEE, University of Queensland, Brisbane, QLD, Australia

Mahdi Mehrtash Department of Electrical and Computer Engineering, Louisiana State University, Baton Rouge, LA, USA

Pouria Mistani Department of Mechanical Engineering, University of California Santa Barbara, Santa Barbara, CA, USA

Ali Mohammadi Department of Electrical and Computer Engineering, Louisiana State University, Baton Rouge, LA, USA

Mohammad Mohammadi School of Electrical and Computer Engineering, Shiraz University, Shiraz, Iran

Ruchita Nale Department of Electrical Engineering, NIT Raipur, Chhattisgarh, India

Shahrina Md Nordin Department of Management and Humanities, Universiti Teknologi PETRONAS, Seri Iskandar, Perak, Malaysia

Samira Pakravan Department of Mechanical Engineering, University of California Santa Barbara, Santa Barbara, CA, USA

Vineet Raghu School of Computing and Information, Department of Computer Science, University of Pittsburgh, Pittsburgh, PA, USA

Farnaz Safdarian Department of Electrical and Computer Engineering, Louisiana State University, Baton Rouge, LA, USA

Caroline H. Santoso Department of Business Administration, Soochow University, Taipei, Taiwan

Sérgio F. Santos C-MAST, University of Beira Interior, Covilhã, Portugal

Miadreza Shafie-Khah C-MAST, University of Beira Interior, Covilhã, Portugal

Pierluigi Siano Department of Industrial Engineering, University of Salerno, Salerno, Italy

Saber Talari C-MAST, University of Beira Interior, Covilhã, Portugal

Jei-Zheng Wu Department of Business Administration, Soochow University, Taipei, Taiwan

About the Editors

M. Hadi Amini is currently a Ph.D. candidate in the Department of Electrical and Computer Engineering at Carnegie Mellon University, Pittsburgh, PA, where he received his M.Sc. in Electrical and Computer Engineering in 2015. Prior to that, he received his B.Sc. from the Sharif University of Technology, Tehran, Iran, in 2011, and his M.Sc. from Tarbiat Modares University, Tehran, in 2013, both in Electrical Engineering. He serves as reviewer for several high-impact journals, and international conferences and symposiums in the field of power systems. Hadi currently serves as the President of Carnegie Mellon University Energy Club. He serves on the technical program committee of "IEEE Int'l. Conf. on Smart Energy Systems and Technologies" (SEST 2019). He has published more than 50 refereed journal and conference papers in the smart energy systems and electrified transportation network-related areas. He serves as the lead editor for *Sustainable Interdependent Networks*. He is the recipient of the best paper award of *Journal of Modern Power Systems and Clean Energy* in 2016, best reviewer award of *IEEE Transactions on Smart Grid* from the IEEE Power & Energy Society in 2017, outstanding reviewer award of *IEEE Transactions on Sustainable Energy* in 2017, and the dean's honorary award from the president of Sharif University of Technology in 2007. Hadi is a member of *IEEE-Eta Kappa Nu* (IEEE-HKN) Sigma Chapter, the honor society of IEEE. He ranked 26th among about 270,000 participants in the Iranian Nationwide University Entrance Exam for B.Sc. degree in 2007.

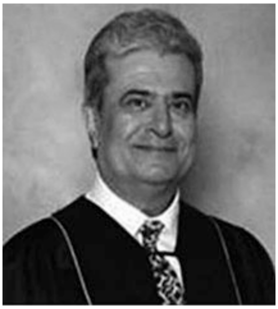
His current research interests include interdependent networks, distributed/decentralized optimization algorithms in energy systems, transportation electrification, smart grid, and cybersecurity of power systems (Homepage: www.HadiAmini.com).

Kianoosh G. Boroojeni received his Ph.D. in Computer Science. He received his B.Sc. from the University of Tehran in 2012 and his M.Sc. from Florida International University in 2016. His research interests include smart grids and cybersecurity. He is the author/coauthor of three books published by MIT Press and Springer. During his Ph.D. years, he published more than thirty publications in the form of book chapters, peer-reviewed journal papers, and conference papers. He is currently collaborating with Dr. S. S. Iyengar to study some network optimization and security problems in the context of smart urban development.

S. S. Iyengar is a Distinguished University Professor, Distinguished Ryder professor, and Director of the School of Computing and Information sciences and is the founding Director of the Discovery Lab at Florida International University. He has published over 600 research papers and has authored/coauthored/edited 24 books published by MIT Press, John Wiley & Sons, Prentice Hall, CRC Press, and Springer. He is a member of the European Academy of Sciences, a Fellow of IEEE, a Fellow of ACM, a Fellow of AAAS, a Fellow of NAI, a Fellow of AIMBE, a Fellow of the Society of Design and Process Program (SPDS), and a Fellow of the Institution of Engineers (FIE). He was awarded a Distinguished Alumnus Award of the Indian Institute of Science, Bangalore, and was awarded the IEEE Computer Society Technical Achievement Award for the contributions to sensor fusion algorithms and parallel algorithms. He is also a senior Fulbright distinguished specialist award winner. He is a Golden Core member of the IEEE-CS, and he has received a Lifetime Achievement Award conferred by the International Society of Agile Manufacturing (ISAM). Prof. Iyengar is TIMES NETWORK NRI award winner in 2017. He has served on many National Science Boards such as NIH—National Library of Medicine in Bioinformatics, National Science Foundation review panel, NASA Space Science, Department of Homeland Security, Office of Naval Security, and many others. He is also the founding editor of the *International Journal of Distributed Sensor Networks*. He has been the editor for many IEEE journals. He is presently the editor of *ACM Computing Surveys* and other journals. His work has been featured on the cover of the National Science Foundation's breakthrough technologies in both 2014 and again in 2016.

Panos M. Pardalos is a Distinguished Professor and the Paul and Heidi Brown Preeminent Professor in the Departments of Industrial and Systems Engineering at the University of Florida, and a world-renowned leader in Global Optimization, Mathematical Modeling, and Data Sciences. He is a Fellow of AAAS, AIMBE, and INFORMS and was awarded the 2013 Constantin Caratheodory Prize of the International Society of Global Optimization. In addition, Dr. Pardalos has been awarded the 2013 EURO Gold Medal prize bestowed by the Association for European Operational Research Societies. This medal is the preeminent European award given to Operations Research (OR) professionals for "scientific contributions that stand the test of time." Dr. Pardalos is also a Member of the New York Academy of Sciences, the Lithuanian Academy of Sciences, the Royal Academy of Spain, and the National Academy of Sciences of Ukraine. He is the founding editor of *Optimization Letters*, *Energy Systems*, and co-founder of the *International Journal of Global Optimization*. He has published over 600 papers, edited/authored over 200 books, and organized over 80 conferences. He has about 56,000 citations on his work, an H-index of 95, an i10-index of 575 (Google Scholar), and has graduated 62 Ph.D. students so far.

Frede Blaabjerg is a professor at Aalborg University, Department of Energy Technology. After graduation he was at ABB Scandia for 1 year and then he got the opportunity to become a Ph.D. student at the Institute of Energy Technology (now department), Aalborg University, 1988–1992, quickly taking larger responsibilities in the department and became a full professor in Power Electronics and Drives at the Institute of Energy Technology in 1998. Between 2000 and 2006, Frede Blaabjerg held positions such as Program Research Leader in Control of wind turbines at the Risoe (2000–2002); in 2000 and 2002 he was a visiting professor at the University of Padova, Italy, and Curtin University of Technology, Perth, Australia, respectively. From 2006 to 2010 he was the Dean of the Faculties of Engineering, Science and Medicine at Aalborg University, Denmark, an organization with a budget in 2010 at around 1300 Mio DKK. He decided to return to research in 2010. The Danish industry asked him to help to establish research in power electronics reliability, and he was able to initiate the Center of Reliable and Efficient Power Electronics (www.corpe.et.aau.dk), which today has more than ten companies involved in the research as well as many international collaborators. He attracted also an ERC advanced grant called Harmony (www.harmony.et.aau.dk) in 2012. Today, he is Villum investigator. A number of minor projects are also a part of the project portfolio today and his team has 30–40 people (dependent on number of guest and active projects). He became a visiting professor with Zhejiang University in 2009, and he is guest professor at Harbin Institute of Technology, Shandong University, and Shanghai Maritime University. He has published more than 1000 scientific papers. Conference papers are used as a platform to train PhDs and postdocs and then publish the best results in journals. However, many conference papers have received awards. Today more than 500 papers are published in journals. He has published ten edited books in power electronics and four monographs. The citations are quite high in the field of electrical engineering with +33000 in Web of Science (h-index 87); +51000 in Scopus (h-index 107), and +81000 in Google Scholar (h-index 132). In 2014, 2015, 2016, 2017, and 2018 he was among the most 250 cited in Engineering (Thomson Reuter). He is honoris causa at Politehnica of Timisoara, Romania, and Tallinn Technical University, Estonia. In 2019 and 2020 he will be President of IEEE Power Electronics Society.



Asad M. Madni served as President, COO, and CTO of BEI Technologies Inc. from 1992 until his retirement in 2006. He led the development and commercialization of intelligent micro-sensors, systems, and instrumentation for which he has received worldwide acclaim. Prior to BEI he was with Systron Donner Corporation for 18 years in senior technical and executive positions, eventually as Chairman, President, and CEO. Here, he made seminal and pioneering contributions in the development of RF and Microwave Systems and Instrumentation, which significantly enhanced the capabilities of the US Tri-Services and allies. He is currently an Independent Consultant, Distinguished Adjunct Professor/Distinguished Scientist at UCLA ECE Department, Faculty Fellow at the UCLA Institute of Transportation Studies, Adjunct Professor at Ryerson University, and Executive Managing Director and CTO of Crocker Capital. He received an A.A.S. from RCA Institutes Inc., B.S. and M.S. from the University of California Los Angeles (UCLA), Ph.D. from California Coast University, S.E. from MIT Sloan School of Management, D.Sc. (h.c.) from Ryerson University, D.Eng. (h.c.) from Technical University of Crete, Sc.D. (h.c.) from California State University and California State University Northridge, and Ph.D. degrees (h.c.) from Universiti Kebangsaan Malaysia and from National Chiao Tung University, Taiwan. He is also a graduate of the Engineering Management Program at the California Institute of Technology, the Executive Institute and Director's College at Stanford University, and the Program on Negotiation for Senior Executives and Promoting Innovation and Organizational Change at Harvard University. He is credited with over 180 refereed publications, 69 issued or pending patents, and is the recipient of numerous national and international honors and awards including IEEE Frederik Philips Medal, UCSD Gordon Medal for Engineering Leadership, Mahatma Gandhi Pravasi Samman Gold Medal, Ellis Island Medal of Honor, IET (UK) J.J.Thomson Medal, IEEE Millennium Medal, TCI College Marconi Medal, UCLA Professional Achievement Medal, UCLA Engineering Alumnus of the Year Award, UCLA Engineering Lifetime Contribution Award, UCLA EE Distinguished Alumni Award, IEEE-HKN Vladimir Karapetoff Award, IEEE AESS Pioneer Award, IEEE HKN Eminent Member Award, IEEE IMS Career Excellence Award, and Tau Beta Pi Distinguished Alumni Award. In 2011 he was elected to the US National Academy of Engineering "for contributions to development and commercialization of sensors and systems for aerospace and automotive safety." In 2014 he was elected a Fellow of the National Academy of Inventors "for demonstrating a highly prolific spirit of innovation in creating or facilitating outstanding inventions that have made a tangible impact on quality of life, economic development, and the welfare of society." He is a Fellow/Eminent Engineer of 15 of the world's most prestigious professional academies and societies and has been awarded six honorary professorships.

Chapter 1
Interdependent Networks from Societal Perspective: MITS (Multi-Context Influence Tracking on Social Network)

Ramesh Baral, S. S. Iyengar, and Asad M. Madni

Introduction

Overview

The real-world system can be represented in terms of multiple complex and semantically coherent networks. The networks have some correlation among each other and complement each other's functionality. Such correlated networks are termed as interdependent networks. The notion of a smart city can be represented as an integration of several interdependent networks that can facilitate secured and efficient management of a city's assets, such as transportation, power grids, water supply channel, distributed sensor networks, societal networks, and other services. In this chapter, we introduce the societal perspective of interdependent networks, where the users' and locations' networks are exploited to track the influential user and location nodes.

The task of identifying and tracking influential nodes in the ever-growing information networks is crucial to real-world problems that require information propagation (e.g., viral marketing). The exploitation of social networks for influential node detection has been quite popular in the last decade. However, most of the studies have focused on networks with homogeneous nodes (e.g., user-user nodes),

R. Baral (✉) · S. S. Iyengar
School of Computing and Information Sciences, Florida International University, Miami, FL, USA
e-mail: rbara012@fiu.edu; iyengar@cs.fiu.edu

A. M. Madni
Department of Electrical & Computer Engineering, University of California Los Angeles, Los Angeles, CA, USA
e-mail: ammadni@ee.ucla.edu

© Springer Nature Switzerland AG 2019

M. H. Amini et al. (eds.), *Sustainable Interdependent Networks II*,
Studies in Systems, Decision and Control 186,
https://doi.org/10.1007/978-3-319-98923-5_1

and have also ignored the impact of relevant contexts. The information networks have heterogeneous entities that are interconnected and complement each other's functionality. Hence, the classical techniques popular in modeling the spreading of epidemics in simple networks may not be efficient.

We propose a model called MITS (**M**ulti-context **I**nfluence **T**racking on **S**ocial Network) that represents the contextual exploitation of heterogeneous nodes (i.e., user-location nodes in Location-based Social Networks (LBSN)), formulates the locality-aware spatial-socio-temporal influence tracking problem using Brooks-Iyengar hybrid algorithm, and uses the geo-tagged check-in data to identify and track the locality influence. The empirical evaluation of the proposed model on two real-world datasets, using the Susceptible-Infected-Recovered (SIR) epidemic technique, coverage, and ratio of affection metrics demonstrates a significant performance gain (e.g., 10–85% on coverage and 14–39% on ratio of affection) of the proposed model against other popular techniques, such as degree centrality, betweenness centrality, closeness centrality, and PageRank.

Background and Motivation

The notion of a smart city can be represented using different complex interdependent networks. The first volume of this book [1] presents the investigation of complex and interdependent networks from both theoretical and practical perspectives, including the networked control systems, graphics processing unit, smart cities, dynamic social networks, electrified transportation networks, and sustainable campus development. There are many interesting real-world examples of interdependent networks, such as power grid, transportation network, water supply channel, communication network, societal network, the Internet and the World Wide Web, points-of-interest network, phone call network, actor's collaboration network, co-authorship collaboration and citation network, genetic, metabolic, and protein network, and many other relevant services [2–6]. An optimal and secured operation of resources among these interdependent networks is needed to fulfill the goal of a smart city. The flow of information among these interdependent networks can play significant role on our daily life, for instance, the real-time tracking of traffic can be propagated on social networks, helping travelers to select alternate routes, real-time tracking of weather from distributed sensors can help residents to plan their outdoor activities, tracking of information flow on social networks can help to identify current trend and influential activities (e.g., trends on disasters, such as hurricane, trends on disease spread, trends on political activities, etc.), the contextual analysis of distributed sensor data can help in movement of disabled individuals [7], social network analysis (e.g., social interaction of factory workers [8], phone calls [9], communication networks on Internet [10], citation network [11]), interdependent power and transportation networks [12], metabolic networks (e.g., understanding cancer cell growth [13]), brain networks (e.g., study of brain dynamics [14–16]), community detection [17], island evolution in large epitaxial systems [18], and so forth. Despite the usefulness, the structural complexity, dynamic network and complexity, diverse nodes and connection are the major challenges behind the study of complex networks [19]. The interdependent networks are functionally correlated and the failure of a part of one network can have adverse impact on another. The exploration of their failures (e.g., blackouts resulting from cascading failures of power grid, communication systems, and financial transactions) and robustness are also of great interest [20–30] in the research community.

The graph theory [31–33] is the classical framework applied to solve many problems related to complex networks. The shortest path between nodes, clustering index, the degree centrality [34, 35], betweenness centrality [36, 37], closeness centrality [38], and k-shell decomposition methods [39] account for local or global topological network structures (see section "Related Research" for detail). The exploration of social interactions started in the early 90s [40]. The exploration of student's choice on the companions [41] and social interactions between factory workers [8] are some of the early studies in social network analysis. The concept of random graphs (randomly selecting a node to form a cluster with already selected nodes) to analyze the topology of graphs [42] was used to model gene networks, ecosystems of disease and computer viruses [43, 44]. The scale-free networks (modeling the connectedness of nodes) are believed to be robust to random failures [45], and were explored for therapeutic drugs [46] and metabolic networks [46, 47]. The comprehensive studies from Boccaletti et al. [6] and Newman [48] present different phases of development of complex and interdependent networks.

One of the interesting real-world applications of complex network is the social network (e.g., Facebook,[1] Twitter,[2] Yelp,[3] etc.). The social networks can be exploited for different practical problems (e.g., friendship recommendation, tag prediction, opinion-sentiment analysis, location recommendation, item recommendation, etc.). This chapter focuses on identifying and tracking of influential nodes in LBSN. The task of influential item detection has been a popular research problem in the past decade. The influence maximization problem in a graph $G=\langle U,V \rangle$ selects a set of seed nodes in such a way that the expected spread of information (i.e., influence spreads) in the graph is maximized [49]. There are many real-world problems that exploit influence detection techniques for their business needs. As an example, in a marketing business, one can identify few influential customers and distribute promotional items to them. The strategy is to select a smallest possible subset of customers who can positively influence (e.g., via word-of-mouth effect) their networks towards the consumption of the promotional items, and propagate the influence on the network (i.e., viral marketing) to an expected scale.

An interesting example is the exploitation of social networks to identify the influential candidate in US presidential election. For the 2016 election, several models predicted ∼80% winning chances of Hillary Clinton. Most of those studies

[1] www.facebook.com.

[2] www.twitter.com.

[3] www.yelp.com.

exploited user polls, activities and posts from different social networks to capture the correlation between different parameters and to formulate the influence propagation for both candidates, and predicted the winning likelihood using their influence scores. As the correlation need not necessarily imply causation, the actual result was opposite of the predictions. This implies that those models should have been impacted by some noisy information from the social networks. For instance, for any two users, having posts in support of one candidate need not necessarily indicate their voting decision. A contextual exploitation of information on social networks is essential to model the influential parameters and to handle the noisy information.

The influential sensor measure to project the correct measure via different sensor fusion techniques [50–52] is another interesting application. The influence maximization can also be exploited on Point-of-Interest (POI) domain by exploiting the check-in preferences (e.g., likes/dislikes, tags, emoticons, reviews, stars/ratings, etc.) shared on LBSN. The sharing of positive experience can induce the linked users towards the consumption of relevant items. Intuitively, this gives us the formulation of influence tracking and influencer identification in LBSN, which can be modeled to maximize the number of potential visitors to a given POI. In this paper, we study navigation patterns of users based on LBSN data to determine influential locations (interchangeably termed as POI in this paper).

Figures 1.1 and 1.2 illustrate the spatial influence of a POI and user to the nearby POIs. As shown in Fig. 1.1, the spatial influence of the *Statue of Liberty* is high to

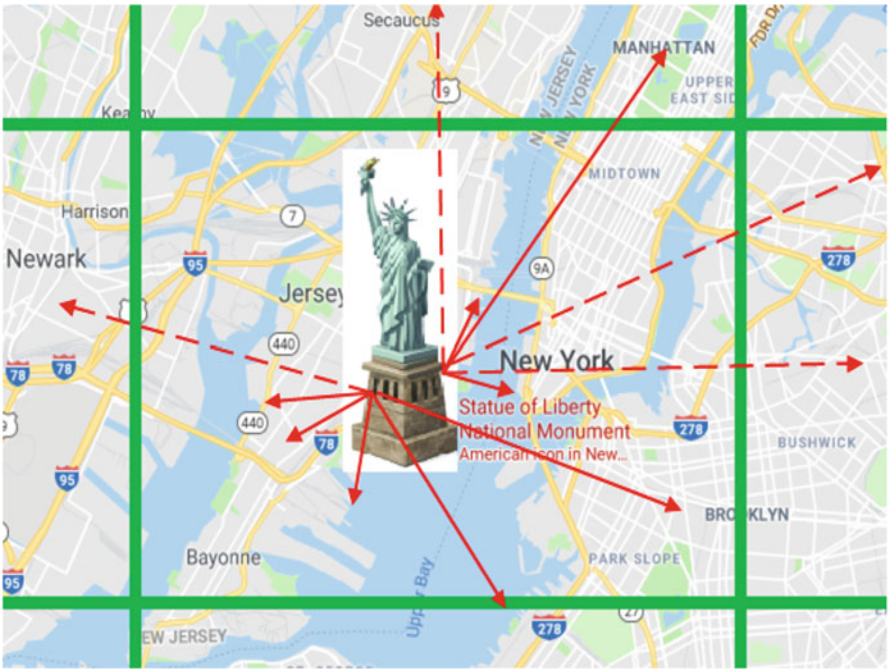


Fig. 1.1 POI grid distance influence

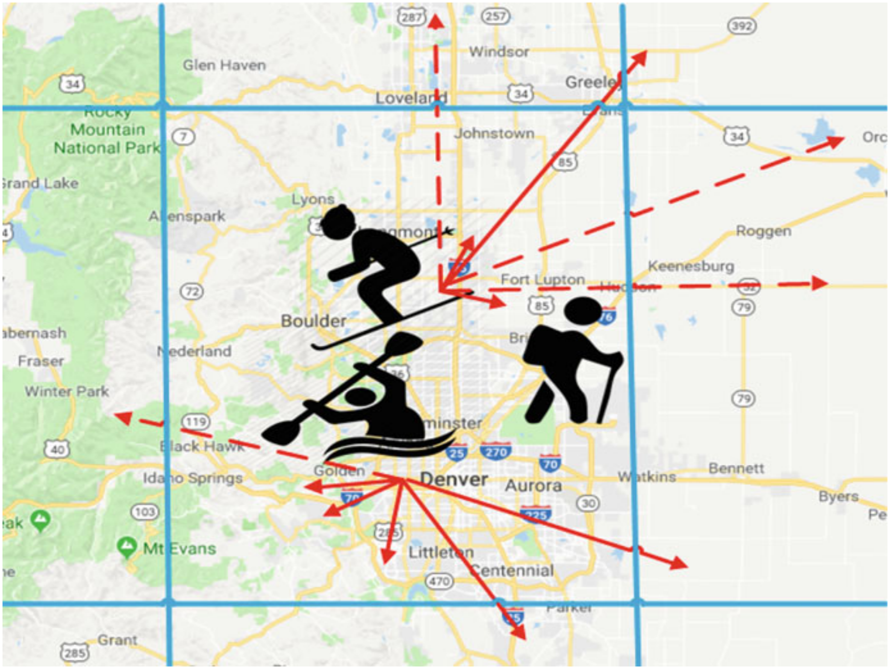


Fig. 1.2 User grid distance influence

the nearby POIs. This implies most of the users who visit the *Statue of Liberty* have high chance of visiting the nearby POIs. The influence decreases with the distance, i.e. the farther POIs have less spatial influence from it. Figure 1.2 shows the user influence to the nearby POIs. Whenever a user has some activity on a region or a POI, the nearby POIs have high chance of being visited by the user. The category of POI, time of a day, and social relation of user also play crucial role in modeling the influence of user and POIs.

There are many interesting studies that are focused on finding influential users [53], popular events [54], or popular locations [55], but our study is focused on identifying the sets of users and POIs that have high spatial impact on other POIs. With the growing usage of smart-phones and social networks, exploitation of spatial information from mobile customers is essential in identifying the spatially influential entities, and tracking their evolution over time.

The research formulation of influence maximization was first described by Domingos and Richardson [56]. It was first formulated as a discrete optimization problem by Kempe et al. [49], who also proved it as an NP-hard problem, and proposed a greedy optimization algorithm. However, the greedy algorithm executes a Monte Carlo simulation to approximate the solution of influenced set size, and is computationally complex. The classical techniques, such as degree centrality, betweenness centrality, closeness centrality, and k-shell decomposition, are quite popular in identifying influential nodes in a network. Some of the classical techniques, such as the degree centrality [34, 35], betweenness centrality [36, 37], closeness centrality [38], and k-shell decomposition methods [39], account for local or global topological network structures, with some limitations. These techniques mostly shine with large networks, are unable to handle small propagation probability as they can identify only few central and overlapping nodes as the influential nodes of the network, do not handle spreading and propagation probability, and are difficult to model on multi-context and heterogeneous networks.

Furthermore, the existing studies focused on location information in influence maximization only, exploited location as a simple user property, and did not analyze the contextually dynamic user mobility behaviors. In this paper, we incorporate multiple contexts (e.g., categorical, social, spatial, and temporal) of user check-ins to define the influence scores due to check-ins, and influence scores due to spatial impact. Such scores are then exploited via optimal region technique utilizing the Brooks-Iyengar algorithm [57] to find a set of users and POI influencers on location grids. The optimal region technique also helps to filter out the noisy nodes from the network. An extensive evaluation on two real-world datasets demonstrates the efficiency of our proposed model when compared to the several classical methods, such as degree centrality, closeness centrality, betweenness centrality, and PageRank-based methods. The core contributions of our study are: (1) it formulates the location promotion problem as influential user and influential POI tracking problem, (2) it presents a multi-context influence formulation by incorporating the social, temporal, categorical, and spatial attributes in the influence tracking task, and exploits an optimal region technique to find the influencing nodes in a network, and (3) it extensively evaluates the proposed model with two real-world datasets.

Related Research

The ***centrality measure*** technique is one of the classical techniques and is focused on ranking nodes in networks. A simple centrality measure is the *degree centrality* (DC) [58] of a node and is defined as the number of nearest neighbors. This technique assumes that a node with larger degree is likely to have higher influence than a node with smaller degree. However, in some cases, this method fails to identify influential nodes, since it considers only very limited information. The *closeness centrality* (CC) [38] measure of a node v is defined as the reciprocal of the sum of geodesic distances to all other nodes V in the network: $C_c(v) = \frac{1}{\sum_{v' \in (V-v)} d_G(v, v')}$, where $d_G(v, v')$ is the geodesic distance between v and v'. Closeness gives a measure of how long it will spread information from a given node to other reachable nodes in the network.

The *betweenness centrality* (BC) [59] is a centrality measure of a node and is defined as the fraction of shortest paths between node pairs that pass through the node of interest. It gives a measure of the influence of a node over the information spread through the network or the expected load of a node in a transportation network. For a network G= (V,E) with n = | V | nodes and m=| E | edges, the *betweenness centrality* of a node v is defined as $C_B(v) = \sum_{s \neq v \neq t \in V} \frac{\sigma_{st}(v)}{\sigma_{st}}$, where σ_{st} is the number of shortest paths between nodes s and t, and $\sigma_{st}(v)$ denotes the number of shortest paths between s and t which pass through node v. Some studies [60–63] have shown that the betweenness and closeness centrality measures can better quantify the influence of a node, but have higher computational complexity. They also claimed that the centralities based on PageRank [61] are even more relevant but more time-consuming. Though these classical techniques may work for simple networks, they have no provision for information rich networks, such as LBSN that contains multiple contexts.

The ***k-shell decomposition*** method is another popular approach and is implemented by repeatedly deleting the nodes with degree one, and then nodes with degree two, and so on. The first iteration of node deletion is repeated until all nodes' degrees are larger than one. All of these removed nodes are assigned to 1-shell. Then recursively all the nodes with degree of at most two are removed until all nodes' degrees are larger than two. The removed nodes are assigned to 2-shell. The process is repeated until all of the nodes are assigned to one of the shells [64]. In some cases, the centrality measures can have little effect on the range of the spreads and can have less impact than the strategically oriented nodes in the center of a network and with smaller degree. Some of the existing studies [39] have also shown that k-shell method can outperform the degree centrality index in many real networks.

The **Independent Cascade Model (ICM)** [49] exploits the propagation probability in a graph. Given an edge ⟨u,v⟩, and node *u* is active at time *t*, the propagation of edge ⟨u,v⟩ at time *t+1* is defined as p(u,v). The process starts with some seed nodes as active nodes and rest as inactive. The propagation is controlled using some measures, such as node degrees [49], and the process is repeated until some node gets activated. Barbieri et al. [65] extended a similar concept and incorporated topic-based information propagation. Zhu et al. [66] proposed the Gaussian-based and distance-based user mobility models, to formulate the location aware propagation probability for location promotion. Their model focused on finding seed users that can influence check-ins to a given location. They did not focus on finding the influential locations.

Wang et al. [67] proposed a community-based greedy algorithm to find the influential nodes. They extended the basic independent cascade model and exploited the dynamic programming and information diffusion among the nodes to split them into small communities. Lu et al. [60] proposed a random-walk-based model called LeaderRank and identified influencers in social networks. It outperformed the PageRank [61] algorithm in identifying the influential nodes for opinion spreading and protecting from the spammers' attacks. Such ranking-based models may not be efficient for undirected networks which will degenerate the degree centrality. Chen et al. [68] proposed a local centrality measure that used the nearest and next nearest neighbors. The local centrality $C_L(v)$ of a node v was defined as: $Q(u) = \sum_{w \in \tau(u)} N(w)$; $C_L(v) = \sum_{u \in \tau(v)} Q(u)$, where $\tau(u)$ is the set of nearest neighbors of node u and $N(w)$ is the number of the nearest and the next nearest neighbors of node w. Zhang et al. [69] used the information transfer probability between any pair of nodes and the k-medoid clustering algorithm for identifying influential nodes in complex networks with community structure.

Li et al. [70] proposed an in-degree based greedy model that focused on finding set of influencing users for a query region and the location of users. However, they did not focus on the mobility of users. The in-degree technique also cannot capture the set of influential nodes that have smaller degrees but yet contextually relevant for the target domain. Zhu et al. [55] focused on finding the set of influential users for location promotion.

The exploitation of k-truss model from Malliaros et al. [71] also demonstrated better performance against the degree centrality measures. Recently, Wang et al. [72] proposed a multi-attribute ranking technique by exploiting the neighborhood's effect on the influence capability of a node. Wang et al. [73] proposed a fast ranking method to evaluate the influence capability of nodes using a k-shell iteration factor. They defined a relation to incorporate the degree and number of neighbors of a node to represent the influence of a node. The famous k-shell method treats nodes based on the degree at an instant and is not concerned about the original degree of the nodes and also does not address the closeness of a node to the core nodes and the location of nodes in a network.

We can see that most of the existing studies focused on identifying homogeneous influential nodes in different networks. Furthermore, exploitation of multiple contexts for heterogeneous influential node detection is less explored. Our study has the following uniqueness in comparison with the existing studies: (1) it formulates the influence identification problem as a heterogeneous graph (i.e., user-POI graph) and identifies heterogeneous nodes (e.g., user and POI) as influential nodes in a network, (2) it exploits multiple contexts and defines each node with an interval of two different types of scores (i.e., score due to check-in influence and score due to spatial influence). This not only facilitates the incorporation of spatial and check-in popularity, but also handles the trade-off between the spatial and check-in influences, (3) it exploits the optimal region technique based on Brooks-Iyengar hybrid algorithm [57], and eliminates the noisy nodes that have small overlap with other nodes, and (4) it presents a simple and efficient technique for locality-based (i.e., influential nodes on different localities) influence maximization in location-based network.

Methodology

Many of the existing studies have defined a single composite score to identify the influential nodes in social networks. The LBSN is a special case that has many implicit factors (e.g, check-in time, location category, social relation, distance to a location, utility of a location, and so on) that can play a crucial role in identification of influential nodes. The Point-of-Interest (POI) domain can exploit such implicit