Optimization and Inference for Physical Flows on Networks (17w5165)

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1 Overview of the Field

Mathematical models that describe the flow of fluids, movement of particles, or transfer of information over a network of channels appear in a wide range of fields of theoretical and scientific study, as well as important engineering applications. Particular interest is devoted to models for which the network structure is represented using graphs where flows on edges and conditions at nodes are governed by sets of physical laws, which may be steady or dynamic, and deterministic or stochastic. Important examples of such physics-governed network flow systems include the electric power grid, natural gas transmission systems, and traffic flows of air or land vehicles. While these large-scale engineered systems have been the subject of extensive study, recent developments in applied mathematics and computation promise a breakthrough in our ability to analyze them and develop new methods for efficient and reliable operations through optimization and control.

Numerous problems of practical interest in applications of flow networks can be mathematically posed as optimization and control. and inference and learning problems. For example, the Optimal Power Flow (OPF) problem in electric transmission networks is an optimization problem that seeks to minimize the cost of power generation among distributed sources subject to the physical constraints of transmission networks. Alternatively, given a continuous stream of noisy/uncertain phase measurements throughout the power grid, we may infer congestion in the network. The relation between these problems may be used to actively control reactive power generation at different locations or change the network topology. As in the case of the power grid, the infrastructure networks of interest may be very large, and may consist of sub-networks or components characterized by qualitatively different physics and/or dynamics on multiple spatial and temporal scales. Therefore, the scaling properties for the mathematics and computational algorithms used to address these problems require careful investigation. Moreover, these problems tend to have intrinsic features such as non-linearities and non-convexities that are dictated by the physical laws governing flows through the network. Such properties make the design of scalable algorithms for these problems a challenge.

The theoretical sides of the relevant mathematical fields, which include optimization, graph theory, statistical inference, dynamical systems, partial differential equations (PDEs), among others, have each given rise to sophisticated computational techniques. However, problems of optimization and inference for physical flow networks require methods from each of these disciplines to be further developed in coordination with one another. For instance, a very accurate and efficient method for simulation of flow dynamics governed by PDEs may be unsuitable for use within an optimization algorithm. Instead, appropriate models that are tractable for optimization, yet accurately represent the physics involved, may be used to develop optimal control algorithms with significantly improved scalability and stability. Similarly, inference algorithms for stochastic state estimation on networks, and the related marginal probabilities, need to be designed in a way that they provide accurate input for stochastic optimization problems. The objective of this workshop was to bridge these mathematical and methodological gaps in the context of large-scale networks. by bringing together an interdisciplinary community of researchers working in the fields of network science, optimization, dynamical systems, optimal control, machine learning, and statistical physics to provide an environment of interaction at the interfaces of these fields. The purpose was to exchange and combine new and emerging ideas with particular focus on inference, learning and optimization for physical networks characterized by dynamics and uncertainty.

2 Recent Developments and Open Problems

Recently, significant progress progress has been made in mathematical techniques for Optimization, Optimal Control, and algorithms for learning and inference in Graphical models. At the same time need for new methods in the aforementioned topics have exploded in many application areas. The growing use of renewable energy for power generation and need for improved economic and reliable operation of the power grid requires methods for non-linear non-convex optimization and optimization under uncertainty in large networks. Due to the increase in the use of gas generators for balancing out fluctuations in the electric power grid, the gas transmission systems are witnessing an unprecedented level of fluctuation and stochasticity, creating a need for new and efficient methods for optimal and robust optimal control that can be applied to the non-linear PDE governed gas network physics. The advent of large data, need for state estimation in infrastructure networks require fast and sample optimal learning algorithms for graphical models, as well as new methods for inference.

While several methods and algorithms have been developed recently for these application areas, there are still several open problems and unmet requirements that can be potentially resolved by interaction between the applied mathematics and algorithms community and the engineering community. Several convex relaxations and approximation methods such as the Lasserre's hierarchy have been successfully used to solve the so-called Optimal Power Flow Problem, but further specialization is required to make the algorithms scalable. Optimization under uncertainty has been extensively studied recently for the linear DC approximation of the power flow equations, but methods for uncertainty quantification and optimization under uncertainty for the full non-linear AC power flow physics remain unexplored.

Traditional high fidelity simulation methods perform poorly to solve optimal control problems in network flows governed by non-linear partial differential equations. Recently it has been shown that a lower fidelity representation of the non-linear network dynamics that is optimization friendly can solve the same problem much more efficiently. The extention of these methods to accommodate uncertainty, i.e., to solve a robust optimal control problem remains open. In addition, there is still much to be explored in the field of PDE constrained network optimal control problems.

Graphical Models have received a lot of attention due to their ability to naturally model network problems by capturing the network structure and the corresponding dependency between variables succinctly via the underlying graph. Recent work has demonstrated successfully the use of Belief Propagation on tree networks to solve the Optimal Power Flow problem. However, the case of loopy networks, and general methods to handle continuous Graphical Models remains open. In the field of learning structure/parameters of a Graphical Model from data, numerous methods based on regularized M-estimators that exploit convex optimization have been proposed. However, with huge advances in mixed integer programming and the availability of powerful commercial solvers allow the use of learning algorithms based on non-convex optimization, which is an active area of research with several open ends.

This workshop aimed at generating new ideas to solve the above-mentioned open problems by bringing together a multi-disciplinary community from both the applied mathematics and the engineering applications side. The next section summarizes the various presentations in the three broad topics mentioned above.

3 Presentation Highlights

The proposed schedule involved surveys of mathematical fields and motivating applications so that all participants learned the fundamental assumptions and perspectives of each field. In addition, leaders in each area have delivered focused technical presentations of recent ideas, techniques, and research results that could be adopted by participants from other fields and disciplines. Significant focus was placed on inference, learning and optimization problems involving physical processes that occur over network systems. Some of the problems that we considered, such as optimization of electric power systems, are themselves mature fields under active investigation, while others are in an exploratory stage and have not yet been addressed by the mathematically oriented research community. All of the problems have important common features. They are (a) stated on large graphs/networks; (b) constrained by physics-related constraints that are expressed through algebraic equations, ordinary or partial differential equations, or a mix; (c) require re-formulation to facilitate optimization; (d) depend on practical algorithmic solutions such as approximations or relaxations with analytic or numerical guarantees. The presentations can be categorized into three broad categories: (i) Optimization methods in Power Systems, (ii) Optimal Control in Power Systems and Gas Networks, and (iii) Graphical Models - inference, learning and optimization.

3.1 Optimization methods in Power Systems

Miles Lubin and Line Roald: Chance Constraints for Improving Security of AC Optimal Power Flow In the two linked talks the speakers presented a new method to account for uncertainty in the AC optimal power flow problem. Using a linearized model around an operating point, the presenters showed how to solve a convex optimization problem that simulates real-time proportional response throughout the system and uses chance constraints to enforce physical limits. For the chance constraints enforcing line flow, an approximation based on two-sided chance constraints was developed. The speakers have also discussed experimental part where they reported that solution to this convex problem can be corrected back to AC feasibility and is significantly more robust than the solution to the deterministic AC-OPF problem [19].

Andy Sun: Optimal Transmission Switching with DC and AC Power Flows: New Formulations and Strong Relaxations In this talk, the problem of optimal transmission switching (OTS) in a power grid to reduce operating cost and improving reliability was discussed. The author explained study of OTS problems under both DC and AC power flow models. For the DC-OTS problem, a cycle-based reformulation and characterize the convex hull of the cycle-induced relaxation was proposed; for AC-OTS, an MISOCP relaxation and strengthen it withSDP and McCormick-based disjunctions were proposed. It was shown that the proposed reformulations and algorithms efficiently solved IEEE and NESTA instances and lead to significant cost benefits with provably tight bounds [8].

Cédric Josz: Application of complex polynomial optimization to optimal power flow Multivariate polynomial optimization where variables and data are complex numbers is a non-deterministic polynomial-time hard problem that arises in various applications such as electric power systems, signal processing, imaging science, automatic control, and quantum mechanics. Complex numbers are typically used to model oscillatory phenomena which are omnipresent in physical systems. A complex moment/sum-of-squares hierarchy of semidefinite programs to find global solutions with reduced computational burden compared with the Lasserre hierarchy for real polynomial optimization was proposed in this talk. The authors applied the approach to large-scale sections of the European HV electricity transmission grid. Thanks to an algorithm for exploiting sparsity, instances with several thousand variables and constraints can be solved to global optimality. In discussions after the presentation the author has mentioned, that other approaches for solving the deterministic AC OPF were presented at the workshop. These include SOCP and SDP relaxations proposed by Andy Sun, as well as the graphical models approach by the team at Los Alamos National Laboratory. In addition, more complicated problem were presented, such a chance-constrained AC OPF. In the following discussions it was also noted that link between the moment approach and graphical models need to be elucidated in the future. Synergies between both approaches could lead to advances in power systems optimization and to future collaborations between researchers in different areas of applied mathematics (statistics, information theory on one hand, and numerical optimization on the other hand) [7].

Dvijotham Krishnamurthy: Robust feasibility analysis and robust optimization for infrastructure networks The presenter addressed the problem of insuring network security under uncertainties, caused by renewable energy sources, and non-traditional energy demands. He presented a fast and reliable tool for constructing inner approximations of steady state voltage stability regions in multidimensional injection space such that every point in our constructed region is guaranteed to be solvable. The method is supported by numerical simulations that demonstrate that this approach outperforms all existing inner approximation methods in most cases. The stability regions were also shown to cover substantial fractions of the true voltage stability region. This technique has important applications, such as fast screening for viable injection changes, constructing an effective solvability index and rigorously certified loadability limits. [14].

Dongchan Lee: Reachability analysis of transient stability with linear programming relaxation Transient security assessment of power system remains highly challenging task due to the nonlinear and complex nature of the system. The current practices in the industry are mostly based on time-domain simulations, which are computationally expensive especially under uncertainties. In order to overcome the limitations of the existing techniques, the author proposed a reachability analysis approach. He first described a generator model with a set of algebraic equation with the Euler's method. Then the author considered evolution of the system states in a polytope template, which can be solved with linear programming relaxation at every time step. This approach allows to consider potentially any high order generator model. The effect of uncertainty was discussed which, as the workshop showed, is a growing theme in the community. The author has looked at this problem from the prospectives of transient stability and has reported development of algorithms to efficiently assess the security of the power grid. In the result of the follow up discussions the presenter has stated that the workshop was a great opportunity to talk to other researchers and think about future directions. Thanks to the workshop the presenter got the opportunity to meet researchers from Los Alamos National Lab, whom he is planning to collaborate with in the summer of 2017 [10].

Jean Bernard Lasserre: A moment SOS approach for some chance constraints issues on semi-algebraic sets In the talk the author has described a general framework to handle chance-constraints. It consists of posing the problem as an infinite-dimensional LP in an appropriate space of measures. Then when data are polynomials and semi-algebraic sets one may invoke the moment-SOS approach. For instance it allows to approximate the feasible set associated with a chance constraint by the superlevel set x: p(x) ¿=0 of some polynomial of degree "d" whose coefficients are optimal solutions of an SDP. The larger "d" the better is the approximation. The presenter has mentioned in the discussion period that he was particularly interested by the various papersrelated to the OPF. The presenter have discussed with Sidhant Misra extensively about how to handle chance constraints via the moment-SOS approach. This could be further developed and extended during the internship of the presenter PhD student Tillman at LANL in the summer of 2017 [9].

Daniel Molzahn: Error Bounds on Power Flow Linearizations: A Convex Relaxation Approach The power flow equations model the relationship between the voltages phasors and power flows in an electric power system. The nonlinearity of the power flow equations results in algorithmic and theoretical challenges, including non-convex feasible spaces for optimization problems constrained by these equations. Accordingly, many practical approaches for solving power system optimization and control problems employ linearizations of the power flow equations. By leveraging developments in convex relaxation techniques, this presentation describes recent progress regarding a method for bounding the worst-case errors resulting from power flow linearizations. Specifically, with a focus on the DC power flow approximation, this presentation characterized the worst-case error in the line flows over a specified range of operational conditions. In terms of links to other presentations and attendees, the presenter noticed in the follow up discussions that the audience was exactly the right group of people for my work. For instance, the approach the presenter used to develop worst-case error bounds on power flow linearizations applies the complex hierarchy of moment/sum-of-squares relaxations presented by Cedric Josz. This hierarchy is also closely related to a hierarchy of relaxations proposed by Jean Bernard Lasserre. The inner approximations proposed by Dj (Krishnamurthy Dvijotham) are also closely related in that the convex relaxations develop outer approximations that complement Dj's inner approximations of the feasible spaces of power system optimization problems.The presenter has also discussed an application of the worst-case error bounds to the topology identification algorithm presented by Deepjyoti Deka. Regarding the development of new work and extending existing ideas, the presenter specifically had discussions with Cedric Josz and Jean Bernard Lasserre on new applications of the hierarchies of convex relaxations, with Dj, Florian Dorfler, Savario Bolognani, and Deepjyoti Deka on extensions and applications of the worst-case error bounds I presented, and with Sidhant Misra and Line Roald on issues related to chance constraints in power system optimization problems with AC power flow models. The presenter has emphasized that he had enjoyed discussions with a variety of other researchers on their work [4].

3.2 Control in Power Systems and Gas Networks

Florian Dörfler: Control of Low-Inertia Power Systems: Naive & Foundational Approaches A major transition in the operation of electric power grids is the replacement of bulk generation based on synchronous machines by distributed generation based on low inertia power electronics sources. The accompanying loss of rotational inertia and fluctuations by renewable sources jeopardize the system stability, as testified by the ever-growing number of frequency incidents. As a remedy, numerous studies demonstrate how virtual inertia can be emulated through various devices, but few of them address the question of where" to place this inertia. It is however strongly believed that the placement of virtual inertia hugely impacts system efficiency, as demonstrated by recent case studies. A major transition in the operation of electric power grids is the replacement of synchronous machines by distributed generation connected via power electronic converters. The accompanying loss of rotational inertia and the fluctuations by renewable sources jeopardize the system stability. The problem of inertia allocation has been hinted at before, where the grid is modeled by the linearized swing equations, and eigenvalue damping ratios as well as transient overshoots (estimated from the system modes) are chosen as optimization criterion for placing virtual inertia and damping. The resulting problem is highly non-convex, but a sequence of approximations led to some insightful results. The presented work focused on network coherency as an alternative performance metric, that is, the amplification of stochastic or impulsive disturbances to a quadratic performance index measured by the H2 norm. As performance index, a classic coherency criterion was chosen that penalizes angular differences and absolute frequencies, which has recently been popularized for consensus and synchronization studies as well as in power system analysis and control. A foundational analysis was presented for model reduction for low-inertia power systems, and a coherency metric was proposed. A system-theoretic methodology for optimal inertia allocation was presented, which included theorems on performance bounds and optimal resource allocation given the assumption of uniform disturbance-damping. Finally, a tractable computational method for the general case of optimal inertia allocation was presented [15].

Saverio Bolognani: Networked Feedback Control for a Smart Power Distribution Grid Emerging challenges in distribution grids were discussed, including distributed microgenerators, high spatio-temporal electric mobility, the constraints of grid congestion, and unsustainable grid reinforcement. Tractable methodologies for virtual grid reinforcement using feedback control was then presented, based on distributed model-free control and centralized chance-constrained decision-making. A fundamental control system model for power distribution grids was stated with underdetermined sensing using meters for voltage, line currents, and transformer loading, and underactuated control using tap changers, reactive power compensators, and active power management. The collection of hard, soft, and chance- constraints used in the optimal power flow (OPF) problem were reviewed, and disturbance attenuation for distribution grid dynamics was developed using a linearization approach on the tangent space to the solution manifold [2].

Michael Herty: Modeling, Simulation and Optimization of Gas Networks There has recently been an intense discussion on physical phenomena on graphs and in particular in the context of gas pipeline network dynamics. An overview of the physics and engineering modeling typically used in the academic literature was given. A new model for representing gas flow dynamics in pipeline networks by asymptotic analysis was presented. The model is derived from the isothermal Euler equations using phenomenological approximations. The derivation of the model was presented as well as numerical results to illustrate order of accuracy, validity, and properties of the approximation. A comparison of the new model with existing models from the mathematical and engineering literature was given, in particular with respect to solution of the full-physics Euler equations. Concepts for nodal control of gas networks using the developed model were discussed [6].

Anatoly Zlotnik: Discretization for optimal control of physical flows on networks A fundamental application for optimal control of physical flows on networks is the operation of large-scale natural gas transmission pipelines. A control system model was outlined for the distributed dynamics of compressible gas flow through large-scale pipeline networks with time-varying injections, withdrawals, and control actions of compressors and regulators. The gas dynamics PDE equations over the pipelines, together with boundary conditions at junctions, were shown to be reducible using lumped elements to a sparse nonlinear ODE system with compact expression in graph theoretic notation. This system was developed as a consistent discretization of the PDE equations for gas flow that can be used to represent the dynamic constraints for optimal control problems for pipeline systems with known time-varying withdrawals and injections and gas pressure limits throughout the network. A problem formulation for intra-day economic optimal control of large-scale pipelines was presented, and an example of tractable, validated solution was discussed [23].

Anders Rantzer: H-infinity optimal control on networks Classical control theory does not scale well for large systems like traffic networks, power networks and chemical reaction networks. However, in this lecture we will present a class of networked control problems for which scalable distributed controllers can be proved to achieve the same performance as the best centralized ones. The control objective is stated in terms of frequency weighted H-infinity norms. This makes it possible to combine disturbance rejection at low frequencies with robustness to high frequency measurement noise and model errors. An optimal controller is given in the form of a multi-variable PI (proportional integrating) controller, which is distributed in the sense that control action along a given network edge is entirely determined by states at nodes connected by that edge. Fundamental bounds on the achievable performance are given in terms of the algebraic connectivity of the network graph [16].

Mihailo Jovanovic: Low-complexity modeling of partially available second-order statistics: theory and an efficient matrix completion algorithm State statistics of linear systems satisfy certain structural constraints that arise from the underlying dynamics and the directionality of input disturbances. The problem of completing partially known state statistics was described. The aim of this work is to develop tools that can be used in the context of control-oriented modeling of large-scale dynamical systems. For the type of applications of interest, the dynamical interaction between state variables is known while the directionality and dynamics of input excitation is often uncertain. Thus, the goal of the mathematical problem that we formulate is to identify the dynamics and directionality of input excitation in order to explain and complete observed sample statistics. More specifically, we seek to explain correlation data with the least number of possible input disturbance channels. We formulate this inverse problem as rank minimization, and for its solution, we employ a convex relaxation based on the nuclear norm. The resulting optimization problem is cast as a semidefinite program and can be solved using general-purpose solvers. For problem sizes that these solvers cannot handle, we develop a customized alternating minimization algorithm (AMA). We interpret AMA as a proximal gradient for the dual problem and prove sub-linear convergence for the algorithm with fixed step-size. We conclude with an example that illustrates the utility of our modeling and optimization framework and draw contrast between AMA and the commonly used alternating direction method of multipliers (ADMM) algorithm [22].

Dennice Gayme: Evaluating performance in linear oscillator networks: from vehicle platoons to power grids Two measures of synchronization performance for networks of coupled linear oscillators were defined and characterized. The first is the aggregate steady state variance of the system due to a disturbance at a single node. The second is the steady state variance of the phase difference between a given pair of nodes due to distributed disturbances. Both metrics are quantified in terms of the H2-norm of an appropriately defined linear system. A systematic framework was presented that allows computation of these metrics for networks over graphs with arbitrary structure. The framework was used to derive relationships between both measures of synchronization performance and the effective resistance between particular nodes in the graphs underlying the oscillator networks. Interpretations were given of the second performance metric as both a local and global measure of network performance. Finally, the theory was applied to two applications; the evaluation of the transient real power losses in power grids and the characterization of coherence for a certain class of vehicle platoons with relative and absolute velocity feedback [5].

3.3 Graphical Models

Nicholas Ruozzi: Continuous Graphical Models Computing the mode or MAP assignment in a probabilistic graphical models is generally intractable. As a result, for discrete graphical models, the MAP problem is often approximated using linear programming relaxations. When much of the research has focused on characterizing when these relaxations are tight, only a few results are known for their continuous analog. The presenter focused on the latter problem showing that one can use graph covers to provide necessary and sufficient conditions for continuous MAP relaxations to be tight. In particular this characterization give simple proofs that the relaxation is tight for log-concave decomposable and log supermodular decomposable models. The presenter concludes by exploring the relationship between these two seemingly distinct classes of functions and provides specific conditions under which the MAP relaxation can and cannot be tight [18].

The presenter asked other participants for feedback and discussions about other classes of continuous graphical models where such questions could be ask and answered. In particular if it could be relevant and possible to find the mode of the probability distribution with a message-passing technique beyond Gaussian graphical models.

Patrick Rebeschini: Min-sum and network flows This talk was about message-passing algorithms for solving systems of linear equations in the Laplacian matrices of graphs and to compute electric flows. These two problems are fundamental primitives that arise in several domains such as computer science, electrical engineering, operations research, and machine learning. Formers algorithms that have been proposed are typically centralized and involve multiple graph theoretic constructions or sampling mechanisms that make them difficult to implement and analyze. On the other hand, message-passing routines are distributed, simple, and easy to implement. The presenter establishes a framework to analyze message-passing algorithms to solve voltage and flow problems. The presenter shows that the convergence of the algorithms is controlled by the total variation distance between the distributions of non-backtracking random walks that start from neighbor nodes. More broadly, his analysis of message-passing introduces new insights to address generic optimization problems with constraints [17].

This talk connected the community of graphical modeling, optimization and power systems by combining techniques of the earlier to solve problems for the latter in an efficient and decentralized fashion. In follows up discussions both theoretical aspects and applicability to concrete problems were discussed.

Sungsoo Ahn: Optimizing Gauge transformation for inference in graphical model Computing partition function is the most important inference task arising in applications of Graphical Models (GM). Since it is computationally intractable, approximate algorithms are used to tackle the problem. In this talk, the presenter introduced the technique, coined gauge transformation, modifying GM factors such that the partition function stay the same (invariant), and propose two optimization formulations which generalize the Bethe Free Energy, Belief Propagation approach. Then the optimizations are solved efficiently by Alternating Direction Method of Multipliers (ADMM) algorithms. The first algorithm provides deterministic lower bounds of the partition function. The algorithm is exact for GMs over a single loop with a special structure, even though the popular Belief Propagation algorithm performs badly in this case. The second algorithm is of a randomized, Monte Carlo, type. It lowers sample variance, which can be further reduced with the help of annealed/sequential/adaptive importance sampling. The experiments show that the newly proposed Gauge-ADMM algorithms outperform other known algorithms for the approximate inference task [1].

The talk shares some common interest to that of Nicholas Ruozzi, "Continuous Graphical Models". In the follow up discussions it was suggested to consider the gauge transformation approach of discrete GMs to the framework to continuous graphical models and analyze its connection to existing algorithms for continuous GMs.

Marc Vuffray: Optimal Learning of Sparse Graphical Models Graphical Models represent multivariate probability distributions for which direct dependencies between random variables are captured by a network. Graphical Models are widely used for uncertainty management, inference and model reductions.

In many applications the network of a Graphical Models is expected to be sparse i.e. the number of edges is of the same order than the number of nodes. As Graphical Models are often not known a priori or cannot always be deduced from first principles, it is of importance to learn Graphical Models from data. In this talk the presenter has focused on efficient methods for learning Graphical Models over discrete random variables and Gaussian random variables when data take the form of several independent observation of random variables. Several low-complexity learning-algorithms that achieve or quasi-achieve the information theoretical lower-bound on data-requirement were proposed [21, 13, 12].

The talk was well received in particular by non-experts in the field of machine learning. The comments and discussions undertaken after the presentation focused on being aware of the problem of data acquisition and data processing in a network. In particular, how reconstruction imprecision based on finite data can have an impact in the control of these networks and what tools can help to overcome this problem. The methods and setting in this talk connected the fields of Gaussian graphical models and learning or solving inverse problems.

Andrey Lokhov: Reconstructing the power grid dynamic model from sparse measurements The presenter discusses the problem of parameter reconstruction in the power grid dynamics from the observations coming from the phasor measurement units (PMUs). The presenter assumes that the dynamics is described by a system of coupled linearized second-order differential swing equations. The fluctuations on individual nodes are assumed to be independent and Gaussian. Given the data coming from the sparsely located PMU sensors, the goal is to learn the inertia and the damping coefficients of the generators using the statistics of the ambient fluctuations. Adopting the description of the process as a multivariate stochastic Ornstein-Uhlenbeck process, the presenter discusses the strengths and the limitations of several approaches to this problem, based on the method of covariance matrices, as well as the maximum likelihood and least-squares estimators.

The framework presented in this talk interested specialists in control for developing using better real time actuation of the system. The presenter engaged in further discussions for possible collaborations on this interdisciplinary integration with Pr. Jovanovic & Pr. Gayme.

Deepjoti Deka: Topology Learning in Power Grids from Ambient Dynamics Estimation of the operational topology of the power grid is necessary for optimal market settlement and reliable dynamic operation of the grid. The presenter introduces a novel framework for topology estimation for general power grids (loopy or radial) using time-series measurements of nodal voltage phase angles that arise from the swing dynamics. The learning method utilizes multivariate Wiener filtering to unravel the interaction between fluctuations in voltage angles at different nodes and identifies operational edges by considering the phase response of the elements of the multivariate Wiener filter. The performance of this learning framework has been demonstrated through simulations on standard IEEE synthetic test cases [20].

A talk similar in flavor to that of Andrey Lokhov but focused on a concrete application in power systems. The presenter engages in discussions afterwards with A. Lokhov and with the same participant in control theory of power networks.

Yury Maximov: Statistical Learning with Proxies for Power Flow Feasibility In power systems and in particular in energy transmission systems it is of importance to determine if a state, i.e. a set of power productions and consumptions, can be realized in a safe and secure fashion. The presenter shown an approach that uses sampling and machine learning to develop a classifier for secure and insecure states. This statistical machine learning can provide probabilistic guarantees for the quality of the classifier, i.e., it guarantees that we do not treat an unsolvable state as a solvable one. This algorithm approximate the solvability region, which enables in particular to provide polyhedral approximations of the solvability region, as well as more sophisticated convex approximations.

This talk was of interested and well received by scientists from the power system community present at the conference with many implementations related questions asked after the talk. This approach for finding the feasibility set is an original and novel approach which combines knowledge from machine learning and power systems.

3.4 Other Topics

Vijay Subramanian: Mean field Games: Incentive and Lottery Mechanisms Motivated by systems with a large number of strategic players, such as in Internet marketplaces, the speaker explored the use of incentive and lotterymechanisms in mean-field games.

First, he considered real-time streaming of video to co-located wireless devices where cooperation among the devices would lead to greatersystem efficiency. Based on ideas drawn from truth-telling auctions, a mechanism that achieves this cooperation via appropriatetransfers (monetary payments or rebates) in a setting with a large number of devices, and with peer arrivals and departures was designed. Furthermore, thecomplexity of calculating the best responses under this regime is low. This allowed to implement the proposed system on an Android testbed, and illustrateits efficient performance using real world experiments. The tools developed here easily generalize to other resource allocation problems.

Second, the general problem of resource sharing in societal networks, consisting of interconnected communication,transportation, energy and other networks important to the functioning of society was considered. Participants in such network need to take decisions daily, bothon the quantity of resources to use as well as the periods of usage. With this in mind, the presenter discussed the problem of incentivizing users to behavein such a way that society as a whole benefits, specifically by rewarding users with lottery tickets based on good behavior, and periodicallyconducting a lottery to translate these tickets into real rewards. The user decision problem was posed as a mean field game (MFG), and theincentives question as one of trying to select a good mean field equilibrium (MFE). The existence of such an MFE under differentsettings was shown, and it was also illustrated how to choose an attractive equilibrium using as an example demand-response in energy networks [11].

The two topics discussed are based on the joint work of the speaker with Srinivas Shakkottai (TAMU) and Jian Li (UMass Amherst), with the first also withRajarshi Bhattacharyya(TAMU) and Suman Paul (TAMU), and the second also withLe Xie (TAMU), Bainan Xia (TAMU), Xinbo Geng (TAMU), Hao Ming (TAMU).

In the following discussions the presenter stated his intent to look into Belief Propagation with mixed integer and real variables as well as the LP-BP versions of it.

Gunnar Fltterd (KTH) and Carolina Osorio (MIT): Stochastic network link transmission model Stochastic network link-transmission model

In this presentation based on a joint work with Carolina Osorio (MIT) the presenter has described the link transmission model which has recently gained popularity as an efficient yet exact model of kinematic waves on road networks. The presenter formulated a stochastic instance of this model, where the number of vehicles anywhere in the network is a distributed quantity. The model approximates network-wide stochastic dependencies. Multiple questions related to connections between the model setting and other physical network flow problems discussed during the workshop was raised. The subject requires further work and investigation.

Philippe Jacquod: Multistability and topologically protected loop flows in meshed planar networks The presenter shown that the number of stable fixed points of locally coupled Kuramoto models depends on cycles in meshed networks. In particular one should expect that the number of fixed points increases for meshed networks with more cycles and with longer cycles. The presenter shows an upper-bound for the number of stable fixed point in planar networks which support this intuition and has identified network topologies carrying stable fixed points with angle differences larger than /2. Compared to earlier approaches this bounds is lower and hence much closer to the true number of stable fixed points. [3].

4 Outcome of the Meeting

The workshop helped to highlight and appreciate new connections between the mathematical areas of dynamical systems, network science, control theory, optimization, and applied probability. Bringing together the theory and applications community helped emphasize the important modeling aspects in each application, problems of importance. Developing efficient algorithms for optimization under uncertainty in networks invariably needs additional structures, assumptions and simplifications, and domain specific knowledge from the applications community helped identify what aspects of the system modeling are mandatory, and in what parts simplification is acceptable. Presentations from the theory/methods community brought to attention potential new directions to solve challenging problems in the application areas of infrastructure networks.

The schedule involved an entire day for discussions. Several new problems, solution methods, and new collaborations were conceived during these discussions. Some examples of new ideas include using Lasserre's hierarchy to solve stochastic optimization problems in non-linear networks, direct approximations to non-linear network physics around an operating point that allow for efficient optimization and uncertainty quantification.

The workshop has received very positive informal feedback, and we anticipate the new ideas and collaborations to lead to new and exciting advancements in the field. All of this was made possible by the BIRS through its excellent organization, facilities and support staff.

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