

Ongoing Research Projects

1. Sponsor: National Science Foundation

Project: "Reformulation-Linearization Technique for Discrete and Continuous Nonconvex Optimization with Applications."

The research objective of this project is to develop theoretical and computational tools for solving difficult, large-scale, discrete and continuous nonconvex optimization problems. The work will focus on extending and refining a reformulation-linearization/convexification technique (RLT). The RLT is a methodological concept for enhancing problem solvability by constructing improved (tightened) mathematical models in lifted, higher-dimensional spaces. The intent of this study is to address several theoretical and algorithmic developments as well as computational implementation issues related to the RLT, and to identify and exploit mathematical structures that arise from applying it. Specifically, the work will include (1) an extension of the underlying RLT theory through the use of Lagrange interpolating polynomials to characterize structures of the convex hull of discrete sets by way of enhancing the ability to solve integer programs; (2) a unified RLT approach with semidefinite programming constructs along with filtering and basis-reduction techniques that can be used to design effective algorithms for solving discrete as well as continuous nonconvex optimization problems; and (3) the development of tailored methods for solving both discrete and nonlinear problems having certain special structures that arise in particular applications.

The results of this study are expected to lead to more efficient tools for solving a variety of challenging nonconvex optimization programs, both discrete and continuous. The discrete programs arise in such diverse areas as clustering, cryptography, facility layout, logical inference, and scheduling, while the continuous nonconvex programs have applications in engineering design, network design, risk management, and Homeland Security. The research will also demonstrate how the algebraic properties of Lagrange interpolating polynomials can be exploited to analyze and generate cuts for mixed-integer and continuous nonlinear programming problems. Conceptually, the research will unify the realms of discrete and continuous optimization, and improve understanding of these domains.

2. Sponsor: National Science Foundation, Federal Aviation Administration (under the umbrella of the National Center of Excellence in Aviation Operations Research - NEXTOR), and National Aeronautics and Space Administration

Projects: Several projects dealing with Collaborative Decision Making and air traffic management and control issues in the terminal area and in the en-route national airspace.

This research effort addresses tactical and strategic planning decision support systems to aid Air Traffic Control (ATC) personnel manage the air traffic in the terminal area and

in the en-route National Airspace System (NAS), as well as to aid policy makers in planning future directions and in formulating various operational guidelines. Related to the en-route airspace, a comprehensive *Airspace Planning and Collaborative Decision Making (APCDM)* is being developed to select among alternative flight-plans for a set of flights in a collaborative decision making framework between FAA and airline carriers. The model considers various issues concerned with safety and collision avoidance, sector workload, fuel and delay costs, equity among the involved airlines, and the bartering of slot exchanges under the imposition of Ground Delay Programs. Related to the terminal area at hub airports, a comprehensive decision support system called the *Airport Ground Control Advisory System (AGCAS)* is being developed to aid in ground control issues pertaining to aircraft sequencing and runway operations, and pertaining to taxiway and airport ground network operations. The intent of this research is to develop a vision for an overall framework for ground and en-route air-traffic control, describing existing capabilities, and identifying needs and opportunities for improvements and coordination. The long-term impact expected from this research effort will be to improve airspace and airport handling capacities and to reduce delays and congestion effects through a more efficient and effective control and management of resources and operations.

3. Sponsor: National Science Foundation

Project: “Integrated Operations Planning Models and Algorithms for the Airline Industry.”

This project focuses on the development of mathematical models that will serve to integrate the airline operational planning problems of fleet assignment, aircraft routing, and crew scheduling, and to design and test effective solution methodologies. Three models are being investigated for this purpose along with exact and heuristic decomposition solution approaches that include polyhedral analyses for generating valid inequalities, stabilized branch-and-price-and-cut, Lagrangian relaxation, and model enhancements using the Reformulation-Linearization Technique in order to cope with the large-scale model formulations. The models and solutions procedures are being tested and validated through computational experiments on real-data provided by United Airlines and Tunis Air. The principal goal of this project is to demonstrate the benefits of simultaneous consideration of schedule planning, aircraft fleet assignment and routing, and crew scheduling, and thereby positively impact the profitability and service quality of airline companies. By recognizing the interplay among these operational planning problems and integrating them within consolidated models, airlines will be able to make more profitable decisions over the traditional sequential process that examines these interrelated problems separately. The solution methodologies developed for addressing the large-scale models will also contribute toward the repertoire of concepts and approaches for solving other related scheduling and discrete optimization problems.

4. Sponsor: National Science Foundation

Project: “Novel Modeling and Analytical Approaches for Primary Pharmaceutical Manufacturing Scheduling and Related Problems.” (With Dr. S. C. Sarin)

This grant provides funding for developing optimization models and algorithms for analyzing the primary manufacturing operational stage of the pharmaceutical supply chain, which is responsible for the production of active pharmaceutical ingredients. The designed approach will determine optimal assignment and sequencing of pharmaceutical products to various processing bays of a primary manufacturing facility in order to meet customer requirements at minimal production costs (which include contributions from both the setups required and inventory incurred to achieve a quick turn-around), given a set of equipments with specified capacities as well as a product-mix and demand rate for each product. A decomposition-based methodology will be developed for determining (near-) optimal batching, assignment, and sequencing decisions. Certain important special cases that arise in practice will also be studied. The models and solution methodologies developed will be tested on real-life problem instances encountered by the *Boehringer Ingelheim Chemical* plant, located in Petersburg, Virginia, which is devoted to the production of active pharmaceutical ingredients and intermediaries for the pharmaceutical industry.

If successful, the results of this research will lead to increasing the responsiveness to market demand by reducing cycle time delays in practice, while curtailing manufacturing costs. The models to be investigated include as substructures the high multiplicity asymmetric travelling salesman problem and the classic job shop scheduling problem. The polyhedral analysis based on the proposed research effort will also serve to enhance the independent solution of these problems, which are important in their own right. In addition, the proposed research will contribute toward providing insights and computational tools for analyzing other batch production facilities, such as in semiconductor manufacturing.

5. Sponsor: National Science Foundation

Project: “Cross-Layer Optimization for Video Transport in Wireless Ad Hoc Networks.” (With Dr. Y. T. Hou)

As wireless ad hoc networks become widely available in the near future, video communications is likely to play a pivotal role in wireless applications. The objective of this research is to offer a fundamental study of video communications over dynamic ad hoc networks. The approach is to exploit recent advances in multiple description coding, multi-path routing, packet scheduling, and per-node power control across the layers of the protocol stack. Specifically, there are three main thrusts in the research activities: (1) cross-layer modeling and theoretical study; (2) design of distributed algorithms and protocols; and (3) test-bed prototyping and validation.

The intellectual merit of this project includes the following components. First, there is very limited research pursuing a holistic consideration of video transport under the impact of multiple lower layers. But such efforts are necessary to optimize video performance. This research will thus offer new cross-layer video optimization models and theoretical results. Second, the efforts on the development of distributed algorithms and protocols will offer not only practical operational algorithms, but algorithms that can approach the theoretical limits. Finally, the efforts on test-bed prototyping will offer deeper insights into the challenges associated with video communications over ad hoc networks as well as valuable feedback to the theoretical and algorithmic research.

The broader impacts of this project include: (1) the development of new educational materials to bridge the gap between software applications, networking, and wireless communication, and (2) research experience for undergraduates and special opportunities for underrepresented students.

6. Sponsor: National Science Foundation

Project: “NeTS-Medium: Throughput Optimization for Cooperative Relaying in Wireless Networks.” (With Dr. Y. T. Hou and Dr. S. F. Midkiff)

Spatial diversity has proved to be very effective in increasing wireless network capacity and reliability. Although Multiple-Input-Multiple-Output (MIMO) offers spatial diversity by employing multiple antennas, such an approach may not always be practical, particularly as the footprint of multiple antennas may not fit on some wireless nodes (e.g., handheld devices). In this project, we explore *Cooperative Communications* (CC), where each node is only equipped with a *single* antenna and spatial diversity is achieved by exploiting the antennas on other nodes in the network. Although CC at the physical layer has been under intensive research in recent years, results on CC in ad hoc networks remain limited, particularly those on throughput performance limits. We find that the main challenges in this research stagnation are the tight coupling of channel state, the presence of network coding noise, and the complex structure of mathematical formulation of the underlying theoretical problems. The goal of this project is to optimize network level throughput by exploiting cooperative relaying at the physical layer. Rather than pursuing information-theoretic capacity limits at the physical layer, we focus on designing network level algorithms based on analytical models for cooperative relaying such that network level throughput can be maximized. Such efforts are both necessary and important to fully understand the potential and performance limits of cooperative relay networks. Specifically, there are three inter-dependent research thrusts in our proposed research: (1) Optimal Use of Network Coding in Cooperative Relay Networks; (2) Relay Node Selection for Throughput Maximization; and (3) Performance Limits of Cooperation in Multi-hop Relay Networks. The outcome of this research will establish some important building blocks for the theory of cooperative relay networks; it will also offer important insights on some practical issues for implementation.