

Preface

Smart communication, computing, sensing, and actuation devices are increasingly permeating through our world in an unstoppable manner. These technological advances are fostering the emergence of a variety of large-scale networked systems and applications, including multivehicle networks, the smart grid, smart buildings, medical device networks, intelligent transportation systems, and social networks. It has been an efficient practice to abstract these complex systems as *multi-agent networks*. In particular, each agent in the network represents a strategic entity and is able to communicate, sense, compute, and autonomously react to surrounding changes. The interactions among the agents allow them to solve problems beyond their individual capabilities, resulting in a whole that is certainly more than the sum of its parts.

In order to ensure that the network performs at an optimal level, agents face the problem of choosing the best option among a set of candidates. *Distributed optimization-based control* (DOC, for short) provides a holistic and mathematically rigorous framework to entail network-wide optimal decision making and control. In particular, desired network-wide behavior is encoded as a DOC problem where agents seek for different subobjectives and are required to obey inhomogeneous constraints of physical dynamics and decision choices. This class of problems is characterized by a number of salient features. First, the network consists of a large number of geographically distributed agents. Second, due to information privacy, the agents may not be willing to disclose their own components which define the DOC problem. Third, the agents are expected to self-adapt to internal faults and external changes. Given these features, the top-down frameworks in classic centralized and hierarchical approaches are not well suited for the needs of DOC. It necessitates bottom-up paradigms, i.e., the synthesis of distributed algorithms which allow the agents to coordinate with others via autonomous actions and local interactions resulting into an emerging network-wide behavior that globally optimizes the problem of interest. Bottom-up paradigms are characterized by that the desired global behavior emerges from local actions and interactions.

In a number of engineering applications, agents are required to operate in dynamically changing, uncertain, and hostile environments. Take multivehicle

networks as an example. Due to a limited communication bandwidth, underwater vehicles can only exchange information intermittently and thus intervehicle communication topologies frequently change over time. Ground vehicles may be commanded to perform surveillance missions in a region where the environmental information is not provided in advance. In addition, aerial vehicles operate far away from base stations and thus can be compromised by human adversaries who may attack the cyber infrastructures. In order to ensure the high performance and high confidence of multi-agent networks, DOC should explicitly take into account the unforeseeable elements during the algorithm design and performance analysis.

An Outline of the Book

This book aims at a concise and in-depth exposition of specific algorithmic solutions for DOC and their performance analysis. We focus on addressing the particular challenges induced by the environmental complexities: topological dynamics, environmental uncertainties, and cyber adversaries via integrating miscellaneous ideas and tools from Dynamic Systems, Control Theory, Graph Theory, Optimization, Game Theory, and Markov Chains. To achieve this goal, we organize the book in the following way:

Chapter 1 presents a summary of mathematical tools for DOC used in this book. We start with the consensus problem, a canonical problem in multi-agent networks. In particular, we introduce the matrix representation of multi-agent networks as well as the algorithms and convergence results for static and dynamic average consensus. After this, we present a concise introduction to convex optimization and noncooperative game theory. We conclude with a treatment of Markov chains and stochastic stability.

Chapter 2 studies a class of generic distributed convex optimization problems. In particular, each agent is associated with a private objective function and a private convex constraint set. Meanwhile, all the agents are subject to a pair of global inequality and equality constraints. The key feature of the problem is that all the component functions depend upon a global decision variable. The agents aim to agree upon two global quantities: (1) a global minimizer of the sum of all private objective functions, simultaneously enforcing all the given constraints; (2) the induced optimal value.

Chapter 3 investigates a game theoretic solution of an optimal sensor deployment problem. In particular, a set of mobile visual sensors are self-deployed in a geographically extended environment to accomplish a variety of Intelligence, Surveillance and Reconnaissance (ISR) missions, such as environmental monitoring, source seeking, and target assignment. The key feature of the problem is that the environmental distribution function is unknown *a priori* but its values can be measured on site.

Chapter 4 considers attack-resilient distributed formation control of operator-vehicle networks. Through communication infrastructures, human operators

remotely control a group of vehicles such that the vehicle team is able to finish the given cooperative mission, e.g., formation achieving. The key feature of the problem is that the communication network is compromised by external cyber attackers who aim to abort the cooperative mission.

The Intended Audience

The intended audience of the book consists of first-year or second-year graduate students in Control, Robotics, Decision Making, Optimization, and Distributed Algorithms from Aerospace Engineering, Computer Science, Electrical Engineering, Mechanical Engineering, and Operations Research. The students are assumed to have a basic background in Mathematical Analysis, Probability Theory, Stochastic Processes, Control Theory, Decision Theory, and Numerical Computation. Yet we hope that the students who do not have a sufficient background can still capture essential ideas. The researchers in Control, Robotics, Decision Making, Optimization, and Distributed Algorithms may also find the book useful as a reference.

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