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Wireless Sensor Networks

Distributed Consensus Estimation

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Preface

The increasing applications of wireless sensor networks (WSNs) witness the fact that the cooperative effort of sensor nodes can accomplish high-level tasks with sensing, data processing, and communication. Instead of sending the raw data to the fusion centers, sensor nodes execute distributed estimation for practical applications by locally carrying out simple computation and transmitting only the required and/or partially processed data. However, the network-wide information fusion capability and efficiency of the distributed estimation remain largely under-investigated. Moreover, the large-scale of WSNs imposes distinguished challenges on systematic analysis and scalable algorithm design to satisfy fundamental estimation criteria.

In this monograph, we focus on network-wide estimation (and tracking) capability of physical parameters from the system perspective. This problem is of great importance since fundamental guidance on design and deployment of WSNs is vital for practical applications. The metrics of network-wide convergence, unbiasedness, consistency, and optimality are discussed by considering network topology, distributed estimation algorithms, and consensus strategy. It reveals from systematic analysis that proper deployment of sensor nodes and a small number of low-cost relays (without sensing function) can speed up the information fusion and thus improve the estimation capability of WSNs. In Chap. 1, we introduce the spatial distribution of sensor nodes and basic scalable estimation algorithms for WSNs. Brief review of the existing works is given in Chap. 2 to show the collaborative and distributed processing of information with sensor observations and local communications. In Chap. 3, we exploit the consensus based estimation capability for a class of relay assisted sensor networks with asymmetric communication topology. By explicitly taking the functional heterogeneity between sensor nodes and relay nodes into account, a distributed consensus-based unbiased estimation (DCUE) algorithm is proposed. In Chap. 4, for the same relay assisted networks but with symmetric communication topology, we investigate the problem of filter design for mobile target tracking over WSNs. Allowed with process noise of the target and observation noise of sensor nodes, consensus-based distributed filters are designed for sensor nodes to estimate the states (e.g., position and speed) of mobile target. In Chap. 5, it is exploited on how to deploy sensor nodes and relays to satisfy the prescribed distributed estimation capability. A two-step algorithm is presented to meet the requirements of network connectivity and estimation performance. Finally, we draw conclusions and give a discussion on future work in Chap. 6.

This monograph is hopefully found to be helpful for graduate students and professionals in the fields of networking, computing, and control who are working on the research of topology analysis, sensor fusion, distributed computation and optimization, and especially of distributed estimation and control over WSNs.

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Abbreviations

DCUE	Distributed consensus based unbiased estimation
DOCF	Distributed optimal consensus filter
DoE	Disagreement of estimate
HDCUE	Homogeneous DCUE algorithm
HWSN	Heterogeneous wireless sensor network
KCF	Kalman-consensus filter
LMS	Least-mean-square
MSD	Mean-square deviation
MSE	Mean square error
RMSE	Root-mean-square error
RN	Relay node
SCC	Strongly connected component
SN	Sensor node
SNR	Signal-to-noise ratio
WCC	Weakly connected component
WSN	Wireless sensor network

Chapter 1
Introduction

Wireless sensor networks (WSNs) [1] are massively distributed systems for sensing and processing of spatially dense data. They are composed of large number of nodes deployed in harsh environments to execute challenging tasks including security/surveillance, environmental monitoring, health monitoring, industrial automation, and disaster management, etc. Although the nodes only have limited resources, complicated tasks such as distributed detection and estimation [2] can be accomplished via nodes' cooperation. The main argument is that a distributed sensor network can leverage its performance by aggregating information gathered by individual nodes, which is known as information fusion. The primary goal of sensor fusion is to process and progressively refine information from multiple nodes to eventually obtain situation awareness.

However, there is a gap between the wealth of the captured information and the understanding of the physical situation. The applications in various areas arise a common problem: for a given environment, how to estimate the spatial and temporal distribution of physical parameters of interest based on local node observations, which are probably disrupted by noise, in a distributed manner by means of simple computations and local data exchange. Thus, distributed estimation is a key process to bridge the gap by locally carrying out computations and transmitting only the required and/or partially processed data over WSNs.

1.1 Motivation of Distributed Consensus Estimation

WSNs have attracted increasing attention recently due to their wide applications. Significant advances have been made for communication, signal processing, routing, and sensor deployment or selection, etc. However, in many application scenarios, a large number of low cost sensors are deployed in order to sense or monitor the environments or equipments. This introduces a straightforward question: how to acquire the accurate and real-time status of the monitored fields or objects? To answer this question, we resort to the study of estimation. Distributed consensus estimation is the most widely adopted method in WSNs.

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