Preface

Wireless sensor networks (WSNs) have become an important technology in the realization of many applications, including both simple event/phenomena monitoring applications and heavy-duty data streaming applications. While many systems are being developed, we focus on two fundamental operations: information processing and information routing. In the data-centric operating paradigm of WSNs, these two operations are tightly related and must be performed in a collaborative fashion.

A major concern in designing and operating WSNs is their energy-efficiency. Cross-layer optimization is widely accepted as an effective technique to ameliorate this concern. The basic idea is to share information across different system layers and to enable tradeoffs involving multiple layers, which provides a larger optimization space for system design. Cross-layer optimization in the context of collaborative information processing and routing is the motivation of this book.

Objectives:

This book presents state-of-the-art techniques for cross-layer optimization to improve the energy-efficiency of information processing and routing in wireless sensor networks. Besides providing a survey on this important research area, three specific research topics are addressed in detail: real-time information processing in a single hop cluster, real-time information transport over a given tree substrate, and information routing for computationally intensive applications. We choose these three topics because (1) each of them is important and challenging in itself, and (2) together they constitute a complete operating flow of information processing and routing. The presented techniques provide a framework above which various extensions can be overlaid.

We focus on the use of three system knobs for cross-layer optimiza-

tion: voltage scaling, rate adaptation, and tunable compression. These system knobs can be used to explore the tradeoffs between communication/computation energy and latency, as well as the balance between computation and communication. The presented techniques are based on a high level system model that suitably abstracts details of low level hardware, networking protocols, and signal processing techniques.

We intend to (1) illustrate significant research results in cross-layer optimization for collaborative information processing and routing, and (2) motivate more research efforts in this crucial area from both theoretical and practical perspectives.

Book Organization:

In Chapter 1, we give an introduction to WSNs by discussing the enabling technologies of WSNs, the evolution of wireless sensor nodes, the application domain of WSNs, and related research topics and challenges.

In Chapter 2, we elaborate on the concept of information processing and routing in data-centric operating paradigm of WSNs. This is followed by a discussion of cross-layer optimization for energy minimization. A survey of state-of-the-art cross-layer optimization techniques is then presented.

The techniques presented in this book are centered around three system knobs: voltage scaling, rate adaptation, and tunable compression. In Chapter 3, we first give a list of common notations that are used throughout the book. We then describe the energy models of the above knobs. In particular, we demonstrate the tradeoffs involved in these knobs.

In Chapter 4, we consider **collaborative data processing** in a single hop cluster that behaves as a basic operating unit across the network. We investigate the assignment and scheduling of a set of real-time communicating tasks onto the cluster under a novel performance metric — to balance the energy cost of all nodes within the cluster. We focus on exploring the energy-latency tradeoffs with adjustable computation and communication speed, enabled by techniques such as voltage scaling and rate adaptation. We present integer linear programming formulations for optimal solutions as well as a 3-phase heuristic. Our techniques are shown to achieve up to 10x lifetime improvements in simulated scenarios.

In Chapter 5, we investigate the **transportation of information** to the base station over an existing routing substrate (i.e., a data gathering tree) within a user-specified latency constraint. We again explore the energy-latency tradeoffs through rate adaptation. By exploiting the dependency between communication links over the tree, we have developed

both off-line and on-line techniques to adjust the communication speed for energy minimization. Energy conservation up to 90% is achieved by our techniques.

In Chapter 6, we focus on the **construction of a routing tree** that minimizes the total energy costs of data compression and communication. Such an objective is novel compared with traditional maximum compression philosophy, and is crucial for advanced computationally intensive applications, where a balance between computation and communication energy is necessary. We utilize the concept of tunable compression with a suitable model to capture the tradeoffs between the compression time and the output size. By revealing the inherent tradeoffs between two simple tree constructions — shortest path tree and minimal steiner tree — via both analysis and simulation, we show that the minimal steiner tree is a practical solution with acceptable performance for systems with both grid and arbitrary deployment.

We expect that the contents presented in this book will motivate further research and implementation in the field of collaborative information processing and routing. Yet, many real-world challenges need to be overcome. We briefly discuss these challenges in Chapter 7.

Target Audience:

Most of the technical contents presented in this book are intended for scholars and researchers in academic institutions as well as industrial research groups. This book will benefit scholars and researchers by presenting (1) a survey of state-of-the-art techniques on information processing and routing and cross-layer optimization for energy-efficiency, and (2) a systematic framework to perform cross-layer optimization at various stages of information processing and routing, with results on three specific case studies.