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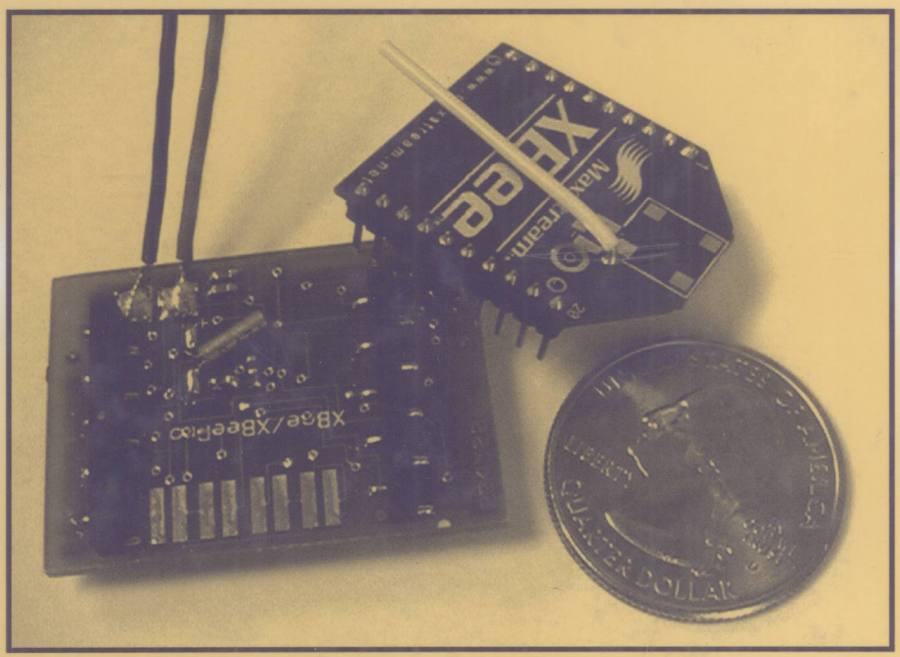
Protocols, Performance, and Control



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Wireless Ad Hoc and Sensor Networks

Protocols, Performance, and Control

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Dedication

This book is dedicated to my parents, Sarangapani Jagannathan and Janaki Sarangapani; my wife, Sandhya; my daughter, Sadhika, and my son, Anish Seshadri

Preface

The purpose of this book is to initiate the newcomer into the control of computer and wireless communication networks, one of the fastest growing fields in the engineering world. Technical concepts, which are at the core of the design, implementation, research and invention of computer network and wireless communication network control protocols, are presented in an order that is conducive to understanding general concepts, as well as those specific to particular wired, cellular, wireless ad hoc, and sensor networks.

The unprecedented growth of Internet traffic and the huge commercial success of wireless communications, along with the emerging popularity of Internet Protocol (IP)-based multimedia applications are the major driving forces behind the current and next-generation network evolution wherein data, voice, and video are brought into wired, ad hoc, and sensor networks that require diverse quality of service (QoS). Wired and cellular networks have certain infrastructure — for instance, a router in the case of computer networks and a base station in the case of wireless cellular networks — to route and to perform certain functionality. By contrast, an ad hoc network, which does not need any fixed infrastructure, also has many applications including home and personal area networking, sensor networking, search-and-rescue missions, weather prediction, and so on. Sensor networks are currently being addressed to monitor the health of industrial machinery, civil and military infrastructure, forest fire, earthquake monitoring, tsunami alerts, homeland security, and many other applications. Given the promising applications, this book addresses the basic theory, architectures, and technologies that are needed in order to implement QoS control in wired and wireless networks.

The success of telecommunications in supporting a wide variety of Internet services, such as multimedia conferencing and video-on-demand, depends on (in addition to high-speed transmission and switching technologies), reliable control in the underlying high-speed networks to provide guaranteed QoS. Computer networks require sophisticated, real-time controllers to manage traffic and to ensure QoS because Internet traffic is dominated by multimedia services, which have bursty traffic characteristics and various quality of service (QoS) and bandwidth requirements. As the line speed is increasing towards 100 Gbit/sec, and

the number of connections in each line increases to several hundreds of thousands, implementing QoS control, under the constraints of timing and memory requirements, becomes extremely difficult. Moreover, as the traffic pattern and bandwidth required for establishing a connection are typically difficult to determine beforehand, adaptive techniques hold out the promise of improved learning under uncertainty. The QoS control techniques in wired networks include flow and congestion control, admission control, buffer management, fair scheduling, and so on. This book provides an overview of the existing QoS control techniques and describes in detail the most recent adaptive ones, along with practical approaches to implement the techniques in high-speed networks.

On the other hand, in modern wireless networks, distributed power control (DPC) for transmitters along with rate adaptation allows interfering communications sharing the same channel to achieve the required QoS levels. Moreover, unlike in wired networks, the channel state affects the power control, rate adaptation, and routing protocols. Further, attaining QoS goals of the users requires a unified approach to protocol development across physical, transport, and network layers so that cross-layer optimization must be taken into consideration. This book covers existing, and the most recent, protocol designs for cellular, ad hoc, and sensor networks. Most important, the book presents certain underlying QoS control techniques, which were developed using Lyapunov-based design so that the controller performance can be demonstrated. Thorough development, rigorous stability proofs, and simulation, examples are presented in each case.

Chapter 1 lays the foundation of QoS control in wired and wireless networks and presents a systematic overview of QoS control methods including admission control, traffic rate and congestion control, and QoS routing. Background information on the Internet, asynchronous transfer networks (ATM), as well as cellular, ad hoc, and sensor networks is discussed. The QoS parameters for networks in general are introduced. In Chapter 2, background on dynamical systems, Lyapunov analysis, and controllability of dynamical systems is given. Chapter 3 focuses on congestion control of high-speed networks — Internet and ATM using Lyapunov-based analysis and protocol design. The congestion control techniques address the regulation of traffic loading across a network for congestion avoidance and recovery.

In Chapter 4, admission control is discussed in detail using hybrid system theory in order to make suitable network decisions as to whether or not any new connections based on QoS requirements should be allowed. Chapter 5 explores the distributed power control (DPC) of CDMA-based cellular and peer-to-peer networks in the presence of

channel uncertainties. Active link protection schemes for existing cellular users are discussed to meet a desired QoS level. In Chapter 6, the DPC is extended to wireless adhoc and wireless sensor networks. The medium access control protocol design to implement the DPC is presented as well. An important aspect of any QoS control system is its implementation on actual hardware using motes. Therefore, in Chapter 6, we develop the framework needed to implement QoS control at each network node using UMR mote hardware. A benchmarking test-bed that is developed for testing and validating the wireless ad hoc and sensor network protocols is also presented. Thorough overhead analysis is described and hardware implementation of DPC is covered.

Chapter 7 presents a historical overview of different packet scheduling schemes and how to regulate the flow of packets among contending flows at a network node so that the QoS requirements of each flow can be met. Additionally, the framework needed to implement QoS control at each network node using embedded computer hardware is also discussed. Using the benchmarking test-bed, the effect of channel uncertainties in the case of wireless networks on packet scheduling is detailed and performance of the scheduling protocol is evaluated. Chapter 8 covers link state routing using the QoS parameters for each connection. The decision of selecting one path from many may depend upon the resource availability along the path. The link state routing protocol is extended to wireless networks where resources, transmitter powers, and expected delays are taken into account. A dynamic optimal link state routing protocol is detailed. Hardware implementation of the routing protocol is also covered.

Chapter 9 describes predictive congestion protocol for wireless sensor networks. Analytical proofs are provided. In Chapter 10, the DPC is extended to a different type of wireless network referred to as radio frequency identification networks. Using DPC, improvement in read rates and coverage is presented.

The book surveys the most recent technical works that readers can refer to for the most up-to-date development of control techniques, both in wired and wireless networks. The book should be useful as a senior undergraduate or a graduate level course in electrical and computer engineering and computer science departments. This book is also useful to software, hardware, and system engineers in the networking design and operation.

Special thanks to my students — in particular, Maciej Zawodniok, Sarat Dontula, Niranjan Regatte, Kainan Cha, Anil Ramachandran, and James Fonda who forced me to take the work seriously and be a part of it. Without monumental efforts of proof checking by Atmika Singh, typing

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