Advances in Multi-Channel Resource Allocation

Throughput, Delay, and Complexity

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ABSTRACT

The last decade has seen an unprecedented growth in the demand for wireless services. These services are fueled by applications that often require not only high data rates, but also very low latency to function as desired. However, as wireless networks grow and support increasingly large numbers of users, these control algorithms must also incur only low complexity in order to be implemented in practice. Therefore, there is a pressing need to develop wireless control algorithms that can achieve both high throughput and low delay, but with low-complexity operations. While these three performance metrics, i.e., throughput, delay, and complexity, are widely acknowledged as being among the most important for modern wireless networks, existing approaches often have had to sacrifice a subset of them in order to optimize the others, leading to wireless resource allocation algorithms that either suffer poor performance or are difficult to implement. In contrast, the recent results presented in this book demonstrate that, by cleverly taking advantage of multiple physical or virtual channels, one can develop new low-complexity algorithms that attain both provably high throughput and provably low delay. The book covers both the intra-cell and network-wide settings. In each case, after the pitfalls of existing approaches are examined, new systematic methodologies are provided to develop algorithms that perform provably well in all three dimensions.

KEYWORDS

multi-channel, wireless networks, resource allocation, scheduling, utility maximization, throughput, delay, low-complexity, performance guarantee, CSMA

To Siwei, Jacob, and my parents

– Bo Ji

To Lining, Alice, and Jenny

– Xiaojun Lin

To Jasmine, Sanaya, and Zarius

– Ness B. Shroff

Contents

Preface

With the advent of smart phones, smart devices, and the Internet of Things, wireless technology has become part of our daily lives. Wireless technology has spawned a plethora of services that span business, science and engineering, entertainment, safety and security, health monitoring, and cover a large portion of our social interactions. Due to the prevalence of these new services, today's wireless networks are witnessing not only an unprecedented growth in the volume of traffic, but also a dramatic change in the types of traffic (e.g., a much higher percentage of voice/video traffic with more stringent delay requirements). These new trends require next-generation wireless networks to provide not only high data rates (tens of gigabits per second), but also ultra-low latencies (sub-millisecond). Moreover, as wireless networks grow and support an increasingly large number of users, resource allocation algorithms must also incur low complexity in order to be implemented in practice. This book presents an overview of recent development of new low-complexity algorithms that achieve provably guaranteed performance in both throughput and delay for multi-channel wireless systems, which are increasingly common in modern wireless networks. The new approaches and frameworks described in this book demonstrate that, by cleverly taking advantage of multiple channels, one can simultaneously achieve high throughput, low delay, and low complexity.

This book focuses on two important network settings of practical interest: intra-cell scheduling (Chapter 2) and network-wide scheduling (Chapter 3). In each chapter, we first examine the pitfalls of existing approaches, and then describe new systematic methodologies that exploit multiple physical or virtual channels for developing resource allocation algorithms that are provably efficient in all three dimensions. In order to address the technical challenges, a wide array of analytic tools are exploited, such as stochastic optimization, queueing theory, algorithm design, large-deviations theory, and Lyapunov analysis. On the other hand, to make the book accessible to a wider audience, we provide several illustrative examples and numerical simulation results, which aid readers in understanding the novel ideas and key intuitions behind the developed algorithms. We believe that this book will be useful for both researchers and practitioners in the field of communications and networking.

We would like to thank Prof. Jean Walrand for reaching out to us and providing us the opportunity to work on this book. We thank Manu Sharma, Gagan R. Gupta, and Po-Kai Huang for contributing to earlier text and results in the book. Many thanks also to Prof. Bin Li of the Department of Electrical, Computer, and Biomedical Engineering at the University of Rhode Island and anonymous reviewers for reading an earlier version of the manuscript and providing valuable feedback. We would also like to thank Prof. R. Srikant for serving as editor and Morgan & Claypool Publishers for helping us produce the final version of the book. Last but not least, the

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