SECURITY AND COOPERATION IN WIRELESS NETWORKS
Thwarting Malicious and Selfish Behavior in the Age of Ubiquitous Computing

As wireless networking becomes almost ubiquitous, it is important to anticipate potential malicious and selfish misdeeds. This self-contained text is the first to provide a scholarly description of security and non-cooperative behavior in wireless networks.

The major networking trends are analyzed and their implications explained in terms of security and cooperation. Key problems such as cheating with identities, illegitimate access to confidential data, attacks against privacy, and “stealing of bandwidth” are described along with the existing security techniques and putative methods of protection for the future. The fundamental questions of security: user and device identification; establishment of security associations; secure and cooperative routing in multi-hop networks; fair bandwidth distribution; privacy protection, and so on, are approached from a theoretical perspective and supported by real-world examples including ad hoc, mesh, vehicular, sensor, and RFID networks. The important relationships between trust, security, and cooperation are also discussed.

End of chapter homework problems test the reader and open new directions of thought; and two tutorials in the appendices, on cryptographic protocols and game theory, provide a review of the background material required to grasp the core concepts.

Ideal for senior undergraduates and graduate students of electrical engineering and computer science, this book will also be an invaluable resource on thwarting malicious and selfish behavior for researchers and practitioners in the wireless industry.

Supplementary material for this title, including lecture slides and instructor-only solutions, are available online at http://www.cambridge.org/9780521873710 and http://secowinet.epfl.ch.

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To Zsombi, Benci, and Boti
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Preface

We have entered the era of wireless networks. By now, the number of wireless phones has superseded that of wired ones. Wireless LANs are routinely used by millions of nomadic users. Wireless devices have become commonplace in offices, private homes, factories, and hospitals. And technologists promise us a world of ubiquitous computing, in which myriads of tiny, untethered sensors and actuators will communicate with each other, promptly taking care of our various needs and wishes.

In addition to this pervasiveness, we are witnessing a change of paradigm: initially, wireless devices had limited or no programmability and were managed (and secured) in a highly centralized fashion. Today, high-tier wireless end-systems are full-fledged personal computers and take an increasingly active role in the networking mechanisms. In the extreme case of multi-hop ad hoc networks, the end-systems are the network.

Unfortunately, this evolution is creating new vulnerabilities. Even existing wireless networks (and especially wireless LANs) exhibit a number of security weaknesses, some of which have been painstakingly fixed a posteriori. It is now clear that the security solutions devised for wired networks cannot be used as such to protect the wireless ones. An additional problem is that the frenzy to commercialize quickly new products and new services is in contradiction with the design of a well-thought (and possibly standardized) security architecture.

This textbook aims at preventing ubiquitous computing from becoming a pervasive nightmare. It contains a thorough description of existing and envisioned mechanisms devised to thwart misdeeds against wireless networks. Indeed, we believe that the protection of wireless networks now requires more attention and a more systematic a priori approach.

In addition to the usual security concerns of networking, we need to address selfish behavior. The reason is that each wireless communication makes use of a fraction of the spectrum that has been and will remain a scarce resource. Moreover,
most wireless devices are battery-powered, and for them energy is scarce as well. Consequently, the behavior of a wireless device can affect the service enjoyed by another, neighboring device. Likewise, the behavior of a wireless network can affect the performance of another wireless network, especially if both networks operate in the same frequency band. These are the reasons we mention “cooperation” in the title of this book; wherever appropriate, we will make use of game theory in order to formalize the problems.

We believe this textbook to be the first of its kind regarding the treatment of security and cooperation in wireless networks. Owing to the constant evolution of the field, one of the major challenges of writing such a book is ensuring that it will have a reasonably long shelf life (and that the material learned from this book has long lasting value). The strategy we have adopted is to focus on the principles and to keep examples as generic as possible.

What this book is not
This book covers a substantial amount of material, but it obviously does not aim at covering everything. In particular, it is not an introduction to security or cryptography, nor is it a tutorial on game theory (but we do provide an appendix on each of these topics for the convenience of the reader). It is not an introduction to wireless networks. It is not a book on wired networks security. It is not a handbook on jamming and anti-jamming techniques. It is also not a book on wireless security standards (the reader is referred to the numerous books recently published on this topic). Finally, the book is not about the computing aspects of security, such as the protection against viruses.

What this book is about
The book provides a thorough analysis of the major trends in wireless networks and explains the implications in terms of security and cooperation. It provides a detailed description of the problems and a precise explanation of mainstream solutions wherever they exist, and of potential solutions otherwise. The structure of the book is captured by the following figure.

The twelve chapters are organized in three parts. Part I is an introduction, providing some background information. Chapter 1 describes how existing wireless networks are secured. Chapter 2 contains a description of upcoming wireless networks, such as mesh, vehicular, sensor and RFID networks. It identifies general trends, such as increasing decentralization and growing programmability of the devices and discusses their implications in terms of security and cooperation. Chapter 3 is devoted to the difficult issue of trust in wireless networks; it explains the
relationships between trust, security, and cooperation, and discusses the adversary model.

Part II describes the techniques aiming at thwarting malicious behavior: as such, it makes use primarily of security techniques. Chapter 4 addresses the problem of naming and addressing; it explains how the Sybil and the replication attacks can be thwarted in such networks. Chapter 5 explains how security associations can be set up between wireless devices, notably by exploiting their physical proximity. Chapter 6 addresses secure neighbor discovery and explains the wormhole attack along with techniques to thwart it. Chapter 7 provides techniques to secure the fundamental operation of routing in wireless multi-hop networks. Finally, Chapter 8 addresses the crucial issue of privacy in upcoming wireless networks.

Part III focuses on the techniques intended to prevent selfish behavior; therefore, it heavily relies on game theory. Chapter 9 focuses on the MAC layer. It first explains the techniques by which a WiFi selfish user can increase its share of the bandwidth, at the expense of well-behaved users; then it provides a detailed study of selfish behavior in pure ad hoc networks. Chapter 10 discusses the problem of selfishness in packet forwarding, and explains why incentives to cooperate are needed. Chapter 11 addresses the difficult question of the co-existence of operators in the same part of the spectrum. Finally, Chapter 12 describes examples of protocols that encourage selfish devices to adopt a desirable behavior.

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1 As we will see, malicious behavior encompasses many misdeeds, including the willingness to access unauthorized information or to deliberately affect the availability of the network for other users.

2 Selfish behavior, as we will see, means the overuse of a common resource.
Preface

Appendix A contains a detailed description of those topics of security and cryptography that are needed to understand the book. Likewise, Appendix B provides a tutorial on game theory for wireless networks.

In order to make the book more concrete, we make use of several running examples to illustrate the various concepts we have introduced; these examples belong to the families of upcoming networks identified in Chapter 2: personal communication networks (including community, mesh, and mobile ad hoc networks), vehicular networks, as well as sensor and RFID networks.

Some of the chapters are specific to a given protocol layer: Chapters 6 and 9 are focused on the MAC layer, whereas Chapters 7, 10, and 12 are related to the network layer.

Intended audience

This textbook is intended for Master’s and Ph.D. students as well as for researchers. It should also be of interest for the practitioners who want to get a broader view of the field.

Some familiarity with networking and security principles is useful for a proper understanding of this book.

About the title

The title of this book, Security and Cooperation in Wireless Networks, is well suited for the security aspects. But the word “cooperation” can be misleading, because it can be confused with the notion that wireless devices cooperate with each other at the physical layer (e.g., for beamforming). The usual term in networking is “non-cooperative behavior,” but it is not particularly appropriate for the title of a book.

How to use this book

This book is designed to be covered in a one-semester course. If the students have little background on security, it is appropriate to start the course by covering Appendix A. Covering Part I should then be straightforward. At the end of Part I, the students could be encouraged to read the description of the security scheme of a wireless system not covered in the book (e.g., WiMAX) and check if they can understand it.

In Part II, each chapter can be addressed relatively independently, but the proposed order should make the understanding easier.
Preface

In current engineering and computer science curricula, game theory is usually not taught. Hence, with all likelihood, it will be necessary to first cover Appendix B before tackling Part III. Each of the four chapters of that part is fairly self-contained and can therefore be studied independently of the other. However, the beginning of the first of them (Chapter 9) is particularly intuitive because it addresses the concrete reality of WiFi systems. The last chapter (Chapter 12) is especially important as it combines the concepts of security and cooperation.

In case only a few hours per week are available, another approach consists in covering Part I and Part II in one semester, and then Part III in a follow-up (maybe optional) course in the following semester. Indeed, the two first parts of the book constitute a self-contained introduction to wireless security.

Additional material

The URL of the Web site of this book is http://secowinet.epfl.ch/ available directly or through www.cambridge.org/9780521873710. Additional material, such as slide shows (in pdf or PowerPoint\textsuperscript{3} formats) is available there.

\textsuperscript{3} Trademark of Microsoft Inc.
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