Coexistence in Wireless Networks

The increasing popularity of wireless networks makes interference and cross-talk between multiple systems inevitable. This book describes techniques for quantifying this, and the effects on the performance of wireless networks operating in the unlicensed bands. It also presents a variety of system-level solutions, obviating the need for new hardware implementations. The book starts with basic concepts and wireless protocols before moving on to interference performance evaluation, interference modeling, coexistence solutions, and concluding with common misconceptions and pitfalls. The theory is illustrated by reference to real-world systems such as Bluetooth and WiFi. With a number of case studies and many illustrations, this book will be of interest to graduate students in electrical engineering and computer science, to practitioners designing new WLAN and WPAN systems or developing new techniques for interference supression, and to general users of emerging wireless technologies.

Nada Golmie received her Ph.D. in Computer Science from the University of Maryland, College Park, in 2002. Since 1993 she has been a research engineer for the advanced networking technologies division at the National Institute of Standards and Technology (NIST). This publication, however, is not affiliated with her work there. Nada's research has led to over 100 papers published in professional conference proceedings and journals, and has contributed to industry-led consortia.

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Challenges and System-Level Solutions in the Unlicensed Bands

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To my parents

To Geof

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Preface

Wireless networks are rapidly becoming a part of the ubiquitous computing environment, and whether they are enterprise networks or in public hot spots (for example in airports, hotels, homes), often they are deployed in infrastructureless environments. The rapid specification development phase and the tight time to market cycle that follows leave little room for performance enhancements and proper coexistence consideration.

Why did I write this book?

Having gone through a somewhat complete performance analysis and coexistence development cycle for wireless network technologies being developed by the IEEE 802 standard working groups, and having gained some experience on the topic, I feel compelled to share it with other network engineers and researchers that are pursuing similar objectives. In particular, I would like to share the methodologies developed and the lessons learned from this process with others embarking on a similar quest.

The audience for this book includes: (1) researchers interested in performance evaluation and interference mitigation techniques; (2) wireless systems engineers and practitioners designing wireless communication systems; (3) users of wireless networks.

This book is unique because it focuses on a system level view of the problem of interference and its solution space. Generally, interference is dealt with at the physical layer. There are several outstanding books that focus on the accurate characterization of the wireless channel in addition to the development of physical layer techniques for filtering and anti-jamming. By considering a system level view for the interference problem and providing methods for evaluating interference at the system level including the medium access control layer, the transport, and the application layers, this effort is intended to (1) complement previous work aimed at the physical layer, (2) provide more accurate tools for quantifying interference and its impact on the system performance, and (3) develop a catalog of coexistence techniques that could be applied in various environments and for different technologies.

About the organization of this book

The structure of this book is as follows.

Chapter 1 provides and introduction to the subject of coexistence in wireless networks.

Chapter 2 covers some of the basic concepts and the design choices in the development of physical and media access control layer protocols. Examples for select technologies of interest, such as Bluetooth and IEEE 802.11b, are given in order to illustrate the concepts described.

Chapter 3 defines an interference model in the context of this book. Some of the major building blocks for conducting a performance analysis study are discussed, including the terminology, performance metrics, and the system parameters affecting the performance.

Chapter 4 consists of an open-loop interference model. In this chapter approximations for evaluating interference at the victim's receiver while ignoring the interactions between the interferer and the victim system are given. This open-loop evaluation consists of a mathematical analysis technique based on a probability of packet collision in time and frequency.

Chapter 5 describes a closed-loop modeling environment in order to capture the mutual effects of interference on each end device including the protocol interactions. A modeling and simulation methodology is presented that includes the number of devices and their placement on a two-dimensional grid, setting the transmission power of the radios, and defining the traffic distribution pertaining to the applications considered.

Chapter 6 discusses channel estimation and selection techniques that constitute the basis for most interference mitigation techniques. Several metrics for channel estimation are presented and explained, including packet or frame loss, received signal strength, and packet acknowledgment. These metrics are then used as criteria for channel selection and interference avoidance.

Chapter 7 describes proven techniques to mitigate interference. The emphasis is on dynamic and system level mechanisms that are able to adapt to the interference environment. The techniques overviewed can be broken up into two broad categories. The first category of solutions consists of temporal and/or spectral sharing of the spectrum. The second category of solutions is about adaptation and the possibility of choosing either the radio or the network that is best suited to the environment.

Chapter 8 includes some common myths and misconceptions associated with interference mitigation solutions. The main goal is to shed some light on the lessons learned while researching and developing solutions.

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I would like to thank David Su at the National Institute of Standards and Technology, who has supported my professional endeavors. I would also like to thank my colleagues at NIST and many exceptional people whom I collaborated with over the years. Their enthusiasm and dedication provided an enriching and stimulating environment for me to learn from and pursue research.

I am indebted to my dad for always believing in me. His pride, love, and encouragement have been and continue to be a constant source of inspiration in my life.

I would like to thank two people who hold a special place in my life. I am especially grateful to my mom, Raja, and my husband, Geof, for their unconditional love, infinite support, and for putting up with me during the writing of this book. It is due to their constant encouragement that I have been able to complete this project.

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Abbreviations

ACK	acknowledgment message
ACKLoss	acknowledgment loss
ACL	asynchronous connectionless link also in Bluetooth
AFH	adaptive frequency hopping
AP	access point
API	application program interface
ARQ	automatic repeat request
AWGN	additive white Gaussian noise
BER	bit error rate
BIAS	Bluetooth interference aware scheduling
BT	Bluetooth technology
CCA	clear channel assessment (used in 802.11)
CCK	complementary code keying
CDMA	code division multiple access
CPU	central processing unit
CRC	cyclic redundancy check
CSMA/CA	carrier sense multiple access/collision avoidance
CTS	clear-to-send
DCF	distributed coordination function (in 802.11)
DIFS	DCF interframe space
DS	direct sequence spread spectrum
FCS	frame check sequence
FDM	frequency division multiplexing
FDMA	frequency division multiple access
FEC	forward error correction
FER	frame error rate
FH	frequency hopping spread spectrum
FIFO	first in first out queueing
FST	frequency status table
GFSK	Gaussian frequency shift keying
GHz	gigahertz

GMSK	Gaussian minimum shift keying
GPS	global positioning system
GSM	global system for mobile communications
IEEE 802.11	a set of IEEE standards for WLANs
IEEE 802.15	a set of IEEE standards for WPANs
ISM	industrial, scientific, and medical frequency band
LD	limiter–discriminator receiver
LIFO	last in first out queueing
LLC	logical link control layer
LMP	link management protocol
MAC	medium access control layer
MANET	mobile ad hoc network
MHz	megahertz
NACK	negative ACK
OFDM	orthogonal frequency division multiplexing
PDF	probability density function
PDU	payload data unit
PHY	physical layer
PLoss	packet loss
QOS	quality of service
RF	radio frequency
RR	round robin scheduling
RSNI	received signal to noise indicator
RSSI	received signal strength indicator
RTS	request-to-send
SCO	synchronous connection-oriented link in Bluetooth
SIFS	short interframe space
SIR	signal to interference ratio
SNR	signal to noise ratio
TCP/IP	transmission control protocol/internet protocol
TDM	time division multiplexing
TDMA	time division multiple access
TPL	transmit power level
UMTS	universal mobile telecommunications system
UNII	unlicensed national information infrastructure band
Wi-Fi	wireless fidelity, generic designation for an IEEE 802.11 network
WLAN	wireless local area network
WMAN	wireless metropolitan area network
WPAN	wireless personal area network