Wireless Ad Hoc and Sensor Networks

Wireless Ad Hoc and Sensor Networks describes the theory of ad hoc networks. It also demonstrates techniques for designing efficient algorithms and systematically analyzing their performance.

Li develops the fundamental understanding required to tackle problems in these networks by first reviewing relevant protocols, then formulating problems mathematically, and solving them algorithmically. Wireless MAC protocols, including various IEEE 802.11 protocols, 802.16, Bluetooth, and protocols for wireless sensor networks are treated in detail. Channel assignment for maximizing network capacity is covered; topology control methods are explored at length; and routing protocols for unicast, broadcast, and multicast are described and evaluated. Cross-layer optimization is also considered.

The result is a detailed account of the various algorithmic, graph-theoretical, computational-geometric, and probabilistic approaches to attack problems faced in these networks, delivering an understanding that will allow readers to develop practical solutions for themselves. This title is an invaluable resource for graduate students and researchers in electrical engineering and computer science departments, as well as for practitioners in the communications industry.

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Wireless Ad Hoc and Sensor Networks

Theory and Applications

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To my wife, Min
my daughter, Sophia
my son, Kevin
and my families

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Preface

Introduction

In the next generation of wireless communication systems, there will be a need for the rapid deployment of independent mobile users. Significant examples include establishing survivable, efficient, dynamic communication for emergency/rescue operations, disaster relief efforts, and military networks. Such network scenarios cannot rely on centralized and organized connectivity and can be conceived as applications of mobile ad hoc networks (MANETs). A MANET is an autonomous collection of mobile users that communicate over relatively bandwidth-constrained wireless links. Because the nodes are mobile, the network topology may change rapidly and unpredictably over time. The network is decentralized; all network activity, including discovering the topology and delivering messages, must be executed by the nodes themselves; that is, routing functionality will be incorporated into mobile nodes.

In many commercial and industrial applications, we often need to monitor the environment and collect the information about the environment. In some of these applications, it would be difficult or expensive to monitor using wired sensors. If this is the case, wireless sensor networks in which sensors are connected by wireless networks are preferred. A wireless sensor network (WSN) consists of a number of sensors spread across a geographic area. Each sensor node has wireless communication capability and some level of intelligence for signal-processing and networking of data. A WSN could be deployed in wilderness areas for a sufficiently long time (e.g., years) without the need to recharge or replace the power supplies. Typical applications of WSNs include monitoring, tracking, and controlling.

The subject of wireless ad hoc networking and sensor networking is enormously complex, involving many concepts, protocols, technologies, algorithms, and products that work together in an intricate manner. The set of applications for MANETs is diverse, ranging from small, static networks that are constrained by power sources to large-scale, mobile, highly dynamic networks. Recently, wireless sensor networks have also been used in Supervisory Control and Data Acquisition (SCADA). SCADA systems are used to monitor or to control chemical or transport processes, in municipal water supply systems, control electric power generation, transmission, and distribution, gas and oil pipelines, and other distributed processes. The design of network protocols for these networks is a complex issue. Regardless of the application, MANETs and sensor networks need efficient distributed algorithms determining network organization, linking scheduling, and routing. However, determining feasible routing paths and delivering messages in a decentralized environment in which network topology fluctuates is not a well-defined problem. Although the shortest path (based on a given cost function) from a source to a destination in a static network is usually the optimal route, this idea is not easily extended to MANETs. Factors such as variable wireless link quality, propagation path loss, fading, multiuser interference, power expended, and topological changes become relevant issues. The network should be able to adaptively alter the routing paths to alleviate any of these effects. Moreover, in a military environment, preservation of security, latency, reliability, intentional jamming, and recovery from failure are significant concerns. Military networks are designed to maintain a low probability of intercept and/or a low probability of detection. Hence, nodes prefer to radiate as little power as necessary and transmit as infrequently as possible, thus decreasing the probability of detection or interception. A lapse in any of these requirements may degrade the performance and dependability of the network.

The basic goals of a wireless ad hoc sensor network generally depend on the application, but the following tasks are common to many networks:

1. *Determine the value of some parameter at a given location*: In an environmental network, one might want to know the temperature, atmospheric pressure, amount of sunlight, and relative humidity at a number of locations. This example shows that a given sensor node may be connected to different types of sensors, each with a different sampling rate and range of allowed values.
2. *Detect the occurrence of events of interest and estimate parameters of the detected event or events*: In the traffic sensor network, one would like to detect a vehicle moving through an intersection and estimate the speed and direction of the vehicle.
3. *Classify a detected object*: Is a vehicle in a traffic sensor network a car, a minivan, a light truck, a bus, and so on?
4. *Track an object*: In a military sensor network, one would like to track an enemy tank as it moves through the geographic area covered by the network.

In these four tasks, an important requirement of the sensor network is that the required data be disseminated to the proper end users. In some cases, there are fairly strict time requirements on this communication. For example, the detection of an intruder in a surveillance network should be immediately communicated to the police so that action can be taken. Because wireless sensors are often powered by batteries only, energy efficiency is critical for the lifetime of a wireless sensor network. Thus, a considerable amount of research has recently been devoted to developing energy-efficient protocols for wireless sensor networks. In addition to energy-efficient protocols, wireless ad hoc sensor network requirements include but are not limited to scalability (to support a large number of mostly stationary sensors for which networks of 10,000 or even 100,000 nodes are envisioned), network self-organization to support scalability and fault tolerance, collaborative signal-processing, and querying ability. Given the large number of nodes and their potential placement in hostile locations, it is essential that the network be able to self-organize; manual configuration is not feasible. Moreover, nodes may fail (either from lack of energy or from physical destruction), and new nodes may join the network. Therefore, the network must be able to periodically reconfigure itself so that it can continue to function. Individual nodes may become disconnected from the rest of the network, but a high degree of connectivity must be maintained. Another factor that distinguishes wireless sensor networks from MANETs is that the end goal is detection/estimation of some events of interest and not just communications. To improve the detection/estimation performance, it is often quite useful to fuse data from multiple sensors. This data fusion requires the transmission of data and control messages, and so it may put constraints on the network architecture. A user may want to query an individual node or a group of nodes for information collected in the region. Depending on the amount of data fusion performed, it may not be feasible to transmit a large amount of the data across the network. Instead, various local sink nodes will collect the data from a given area and create summary messages. A query may be directed to the sink node nearest the desired location.

Recent years have seen a great amount of research in wireless networks, especially wireless ad hoc networks. These works involve a number of theoretical aspects of computer science, including approximation algorithms, computational geometry, combinatorics, and distributed algorithms. Because of the limited capability of processing power, storage, and energy supply, many conventional algorithms are too complicated to be implemented in wireless ad hoc and sensor networks. Some other algorithms do not take advantage of the geometric nature of the wireless networks. Additionally, most of the currently developed location-based algorithms for wireless networks assume a precise position of each wireless node, which is impossible practically. The majority of the algorithms with theoretical performance guarantee developed in this area also assume that all nodes have a uniform transmission range. These algorithms will likely fail when nodes have disparate transmission ranges. In summary, the wireless ad hoc and sensor networks require efficient distributed algorithms with low computation complexity, low communication complexity, and low storage complexity. These algorithms are expected to take advantage of the geometry nature of the wireless ad hoc networks. Several fundamental questions should be answered: Can we improve the performance of traditional distributed algorithms, developed for wired networks, under wireless ad hoc networks? Does the position information of wireless nodes make a difference in algorithm performance? Much of the existing work in wireless ad hoc networking also assumes that each individual wireless node (possibly owned by selfish users) will follow prescribed protocols without deviation. However, each user may modify the behavior of an algorithm for self-interest reasons. How are desired global-system performances achieved when individual nodes are selfish?

This is a new book aimed at the teaching of wireless ad hoc and sensor networks from the algorithmic and theoretical perspective. The primary focus of the book is on the algorithms, especially efficient distributed algorithms, related wireless ad hoc protocols, and some fundamental theoretical studies of phenomena in wireless ad hoc and sensor networks. Many aspects of wireless networking are covered at the introductory level. I tried to cover as many interesting and algorithmic challenging topics related to wireless ad hoc and/or sensor networks as possible in this book. I know that several interesting topics and elegant algorithms are missing. Some are due to lack of space and some are due to the theme of the book. No judgment is implied for algorithms and protocols not covered in this book.

Audience

This book is intended for graduate students, researchers, and practitioners who are interested in obtaining a detailed overview of a number of various algorithmic, graph-theoretical, computational-geometric, and probabilistic approaches to attack certain challenging problems stemming from wireless networks, especially wireless ad hoc and sensor networks. Thus, when I wrote this book, I tried to cover many details for most of the algorithms studied. This book can, in general, serve as a reference resouce for researchers, engineers, and protocol developers working in the field of wireless ad hoc and/or sensor networks. Consequently, most of the chapters are written in such a way that they can be read and taught independently.

While I have tried to make the book (and most chapters) as self-contained as possible, some rudimentary knowledge of algorithm design and analysis, computational geometry, distributed systems, graph theory, linear algebra, networking protocols, and probability theory is required for reading this book.

Organization of the Book

This book essentially is organized based on the layers of wireless networking: the physical and medium-access-control (MAC) layers, the topology control functions that lie between the MAC and network routing layer, and the network routing layer.

The first part of the book presents introductory material that is necessary for the rest of the book.

Chapter 1 briefly reviews the history of wireless communications and discusses different wireless networks, such as infrastructure-based wireless networks (cellular networks) and infrastructureless wireless networks. Among infrastructureless networks, wireless ad hoc networks and wireless sensor networks are briefly discussed.

Chapter 2 covers some fundamentals of wireless transmissions. In this chapter, we study the interference constraints of wireless communications, the wireless propagation model, and the channel capacity of a wireless channel. We also define the communication graph and the interference graph (or conflict graph) induced by a wireless network. Because minimizing energy consumption is critical for the success of many wireless networks, we also review several energy-consumption models that are often used in the literature. Additionally, we discuss a number of mobility models to simulate mobile networks.

The second part of the book is mainly about the MAC protocols for wireless networks. We study CSMA, TDMA, and CDMA protocols.

Chapter 3 concentrates on the CSMA-based wireless MAC protocols. We study how hidden-terminal and exposed-terminal problems are addressed. We also briefly study several typical wireless MAC protocols such as IEEE 802.11 (or WiFi) protocols for wireless LANs, IEEE 802.16 (WiMAX) for mesh networks, and Bluetooth for wireless personal area networks. We briefly review some of the specific MAC protocols proposed for wireless sensor networks that integrate CSMA and TDMA.

Chapter 4 concentrates on the MAC protocols based on TDMA. These protocols assume that the time is slotted and that each link will be assigned some time slots, in which it can transmit data over this link. When a link is assigned a time slot, it is guaranteed that no wireless interference will occur when it uses this link at this time slot. This assignment is often 0/1: A slot either is assigned to a link or is not assigned. When a time slot is not assigned, a link cannot transmit at that specific time slot. We study some TDMA-based link-scheduling algorithms that can provide theoretical performance guarantees.

Chapter 5 concentrates on spectrum channel assignment for wireless networks (cellular networks and wireless ad hoc networks). We first study how to assign channels for a set of access networks such that the network capacity is maximized, or the number of assigned channels is minimized while certain capacity requirements are satisfied. We then study the results for spectrum channel assignment for ad hoc networks. The objective of a channel assignment could be to use the least number of channels to achieve a connected network while the channel availability and network interface constraints at all nodes are satisfied. We also study the transition phenomena of a number of network properties depending on the availability of a wireless spectrum.

Chapter 6 studies several algorithms for assigning a CDMA code to wireless networks when CDMA is supported.

The third part of the book is about topology control and power assignment for wireless networks.

Chapter 7 studies the construction of backbone for wireless networks. Backbone is especially useful for routing in mobile networks. We study several centralized and distributed algorithms that can construct a network backbone (i.e., a connected dominating set) whose size is within a constant factor of the optimum for wireless networks modeled by a unit disk graph. We also study some pure localized algorithms that have lower communication costs, although the theoretical constant-approximation ratio on the backbone size is not guaranteed.

Chapter 8 studies the construction of a backbone network when each wireless node has a weight denoting its cost of being at the backbone. The objective is to minimize the total weight of the backbone. We study several algorithms with good approximation ratios.

Chapter 9 studies topology-control algorithms that will construct flat network topologies with proved performance guarantees. Here, a network topology is said to be flat if every node in the network will assume the same role in network routing. Notice that for a backbone-based structure, the node on the backbone will forward the messages for nodes that are not on the backbone. We study efficient distributed algorithms that can construct energy-efficient network topologies.

Chapter 10 studies the power-assignment problems for wireless networks. Power assignment is selecting a transmission power for each node in the network such that the resulting communication network using the allocated transmission power has certain properties. The objective of a power assignment is often to minimize the total power used by all nodes or to minimize the maximum transmission power of all nodes. The latter is often easy to solve, based on a binary search on all choices of transmission power. We study algorithms that assign transmission powers such that the network is connected, k-connected, or consumes the least power for broadcast or multicast.

Chapters 11 and 12 are related to previous chapters but with different focuses. In these two chapters, we study the so-called transition phenomena of random wireless networks; in other words, the behavior of some certain parameters of the network when the number of nodes in the network goes to infinity. In Chapter 11, we study the critical transmission range r_n when a random network of n nodes distributed in a given region (typically, a unit square or a disk with unit area) is connected with high probability or k-connected with high probability. In Chapter 12, we study the critical node degree needed for producing a connected random network with high probability; the critical transmission range for connectivity in sparse networks or in mobile networks; the critical transmission range for a successful routing with high probability for certain localized routing algorithms; and the critical sensing range for covering a region with high probability.

The fourth part of the book is on routing protocols for wireless networks. We study routing protocols for unicast, multicast, and broadcast, and routing protocols with selfish agents.

Chapter 13 studies the energy-efficient unicast routing for wireless networks. We briefly review some typical proactive and reactive unicast routing protocols proposed in the literature, such as DSDV, OLSR, AODV, DSR, and opportunistic routing. We also study geographic routing protocols that utilize the geometry information of wireless nodes to improve the routing performance. Cluster-based hierarchical routing is also briefly discussed.

Chapter 14 studies energy-efficient routing protocols for broadcast and multicast. We first study some centralized algorithms for energy-efficient broadcast and multicast. These algorithms are often based on the node-weighted or link-weighted Steiner tree algorithms proposed in the literature. Later, we study several distributed or localized methods that are practically efficient.

Chapter 15 studies the routing from another point of view. In all previous protocols, it has been assumed that all wireless nodes will follow predescribed protocols without deviation. In practice, this may not be true, especially when wireless nodes are owned by individuals. In this chapter, we study how to design routing protocols when we know that individual nodes may not follow a routing protocol for their own benefit. We study this problem mainly using a game-theoretical approach, although a number of different approaches are also briefly discussed. In the game-theoretical-based approaches, wireless nodes will be compensated for their services to others. We study how each individual relay node is paid and how the payment to these nodes is implemented. For multicast, we also study algorithms that will fairly share the payments to relay nodes among potential receivers.

Chapter 16 studies how to improve the network through a cross-layer approach of jointly optimizing routing, link scheduling, and channel assignment. We formulate this problem as mixed-integer programming and then relax it to linear programming. By combining it with link scheduling, we show that the relaxed linear-programming formulation will find a solution that is at least a constant factor of the optimum for a number of network models.

The fifth and the last part of the book is devoted to studying a few other interesting topics in wireless networks; for example, location tracking, the performance of random networks, and security.

Chapter 17 studies finding the location of wireless sensor nodes and tracking the position of a moving object by using wireless sensor networks.

In previous chapters, especially Chapter 16, we study what maximum throughput is achievable by a given wireless network under a certain wireless interference model.

Chapter 18 concentrates on the asymptotic network capacity of a random network. We study how the capacity of wireless networks scale with the number of nodes in the networks (when given a fixed deployment region) or scale with the size of the deployment region (when given a fixed deployment density) for a number of operations, such as unicast and broadcast. We especially study a pioneering work by Gupta and Kumar on the network capacity of a random network for unicast. We also study the network capacity for broadcast under various channel models.

Chapter 19 concentrates on ensuring security in wireless networks. We mainly focus on some fundamentals of cryptography, some key-predistribution protocols, and some secure routing protocols proposed in the literature. Cryptography will provide us some fundamental tools such as symmetric-key and asymmetric-key encryption, digital signature, and hash functions to implement some security protocols. We then review some secure routing protocols proposed in the literature.

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I am sure that I have missed many others, although not intentionally; I thank all of you.

XiangYang Li
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Abbreviations

1D	one-dimensional
2D	two-dimensional
2G	second-generation
3D	three-dimensional
3G	third-generation
ABR	associativity-based routing
ACK	acknowledgment (frame)
A/D	analog-to-digital (conversion)
AES	Advanced Encryption System
AFR	adaptive face routing
AHLoS	ad hoc localization system
AIFS	arbitration interframe space
Algorithm KV	algorithm of Khuller and Viskhin
AMPS	Advanced Mobile Telephone System
amp	amplifier
AoA	angle of arrival
AODV	ad hoc on-demand vector (routing)
AP	access point
APS	ad hoc positioning system
APX	approximable
APXH	APX-hard
AS	autonomous system
ATIM	ad hoc traffic indication map
ATM	asynchronous transfer mode
AWA	Accessos Web Alternativos
BAIP	broadcast average incremental power
BB	budget balance
BFS	breadth first search
BGP	border gateway protocol
BI	busy indication
BIP	broadcasting incremental power
BP	aBeacon period
BPS	bounded-degree planar spanner
BPSK	binary phase shift keying
BSC	base station controller

CA	collision avoidance (CSMA/CA often)
CBC	cipher-block chaining (mode)
CBT	core-based tree
CBTC	cone-based topology control
CCA	clear channel assessment
CCM	combined cipher machine
CCR	critical coverage range
CDMA	code-division multiple-access
CDS	connected dominating set
CEDAR	core-extraction distributed ad hoc routing
CFB	cipher-feedback (mode)
CF-End	contention-free end
CFP	contention-free period
CF-Poll	contention-free poll
CG	conflict graph
CGSR	cluster-head gateway switch routing
CM	cross-monotone
CNN	critical neighbor number
CP	contention period
CPA	closest point of approach
CPU	central processing unit
CRC	cyclic redundancy check
CSMA	carrier-sense multiple-access (protocol)
CSP	collaborative signal processing
CT2	cordless telephone
CTR	critical transmission range
CTS	clear-to-send (mechanism)
CW	contention window
D/A	digital-to-analog (conversion)
DAG	directed acrylic graph
D-AMPS	digital advanced mobile phone service
DARPA	Defense Advanced Research Projects Agency
DC	differential cryptanalysis
DCA	dynamic channel assignment
DCF	distributed coordination function
DECT4	digital European cordless telephone
Demod	demodulator
DES	data encryption standard
DG	disk graph
D-H	Diffie–Hellman
DIFS	distributed interframe space
DM	dense model
D-PRMA	distributed packet-reservation multiple-access (protocol)
DPT	distributed prediction tracking
DRAND	a protocol that technically is defined as distributed randomized TDMA scheduling

DREAM	distance routing effect algorithm for mobility
DS	dominating set
DSA	digital-signature algorithm
DSDV	destination-sequenced distance-vector [routing (protocol)]
DSL	digital subscriber line
DSN	Distributed Sensor Networks (program)
DSP	digital signal processing
DSR	dynamic source routing
DSSS	direct-sequence spread spectrum
DST	directed Steiner tree
DT	Delaunay triangulation
DV	distance vector
DVMRP	distance-vector multicast routing protocol
EAX	designation of a two-pass authenticated encryption scheme
EC	Euler circuit
ECB	electronic codebook (mode)
ECC	elliptic curve cryptography
EDCA	enhanced DCF channel access
EDGE	enhanced data rate for GSM evolution
EFF	Electronic Frontier Foundation
EIFS	extended interframe space
ELSD	equal link split downstream
EMST	Euclidean minimum spanning tree
ERNG	extended relative neighborhood graph
ETX	expected transmission count
ExOR	name given to an opportunistic multihop routing protocol
FDMA	frequency-division multiple-access
FFT	fast Fourier transform
FGSS	fault-tolerant global spanning subgraph
FHSS	frequency-hopping spread spectrum
FIPS	Federal Information Processing Standard
FLSS	fault-tolerant local spanning subgraph
FM	frequency modulation
FNR	farthest-neighbor routing
FP	final permutation
fPrIM	fixed-protocol-interference model
FPTAS	fully polynomial-time-approximation scheme
FSK	frequency-shift-keying
GC	graph coloring
GFR	greedy–face routing
GG	Gabriel graph
GOAFR	greedy other adaptive face routing
GPRS	General Packet Radio Service
GPS	global positioning system

GPSR	greedy perimeter stateless routing
GRG	geometric random graph
GSM	Global System for Mobile Communication
GTFT	method proposed in a paper
HC	hybrid coordinator
HCCA	HCF-controlled channel access
HCF	hybrid coordination function
HRMA	hop reservation multiple access
IARP	intrazone routing protocol
IBSS	independent basic service set
IBSSID	IBSS identifier
IC	incentive compatible
ICDS	induced connected dominating set (graph)
ID	identification
IEEE	Institute of Electrical and Electronics Engineers
IF	intermediate-frequency
iff	if and only if
IG	interference graph
IMBM	iterative maximum-branch minimization
IMRG	incident MST and RNG graph
IMS	IP (Internet Protocol) Multimedia Subsystem
IP	integer programming (formulation)
IP	Internet protocol
IP	initial permutation
IPTV	Internet protocol television
IR	individual rationality
IS	independent set
ISM	Industrial, Scientific, and Medical
ISP	Internet service provider
IT	information technology
IV	initial value
IV	initialization vector
kbps	kilobits per second
kbytes	kilobytes
kNN	*k*-nearest-neighbor (classifier)
LAN	local-area network
LAR	location-aided routing
LBM	location-based multicast
LC	linear cryptanalysis
LCP	least-cost path
LCPT	least-cost path tree
LDEL	local Delauney graph
LEARN	localized-energy-aware restricted neighborhood (routing)
LLACK	link-layer acknowledgment

LMST	localized minimum spanning tree
LNA	low-noise amplifier
LP	linear programming
LPL	low-power listening
LSS	local spanning subgraph
LST	least-cost Steiner tree
MAC	medium-access control
MAN	metropolitan-area network
MANET	mobile ad hoc network
MAP	maximum a posteriori probability
MATSF	name of a protocol proposed in a paper (from MANET time synchronization)
MBGP	multiprotocol extension for a border gateway protocol
MBS	Mobile Broadband System
MC-CDMA	multicode CDMA
MCDS	minimum connected dominating set
MCG	mutual-communication graph
MCMT	minimum-cost multicast tree
MCU	microcontroller unit
MDS	minimum dominating set
MEMS	Micro-Electro-Mechanical Systems
MFR	most-forwarding routing
MG	mutual-inclusion graph
MGC	minimum graph-coloring (problem)
MIB	management information base
MIMO	multiple-input multiple-output
MIP	multicast independent protocol
MIS	maximum independent set
ML	maximum-likelihood (classifier)
MMAC	multichannel MAC
MNP	monotone nonincreasing property
Mod	modulator
MOSPF	multicast open shortest path first
MPR	multipoint relay
MSC	mobile switching center
MST	minimum spanning tree
MUP	multiradio unification protocol
MVC	minimum vertex cover
MWCDS	minimum weighted connected dominating set
MWIS	maximum weighted independent set
MWVC	maximum weighted vertex cover
NAV	network allocation vector
NFR	no-free-rider
NIC	network interface card
NIST	National Institute of Standards and Technology
NNG	nearest-neighbor graph

NNR	nonnegative sharing
NP	nondeterministic polynomial
NPH	NP-Hard
NST	node-weighted Steiner tree
OAFR	other adaptive face routing
OCB	offset codebook (mode)
OFB	output feedback (mode)
OFDM	orthogonal frequency-division multiplexing
OFSF	orthogonal fixed-spreading-factor (code)
OLSR	optimized link-state routing (protocol)
OSPF	open shortest path first
OURS	optimal unicast routing system
OVSF	orthogonal variable-spreading-factor (code)
PA	power amplifier
PACS	personal-access communications systems
PAN	personal-area network
P-BIP	pruned broadcasting incremental power
PC	point coordinator
PCF	point coordination function
PCI	peripheral component interconnect
PDA	personal digital assistant
PhIM	physical-interference model
PHY	physical-layer (specification)
PI	planar and internal-node
PIFS	point-coordination-function interframe space
PIM-SM	protocol-independent multicast-sparse mode
PKCS	Public Key Cryptography Standard
P-MST	pruned minimum spanning tree
POMDP	partially observable Markov decision process
PP	primal linear programming
PrIM	protocol-interference model
PRMA	packet-reservation multiple-access (scheme)
PS	power-save (state or mode)
PSM	power-saving mode
P-SPT	pruned shortest-path tree
PSTN	public-switched telephone network
PTAS	polynomial-time-approximation scheme
PTC	polynomial-time computability
PTDMA	probabilistic time-division multiple access
QAM	quadrature amplitude modulation
QoS	quality of service
QPSK	quadrature phase-shift keying
RAD	random-assessment delay
RAM	random-access memory

RBOP	related neighborhood-graph-based broadcast-oriented protocol
RF	radio frequency
RIP	routing information protocol
RNG	relative neighborhood graph
RON	resilient overlay network
RP	rendevous point
RPB	reverse-path-broadcasting (scheme)
RPF	reverse-path forwarding (lookup)
RREP	route reply
RREQ	route request
RSA	Rivest–Shamir–Adleman
RSS	received signal strength
RTS	request-to-send (mechanism)
RWP	random-waypoint (model)
Rx	receive
SBT	share-based tree
SCADA	supervisory control and data acquisition
SCH	set-cover hard
SIFS	short interframe space
SINR	signal-to-interference-noise ratio
SIR	signal-to-interference ratio
SMS	short messaging service
SOP	spectrum opportunity
SPAN	a topology maintenance protocol proposed by Chen *et al*. (2002)
SPF	shortest path first
SPS	Standard Positioning Service
SPT	shortest-path tree
SSCH	slotted seeded channel hopping (protocol)
SSR	signal stability routing
SSR	security stochastic routing
STASF	a synchronization protocol proposed in a paper by Zhou and Lai (2005)
SURAN	Survivable Radio Network (project)
SVM	support vector machine
TA	trust authority
TACS	Total Access Communications System
TATSF	a synchronization protocol proposed in a paper
TBTT	target Beacon transmission time
TC	traffic class
TCP	transmission control protocol
TDM	time-division multiplexing
TDMA	time-division multiple-access
TDoA	time difference of arrival
ToA	time of arrival
TORA	temporarily ordered routing algorithm
TSF	timing synchronization function
Tx	transmit

TxIM	transmitter-interference model
TxoP	transmit opportunity
UDG	unit disk graph
UDP	user data-gram protocol
UMTS	Universal Mobile Telecommunication System
UPVCS	undirected minimum-power *k*-vertex-connected subgraph
US	ultrasound
UWB	ultrawideband
UWCDS	unicast weighted connected dominating set
VC	Vapnik and Chervonenkis
VCG	Vickrey–Clarke–Groves (mechanism)
VCO	voltage-controlled oscillator
VHF	very-high-frequency
VMST	virtual minimum spanning tree
VoIP	voice over IP
VOR	VHF omnidirectional ranging (aircraft navigation system)
VoWIP	voice over wireless IP
WAN	wireless ad hoc network
WCDMA	wideband code-division multiple-access
WCDS	weighted connected dominating set
WEP	wired equivalent privacy (encryption)
WiFi	common name used to refer to a wireless local-area network
WiMAX	Worldwide Interoperability for Microwave Access
WINS	a type of sensor node by Rockwell
WLAN	wireless local-area network
WMAN	wireless metropolitan-area network
WMN	wireless mesh network
WPA	WiFi protected access (mode)
WPAN	wireless personal-area network
WRP	wireless routing protocol
WSN	wireless sensor network
WWAN	wireless wide-area network
WWiSE	Worldwide Spectrum Efficiency (standard)
YG	Yao graph