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Physical Layer Security in Random Cellular Networks

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To our families and Xi'an Jiaotong University

Preface

The main objective of this book is to investigate the wireless physical layer security in random cellular networks. Security is a fundamental issue in data communications. In wireless communications, security becomes more challenging due to the openness of wireless medium and its inherent vulnerability to eavesdropping. Recently, physical layer security has become an emerging research front which provides promising confidentiality for wireless transmissions. The theoretical basis of physical layer security approaches is dated back to information theory, which takes full consideration of the characteristic of wireless channels. Compared to conventional cryptographic encryption and decryption technologies to guarantee secrecy, physical layer security approaches bypass the secret key generation and distribution issues, thereby resulting in significantly lower complexity and more savings in computational resources, which makes it very competitive in many wireless applications.

Although there already have been great advances in the topic of physical layer security, most of the researches focus on the point-to-point secrecy communications. In a wireless cellular network there are a large amount of concurrent transmissions between different base station-user pairs sharing a same frequency band, which causes ubiquitous interference in the whole network. The most significant difference in a wireless cellular network is that the transmission is highly interference-limited. Basically for any receiver, the signals for the other receivers are interferences. The aggregated interference can greatly influence the secrecy performance of a wireless link. There are significantly different levels of interference that will be caused due to different path loss, shadowing, and fading, and all these effects depend heavily on the spatial locations of the terminals. Therefore, the network geometry and spatial distribution of interferers become the primary factor to impact the secrecy performance of a wireless transmission.

In this book, we will focus on the networks under the framework of stochastic geometry, which is used to model the random distributions of legitimate users/eavesdroppers and the random deployment of base stations/access points. In the first two chapters, we introduce the basic ideas of physical layer security and primary knowledge of stochastic geometry theory, especially several useful properties of Poisson point process. In Chap. 3, we introduce the physical layer security in a single-cell cellular under time division multiple access (TDMA) when the eavesdroppers are randomly located as a Poisson point process. Moreover, in Chap. 4, we elaborate the network-wide physical layer security in a multi-tier heterogeneous network, where all the locations of users, eavesdroppers and deployment of base stations are modeled as Poisson point processes. Chapter 5 includes the impact of the full-duplex transceivers on security performance of random ad hoc network, which could be considered as a special case of uplink transmissions in a random cellular network. Lastly, Chap. 6 concludes the book and discusses the possible future research directions. This book will present the readers a timely report of state-of-the-art techniques about physical layer security under the framework of stochastic geometry, and provide an explicit snapshot of this emerging topic.

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Contents

Acronyms

AES	Advanced encryption standard
AN	Artificial noise
AP	Access point
ARSP	Average received signal power
AWGN	Additive white Gaussian noise
BPP	Binomial point process
BS	Base station
CCDF	Complementary cumulative distribution function
CDF	Cumulate distribution function
CDI	Channel distribution information
CRN	Cognitive radio network
CSI	Channel state information
DMC	Discrete memoryless channel
DPTS	Dynamic parameter transmission scheme
FAP	Femto access point
FD	Full duplex
HCN	Heterogeneous cellular network
HCPP	Hard core point process
HD	Half duplex
ICSI	Instantaneous channel state information
MAC	Multiple access control
MIMO	Multiple-input multiple-output
MISO	Multiple-input single-output
MMSE	Minimum mean square error
MRC	Maximal ratio combining
PCP	Poisson cluster process
PDF	Probability density function
PGFL	Probability-generating functional
PP	Point process
PPP	Poisson point process

QoS	Quality of service
RSA	Rivest–Shamir–Adleman
SCSI	Statistical channel state information
SI	Self-interference
SIC	Successive interference cancellation
SIMO	Single-input multiple-output
SINR	Signal-to-interference-plus-noise ratio
SIR	Signal-to-interference ratio
SNR	Signal-to-noise ratio
SOP	Secrecy outage probability
SPTS	Static parameter transmission scheme
TDMA	Time division multiple access
UE	User equipment
ZF	Zero forcing

Notations

$\mathbb{C}^d$	d-dimensional field of complex numbers
$\mathbb{R}^d$	d-dimensional field of real numbers
$\mathbb{R}^+$	Positive field of real numbers
$\mathbb{N}$	Set of natural numbers
$H(X)$	Shannon entropy of discrete random variable X
$H(X\|Y)$	Conditional entropy of X given Y
$I(X;Y)$	Mutual information between random variables X and Y
$\mathbb{P}\{A\}$	Probability that event A takes place
$\mathbb{E}_X$	Expected value over random variable X
$\mathbb{I}(A)$	Indicator function, $\mathbb{I}(A) = 1$ when A is true; otherwise, $\mathbb{I}(A) = 0$
$\|\mathscr{W}\|$	Cardinality of set $\mathscr{W}$
$\log_n(\cdot)$	Base-n logarithm
$\ln(\cdot)$	Natural logarithm
$[x]^+$	Positive part of x, that is $[x]^+ = \max(x, 0)$
$(\cdot)^{-1}$	Inverse
$(\cdot)^\dagger$	Conjugate
$(\cdot)^{\mathrm{T}}$	Transpose
$(\cdot)^{\mathrm{H}}$	Hermitian transpose
$\|\cdot\|$	Absolute value
$\\|\cdot\\|$	Euclidean norm
$CN(\mu, \sigma^2)$	Complex Gaussian distribution with mean μ and variance σ^2
$\mathrm{Exp}(\lambda)$	Exponential distribution with rate parameter λ
$\Gamma(\alpha, \beta)$	Gamma distribution with shape parameter α and scale parameter β
$f_X(\cdot)$	Probability density function of random variable X
$F_X(\cdot)$	Cumulate distribution function of X
$\bar{F}_X(\cdot)$	Complementary cumulative distribution function of X
$F_X^{-1}(\cdot)$	Inverse function of $F_X(\cdot)$
$\mathscr{B}(o, r)$	A disk with center o and radius r
$\frac{d^m f(\cdot)}{dx^m}$	m-order derivative of function $f(\cdot)$ on variable x

$\frac{\partial f(\cdot)}{\partial x}$	Partial derivative of function $f(\cdot)$ on variable x
$f^{(m)}(x)$	m-order derivative of function $f(x)$ on variable x
$\mathscr{L}_I(s)$	Laplace transform of variable I at s, that is, $\mathscr{L}_I(s) = \mathbb{E}_I[e^{-sI}]$
$\boldsymbol{h}$	Column vector
$\boldsymbol{H}$	Matrix
$Tr(\boldsymbol{H})$	Trace of matrix $\boldsymbol{H}$
$\det(\boldsymbol{H})$	Determinant of matrix $\boldsymbol{H}$
$C_{\alpha,N}$	$C_{\alpha,N} \triangleq \frac{\pi\Gamma(N-1+2/\alpha)\Gamma(1-2/\alpha)}{\Gamma(N-1)}$, $\forall N \geq 2$
$\mathrm{Ei}(-x)$	$\mathrm{Ei}(-x) \triangleq -\int_x^{\infty} \frac{e^{-t}}{t} dt$, $\forall x > 0$