

# STOCHASTIC GEOMETRY

FOR WIRELESS NETWORKS

MARTIN HAENGGI

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# Stochastic Geometry For Wireless Networks

**Martin Haenggi**



## **Stochastic Geometry For Wireless Networks:**

**Stochastic Geometry for Wireless Networks** Martin Haenggi, 2013 Analyse wireless network performance and improve design choices for future architectures and protocols with this rigorous introduction to stochastic geometry

*Stochastic Geometry and Wireless Networks* François Baccelli, 2009      **Stochastic Geometry and Wireless Networks** François Baccelli, Bartłomiej Błaszczyszyn, 2010 This volume bears on wireless network modeling and performance analysis The aim is to show how stochastic geometry can be used in a more or less systematic way to analyze the phenomena that arise in this context It first focuses on medium access control mechanisms used in ad hoc networks and in cellular networks It then discusses the use of stochastic geometry for the quantitative analysis of routing algorithms in mobile ad hoc networks The appendix also contains a concise summary of wireless communication principles and of the network architectures considered in the two volumes

**Stochastic Geometry for Wireless Networks** Martin Haenggi, 2013 Analyse wireless network performance and improve design choices for future architectures and protocols with this rigorous introduction to stochastic geometry      **Stochastic Geometry and Wireless Networks: Applications** François Baccelli, Bartłomiej Błaszczyszyn, 2010-02 This volume bears on wireless network modeling and performance analysis The aim is to show how stochastic geometry can be used in a more or less systematic way to analyze the phenomena that arise in this context It first focuses on medium access control mechanisms used in ad hoc networks and in cellular networks It then discusses the use of stochastic geometry for the quantitative analysis of routing algorithms in mobile ad hoc networks The appendix also contains a concise summary of wireless communication principles and of the network architectures considered in the two volumes

Stochastic Geometry Analysis of Cellular Networks Bartłomiej Błaszczyszyn, Martin Haenggi, Paul Keeler, Sayandev Mukherjee, 2018-04-19 Achieve faster and more efficient network design and optimization with this comprehensive guide Some of the most prominent researchers in the field explain the very latest analytic techniques and results from stochastic geometry for modelling the signal to interference plus noise ratio SINR distribution in heterogeneous cellular networks This book will help readers to understand the effects of combining different system deployment parameters on key performance indicators such as coverage and capacity enabling the efficient allocation of simulation resources In addition to covering results for network models based on the Poisson point process this book presents recent results for when non Poisson base station configurations appear Poisson due to random propagation effects such as fading and shadowing as well as non Poisson models for base station configurations with a focus on determinantal point processes and tractable approximation methods Theoretical results are illustrated with practical Long Term Evolution LTE applications and compared with real world deployment results      **Stochastic Geometry Analysis of Multi-Antenna Wireless Networks** Xianghao Yu, Chang Li, Jun Zhang, Khaled B. Letaief, 2019-03-27 This book presents a unified framework for the tractable analysis of large scale multi antenna wireless networks using stochastic geometry This mathematical analysis is essential for assessing and

understanding the performance of complicated multi antenna networks which are one of the foundations of 5G and beyond networks to meet the ever increasing demands for network capacity Describing the salient properties of the framework which makes the analysis of multi antenna networks comparable to that of their single antenna counterparts the book discusses effective design approaches that do not require complex system level simulations It also includes various application examples with different multi antenna network models to illustrate the framework s effectiveness

**An Introduction to Cellular Network Analysis Using Stochastic Geometry** Jeffrey G. Andrews, Abhishek K. Gupta, Ahmad Alammouri, Harpreet S. Dhillon, 2023-06-30 This book provides an accessible yet rigorous first reference for readers interested in learning how to model and analyze cellular network performance using stochastic geometry In addition to the canonical downlink and uplink settings analyses of heterogeneous cellular networks and dense cellular networks are also included For each of these settings the focus is on the calculation of coverage probability which gives the complementary cumulative distribution function ccdf of signal to interference and noise ratio SINR and is the complement of the outage probability Using this other key performance metrics such as the area spectral efficiency are also derived These metrics are especially useful in understanding the effect of densification on network performance In order to make this a truly self contained reference all the required background material from stochastic geometry is introduced in a coherent and digestible manner This Book Provides an approachable introduction to the analysis of cellular networks and illuminates key system dependencies Features an approach based on stochastic geometry as applied to cellular networks including both downlink and uplink Focuses on the statistical distribution of signal to interference and noise ratio SINR and related metrics

*Modeling, Analysis, and Optimization of Random Wireless Networks* Hesham Mahmoud Medhat Mahmoud Elsayy, 2014

**Wireless Stochastic Cellular Networks Stochastic Geometry for Modeling, Analysis and Design of Future Wireless Networks** Jing Guo, 2016 This thesis focuses on the modeling analysis and design of future wireless networks with smart devices i e devices with intelligence and ability to communicate with one another with without the control of base stations BSs Using stochastic geometry we develop realistic yet tractable frameworks to model and analyze the performance of such networks while incorporating the intelligence features of smart devices In the first half of the thesis we develop stochastic geometry tools to study arbitrarily shaped network regions Current techniques in the literature assume the network regions to be infinite while practical network regions tend to be arbitrary Two well known networks are considered where devices have the ability to i communicate with others without the control of BSs i e ad hoc networks and ii opportunistically access spectrum i e cognitive networks First we propose a general algorithm to derive the distribution of the distance between the reference node and a random node inside an arbitrarily shaped ad hoc network region which helps to compute the outage probability We then study the impact of boundary effects and show that the outage probability in infinite regions may not be a meaningful bound for arbitrarily shaped regions By extending the developed techniques we further analyze the

performance of underlay cognitive networks where different secondary users SUs activity protocols are employed to limit the interference at a primary user Leveraging the information exchange among SUs we propose a cooperation based protocol We show that in the short term sensing scenario this protocol improves the network s performance compared to the existing threshold based protocol In the second half of the thesis we study two recently emerged networks where devices have the ability to i communicate directly with nearby devices under the control of BSs i e device to device D2D communication and ii harvest radio frequency energy i e energy harvesting networks We first analyze the intra cell interference in a finite cellular region underlaid with D2D communication by incorporating a mode selection scheme to reduce the interference We derive the outage probability at the BS and a D2D receiver and propose a spectrum reuse ratio metric to assess the overall D2D communication performance We demonstrate that without impairing the performance at the BS if the path loss exponent on cellular link is slightly lower than that on D2D link the spectrum reuse ratio can have negligible decrease while the average number of successful D2D transmissions increases with the increasing D2D node density This indicates that an increasing level of D2D communication is beneficial in future networks Then we study an ad hoc network with simultaneous wireless information and power transfer in an infinite region where transmitters are wirelessly charged by power beacons We formulate the total outage probability in terms of the power and channel outage probabilities The former incorporates a power activation threshold at transmitters which is a key practical factor that has been largely ignored in previous work We show that although increasing power beacon s density or transmit power is not always beneficial for channel outage probability it improves the overall network performance

### **Wireless Algorithms, Systems, and Applications**

Liran Ma, Abdallah Khreishah, Yan Zhang, Mingyuan Yan, 2017-06-09 This book constitutes the proceedings of the 12th International Conference on Wireless Algorithms Systems and Applications WASA 2017 held in Guilin China in June 2017 The 70 full papers and 9 short papers presented in this book were carefully reviewed and selected from 238 submissions The papers cover various topics such as cognitive radio networks wireless sensor networks cyber physical systems distributed and localized algorithm design and analysis information and coding theory for wireless networks localization mobile cloud computing topology control and coverage security and privacy underwater and underground networks vehicular networks internet of things information processing and data management programmable service interfaces energy efficient algorithms system and protocol design operating system and middle ware support and experimental test beds models and case studies

*On Large Cooperative Wireless Network Modeling Through a Stochastic Geometry Approach* Andres Oscar Altieri, 2014 The main goal of this work is to study cooperative aspects of large wireless networks from the perspective of stochastic geometry This allows the consideration of important effects such as the random spatial distribution of nodes as well as the effects of interference and interference correlation at receivers which are not possible when a single link is considered in isolation First some aspects of the performance of the relay channel in the context of a large wireless network are considered

Mainly the performance in terms of outage probability OP of a single full duplex relay channel utilizing decode and forward DF or compress and forward when the interference is generated by uniform spatial deployment of nodes modeled as a Poisson point process The OP performance of these two protocols is compared with a point to point transmission and with a half duplex DF protocol Afterwards the case in which more than one transmitter in the network may use a relay is considered The effects of cooperation versus interference are studied when the users use either full duplex DF or point to point transmissions In a second phase this work explores the advantages that could be obtained through out of band device to device D2D video file exchanges in cellular networks These advantages are measured in terms of the fraction of requests that can be served in a time block through D2D thus avoiding a downlink file transfer from the base station For this a stochastic geometry framework is introduced in which the user file caching policy user pairing strategy and link quality and scheduling issues are considered

*Large-scale Wireless Networks* Junghoon Lee, 2014 Recently the location of the nodes in wireless networks has been modeled as point processes In this dissertation various scenarios of wireless communications in large scale networks modeled as point processes are considered The first part of the dissertation considers signal reception and detection problems with symmetric alpha stable noise which is from an interfering network modeled as a Poisson point process For the signal reception problem the performance of space time coding STC over fading channels with alpha stable noise is studied We derive pairwise error probability PEP of orthogonal STCs For general STCs we propose a maximum likelihood ML receiver and its approximation The resulting asymptotically optimal receiver AOR does not depend on noise parameters and is computationally simple and close to the ML performance Then signal detection in coexisting wireless sensor networks WSNs is considered We define a binary hypothesis testing problem for the signal detection in coexisting WSNs For the problem we introduce the ML detector and simpler alternatives The proposed mixed fractional lower order moment FLOM detector is computationally simple and close to the ML performance Stochastic orders are binary relations defined on probability The second part of the dissertation introduces stochastic ordering of interferences in large scale networks modeled as point processes Since closed form results for the interference distributions for such networks are only available in limited cases it is of interest to compare network interferences using stochastic In this dissertation conditions on the fading distribution and path loss model are given to establish stochastic ordering between interferences Moreover Laplace functional LF ordering is defined between point processes and applied for comparing interference Then the LF orderings of general classes of point processes are introduced It is also shown that the LF ordering is preserved when independent operations such as marking thinning random translation and superposition are applied The LF ordering of point processes is a useful tool for comparing spatial deployments of wireless networks and can be used to establish comparisons of several performance metrics such as coverage probability achievable rate and resource allocation even when closed form expressions for such metrics are unavailable

**Physical Layer Security in Random Cellular Networks** Hui-Ming

Wang,Tong-Xing Zheng,2016-10-04 This book investigates key security issues in connection with the physical layer for random wireless cellular networks It first introduces readers to the fundamentals of information theoretic security in the physical layer By examining recently introduced security techniques for wireless point to point communications the book proposes new solutions to physical layer security based on stochastic geometric frameworks for random cellular networks It subsequently elaborates on physical layer security in multi tier heterogeneous networks With the new modeled settings the authors also verify the security performance with the impact of the full duplex transceivers The specific model design presented here offers a valuable point of reference for readers in related areas In addition the book highlights promising topics and proposes potential future research directions      *Advanced Wireless Networks* Savo G. Glisic,2016-08-08 The third edition of this popular reference covers enabling technologies for building up 5G wireless networks Due to extensive research and complexity of the incoming solutions for the next generation of wireless networks it is anticipated that the industry will select a subset of these results and leave some advanced technologies to be implemented later This new edition presents a carefully chosen combination of the candidate network architectures and the required tools for their analysis Due to the complexity of the technology the discussion on 5G will be extensive and it will be difficult to reach consensus on the new global standard The discussion will have to include the vendors operators regulators as well as the research and academic community in the field Having a comprehensive book will help many participants to join actively the discussion and make meaningful contribution to shaping the new standard      Wireless Communications and Networking for Unmanned Aerial Vehicles Walid Saad,Mehdi Bennis,Mohammad Mozaffari,Xingqin Lin,2020-04-02 The past few years witnessed a major revolution in the area of unmanned aerial vehicles UAVs commonly known as drones due to significant technological advances across various drone related fields ranging from embedded systems to autonomy control security and communications These unprecedented recent advances in UAV technology have made it possible to widely deploy drones across a plethora of application domains ranging from delivery of goods to surveillance environmental monitoring track control remote sensing and search and rescue In fact recent reports from the Federal Aviation Administration FAA anticipate that sales of UAVs may exceed 7 million in 2020 and many industries are currently investing in innovative drone centric applications and research To enable all such applications it is imperative to address a plethora of research challenges pertaining to drone systems ranging from navigation to autonomy control sensing navigation and communications In particular the deployment of UAVs in tomorrow s smart cities is largely contingent upon equipping them with effective means for communications and networking To this end in this book we provide a comprehensive treatment of the wireless communications and networking research challenges and opportunities associated with UAV technology This treatment begins in this chapter which provides an introduction to UAV technology and an in depth discussion on the wireless communication and networking challenges associated with the introduction of UAVs      Interference in Large Wireless

Networks Martin Haenggi, Radha Krishna Ganti, 2009 Interference is the main performance limiting factor of large wireless communication systems To analyze and design these networks it is thus imperative that the interference is statistically characterized or bounded in the presence of various sources of uncertainty including the users positions their patterns of activity and the channel fading states Interference in Large Wireless Networks addresses this problem using basic probability and tools from stochastic geometry Starting with regular networks and the popular Poisson model it discusses increasingly more general networks In addition to the interference itself it also derives explicit expressions for outage probabilities which are indispensable for the optimization of higher level metrics such as the transport capacity or end to end delay Interference in Large Wireless Networks includes an appendix that reviews the underlying mathematical tools which makes it self contained and suitable for graduate students researchers and wireless engineers alike Wireless Algorithms, Systems, and Applications Lei Wang, Michael Segal, Jenhui Chen, Tie Qiu, 2022-11-17 The three volume set constitutes the proceedings of the 17th International Conference on Wireless Algorithms Systems and Applications WASA 2022 which was held during October 28 30 2022 The conference took place in Dalian China The 95 full and 62 short papers presented in these proceedings were carefully reviewed and selected from 265 submissions The contributions in algorithms systems and applications of internet of things information processing and data management radar and sonar networks **Modeling and Analyzing Wireless Networks Using Stochastic Geometry** Junse Lee, 2018 Over the past decade stochastic geometric models and most notably the planar Poisson point process PPP model have become popular for the analysis of spectral efficiency in wireless networks in both the D2D and the cellular contexts 1 By modeling base station BS and user locations as spatial point processes stochastic geometry has recently been recognized as a tractable and efficient analytical tool to quantify key performance metrics This tool provides a natural way of defining and computing macroscopic properties of multiuser information theory These properties are obtained by averaging over all node patterns found in a large random network of the Euclidean plane For example some key performance metrics such as signal to interference and noise ratio and data rate depend on the network geometric configurations This tool has thus been widely adopted for analyzing the network performance and broadening network design This thesis proposes new models to represent several new scenarios Three main scenarios are considered 3 D inbuilding networks MIMO adhoc networks and multihop communication under mmWave networks To do so mathematical tools such as Poisson point processes Poisson line processes Boolean models and Poisson bipolar models are used Each model is 1 generative in that it has a clear physical interpretation 2 leads to explicit analytical representations of important wireless performance metrics and 3 highly parametric with parameters expressing the geometric characteristic of the elements of networks Physical interpretations from these models are quite different from previous results The core of this thesis is focused on the effects of correlated shadowing Shadowing is the effect that the received signal power fluctuates due to objects obstructing the propagation path By introducing an independent shadowing



term over links it is possible to model the effect of shadow fading Most previous papers analyzing urban networks assume that shadowing fields are independent over links With this assumption it is possible to derive simple closed form expressions of important network performance metrics However this assumption cannot capture that shadowing fields are spatially correlated This thesis goes beyond the independent shadowing approximation and analyzes the effects of correlated shadowing on various performance metrics      Performance Analysis of Large Wireless Networks Mudasar Bacha,2018

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