Journal of Trends in Computer Science and Smart technology (TCSST) (2021)
Vol.03/ No. 03
Pages: 161-174
https://www.irojournals.com/tcsst/
DOI: https://doi.org/10.36548/jtcsst.2021.3.001

Stochastic Geometry and Performance Analysis of Large Scale Wireless Networks

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Abstract

Stochastic Geometry has attained massive growth in modelling and analysing of wireless network. This suits well for analysing the performance of large scale wireless network with random topologies. Analytical framework is established to evaluate the performance of the network. Here we have created a mathematical model for uplink analysis and the gain of uplink and downlink is obtained. Then ad-hoc network architecture is designed and the performance of the network is compared with the traditional method. Finally, a new scheduling algorithm is developed for cellular network and the gain parameter is quantified with the help of Stochastic Geometry tool. The accuracy is acquired from extensive Monte Carlo simulator.

Keywords: Stochastic Geometry, Performance Analysis, Ad-hoc Network, Gain, Accuracy

1. Introduction

The Transmit power and available spectrum are the two main parameters in designing a wireless communication channel to avoid path loss. When an electromagnetic signal passes through a wireless medium, the signal gets attenuated naturally [1]. This is a fundamental behaviour of electromagnetic signal. This leads to path loss and for data recovery the transmitters has to transmit the signal with high power to overcome path loss [2]. When a transmitted signal exceeds the transmission range the receiver cannot be able to differentiate the original signal and the thermal noise [3-4]. The SNR of the transmitted signal is kept greater

ISSN: 2582-4104
Submitted: 07.07.2021
Revised: 25.08.2021
Accepted: 07.09.2021
Published: 20.09.2021

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than the threshold value. Thus high transmit power avoids path loss and data is recovered from an attenuated signal [5]. The available spectrum is divided into multiple frequency channels [6]. The relationship of SNR and channel are given by Shannon's formula,

$$C=WLog_2(1+SNR) \quad \text{-----(1)}$$

Stochastic Geometry is used to study the average performance of the network with distributed nodes and spatial realization [7, 8]. Network modelling requires point process techniques such as

a) Binomial point process (BPP) [9]

b) Poisson point process (PPP) [10]

c) Hard core point process (HCPP) [11]

d) Poisson cluster point process (PCPP) [12]

We have used Poisson point process (PPP) for modelling the network. It has two areas namely bounded area and disjoints area. The number of point in bounder area follows Poisson distribution and the number of points in disjoint area is independent. The independent property makes PPP simple and reliable [13]. In this paper we have used Stochastic Geometry for network modelling and analysis network performance with various topologies. There are five main topologies and statistical measures of PPP and they are

a) Campbell's Theorem

b) Probability Generation Function (PGFL)

c) Slivnyak's Theorem

d) Independent Thinning

e) Super Position

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f) Displacement

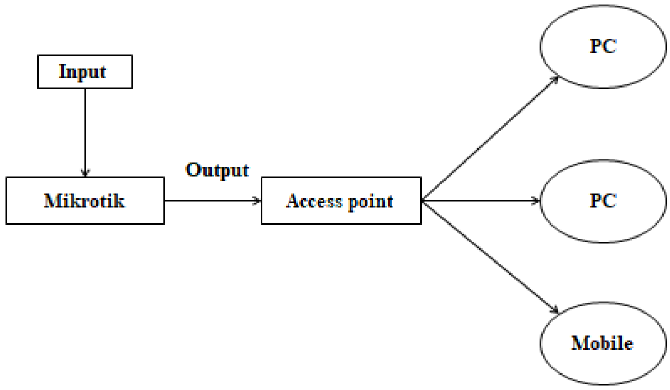

Figure 1. Block Diagram of Large-scale Wireless network

2. Related Work

The performance of cellular network is improved by decoupling downlink and uplink association. The network is limited with single input and single output (SISO) and the gain parameter is analysed by a heterogeneous network [14]. The heterogeneous network is further divided into two categories namely, multiple antenna base station and Single antenna user elements The SIR coverage and rate coverage probability at base station is determined by Maximal ratio combining (MCR) linear receiver using Stochastic Geometry tool [15]. In future, high data rate will be the most demanding factor of wireless network capacity. This is achieved by replacing single tier homogenous network by multi-tier heterogeneous network. Low cost and low power cells are densely implanted to meet the requirement. The fundamental functions of Single tier homogenous network and multi-tier heterogeneous differs [16]. So the basic functionalities of multi-tier heterogeneous network are altered to meet the demand on high data rate. Currently single tier homogenous network is used to perform downlink operations. As the technology is updating every day, the performance of the network has to be improved [17]. To

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achieve that, we have to consider uplink operation. While performing uplink operations separately many errors occur. So to overcome that, we decouple downlink and uplink operations on 5g network. When these two tier network undergoes simulation study, it shows uplink are oriented with low path loss and downlink are oriented with receiver power. This further classifies the users into three groups namely, Femto base station (FBS) with both downlink and uplink, macro base station (MBS) with both downlink and uplink and macro base station (MBS) in downlink and femto base station (FBS) in uplink. This reduces the interference and improves channel performance. The single tier uplink model is obtained from fractional power control (FPC) [18]. Transit power, density and cot-off threshold are the performance metric of multi-tier uplink model. System rate, gain, spectrum efficiency and energy efficiency are derived from DUDe method. Thus the uplink is biased with DUDe and the multi-antenna base station is used to improve the system performance [19].

3. Proposed Work

The motive of this paper is to design models and analysis the large scale wireless network with different topology using stochastic geometry tool. This is further extended to three scenarios namely,

a) Decoupling of uplink and downlink

b) Backscatter communication for IOT

c) Noise

3.1 Decoupling of Uplink and Downlink

The proposed method is used to improve the coverage and rate performance of the cellular network in terms of gain parameter. It follows SISO method and for optimal results we analysis two-tier heterogeneous network. The Two-tier network comprises of multi-antenna base station and single antenna user elements which are considered and decoupling operations

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are performed. This is applied to examine the gain parameter of the system. The base station probability of both the signal to interference ratio (SIR) [20] and the rate coverage are derived from MRC linear receiver [21] in the form of mathematical expression. Then the relationship between the beam forming of two tier network and decoupling of uplink and downlink are examined. Finally small base station is offloaded with UE and the optimal performance is measured.

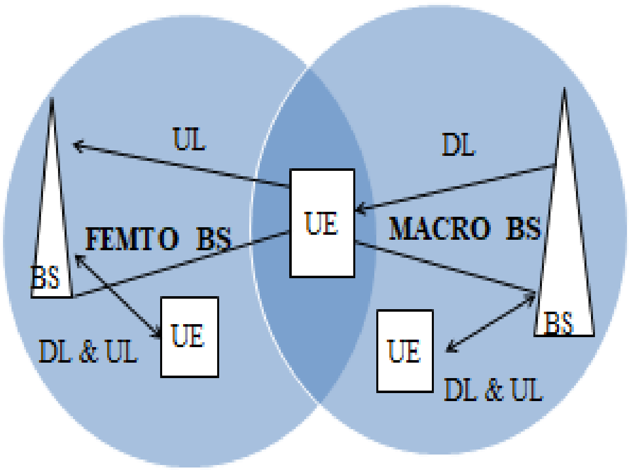

Figure 2. System Model

3.1.1 SIR Coverage Probability

The probability of instantaneous uplink SIR of random base station is greater than the predefined threshold. The uplink SIR coverage probability C is given as,

$$C = C_F A_F + C_M A_M \qquad \text{-------(2)}$$

Where, C stands for coverage, A stands for association, M stands for macro-tier and F stands for femto respectively. It is applicable in ad-hoc network. Recursive method used for analysis but it fails to reduce complex computations. It is noted that it is density invariant.

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3.1.2 Rate Coverage Probability

The rate coverage probability is the probability of the random user achieving target rate or average fraction of achieving target rate. It is given by,

$$R = A_F R_F + A_M R_M \qquad \text{-------(3)}$$

Where R stands for rate coverage probability, A stands for association, M stands for macro-tier and F stands for femto respectively. The SIR and load depends on association area and this remains complex.

3.2 Backscatter Communication for IOT

Combination of power transfer and back scatter communication produces a unique ad-hoc network. This network architecture comprises of passive backscatter nodes [22] and power beacons [23]. The operation of power beacon is to transit continuous sin wave in isotropic direction and the passive backscatter nodes will partially reflects the transmitted signal and stores the remaining energy. This method is called as back scattering modulation [24]. Stochastic geometry is used to derive the coverage probability and network capacity. This method is compared with the traditional method and proves that the performance of new method is improved.

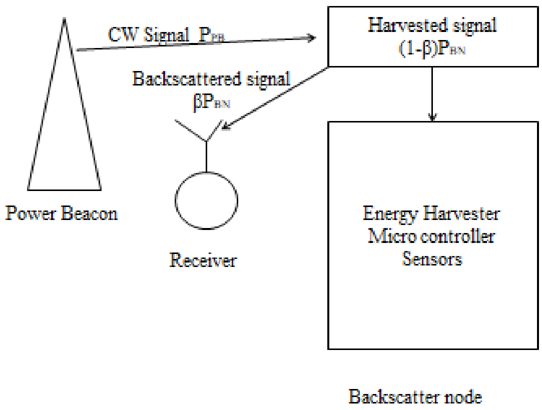

Figure 3. Block Diagram of Backscattering Node

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3.2.1 Performance Metric

The performance of the wireless network is evaluated by two techniques in backscattering method. They are

a) Coverage probability [24]

b) Transmission capacity [25]

3.2.1.1 Coverage Probability

The probability when receiver R_O successfully decodes the signal BN_O with a threshold ϴ, then it is known as Coverage probability. It is denoted by C and given as,

$$C=\mathbb{P}\ [\gamma Ro \geq \Theta] \qquad \text{------(4)}$$

It has two scenarios, initially the nearest NPB will be the harvested energy of BN and in next scenario all PB will be the harvested energy of BN. This has complex calculation in both the cases so we make some assumption in first case and some approximation in second case to reduce the complexity.

3.2.1.2 Transmission Capacity

It is defined as successful transmission of BN_s with its corresponding receiver. It is denoted as T and given by,

$$T= \lambda_{BN}C \qquad \text{------(5)}$$

3.3 Noise

When the interference is optimally low it is considered as TIN (Treats Interference as Noise). For device-to-device communication we have used scheduling algorithm. Each base station selects its user element randomly and optimal TIN conditions are examined within its coverage area. If it fails to meet the condition the base station goes to off state. The interference

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of the cellular network is considered as Noise. Scheduling algorithm is used to predict the interference and convert it as noise. Further, the Scheduling algorithm derives coverage probability of signal to interference and noise ratio (SINR) and spectral efficiency in the form of mathematical expressions which are easy to compute. To obtain SINR coverage probability, asymptotic analysis is carried out using simple optimization algorithm. The resultant parameter of optimal system provided gain in terms of SINR coverage probability. The SINR coverage probability and spectral efficiency are quantified by comparing new scheduling algorithm and classical scheduling algorithm. The performance of the TIN are analysed using stochastic geometry tool. When high level interference is predicted in base station and user element, it turns off the base station and reduces the interference in the cellular network. The relation between rationale and signal strength is analysed with respect to tolerable interference.

4. Result and Discussion

In Decoupling of uplink and downlink method we have used stochastic geometry tool to improve the performance of UL of a two-tier heterogeneous network by decoupling DL and UL. It shows that multi-antenna is used in base station and single antenna is used in user element. Then in Backscatter communication for IOT method dimensional reduction technique is used to analyse the system performance. The coverage area and capacity of the network is obtained in an easily computable form. Finally in noise section the interface is converted into noise and the performance is improved.

The numerical illustration is given to express the performance of the system. This is carried out without making any approximations or assumptions. Analytical framework is designed for simulation. In figure 4 it is observed that probability of TIN is decreased with increase in λb value with respect to μ. This is due to the interference. The figure 5 shows that probability of TIN is increased when α value is increased. This shows the path-loss effect and figure 6 shows that μ value is increased when λb value increases. This gives the probability of SIR coverage.

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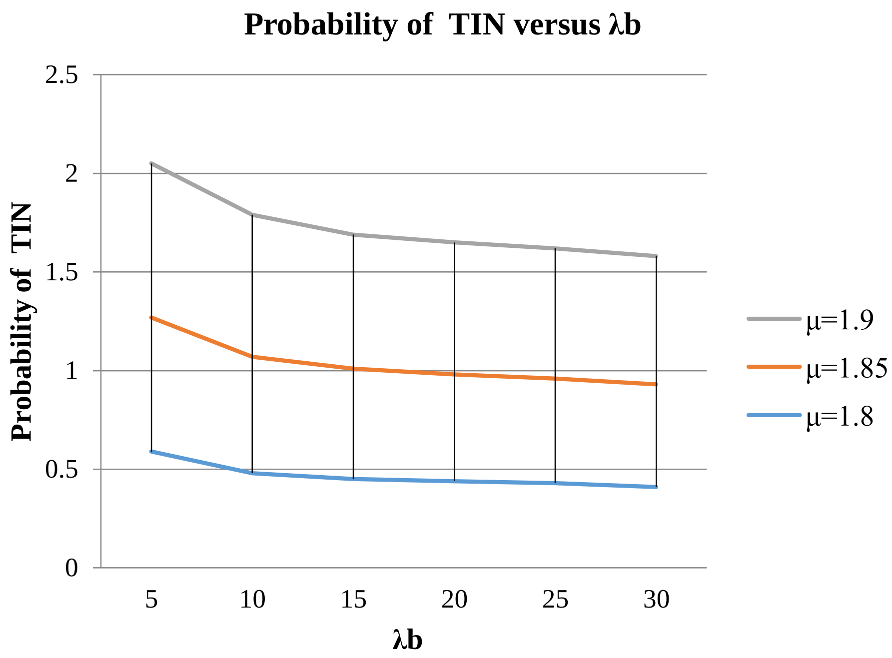

Figure 4. Graphical representation of Probability of TIN versus λb

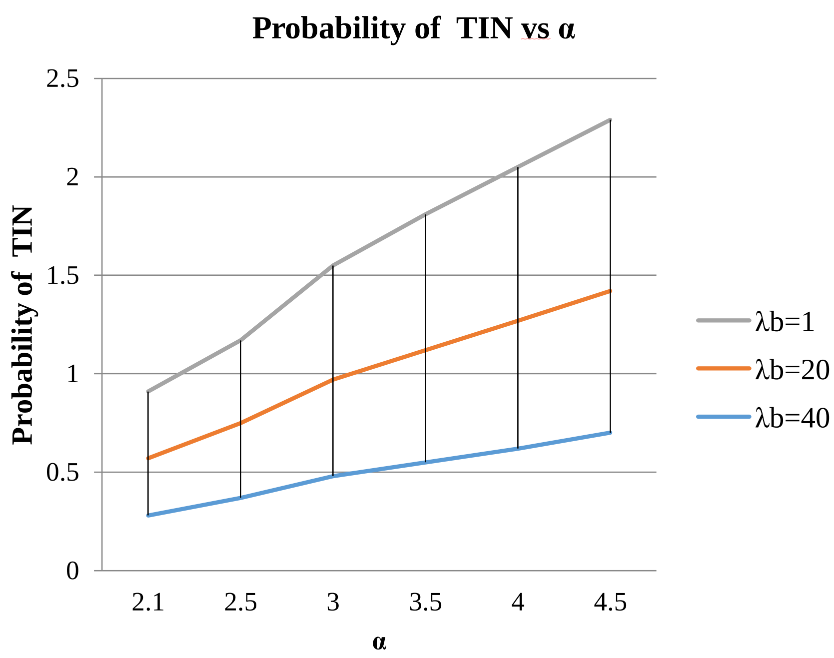

Figure 5. Graphical representation of Probability of TIN versus α

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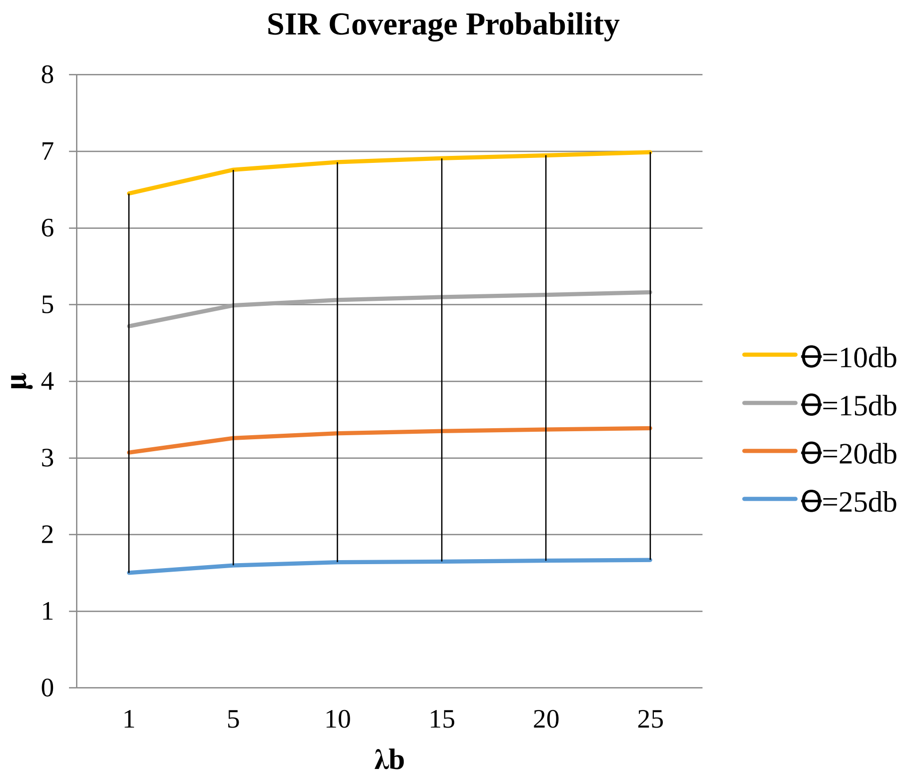

Figure 6. Graphical representation of SIR coverage probability

5. Conclusion

In this paper we have used stochastic geometry tool to design, model and analyse the wireless large scale network with different topologies. PPP is utilized to improve the performance by making easy computations. It is used for modelling spatial models of a network. The correlation of typical node and interfacing node is achieved by decoupling downlink and uplink layer and transferring interference to noise. This results in optimal performance of wireless large scale network. General framework is formed to design ad-hoc network. Scheduling algorithm is used for optimization of cellular network performance. The performance metrics such as SIR, coverage rate, coverage probability, transmission capacity and TIN proves that the stochastic geometry tool has performed successfully.

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Author's biography

Joy Iong-Zong Chen is currently a full professor in the Department of Communication Engineering Dayeh University at Changhua Taiwan. Prior to joining Dayeh University, he worked at the Control Data Company (Taiwan) as a technical manager from Sep. 1985 toSep. 1996. His research interests include wireless communications, spread spectrum technical, OFDM systems, and wireless sensor networks. He has published a large number of SCI Journal papers on the issues addressed by the physical layer for wireless communication systems.

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Moreover, he also majors in developing some applications of the IOT (Internet of Thing) techniques and Dr. Joy I.-Z. Chen owned some patents authorized by the Taiwan Intellectual Property Office (TIPO).

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