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A Survey on Modeling and Coverage Analysis of Heterogeneous Network

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Abstract*: *The next generation networks have undergone thriving advances under the modification of existing cellular networks in order to support high data rates with optimal coverage. This survey is intended as an accessible in giving a keynote to how to model and analyze coverage using stochastic geometry in a heterogeneous cellular network. In order to study the coverage performance in downlink Heterogeneous network (HetNet), Poisson distribution of Base stations is made an assumption. In the first part of this paper, a review of the probabilistic model for deploying of cellular base stations is discussed. In the second part, downlink coverage probability analysis is made for several cell association schemes such as Maximum Signal to Interference plus Noise Ratio (SINR), a nearest base station (BS) association (NBA) and maximum received Power association (MRPA). In connection with the scenario, a toy example is given to deploy hetnet through various Poisson processes. The probabilistic analysis of estimating SINR values provides the network performance characteristics (Randomness, Tractability and accuracy) as functions of parameters. A clear understanding of this modeling approach by identifying a clear classification is presented. Furthermore, the strength and weakness of the given models and comparison of quality parameters are outlined.

Index Terms*: *Cell association schemes, Heterogeneous Networks, Poisson Process, Stochastic geometry.

I. INTRODUCTION

Heterogeneous networks are expansively deployed and upgraded to manage with the ceaseless growth of user - demand and network densification. Traditional cellular networks rely on the assumption of regular hexagonal for optimization and analysis. This has fashioned the importance for vigorous analysis to study the various mathematical models and reasonably accurate analysis of computing SINR statistics, coverage probability and average rate. Several mathematical models have been discussed to derive analytic techniques. A general model assumption is that the location of the base stations is the Poisson process in the plane [1]. A Heterogeneous cellular network would consist of coexisting tiers and user equipment (UEs), where each tier is illustrious by its characteristics such as transmitted power, density and rate. [2]. base stations (BSs) are surrounded by the UEs in the Poisson cluster process and the distance between UEs and BSs are modeled via Gaussian distribution [3]. In regular Hetnets, deployment cannot be directly applied due to the difference in BS to UE density, propagation conditions and in Diversity loss [4]. A mathematical model is developed using stochastic geometry for dealing with interference [5]-[9]. The performance analysis of practical networks, however, is more pessimistic due to the irregular site placements. The dynamic BS deployment operation and cell association were studied together based on energy-saving approach [10,11].

A. Contributions

In this paper, a Hetnet is considered in consisting of different types of BSs and it is referred as a tier, The various models of Poisson Point processes (PPP) and statistical properties of a stochastic geometry are studied in Section I, which covers all path loss-based cell association schemes in a HetNet. The majority of the campaigns reported in this paper are

- To investigate the most appropriate models in different regions of the current Hetnet.
- To analyze the cell association schemes to improve coverage performance
- To compare the system level simulation performance of hetnet by applying these models with specified parameters.

In this article, the focus is made on the literature survey on modeling and analysis of coverage probability of HetNet. An Overview and classification of Hetnet are presented in Figure 1. A detailed taxonomy on the overview classification of the point process is provided. The attractiveness and applicability of the different point processes (PPs) in modeling techniques are discussed in Section II. To assess the link effectiveness of cell association, Section III Provides more details on coverage analysis through various user association schemes such as Max SINR, NBA and MRPA. In section IV the SINR is derived at a reference user randomly placed in the network. If it's received SINR is higher than the pre-specified threshold then the user is said to be in coverage.

Also the downlink analysis will be based on Silvnyak's theorem representing receiver at origin and the BS with maximum average received power strength, the statistical parameters of this typical user are the same in the network. [12-14]. Section V outlines the comparison of quality parameters of both deterministic and stochastic models with conclusion.

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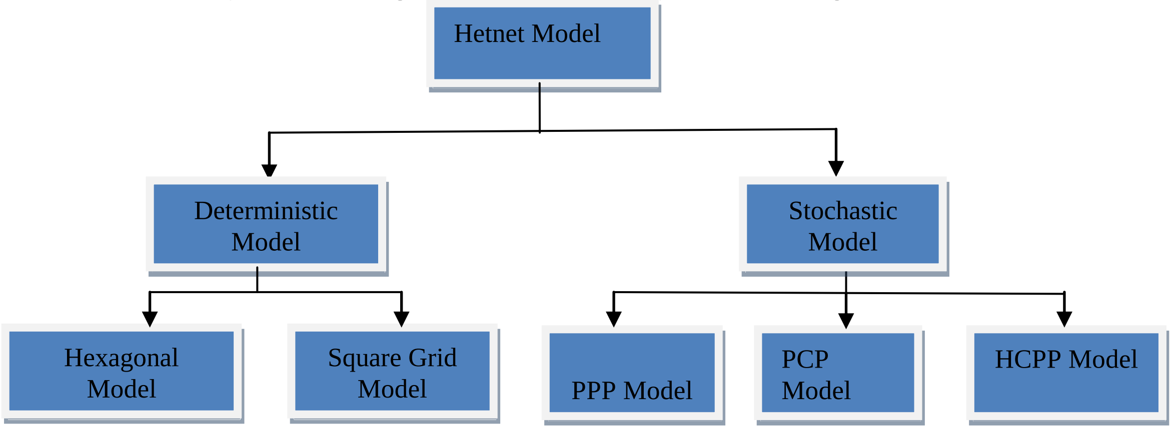

Figure.1 Overview and classification of Hetnet Models

II. STOCHASTIC GEOMETRY MODELS FOR HETEROGENEOUS NETWORK

A Heterogeneous Network as a K-tier cellular network where each tier constitutes the BSs of a specific group, such as macrocell and smallcells. The BSs across each tier may have different characteristics. This provides a tractable tool to analyze irregular placements of BS and users. The spatially distributed BSs are considered as a PPP Φ_k of density λ_k, transmit at power P_k, and have SINR value as maximum as 1.

A. Overview of Random Heterogeneous network models

Poisson point process (PPP) [16, 17] : A poisson point process $\Phi=\{x_1,x_2,x_3,\ldots..\} \subset \mathbb{R}^d$ is a PPP if and only if

(a) The number of points of point process Φ in a set $B \subset \mathbb{R}^d$, denoted by $\Phi(B)$, is a Poisson Random Variable with mean, $\Lambda(B)=\int_B \lambda(x)dx$ i.e.

$$P(\Phi((B)=k)=\frac{\Lambda(B)}{k!}e^{\Lambda(B)}, k=0,1,2,\ldots n \quad (1)$$

(b) The scattering property is defined as the total number of points is independent. If $\lambda(x)=\lambda$ density is a constant, then Φ is called homogeneous PPP.

The Poisson point process is more suitable in designing heterogeneous network with statistical parameters such as tractability and accuracy. In a multitier HetNet, the base stations are distributed spatially and modeled as independent PPP in each tier of Euclidian plane $\mathbb{R}^d$. The comparative results of the actual 4G network are shown in [15] and exemplify that the PPP model provides tight lower bounds than that of popular grid model for performance measures. The various medium access control (MAC) protocol spectrum sharing performance are analyzed for aggregate interference analysis through PPP based modeling in [16,17]

Binomial point process (BPP) [18]:

A binomial point process is a number of points in a compact set $\Phi_w^n=\{x_1,x_2,x_3,\ldots\ldots x_n\}$ when independent points are uniformly distributed over the same set and the result is a binomial point process of points. If the points in binomial random variable with parameters n are

$$P(\Phi_w^n((B)=k)=\sum\binom{n}{k}p^k(1-p)^{n-k} \quad (2)$$

$k=0,1,2,\ldots n$, In a wireless network, BPP is used to model the network of independently and uniformly distributed nodes in a specific area [19].

Hardcore point process (HCPP) [20]:

A Hardcore point process is a kind of repulsive point process in which a hardcore parameter $h \geq 0$ is set between any two points. Retention of point x of homogeneous parent PPP Φ_p is made by dependent thinning operation. Otherwise, the point x is deleted. The resultant HCPP Φ_h is thus given

$$\Phi_h=\{x \in \Phi_p; \|x-y\| \geq h, \forall_y \in \Phi_p\} \quad (3)$$

and its intensity is

$$\lambda_h=\lambda_p \exp(-\lambda_p v_d(b))$$

where $v_d(b)$ is the volume of b(x,h) [21,22]. This is used to model concurrent transmitter point as BS in the wireless network.

Poisson cluster process (PCP) [23]:

Randomly located points tend to form random clusters from a parent PPP Φ called PCP. The underlying point process is sometimes called the parent (point) process, and its points are centers of the cluster disks. The subsequent point process on all the disks is called daughter (point) process and it forms the clusters. A point process with repulsion occurs when points are prohibited to close to each other than a certain predefined distance. A point process with attraction occurs due to environmental conditions, which is also known as a clustering process. BSs are deployed in the dense areas of traffic demand; Cluster process can be more prompt to abstract such behavior. A special case of PCP is the Neyman-Scott process, which has been used as models in spatial statistics and telecommunications Further it is classified into Matern cluster process and Thomas cluster process.

B. Deployment Scenarios and Technical Challenges in 4G

Modeling of traditional cellular network have been simulated by grid-based model, yet real base station model deployments are very much different in BS placements and network planning but irregular and semi-random due to topological factors [24]. Hence a new modeling approach employing stochastic geometry had been adopted for multi-tier Hetnet. For the analysis of multi-tier HetNet, Meticulous yet simple models are required.

Due to unrealistic assumptions, a regular grid-based model leads either to intractable or inaccurate results [25, 26]. Moreover, the BSs are neither resemble nor vary as real deployments due to the variation in link capacities, Hence, traditional grid assumption is an idealized one but not tractable. [27]

Deployment of PPP & PCP Model

A point process can be interpreted as an indiscriminate measure or a random set. Figure 2 represents the line segments those locations that are equidistant from two points of the PPP, and their intersections are the ones that are equidistant from three points of the PPP. Here it is assumed that there are no points outside the $[0, 20]^2$ box. The union of the triangles is the convex hull of the point set.The independent PPP based BSs location fairly resembles practical deployment topologies.

A Matérn PCP is a kind of cluster point process, meaning that its randomly located points tend to form random clusters. Thomas PCP is a type of cluster point process, meaning that its randomly located points tend to form random clusters. The main and only difference between these two cluster point processes is how the points are randomly located in each cluster of a Thomas point process. Figure 3 and 4 represent the cluster point processes.

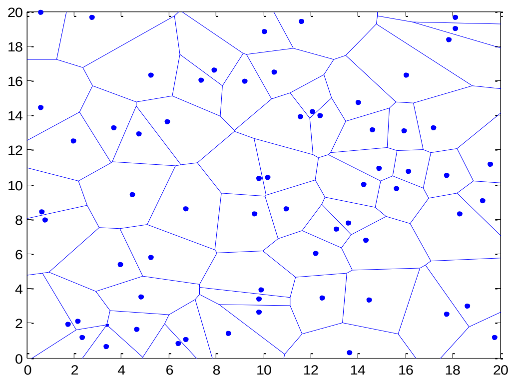

Figure.2 Realization of Hetnet modeled via PPP Model

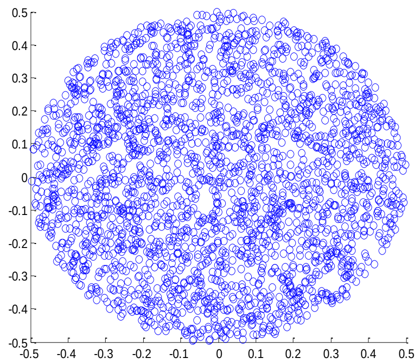

Figure. 3 Realization of Hetnet modeled via Matern PCP model

Each individual point is located according to two independent zero-mean normal variables with variance σ^2. Whereas each point of a Matérn point process is located uniformly in a disk. The randomness of the number of points and the facts that the point process is unordered and simple and thus it is better represented as a set.The points are forbidden to overlap in HCPP.

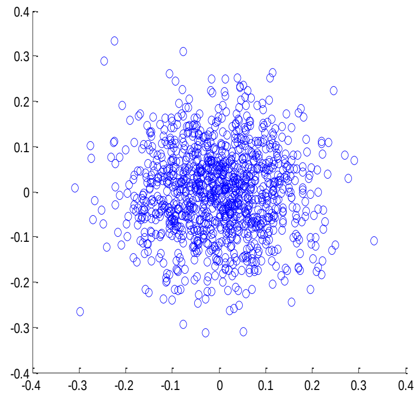

Figure. 4 Realization of Hetnet modeled via Thomas PCP model

The stochastic dependencies amongst the point processes depend on the randomness.

Table 1. Comparison between network models

Approach	Example	Pros	Cons
Grid based model	Deterministic Locations of BSs to the uniformly distributed mobile users	Cell deployment is easier Accurate Evaluation	Not scalable to multipath Actual coverage regions deviate from a regular grid
Wyner Model	Deterministic factor α can be tuned to capture users	Analytically Tractable	A Realistic cellular analysis is complex
PPP model	Independent and identically distributed User location by point process	Non-uniform cell size Tractable	BS might get very closer Complex
HCPP model	Voronoi tessellation where each cell is separated by a minimum distance of δ	minimum distance between the points Correlation of Positions	Much higher intensity of the PPP Repulsion of points

Table 1 shows the comparative analysis between the pros and cons of the networks models. The stochastic dependencies amongst the point processes depend on the key parameters such as randomness, tractability and accuracy.

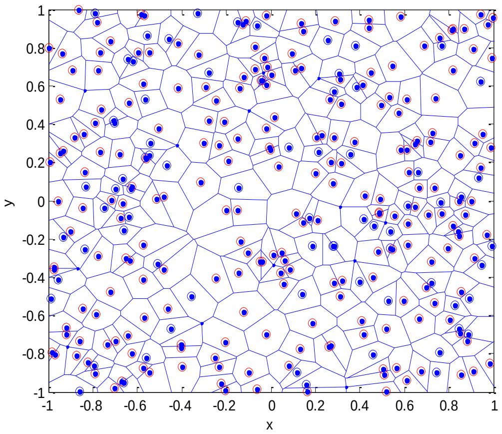

Figure. 5 Realization of Hetnet modeled via HCPP model

The use of repulsive cell planning for sharing regular spectrum in each tier is analyzed in HCPP model. Minimum separation is rendered between the nodes of same frequency band. The non-overlapping patterns are described in terms of radius δ/2. Based on the existing research efforts, the number of potential challenges is identified using table 1 and 2.

Table 2. Categorization based on the Network approach, Geometry and cell radius

Approach	Geometry	Cell Radius	Reference	Remarks
Grid based model	Regular Hexagonal or square grid model	$R = \frac{1}{\sqrt{3}}$	24 -27	Fixed and Deterministic metrics
Wyner Model	1D and 2D model	2R	29-33	Accurate mean based metrics
PPP model	Random Spatial Deployment	$R = \frac{1}{4\sqrt{\lambda}}$	1,2,5, 6,9, 12,28	R shrinks as λ increases
HCPP model	Random scattered and spatial model	$R = \frac{\delta}{2}$	7,35, 40,44	Non overlapping circle of radius

Table 2 shows the taxonomy of stochastic dependencies based on the network type, geometry and their cell radius. The advantage of the modeling approach and their statistical properties are analyzed in a given table 1 and 3. The key parameter affects the performance is cell radius. A benefit of this comparison is very important in choosing the radius. It can be chosen as a function of the density. Then the network becomes denser if cell radius shrinks. It is quite complex to select the radius for the heterogeneous case [34].

The important statistical properties of the PPP are listed in table 3.This statistical properties yields insights about the transformations of PPP.

Table 3. Statistical Properties of PPP

Property	Example	Equation
In dependent thinning	If points are assigned independently and the point process is obtained by removing some fraction of its points with thinning probability $P_o = 1 - Px$ is called the thinned point process with retention probability P.	$P_o = 1 - P_1$ $= \exp(-\lambda_B \pi r^2)$
Super position	The combined homogeneous PPPs are characterized by intensities λ_i, i = 1,2,…m to create new point process. The rate of the new process is the sum of the rates of the processes that were combined.	$\Phi = \sum_{ii=1}^{m} \lambda_i^1$
Displacement	A generalization of the Poisson distribution Process is defined if each point of a PPP is displaced by some random law, , the displaced points will also be PPP	$L_{\Phi_p}(f)$ $= E\sum_{i}^{\exp}(f(Y_i^1))$

III. Coverage Probability for K-Tier Heterogeneous Network

The coverage probability under a spatial point process is discussed in this section. In a cellular network the spatially distributed nodes are connected in two modes of coverage access. The users in each tier tend to be attached to any type of BSs in open access. Whereas in closed access the users in each tier tend to be attached to the BSs in the same tier. The focus is made on the coverage probability (CP) of Hetnet.

A. Coverage Analysis

We classify a representative set of coverage mechanism in Hetnet into three popular categories in each communication link. A user is said to be covered if the communication link is sufficiently good in receiving both signaling and traffic Here good means that (1) strong received signal from the BS (Maximum Received Signal power) (2) The received SINR exceeds threshold value.(β) (3) The nearest BS among all from user (Nearest Base station). [36]

Coverage Probability*

$$P_c(\lambda,\beta,P) = \frac{\alpha[\beta]^{\frac{-2}{\alpha}}}{2\pi \csc(2\pi\alpha^{-1})} \quad (4)$$

Where $P_c(\lambda,\beta,P)$ is coverage probability of hetnet, α is the link attenuation constant, β is the SINR threshold value, P is the transmit power.

* see the proof in [36]

Deployment Parameters

The choice of deployment parameters is the main requirement in designing a network. The deployment parameters that affect coverage are

- The number of tiers in hetnet (K)
- Number of BSs per unit area (density) in the tiers (λ)
- Transmit powers of the BSs in each tier (P)

Open Access

When the typical user can connect to the BS in any given tier is said to be open access coverage. The user can be tagged to any tier of the maximum received power.

Closed Access

When the typical user can only be associated to a particular tier is said to be closed access coverage. The probability of the tagged user in the specific tier is 1 and to another tier will be 0

Open access Vs Closed access

On analyzing the performance of these two approaches, open access coverage in networks is always have better performance than closed access coverage. The key challenge in this system model is complexity to express coverage probability in closed form, particularly when the locations of BSs are derived from a general point process. Evidently, we take different stochastic orders in system configurations [37 -39] It is important to note that the deployment of BSs affect the performance of coverage and capacity

Table 4. Typical Coverage Characteristics of small cell-based indoor Hetnet

Deployment	Coverage (ft^2)	Transmit Power (mW)	Capacity (users)
Residential	5000	20	8
Small/Medium Enterprises	7500	100	32
Large	10000	250	64

Table 4 addresses the typical coverage characteristics of small cell based indoor hetnet. Coverage depends on ways by improving existing macro cell networks, Network base station densification, and Indoor capacity. Three essential components determining localization performance are categorized into [40]

- Active BSs in the specific area
- The localization is relative to the user equipment
- The accuracy of the observed positions.

SINR based K-coverage probability

The review evaluated SINR coverage [41] to tackle the issue of predicting network coverage for SINR ≥ 1. Laplace transform is involved to express the distribution of the SINR. The total number of base stations N (T) can achieve SINR threshold level T is called as coverage, namely

$$N(T) = \sum_{x\in\Phi} 1[SINR(x) \geq T \quad (5)$$

K-coverage probability is the probability of the typical user being covered by at least k base stations [41].

$$P_c^T = P\{N(T) \geq K\} \quad (6)$$

Biased nearest Base station Association (NBA)

All users are denoted by set $U \in \mathbb{R}^d$ assumed to create an independent PPP of intensity. Let $U_{m,i}$ denote the set of the users connecting with BS $X_{m,i}$

$$U_{m,i} = X_{m,i} \ \arg\sup\left\{w \left\|X_{l,j} - U_n\right\|^{-\alpha}\right\} \quad (7)$$

The set of all BSs are expressed as $\Phi \overset{\Delta}{\equiv} U_{m=1}^{M}\Phi_m$ in the Heterogeneous network, this nearest base station association scheme makes the user to connect with the nearest base station. [42].

Maximum Received Power Association (MRPA)

The strongest average received power is the main constraint for a typical receiver to connect with the BSs in this scheme, which is a common approach in cellular systems. This association rule is generally not maximizing coverage in MIMO Hetnet and requires a biased association rule. [43 & 44]

$$C = (x_1x_2x_3........x_n) : X = \arg\max \sum_{i=1}^{n} \frac{P_v(x_i)}{\|x_i\|} \quad (8)$$

where C denotes the n BSs locations with strongest received power $P_v(x_i)\|x_i\|^{-\alpha}$

Effect of distance between the user and Associated Base Stations

The effect of users distance distribution between a mobile user and any base station (BS) is derived in [45]. The distance is Gamma distributed. In case of the nearest BS, Rayleigh distribution is abstracted to reduce the fading effect. The typical user catches the desired signal power of nearest BS $R_1 = \frac{1}{\sqrt{2\lambda\pi}}$, where λ is the BS density of network. It is assumed to have a uniform path loss exponent α. As established in [46], the density $\lambda \propto \frac{1}{\delta^2}$ inversely proportional to inter-site distance (δ). However, recent research requires advanced radio resource allocation, radio energy harvesting, load balancing and hand-over. The distance distribution is independent in each tier of a heterogeneous network.

Effect of additional tier on coverage probability

There are three promising schemes of providing additional tier to improve the coverage network are i) SISO(Single input Single output) ii) full SDMA(Space Domain Multiple Access), iii) SU-BF(Single User-Beam forming) [47].

An assumption is made for all tiers are operating in open access. Out of these three approaches, SU-BF performs good results in the highest coverage. Full SDMA is the least coverage among all. This is because SDMA has no additional gain but SU-BF case has an additional beamforming gain. SISO provides the proximity gain.

Effect of Antenna Heights in Dense Cellular Networks

The antenna height difference between BS and user equipment (UE) is very important in coverage, if the difference is zero, then the network. The performance of coverage will be continuously decreased toward zero even though the BS density is increased in ultra-dense hetnets.

Effect of RSRP and SINR in coverage

RSRP is Reference signal receive power provides the absolute knowledge to the user, the linear average power (in Watts) is a good indicator about the coverage boundary. It is all about the received strength of cells after experiencing path loss.

Table5. Quality Parameters of Coverage Analysis

Reference Signal Receive Power (dBm)		
Minimum Received Power	Maximum Received Power	Coverage
-70	-90	Good
-91	-110	Normal
-110	-130	Bad
Signal to Interference to Noise Ratio (dB)		
Minimum SINR	Maximum SINR	Coverage
16	30	Good
1	15	Normal
-10	0	Bad

A way to measure the quality of coverage is SINR. It is all about the energy of signal fades with distance. Path Loss varies with respect to green parameters such as Background noise and Interference due to concurrent transmission

Effect on Radius of cell

Consider R_1 and R_2 are the two consecutive nearest distances of Φ_b to the origin. The dominant interferer is calculated using $R = \frac{R_2}{R_1}$. It corresponds to the distance ratio between a typical UE and its serving BS. The user is located near the cell edge if the value of R is close to 1. Hence the received SIR from the cell edge user is expected to be very low. Constructively R should be greater than or equal to 1.

IV. Downlink Analysis Numerical Results

Future networks are distinctly characterized by the mobility of nodes and sub-networks and the need for ubiquitous connectivity. Mobile devices should be able to maintain unified connectivity across heterogeneous networks. A generally accepted user-oriented metric is

end-to-end throughput or "goodput". But this may not completely capture the utility of a network since some services may have a great impact for users but with lower communication bandwidth. A measure of coverage of a network is the amount of information that is being shared. A related issue is what types of metrics can be integrated with user control.

A toy example illustrative realization is shown in Figure. 6. A 20 km x20 km section of an urban area heterogeneous network is deployed through a PPP model. The mobile users are assumed to be located with density λ_u. Each UHF based macro base station is spatially located through PPP with density λ_m and their signals experienced by the user is Rayleigh fading along with the standard power-law path loss.

The user is associated with the strongest average power among the closest BS.

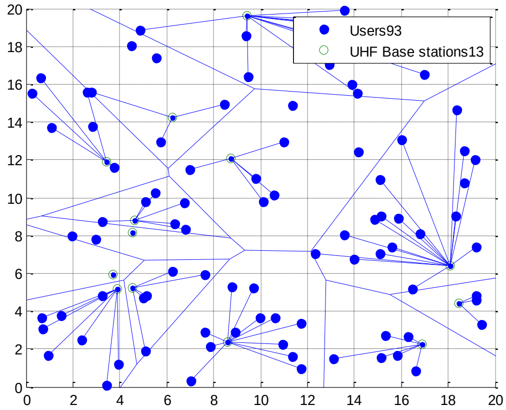

Figure.6 A realization results of the proposed UE and BS distribution PPP model

Let BS have cell association function

$$\Psi_m(x) = \arg\max_{k\in\{m\}} P_m H_m L_{UHF}(r)^{-\alpha} \quad (9)$$

so that users adopt the (unbiased) maximum received power association (MRPA) scheme to select their BS.[48]

A single tier Hetnet is taken with Macro Base Station density $\lambda_m = 0.04$ (4 BSs per square km), and user density $\lambda_u = 0.25$ (250 Users per square km), A realistic assumption in many urban scenarios is made to approximate logarithmic standard deviation of the shadowing greater than 4dB, approximately (4dB to 10 dB). The path loss $L_{UHF}(r)$ for the channel is modeled as

$$L_{UHF}(r) = 20\log(\frac{4\pi f_{UHF}}{c}) + 10\alpha\log(r) + \chi_{UHF} \quad (10)$$

here, r is the direct distance the UE and BS while χ_{UHF} is the log normal random variables (RVs) for UHF link. The operating carrier frequency is assumed to be 2.4 GHz with bandwidth W = 10MHz, path loss exponents α=3 and transmit power P_1 = 46dBm. Consider a user i then downlink SINR is given by the equation:

$$SINR_{DL,i} = \frac{P_{r,DL,ij}}{I_{DL,i} + N_0} \quad (11)$$

where $I_{DL,i}$ is the interference power at the i^{th} user, N_0 is the noise power at the i^{th} user and $P_{r,DL,ij}$ is the power that is received at the i^{th} user from the desired BS j in the downlink. The received power

$$P_{r,DL,ij} = \frac{P_{t,DL,j} h_{ij} G_{ij}}{L_{UHF}(d_{ij}, f_{Ti})}$$

(12)

The Interference Power

$$I_{DL,i} = \sum_{q\in\Phi\backslash j} \frac{P_{r,DL,j} h_{iq} G_{iq}}{L_{UHF}(d_{iq}, f_{Tq})} \qquad (13)$$

Where h_{ij} is the small scale fading power gain with mean µ and standard deviation σ and G_{ij} is the antenna gain between user i and BS j. For simplicity G_{ij} is taken as 1. The effect of maximum power cell association for the users with macro BSs is shown. In figure 7, It can be seen that the association for the desired BS is the same as that of the original PPP. Therefore, the coverage probability of the derived PPP can be obtained by choosing target SIR values. The user density considered for simulation is 250 users/Km2. The performance of the MRPA scheme is evaluated to balance the cell loads between the BSs at different tiers.

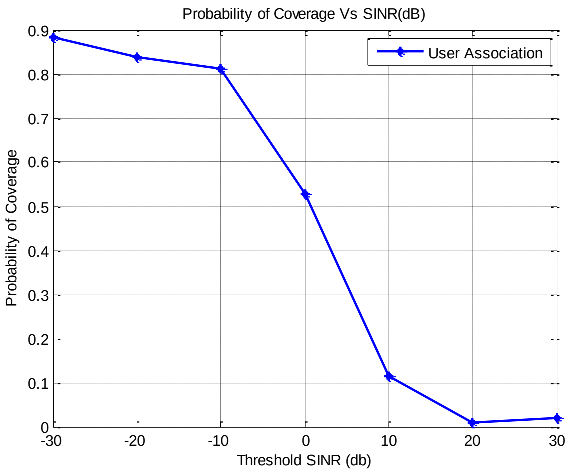

Figure.7 Simulation results of the probability of coverage with different SINR threshold.

The analysis used PPPs to model the deployment of BSs and locations of users. This approach models irregular cell size and shapes that fairly similar to the layout of practical deployments. Since cells have highly varied sizes and shapes, the number of users per BS also highly varies and is generally influenced by the size of each cell and the prevailing user density. It should be noted that the service cannot be denied for a user because of lack of coverage. Hence its performance in cell load balancing is observed and the comparative simulation results are given in Table 6.

V. CONCLUSION

Since HetNet performance is highly influenced by the deployment models and user association scheme, a review of the probabilistic model for deploying of cellular base stations and cell association schemes namely maximum SINR,NBA and MRPA are studied and compared with each other.

Table 6. Comparative analysis of Quality parameter

Hetnet Model	Randomness	Tractability	Accuracy	Flexibility	Computational Complexity
Deterministic Model	Low	High	Low	Low	Low
Stochastic Model	High	High	Medium	High	High

When the HetNet is unbiased, the optimal deployment configuration is expressed in closed form for maximum RPA and maximum SINR schemes. Higher probability of coverage causes the increase in average SINR per user while a lower Probability of coverage decreases the SINR. If Reference Signal Receive Power value decreasing below a certain threshold it strategically defined that they are not enough for the serving coverage for Maximum Received power Association for the user to BSs. Similarly, Universal Cell Association algorithm Nearest Base Station utilizes the Euclidean distance between users. It is important to model correlation in the BS and user locations. The same deployment can be modeled using a Poisson cluster process (PCP) model where the small cells are assumed to lie at the cluster center around which the mobile users form clusters with general distribution. Furthermore, the detailed taxonomy of the given models and comparison of quality parameters are outlined for future research.

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