Capacity and Coverage Trade-off Analysis in Ultra Dense Network

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Abstract— In this paper the capacity verses coverage trade-off in ultra dense network has been analyzed. In the future the number of base stations per user would be more than the number of users itself, such situation would be called as ultra dense networks. In this work stochastic geometry analysis has been employed to deal with such networks.

Keywords— UDN; Hetnet; Stochastic geometry,; Coverage probability, Capacity;

I. INTRODUCTION

As per prediction there would be 1000 times more capacity requirement. This requirement cannot be fulfilled by simply scaling the cellular networks. Hetnet meet this criteria by adapting as per the requirement of users. Future networks are going to be ultra dense networks where the density of base stations is going to be more than the density of users.

Coverage vs capacity analysis shows that more coverage can be provided with moderate rates whereas higher capacity can be provided with less coverage. Capacity is cheap whereas coverage is expensive. Higher capacity can be provided by low power hetnet base stations having more capacity facilitation due to less coverage area.

As the number of base stations are going to be more than users in ultra dense networks, it gives rise to certain complications and issues. Some of them are i) Interference would be higher in ultra dense networks as compared to the previous networks. Manging interference would be the critical issue. ii) the second issue is how to have back-haul connectivity to such large number of low power base stations. The other issues are idle power management etc. Ultra dense network has benefit from the spectrum point of that un-utilized spectrum ca be alloted besides allotting the higher frequencies as well. Other point is that bigger spectrum can be alloted under UDN as the utilization is limited smaller coverage area. It is seen that using hetnet area spectral efficiency can be increased.

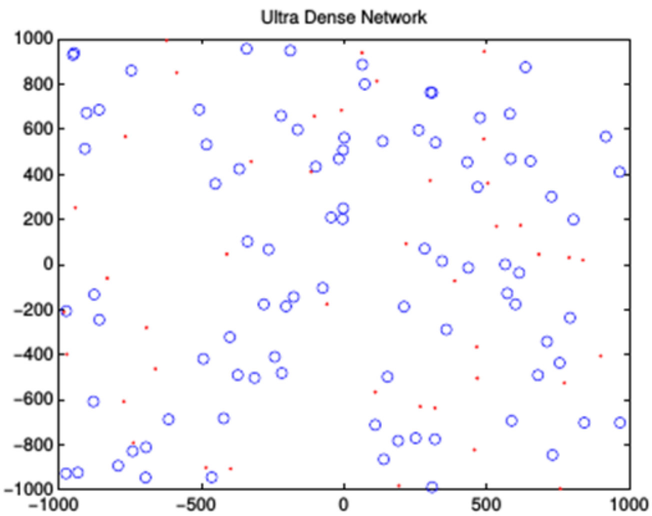
As cellular networks are becoming heterogeneous the deterministic conventional hexagonal grid approach is questionable and hence the results generated by grid model are also questionable. The more near to the practical approach and analytically tractable for hetnet is through spatial random process and stochastic geometry using Poisson Point process (PPP) [1], [2], [3], [4]. But the PPP models suffers from flaw that base station may get very near or even overlap. Further in reality in K-tier network base stations are never deployed very near rather they are deployed in the holes of the other tier. Thus such distribution cannot be captured by PPP rather Gibbs model do provide the such behavior. Hence in this work we have deal with the distribution of K-tier network using Gibbs distribution. But the conventional Gibbs are difficult to tract analytically.

In this work we do analysis on coverage vs capacity trade-off as we move from cellular to UDN. This work we have done using deterimental point process. Some DPP works on hetnet are [5], [6]

The rest of the paper is organized as follows: Section II presents the system model under hetnet scenario. Section III deals with the coverage probability of generalized point process. Section IV describes about the Ginibre point process. Section V describes the results and their analysis, while the last section VI talks about the conclusions.

II. SYSTEM MODEL

A. Network Model and Assumptions



In the above system model circle stands for base stations and red dots stands for users. Both BSs and users are Poisson point distributed. In the figure users density is taken half as compared to BSs and hence the probability of distance between a BS and user r is less as compared to the distance between two users R.

$$\hat{R} : F_{\hat{R}}(r) = P[\hat{R} \leq r] \quad (1)$$
$$= 1 - [\text{no base station active within r}] \quad (2)$$
$$= 1 - e^{-\lambda_u \pi r^2} \quad (3)$$

and

$$\hat{r} : F_{\hat{r}}(r) = P[\hat{r} \leq r] \quad (4)$$
$$= 1 - [\text{no base station within r}] \quad (5)$$
$$= 1 - e^{-\lambda_B \pi r^2} \quad (6)$$

$$\bar{R} = \mathbb{E}[\hat{R}] = \int_0^\infty r f_{\hat{R}}(r) dr \quad (7)$$
$$= \int_0^\infty 2\pi\lambda_u r^2 e^{-\lambda_u \pi r^2} dr \quad (8)$$
$$= \frac{1}{2\sqrt{\lambda_u}} \quad (9)$$

and

$$\bar{r} = \mathbb{E}[\hat{r}] = \int_0^\infty r f_{\hat{r}}(r) dr \quad (10)$$
$$= \int_0^\infty 2\pi\lambda_B r^2 e^{-\lambda_B \pi r^2} dr \quad (11)$$
$$= \frac{1}{2\sqrt{\lambda_B}} \quad (12)$$

and

$$\Gamma = \frac{cP\frac{1}{r^\alpha}}{\sum cP_i \frac{1}{R_i^\alpha} + N} \quad (13)$$
$$\approx \frac{cP\frac{1}{\bar{r}^\alpha}}{\lambda_u cP_i \frac{1}{\bar{R}^\alpha} + N} \quad (14)$$
$$\approx \frac{{\lambda_B}^{\alpha/2}}{{\lambda_u}^{1+\alpha/2} + \frac{N}{c'P}} \quad (15)$$

For fixed maximum rate R_{max}

$$\text{Area capacity} \propto \lambda_u \log(1 + c{\lambda_B}^{\alpha/2}) \qquad \lambda_B \leq {\lambda_B}^*(R_{max}) \quad (16)$$

$$R_{max}\lambda_u \qquad \lambda_B > {\lambda_B}^*(R_{max}) \quad (17)$$

III. COVERAGE PROBABILITY OF GENERALIZED POINT PROCESS

Our focus is on SINR received by a user placed at origin (0,0).

$$\gamma_0 = \frac{F_0 L(|X_{B_0}|)}{I_0 + W_0} \quad (18)$$

where $F_0 = P_0 h^2_0$ follows exponential distribution with mean $1/\mu$. P_0 is transmitted power of serving eNB-1 or UE for the user located at origin and h_2 is small scale fading component and $L = r{-}\alpha$ where α is the attenuation constant. and.

$$I_j = \sum_{j \in N/i} F_j L(|X_{B_j}|) \quad (19)$$

We need to find whether this user is under coverage. The coverage probability of a generalized point process can be

$$p(\gamma_{th}, \alpha) = \mathbb{E}\left[\mathcal{L}_W\left(\mu\gamma_{th}|X_{B_0}|^\alpha\right) \prod_{j \in N/i} \left(1+\gamma_{th}\left|\frac{X_{B_0}}{X_j}\right|^\alpha\right)^{-1}\right] \quad (20)$$

expressed as in [7]

where LW represents Laplace transform of noise

IV. GINIBRE POINT PROCESS

Let C denote the complex plane. Let φ be a realization of a certain point process. Let x 1 , ..., xk , be k-tuples of distinct pairwise elements of C. Let R ⊆ C be a Borel set and f : Rn → R + be any Borel function.

The k-th joint density function of a point process is defined by

$$\mathbb{E}\sum f(x_1, ..., x_k) = \int_{R^n} f(x_1, ..., x_k)\rho^{(k)}(x_1, ..., x_k)dx_1...dx_k \quad (21)$$

Let β be a real number in]0, 1], let λ , a strictly positive real number be the intensity of a point process and c = λπ. The β-GPP is a determinantal point process that can be defined by its correlation functions.

$$\rho^{(k)}(x_1,...,x_k) = \det(K_{c,\beta}(x_i,x_j)), 1 \le i,j \le k), \quad (22)$$

where $K_{c,\beta}$ is a kernel such as $\forall(x,y) \in \mathbb{C}^2$

$$K_{c,\beta}(x,y) = \frac{c}{\pi} e^{-\frac{c}{2\beta}(|x|^2+|y|^2)} e^{\frac{c}{\beta}x\bar{y}} \quad (23)$$

A. Coverage Probability of β- GPP

The coverage probability is expressed as

$$p(\gamma_{th}, s, \alpha, \beta) \quad (24)$$

$$= \beta \int_0^\infty e^{-s} e^{-\gamma_{th} W(\frac{\beta s}{c})^{\alpha/2}} M(\gamma_{th}, s, \alpha, \beta) S(\gamma_{th}, s, \alpha, \beta) ds \quad (25)$$

B. J function

For non Poisson distribution an important term is the J function in terms of location r

$$J(r) = \frac{1-G(r)}{1-F(r)} = (1-\beta+\beta e^{-\frac{c}{\beta}r^2})^{-1} \quad (26)$$

−for r ≥ 1 and where G is the nearest neighbour function and F is the empty space function. In case of uniform PPP with intensity λ, F (r) = G(r) = 1 − e −λπr and J(r) = 1. If

$$J(r) = 1, \text{Poisson distribution} \quad (27)$$

$$J(r) < 1, \text{Custered distribution} \quad (28)$$

$$J(r) > 1, \text{Regular distribution} \quad (29)$$

C. K function

The expected of users under the coverage of a BS can be given by Ripley's K function. The K function is

K(r) = E[number of extra events within distance r of random λ (30)

= E[number of users under the coverage of a BS] (31)

where λ is the density (number per unit area) of events.

K(r) describes characteristics of the point processes at many distance scales

K(r) for homogeneous PPP process is πr^2

D. Interference and Ergodic Throughput

$$\mathbb{E}(I) = -c^{\alpha/2}\beta^{1-\alpha/2}\Gamma(1-\alpha/2) \quad (32)$$

−c − Average ergodic link throughput using round robin scheduling for a mode using at a distance from a random transmitter P_n(k,m) can be given by m as in [8]

$$T_n^{k,m}(r_n^{-\eta_m}) = \int_0^\infty \log_2\left[1+\gamma_{th}^{k,m}(r_n^{-\eta_m})\right]\mathbb{P}\left[\gamma^{k,m} \ge \gamma_{th}^{k,m}\right] d\gamma_{th}^{k,m} \quad (33)$$

V. RESULTS

The results have been analysed by taking λ as parameter for both base stations as well as users but with different values.

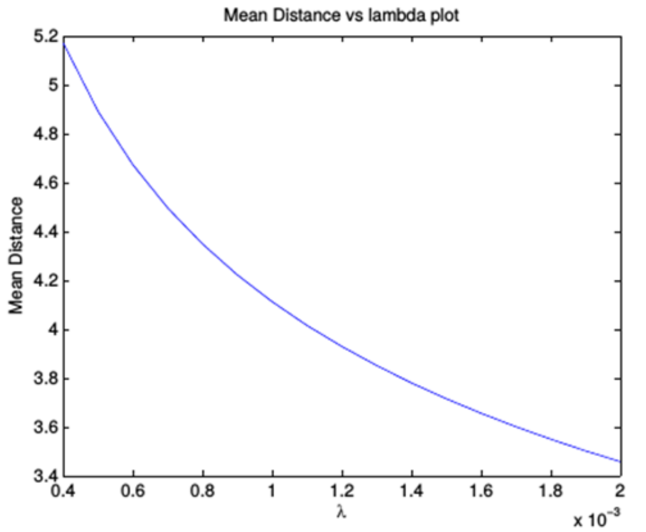


Fig. 2. Mean Distance

It is seen from the above figure that with increase in λ the mean distance goes on decreasing.

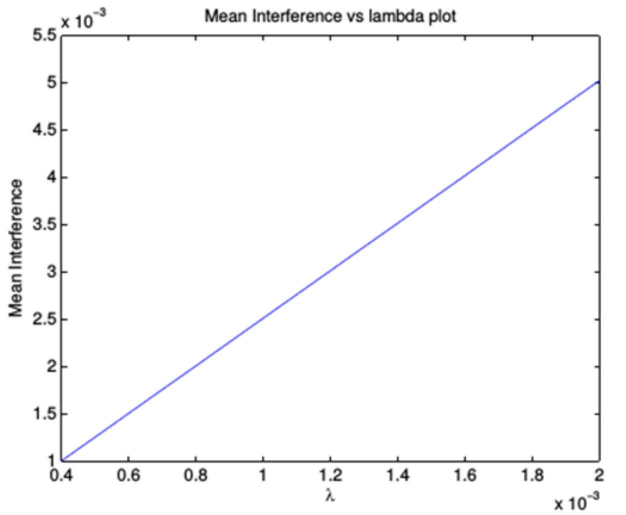


Fig. 3. Mean Interference vs λ

It is seen from this figure that mean interference goes on increasing with λ.

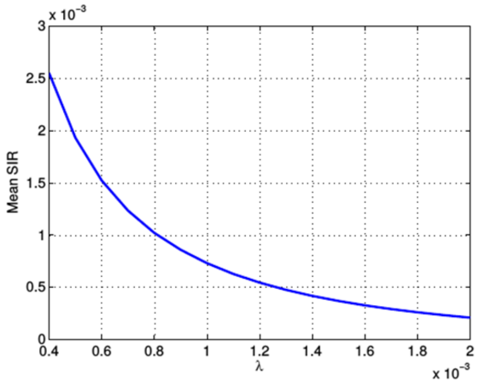


Fig. 4 Mean SIR vs λ

It is seen from this figure that mean SIR goes on decreasing with λ.

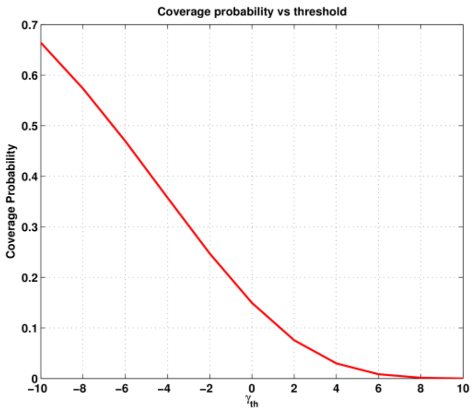


Fig. 5 Coverage probability vs threshold

It is seen from the above figure that with increase in threshold the coverage probability per user goes on decreasing.

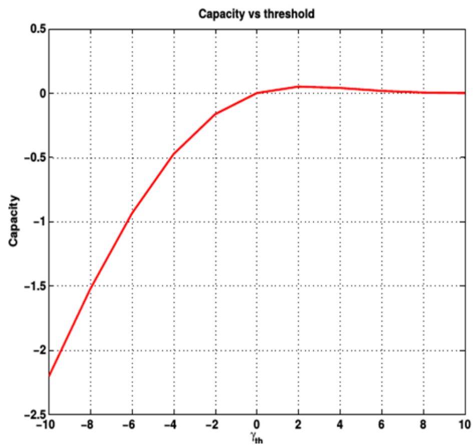


Fig. 6. Capacity vs threshold

t is seen from the above figure that with increase in threshold the capacity/data rate supported per user goes on increasing and thereafter it becomes constant..

VI. CONCLUSIONS

In this work coverage and capacity of UDN has been dealt. It s seen that with higher threshold constraint the coverage probability goes on decreasing whereas the capacity goes on increasing and thereafter it saturates.

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