Stochastic Geometry based Analysis of Downlink Coverage for macro-Cellular Network under Different Association Criteria

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Summary
Future mobile networks should support huge number of customers with high data rates and the current 4G networks are being transformed from 4G to 5G. The deployment of cells with limited range by reusing spectrum is one of the solution which can fulfill this demand. However, the conventional coverage necessity for cell edge remote users is most necessarily met with cells having the large range, i.e. the customary macro cellular design. In modern mobile networks, coverage is quite important than the power requirement of signal as modern receivers are powerful enough to overcome the minimum threshold level. Thus, coverage is an important metric in these cellular networks. Coverage has the relationship with the Signal-to-Interference plus Noise Ratio (SINR). Association criteria plays an important role in modifying the SINR results. Thus, the focus of this research is on SINR parameter to analyze downlink coverage under different camping criteria using stochastic geometry. The simulation results have been obtained for the analytical results of coverage using stochastic geometry under nearest and strongest criteria of association to provide insights about the coverage of cellular network users. The simulation results are quitely fitting to the analytical results. The results indicate that the coverage under maximum instantaneous power is higher than the nearest camping rule.

Key words:
Stochastic Geometry, Coverage, Association Criteria, Signal-to-Interference plus Noise Ratio.

1. Introduction

Future cellular networks should bolster an extensive number of customers with high information rates and the current 4G networks are being transformed from 4G to 5G [1]. The deployment of cells with limited range by reusing spectrum is one of the solution which can fulfill this demand. However, the conventional coverage necessity for cell edge remote customers is most monetarily met with cells having the substantial range, i.e. the customary macro cellular design. In modern mobile networks, coverage is quite important than the power requirement of signal as modern receivers are powerful enough to surpass the minimum threshold level. Thus, Coverage is an important metric in these cellular networks. Coverage has the relationship with the Signal-to-Interference plus Noise Ratio (SINR) so the focus of this paper would be on SINR parameter. Stochastic geometry is a mathematical tool which deals with the mathematical analysis in many fields of study [2]. Nowadays, likewise in other fields of study, this mathematical tool known as stochastic geometry is also getting popularity to mathematically analyze the cellular networks [3] [4] specially of dense nature as in these type of networks, the location of base stations (BSs) or users is random. Similarly, for the dense networks, the pattern of BSs or users' locations are not deterministic and requires the use of Poisson point process to properly model these types of networks. With traditional methods, these complex networks are difficult to analyze. Therefore, stochastic geometry plays an important role to examine the average network behavior for numerous spatial realizations for the BSs dispersed with specific probability distribution [4]. Users are attached to their BSs under different camping criteria. Under this research, two camping rules known as nearest and strongest instantaneous power respectively are used. The details of association rules are given in section III.

In most of the related literature, the results are obtained for downlink SINR with maximum average receive power association criteria [5] [6] [7] [8]. However, in this paper, the analytical results presented in [9] for different camping criteria i.e., nearest and strongest instantaneous power are different from most of the available literature. The macro-tier model is developed, and the results are obtained using MATLAB® to verify the analytical results provided in [9] through simulation studies in order to provide insights about the users' coverage of cellular network under various camping criteria and to examine the performance in terms of coverage under these camping rules mentioned above.

Further, the work is distributed in the following sections: section-2 describes the system model considered which is the macro cellular network along with its path loss model

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to determine the SINR of the said model. Association criteria are discussed in section-3. Section-4 explains the analytical and simulation results of coverage under the two camping or associating rules of nearest and strongest instantaneous power along with the insights about the results. Finally, the presented work is concluded and future work is mentioned to extend this research for multiple tiers in section-5.

2. System Model

System model is shown in Fig. 1 where intended signal in downlink to UE0 from its macro serving BS is shown with solid line and the signals from rest of the BSs transmitting signals to their camped users are the interference signals for UE0, shown with dashed lines. The power transmitted in DL is assumed to be fixed from all BSs. The BSs are also modeled to be distributed as PPP, denoted by Φ. The intended BS is selected as per association criteria considered and discussed in section-3 which are nearest and maximum instantaneous power of BS in the DL. System model for analyzing the downlink SINR distribution of single macro tier cellular network along with its channel model is discussed in this section. The path loss and fading are two entities which determine the overall channel's loss of a link. Path loss is deterministic and can be determined according to the distance whereas fading is random in nature. Path loss is usually given by

$$10\alpha \log_{10}(d) - 10\log_{10} K, \tag{1}$$

where α, K and d are the path loss slope, intercept, and distance in meters respectively. Path loss is usually considered greater than 2. We consider the Rayleigh fading which is exponentially distributed and do not consider the log-normal shadowing as it is not very tractable.

Assuming the single tier of macro BSs which transmit with the fixed power Ptf, in downlink, H is the Rayleigh fading, and R is the received power from the b BS for the user location then the received power is given by

$$R_b = \frac{KP_{tf} H_b}{d_b^{\alpha}} \tag{2}$$

If thermal noise power is negligible and L is total number of interfering BSs then SIR can be written as,

$$SIR = \frac{H_0 / d_0^{\alpha}}{\sum_{b=1}^{L} H_b / d_b^{\alpha}} \tag{3}$$

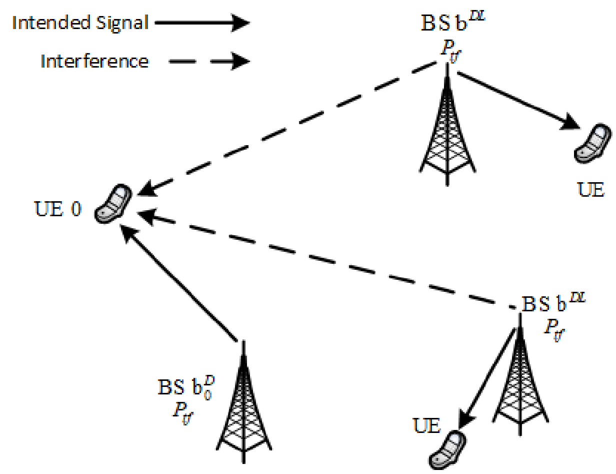

Fig. 1 System Model of macro-tier showing intended and Interference signals.

3. Association Criteria

As BSs form a PPP, the users locations in the network also form another PPP, denoted by Φu. Users can be associated to their serving BSs according to different camping rules, known as association criteria. In the nearest association, user is actually nearest physically to the BS and camped BS is selected on the basis of path loss model given by eq. (1) as the fading is averaged for many BSs at the receiver which consequently is nullified while considering nearest association. The nearest rule mathematically given as

$$b_{UE_0}^{DL} = \arg \min_{b\in\Phi,\, u\in\Phi_u} \{d_u^b\} \tag{4}$$

where UE0 is the intended UE for its camped BS.

Second association criterion is strongest instantaneous power where user is associated to the BS from which it receives strongest instantaneous power. This is mathematically given by

$$b = \arg\, m\,\mathrm{ax}_{b\in\Phi}\, P_{tf} \tag{5}$$

Our interest lies in instantaneous distribution of a randomly selected user's SINR under nearest and strongest power association criteria mentioned above in the downlink (DL).

4. Analytical and Simulation Results

For the theoretical and simulation results of SINR under nearest and strongest power, we model the BSs or location of all BSs by Poisson Point Process (PPP), denoted by Φ which is numerically tractable model for calculating the SINR as compared to other available models like grid model. Later, from the SINR, the coverage results are obtained using stochastic geometry tool, used by the researchers extensively nowadays.

4.1 Physically nearest user to its camped BS

The coverage i.e., P [SINR > γ] is acquired when PDF of the distance between camped BS and user is integrated and is given by [9]

$$f_{d_0}(d_0) = 2\pi\lambda d_0 \exp(-\pi\lambda d_0^2) \quad d_0 \geq 0 \tag{6}$$

While considering the fade attenuation for all non-camped BSs and the fade attenuation on camped BS is exponentially distributed with unit mean i.e., H ~ exp (1), the coverage under nearest association as per [10] is given by

$$P[SINR > \gamma] = \int_0^\infty \exp\{-\frac{\gamma}{\pi^{\alpha/2}} \frac{u_1^\alpha}{\lambda^{\alpha/2} P / N_0} - [1+\gamma^{2/\alpha} G_\alpha(\frac{1}{\gamma^{2/\alpha}})]u_1\} du_1, \ \gamma > 0 \tag{7}$$

where G(.) is given by

$$G_\alpha(z) = E[\gamma(1-\frac{2}{\alpha}, \frac{H}{z^{\alpha/2}})H^{2/\alpha}] - z[1-\mathrm{L}_H(\frac{1}{z^{\alpha/2}})], \quad z \geq 0 \tag{8}$$

The simulation and analytical results of eq. (7) are shown in Fig. 1.
If thermal noise power is zero i.e., N0 = 0 then SINR becomes SIR and is given by [10]

$$G_\alpha(z) = E[\gamma(1-\frac{2}{\alpha}, \frac{H}{z^{\alpha/2}})H^{2/\alpha}] - z[1-\mathrm{L}_H(\frac{1}{z^{\alpha/2}})], \quad \gamma>0 \tag{9}$$

Eq. 9 indicates that SIR does not depend upon transmit power or the density of BSs. If the path loss exponent (α) increased from 2 to 4 and N0 is zero then SIR is calculated by [10] as

$$P[SIR > \gamma] = \frac{1}{1+\sqrt{\gamma}\cot^{-1}(\frac{1}{\sqrt{\gamma}})}, \ \gamma>0 \tag{10}$$

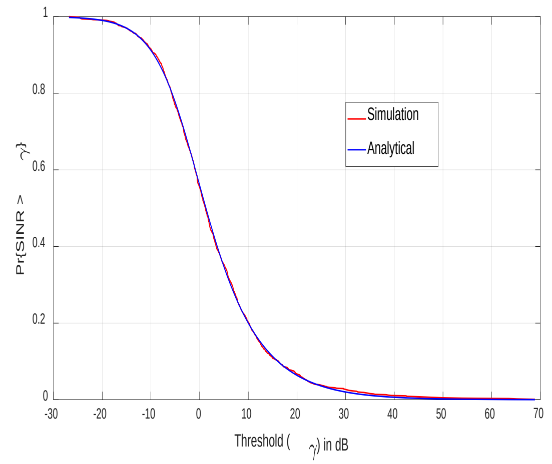

Fig. 2 Coverage (CCDF) of SINR under nearest camping rule or association criteria for γ > 2.

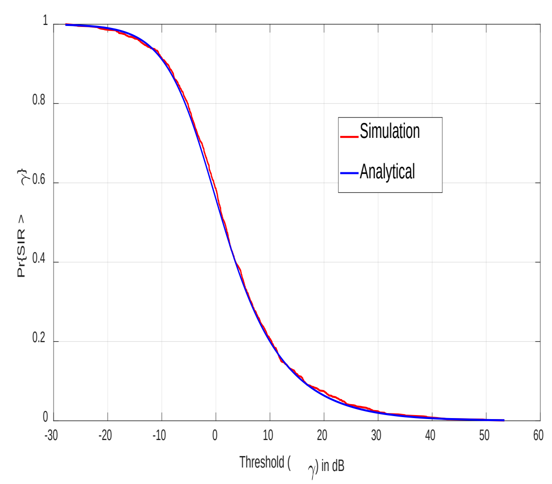

Fig. 3 Coverage (CCDF) of SIR under nearest camping rule or association criteria for α = 4, N0 = 0.

4.2 User camped to strongest BS

Again, for this type of association, we assume the location of BSs are modeled by PPP, Φ. The user associates to a BS from which it receives strongest power as per eq. 5. This rule is also known as maximum SIR camping rule. The mathematical expression for SIR when N0 is zero and SIR is greater than or equal to 1 which is the special case and is given as per [10]

$$P[SIR > \gamma] = \frac{sinc(2/\alpha)}{\gamma^{2/\alpha}}, \quad \gamma \geq 1 \tag{11}$$

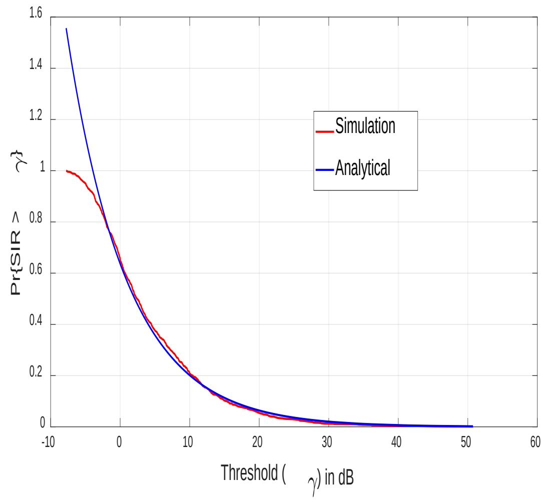

Fig. 4 Coverage (CCDF) of SIR for α = 4, N0 = 0, and γ ≥ 1 (0 dB) under strongest BS camping rule or criteria.

This is the first expression for randomly selected user under strongest BS association rule. The simulation and theoretical results are shown in Fig. 3. It should be noted that the simulation results perfectly match with the theoretical results for the values of γ ≥ 1 (0 dB) as indicated in eq. (11).

On comparing the results of coverage in Fig. 2 and Fig. 3 for both the associations examined, it is quite evident that the coverage under maximum instantaneous power rule is higher than the nearest association. For example, at 0 dB threshold, the coverage under maximum instantaneous power is slightly more than 60% whereas under nearest association, it is slightly lower 60%. Thus, coverage under maximum instantaneous power is higher than nearest camping rule.

5. Conclusion

In this paper, the focus of the research was on SINR parameter to analyze downlink coverage under different camping criteria using stochastic geometry as the conventional coverage necessity for cell edge remote users is most necessarily met with cells having the large range, i.e. the customary macro cellular design. The camping rules considered were the nearest and strongest power in downlink. The locations of base stations were modeled by the Poisson point process. The simulation results were obtained for the analytical results of coverage using stochastic geometry under nearest and strongest criteria of association to provide insights about the coverage of cellular network users under various association criteria. The simulation results were quitely fitting with the analytical results and provided insights about the impact of the studied camping criteria on downlink coverage. It was examined that the coverage (CCDF of SIR) is higher under maximum instantaneous power criteria than the nearest camping criteria. This work was about the single tier of macro BSs. However, this research will be extended for multiple tiers in future to see the impact of different associations on such type of heterogeneous network using stochastic geometry approach.

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