Performance Analysis for User-Centric Cloud Radio Access Network in Millimeter Wave

Yangying Zhang[1,2](✉), Hai Huang[1], Xiaojun Jing[1,2], and Jia Li[3]

[1] School of Information and Communication Engineering, Beijing University of Posts and Telecommunications, Beijing, China
zyangying@163.com

[2] Key Laboratory of Trustworthy Distributed Computing and Service (BUPT), Ministry of Education, Beijing University of Posts and Telecommunications, Beijing, China

[3] School of Engineering and Computer Science, Oakland University, Rochester, USA

Abstract. Millimeter wave (mmWave) and cloud radio access network (C-RAN) are two potential candidates for next generation communication. In this paper, we consider user-centric C-RAN in mmWave with the existence of blockages in urban areas. The remote radio heads (RRHs) are deployed according to a Poisson point process in the circular region $\mathcal{D}$, of radius R. We employ the stochastic geometry theory to analyze the signal-to-noise ratio (SNR), rate, and outage probability. We emphasize the effect of circular region radius on the performance in this network and evaluate the effect with Monte Carlo simulations. The simulation results show that SNR, rate and outage probability have the same asymptotic trends and have the best performance when replace the circular region $\mathcal{D}$ with the line-of-sight (LOS) circular region.

Keywords: Millimeter wave · Cloud radio access network
Stochastic geometry

1 Introduction

With the ever-increasing high data rates of mobile users, many modern network architectures and transmission technologies have been developed. User-centric cloud radio access network (C-RAN) is one of the promising network architectures [1], where a group of remote radio heads (RRHs) distributed uniformly serve the user U located at center. It saves the wireless resource by employing coordinated transmissions among RRHs. And baseband units (BBUs) pool employs centralized baseband processing for using computational resource efficiently [2]. We can expand serving region and improve the coverage and capacity by adding low cost RRHs to network. In addition, coordinated multipoint processing (CoMP) among RRHs can be deployed to limit the overall interference and improve the network capacity [3].

© Springer Nature Singapore Pte Ltd. 2018
S. Sun et al. (eds.), *Signal and Information Processing, Networking and Computers*, Lecture Notes in Electrical Engineering 473,
https://doi.org/10.1007/978-981-10-7521-6_12

The millimeter wave (mmWave) communication has been considered as a promising solution to frequency congestion problem because of abundant available spectrum in mmWave. mmWave technology has been recognized as an enabler for next generation networks to achieve higher data rate and low delay [4]. Investigation of the use of mmWave technology is already underway. Due to susceptibility to blockages and severe attenuation in transmission, mmWave is more suitable for short-range wireless communication. C-RAN system with RRHs distributed densely can make full use of mmWave short-range communication characteristic.

Investigation of the user-centric cloud radio access networks is already underway. With explicit backhaul constraints and power constraints in user-centric C-RAN, the beamforming clustering scheme has been investigated [5]. Under the assumption of high signal-to-noise ratio (SNR) and certain path loss exponent, the outage probability has been investigated and closed form of analysis results have been derived in user-centric C-RANs with randomly deployed RRHs [6]. Generally, when the path loss exponent is uncertain in C-RANs, more accurate analytical results of outage probability and rate have been obtained by employing the Gaussian-Chebyshev integration [7]. The downlink outage probability of C-RAN has been investigated, where RRHs are distributed randomly with multiple antenna [3]. The macro base station and the RRHs cooperate and serve the user simultaneously. They employ maximal ratio transmission or transmit antenna selection under three downlink protocols, namely, selection transmission, all RRHs participating, and minimal number of RRHs participating [3].

In [3, 6, 7], the radii of disks, where user is located at the center, are set artificially. RRHs are uniformly distributed in these disks. The effects of blockages have not been considered. Moreover, how to select the radius and the influence of the radius have not been considered. When considering mmWave C-RAN, radius selection is very important for performance metrics such as signal to interference plus noise ratio (SINR), rate and outage probability. If we select larger radius, due to the effect of the blockages, more RRHs, especially including non-line-of-sight (NLOS) RRHs, will serve the user. while the NLOS RRHs will not improve the SNR and rate performance. If we select smaller radius, a lot of line-of-sight (LOS) RRHs will not serve the user, resulting in poor SNR and rate performance.

In this paper, we analyze the SINR, rate, and outage probability in downlink user-centric mmWave C-RAN. We describe the user-centric C-RAN system model, and channel model in Sect. 2. In Sect. 3, we analyze the cumulative distribution function of SINR and rate as well as outage probability. Simulation results are provided in Sect. 4. We summarize and propose the extension directions in Sect. 5.

2 System Model

We consider a downlink user-centric mmWave C-RAN system shown in Fig. 1(a), where a user U, with an omnidirectional antenna, is served by a group of RRHs deployed randomly over a circular region $\mathcal{D}$, of radius R in Fig. 1(b). The location of RRHs are assumed to obey a homogeneous Poisson point process (PPP) Φ_1 with density λ_1. The number of RRHs N in the circular region $\mathcal{D}$ is Poisson random variable whose distribution law is

$$\Pr\{N \text{ RRH in LoS circle}\} = \frac{A^N}{\Gamma(N+1)} e^{-A}. \tag{1}$$

where A is the intensity and A = $\pi R^2 \lambda_1$. All RRHs employ antenna arrays to achieve higher directional beamforming gain.

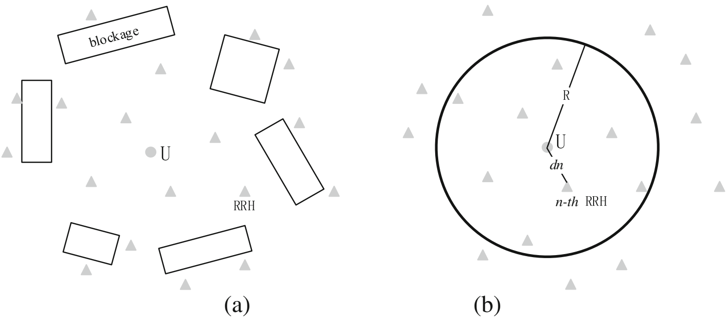

Fig. 1. User-centric mmWave C-RAN

The two fundamental physical differences between the mmWave and (ultrahigh frequency) UHF network are the need for significant directionality and vulnerability to blockages [8]. For tractability, the antenna arrays of RRHs are modeled as sectored antenna model $G_{M,m,\theta}(\phi)$ [9]. Let M, m are main lobe directivity gain and back lobe gain, respectively. θ is the beam width of the main lobe. We assume the directivity gain between the *n-th* RRH and the user is M.

The blockages, assumed to be impenetrable, are modeled as Boolean scheme of rectangles [10], whose centers form a homogeneous PPP Φ_2 with density λ_2, independent of Φ_1. The lengths L and widths W of blockages are identical independent distributed.

We employ the path loss model $1/(1+d_n^\alpha)$, which avoids the singularity issue when $d_n \to 0$. We assume the path loss exponent of LOS propagation is $\alpha = 2$. Assuming Rayleigh fading between the *n-th* RRH and the user is $g_n \sim \mathcal{CN}(0,\ \mu)$ and $\mu = 1$ denotes the mean power of the channel. Then $|g_n|$ is a normalized Gamma random variable. The distance d_n between the *n-th* RRH and the user U is a random variable with distribution function

$$f_{d_n}(x) = \begin{cases} \frac{2x}{R^2} \ ; \ 0 \le x \le R \\ 0 \ \ ; \ else \end{cases}. \tag{2}$$

Assuming that each RRH serves only a user per unit time, and other users must wait until the RRH finish service. And BBU employs the coordination transmission control, which means that the user U associates with a set of cooperating RRHs and we can ignore the interference between the cooperating RRHs.

3 Performance Analysis

In this section, we analyze the SNR, rate and outage probability under the preceding proposed model. First, we evaluate the effect of the blockages, and approximately replace the circular region $\mathcal{D}$ with the LOS circular region, of radius R_{LOS}. Then we analyze the SNR received by the user U, rate and outage probability.

3.1 Radius of LOS Circular Region

In Fig. 1(a), the LOS region observed by the user U has an irregular shape [10]. The LOS region can be approximated by a circular region which has a certain radius. Only RRHs inside this region are considered as LOS propagation to the user.

The LOS propagation through a link of length x means that there is no blockages cross the link, and the probability of LOS propagation is $p(x) = e^{-\beta x}$ in [10], where $\beta = 2\lambda_2(\mathrm{E}[L] + \mathrm{E}[W])/\pi$, and λ_2, E[L], E[W] are the density of blockage, the average length and average width, respectively.

Based on the LOS probability function $p(x)$, the radius of the circular region [10] can be derived as

$$R_{LOS} = \left(2\int_0^{\infty} p(x)dx\right)^{0.5}. \tag{3}$$

We equivalently approximate the LOS region by a fixed circle $B(U, R_{LOS})$ with user U located at the center, which we define as equivalent LOS circular region [10].

3.2 SNR Analysis

Based on the assumption that one RRH can at most serve one user and the effects of blockages, we can ignore inter-RRHs interference. The SINR received by user can be approximated to SNR. We denote the SNR from the *n-th* RRH to user as γ_n, the overall SNR received by the user U is given as [7]

$$\gamma = \sum_{n=1}^{N} \gamma_n. \tag{4}$$

We consider both of small scale Rayleigh fading and path loss. Thus, the received SNR from the *n-th* RRH to the user U can be written as [6]

$$\gamma_n = \frac{M|g_n|^2}{\sigma^2(1 + d_n^{\alpha})}. \tag{5}$$

where σ^2, α are the noise power received at the user and the path loss exponent, respectively. The overall SNR received by the user U is given as [7]

$$\gamma = \sum_{n=1}^{N_1} \gamma_n = \frac{M}{\sigma^2} \sum_{n=1}^{N_1} \frac{|g_n|^2}{(1 + d_n^\alpha)}. \tag{6}$$

where N_1 is the number of RRHs whose signal can be received by user U. If the radius R is shorter than R_{LOS}, this means that not all LOS RRHs serve the user U. If R is larger than R_{LOS}, there are NLOS RRHs serve the user U while the signal strength from these RRHs come close to zero received by U. Thus N_1 is Poisson random variable.

$$\Pr\{N_1 = k\} = \frac{A^n}{k!} e^{-A}, \quad k = 0, 1, 2 \cdots, \mathrm{A} = \begin{cases} \pi R_{LOS}^2 \lambda_1, & R \geq R_{LOS} \\ \pi R^2 \lambda_1, & R < R_{LOS} \end{cases}, \tag{7}$$

The cumulative distribution function (CDF) of SNR can be defined as

$$F_\gamma(t) = P\{\gamma < t\} = P\left\{ \frac{M}{\sigma^2} \sum_{n=1}^{N_1} \frac{|g_n|^2}{(1 + d_n^\alpha)} < t \right\}, \tag{8}$$

where the t is the threshold. When the radius R is smaller than R_{LOS}, only a part of LOS RRHs provide service with the user U. With the increase of R, the SNR received by U will increase. If R is larger than R_{LOS}, all LOS RRHs and a part of NLOS RRHs serve the user U simultaneously. Due to the blockages, the SNR will not increase apparently. We will evaluate the effect of R on the CDF of SNR in Sect. 4.

3.3 Rate Analysis

The rate distribution is vital for assessing the performance of this network. According to the definition, the rate received by U can be written as $R_U = B \log_2(1 + \gamma)$, where B denotes the bandwidth. The cumulative distribution function of R_U can be defined as

$$F_{R_U}(\tau) = P\{R_U < \tau\} = P\{B \log_2(1 + \gamma) < \tau\}. \tag{9}$$

Based on CDF of the SNR, we can deduce the CDF of the rate according to the definition. The effect of R on the rate has the same trend as the SNR. We will show the simulation results of rate in Sect. 4.

3.4 Outage Probability Analysis

The outage probability is one of key performance metrics. In this section, we qualitatively analyze the influence of radius R on outage probability. We denote R_e as targeted date rate received by U. And the outage probability is defined as

$$\begin{aligned} P_{out} &= P\{R_U < R_t\} = P\{B \log_2(1 + \gamma) < R_t\} \\ &= P\left\{\gamma < 2^{\frac{1}{B}R_t} - 1\right\} = \sum_{n=0}^{\infty} F_\gamma(2^{\frac{1}{B}R_t} - 1 | N_1) P\{N_1 = k\}. \end{aligned} \tag{10}$$

4 Simulation Results

In this section, we present Monte Carlo simulation results, and illustrate impact of the radius R_{LOS} on SNR CDF, rate CDF and the outage probability.

We assume that the RRHs density is $\lambda_1 = 3 * 10^{-2}/\text{m}^2$, and the bandwidth allocated to user is $B = 100$ MHz, the antenna gain transmitted from RRHs is $M = 10$ dB. The path loss exponent of LOS propagation is $\alpha = 2$. The density of blockages is $\lambda_2 = 4.4 * 10^{-3}/\text{m}^2$, $\text{E}[L] = \text{E}[W] = 15$ m.

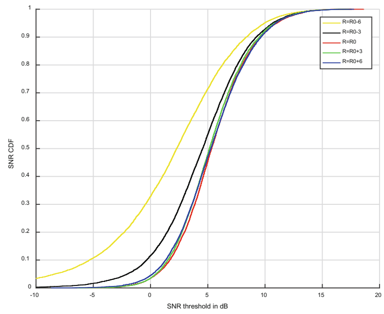

Fig. 2. SNR CDF with different radius. R denotes the radius of circular region. And R0 denotes the radius R_{LOS} of LOS region corresponding to red curve. The yellow and black curve correspond to the case where R is smaller than R_{LOS}, where the other two is for a larger R.

First, we compare the SNR CDF with different radius of circular region in Fig. 2. With the increase of the radius, the CDF of SNR improve rapidly until the radius approaches to R_{LOS}. When the radius surpass R_{LOS}, the CDF of SNR does not change apparently with the increase of radius. The simulation results demonstrate the analysis in Sect. 3. The RRHs outside of LOS circular region do not improve SNR received by the user.

We present the rate CDF with different circular region radius in Fig. 3.

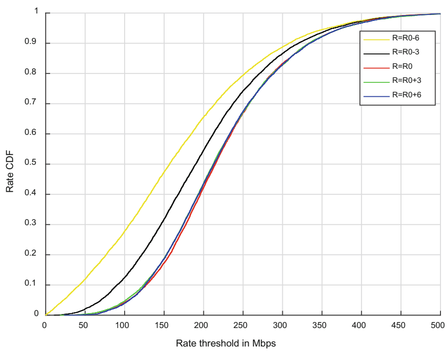

Fig. 3. Rate CDF with different radius.

With the increase of R, the CDF of rate increase until approaching to R_{LOS}. When R is larger than R_{LOS}, the performance do not improve apparently. The CDF of rate has the same trend as the CDF of SNR with the increase of R.

We present the outage probability with different radius and different targeted data rate in Fig. 4.

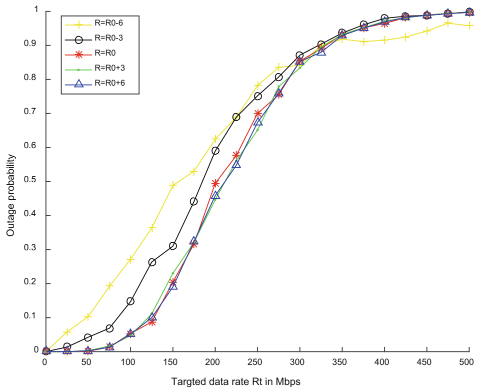

Fig. 4. Outage probability

With the increase of expected data rate, the outage will be more likely to happen. The effect of R on outage probability is same as effect on SNR and rate. Therefore, the system performance will be optimal when the disk radius is equal to the radius of LOS circular region.

5 Conclusions

In this paper, we analyze the SNR, rate, and outage probability based on the stochastic geometry theory in the user-centric mmWave C-RAN considering the blockages. Compared to the existing work, we emphasize the effect of radius on the performance in this network and evaluate the effect with Monte Carlo simulations. This work can be extended in following directions. 3-D antenna gain pattern, which extend the directivity in elevation angles, could be further investigated. The case, where one RRH can serve multi-users simultaneously, could also be investigated in future work.

Acknowledgement. This work is supported by NSFC Project 61471066.

References

1. Chen, N., Rong, B., Zhang, X., Kadoch, M.: Scalable and flexible massive MIMO precoding for 5G H-CRAN. IEEE Wirel. Commun. **24**(1), 46–52 (2017)
2. Quek, T., Peng, M., Simeone, O., Yu, W.: Cloud Radio Access Networks: Principles, Technologies, and Applications. Cambridge University Press, Cambridge (2017)

3. Khan, F., He, H., Xue, J., Ratnarajah, T.: Performance analysis of cloud radio access networks with distributed multiple antenna remote radio heads. IEEE Trans. Signal Process. **63**(18), 4784–4799 (2015)
4. Omar, M., Anjum, M., Hassan, S., Pervaiz, H., Niv, Q.: Performance analysis of hybrid 5G cellular networks exploiting mmWave capabilities in suburban areas. In: 2016 IEEE International Conference on Communications (ICC), Kuala Lumpur, pp. 1–6 (2016)
5. Dai, B., Yu, W.: Sparse beamforming and user-centric clustering for downlink cloud radio access network. IEEE Access **2**, 1326–1339 (2014)
6. Ding, Z., Poor, H.: The use of spatially random base stations in cloud radio access networks. IEEE Signal Process. Lett. **20**(11), 1138–1141 (2013)
7. Yang, Z., Ding, Z., Fan, P.: Performance analysis of cloud radio access networks with uniformly distributed base stations. IEEE Trans. Vehicular Technol. **65**(1), 472–477 (2016)
8. Andrews, J., Bai, T., Kulkarni, M., Alkhateeb, A., Gupta, A., Heath, R.: Modeling and analyzing millimeter wave cellular systems. IEEE Trans. Commun. **65**(1), 403–430 (2017)
9. Hunter, A., Andrews, J., Weber, S.: Transmission capacity of ad hoc networks with spatial diversity. IEEE Trans. Wirel. Commun. **7**(12), 5058–5071 (2008)
10. Bai, T., Vaze, R., Heath, R.: Analysis of blockage effects on urban cellular networks. IEEE Trans. Wirel. Commun. **13**(9), 5070–5083 (2014)
11. Bai, T., Heath, R.: Coverage and rate analysis for millimeter-wave cellular networks. IEEE Trans. Wireless Commun. **14**(2), 1100–1114 (2015)