Millimeter Wave Cloud Radio Access Network Coverage and Capacity

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Abstract. In this paper, the performance of a cloud radio access networks (C-RAN) where remote radio heads (RRHs) operating at millimeter wave (mm-Wave) range are modeled as a homogeneous Poisson point process has been investigated. In this network, due to the high frequency and small wavelength, we use a LOS circle concept from the former study. Considering downlink transmission, we were compared the performance of two different transmission schemes. First is the selection transmission which chooses the best RRH (BR) for transmission. Another scheme is all the RRHs participated (ARP) and transmission the signal together to the typical user. We analysis the outage and capacity of the two schemes and ARP transmission scheme always performed better.

Keywords: Cloud radio access network · Millimeter wave
Remote radio head

1 Introduction

With the explosive growth of mobile traffic demand, the contradiction between spectrum shortage and capacity requirements becomes increasingly prominent. Wireless bandwidth becomes a critical problem for the next generation wireless network, so that recently a lot of research was focused on the high frequency communication. The millimeter wave communication was becoming a promising technology for the future wireless communication system. Due to the high frequency and a small wavelength, mm-Wave communication will suffer from huge propagation loss. To solve this problem, beamforming has been adopted as an essential technique to a directional communication [1]. mm-Wave also experiences penetration loss and sensitive to blockage by obstacles such as building and human body [2]. Therefore mm-Wave communication always considered to be a short distance and directional transmission.

With the increasingly enhanced application scenario of mobile internet, 5G should have the characteristic of higher experiences data-rate and wider bandwidth to support multimedia contents featured by higher definition and living experiences. In recently

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5G communication, many scholars has been proposed cell densification aimed to improve the capacity and area spectral efficiency.

The future 5G communication architecture will be an ultra-dense network by increasing the cell base station density to improve network capacity [3]. But at the same time it will cause highly overall interference which resulting in a limit capacity gain. The characteristic of the cloud radio access networks (C-RANs) make it become a candidate architecture in the future 5G network. The rationale behind this is that baseband processing is centralized and coordinated among sites in the centralized BBU pool, and thus it not only achieves significantly higher data rates than conventional cellular networks but also reduces the capital expenditure (CAPEX) and operating expenditure (OPEX) of the networks [4]. The ideal of the C-RANs is to move the baseband units (BBUs) to a central location/data center and connect it to the radio units, also called remote radio heads (RRHs), via optical fibers [5].

Motivated by the aforementioned background, in this study, we proposed mm-Wave C-RANs architecture. We consider the downlink of a C-RANs where RRHs operating at the mm-Wave connected with BBUs via optical fiber link. The BBUs pool in the cloud is established to coordinate the entire network. In our system, the coordinated multipoint (COMP) has adopted to mitigate the inter-RRHs interference and improve the network capacity [6]. We adopted a LOS circle concept from the former study [7] and use different user association to analysis the performance of the network respectively.

The paper is structured as follows: in Sect. 2 we described the system model and we derive the coverage probability and outage probability expression in Sect. 3. Performance analysis simulation result were presented in Sect. 4 and we draw a conclusion in Sect. 5.

2 System Model

2.1 Network Model

As show in the Fig. 1, we assume a typical user is located in the origin associated by the RRHs which distributed randomly over a circular region K with radius R. Due to severe penetration loss in mm-Wave communication, we only consider the RRHs in the circular which called LOS circle. We assumed that as long as R is larger enough, the RRHs which outside the circular regime can be thought NLOS. RRHs operating at mm-Wave range and the location of the RRHs form a homogenous Poisson Point process (PPP) Φ_R with intensity λ_R. Further, we assume that each RRH transmits with the same power (P_R). We use the method of coordinated multipoint processing (COMP) in C-RAN to get the purpose of mitigating the overall interference and improving the performance of the network.

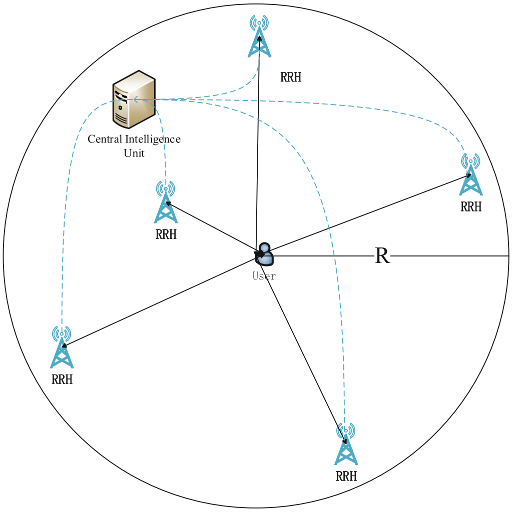

Fig. 1. System model.

2.2 Directional Beamforming

In this network, all RRHs equipped with directional antennas which modelled as a sectorized gain pattern. The antenna gain provide for a typical users was modeled as the following expression [8],

$$G_R(\theta) = \begin{cases} G_{\max} & if \ \ |\theta| \leq \theta_R \\ G_{\min} & otherwise \end{cases}, \quad (1)$$

where θ is the steering angle and θ_R represents the beam-width or main lobe width. It is assumed that when the antenna beams of intended access link are aligned, then the effective gain which desired access link achieve is $G_{\max}$ [8]. Although the user antenna gain pattern can be modelled in the same manner, we considered the omnidirectional antennas for the user in this network.

2.3 Distance-Dependent Path Loss Model

In our work, the path loss between RRHs or MBS with typical user was estimated as [9]

$$PL(\mathrm{d})_{dB} = \alpha + 10\beta \log_{10}(\mathrm{d}) + \zeta_\sigma, \quad (2)$$

where α represents the path loss and β is the path loss exponent. The ζ_σ is modelled as the shadowing effect in dB and σ is the standard deviation of ζ_σ. Motivated by previous works [8, 9], different LOS and NLOS access link experience different propagation environment so that the path loss parameters for the two access link was different. In this paper, we adopted the equivalent LOS ball that only consider the RRHs in the circle region.

2.4 SINR Model

For best RRH transmission, the receive SINR at a typical user, denoted by γ_{BR} is written as

$$\gamma_{BR} = \frac{P_R G_R(\theta) h_R d^{-\alpha}}{N_0 + I_R}, \tag{3}$$

since coordinated multipoint (COMP) has adopted to mitigate the inter-RRHs interference, the inter-tier interference form RRHs can be ignored thus the SINR can be simplified as

$$\gamma_{BR} = \frac{P_R G_{BR}(\theta) h_{BR} d^{-\alpha}}{N_0}, \tag{4}$$

where P_R is the transmission power at each RRH, $G_R(\theta)$ as a function of θ_R which represents the antenna gain for a typical user, d is the distance from the severed RRH to the typical user and $d^{-\alpha}$ represents the path loss gain. $h_R \sim \exp(1)$ is the small-scale fading channel power gain and N_0 is the noise power.

For all RRHs participate in transmission, the SINR can be written as

$$\gamma_{AR} = \sum_{i=1}^{N} \frac{P_R G_{R_i}(\theta) h_{R_i} d_i^{-\alpha}}{N_0}, \tag{5}$$

where N is a random variables that represents the number of RRHs in the LOS circle which follows the Poisson distribution. Note that the SINR in (3) (4) is a random variable, because the locations of the RRH R_i is randomness, and the small-scale fading h_{R_i} and the directivity gain $G_{R_i}(\theta)$ were depended on it. We Using the aforementioned system model and evaluate the mm-Wave C-RAN coverage and outage probability in the following section.

3 Performance Analysis

In this section, we derive the coverage probability and outage probability expression for the downlink mm-Wave C-RAN system under two different transmission schemes.

3.1 Coverage Probability

The downlink SINR coverage probability is defined as

$$P_C(\mathrm{T}, \alpha) = \Pr[\mathrm{SINR} > \mathrm{T}], \tag{6}$$

which means that the probability of the a randomly user will attain a target SINR T or the average fraction of users who at any time achieve SINR T [7].

(1) Coverage of the best RRH transmission scheme can be expressed as

$$\begin{aligned} P_{BR}(\mathrm{T}, \alpha) &= \Pr(\gamma_{BR} > \mathrm{T}) \\ &= \Pr\left(\frac{P_R G_{BR}(\theta) h_{BR} d^{-\alpha}}{N_0} > T\right). \end{aligned} \tag{7}$$

(2) Coverage of the all RRHs jointly transmission can be expressed as

$$\begin{aligned} P_{AR}(\mathrm{T}, \alpha) &= \Pr(\gamma_{AR} > T) \\ &= \Pr\left(\sum_{i=1}^{N} \frac{P_R G_{R_i}(\theta) h_{R_i} d_i^{-\alpha}}{N_0} > T\right). \end{aligned} \tag{8}$$

3.2 Outage Probability

(1) Best RRH for transmission (BR) scheme: In this scheme, we choose the RRH with the best channel for transmission. Since we only consider the LOS propagation, the nearest RRH will be have best channel for transmission. The outage probability is defined as

$$P_{out} = \Pr[\log_2(1 + SINR) < \mathrm{R}]. \tag{9}$$

It can be thought of the probability that a user have not achieve a target rate. The outage event will occurs when all the RRH which has the best channel are in outages. Assume that the number of the RRHs in the circular region K is N, the outage probability for the typical user can be expressed as

$$\begin{aligned} P_{BR}(\mathrm{R}) &= \Pr(\log_2(1 + \gamma_{BR}) < \mathrm{R}) \\ &= \left(1 - \exp\left(-\frac{N_0}{P_{BR} G_{BR}(\theta)} \mathrm{d}^{\alpha}(2^R - 1)\right)\right). \end{aligned} \tag{10}$$

(2) All RRHs participate in transmission (ARP) scheme: In this scheme, all the RRHs in the circular region K are severed for a typical user. Therefore, the outage events occur when the overall rate from the RRHs is in outage. Assuming that all the N RRHs transmission the signal for the typical, the outage probability can be given as

$$P_{AR}(\mathrm{R}) = \Pr(\log_2(1 + \gamma_{AR}) < R). \tag{11}$$

4 Simulation Result

In this section, numerical simulation results are shown to corroborate the derived analytical results. We assume that the mm-Wave C-RAN is operated at the carrier frequency

30 GHz with transmit power $P_R = 30$ dBm and assigned 2 GHz of bandwidth to each user in this paper. The interference between RRHs are ignore due to the COMP adopted to this network. We consider a LOS only downlink transmission and the LOS path loss exponent considered to be $\alpha_{LOS} = 2$.

Figure 2 reveals the probability of coverage of both the best RRH transmission and all RRHs transmission schemes with varying the SINR threshold. It can be seen that the coverage probability of the BR and ARP schemes are decrease with increase SINR threshold. But the ARP scheme has higher coverage probability than the BR scheme. In mm-Wave C-RAN, since the interference between the RRHs can be mitigate due to the COMP technology. It worth to consider how many the number of the RRHs served a user can achieve an optimal effective in the network. We are not only consider the coverage and rate in one user, but also take account of the overall network performance. The density of the RRHs in a user-centric C-RAN would be further study in the future.

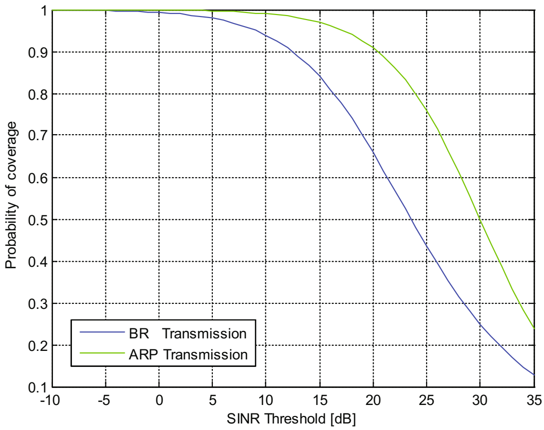

Fig. 2. SINR CCDF when $\lambda = 5 \times 10^{-5} \mathrm{m}^{-2}$.

Figure 3 show the effects of RRH density on coverage probability. We observe when more RRHs are deployed, there is a substantial increase in the coverage probability with both BR transmission scheme and ARP transmission scheme. However, the ARP transmission scheme always achieve higher coverage probability than the BR transmission scheme. In traditional cellular network, with the density of the BSs increased, the coverage probability will through an increased and then rapid due to the inter-tier interference between the BSs. In mm-Wave C-RAN, the interference between the RRHs can be mitigated by COMP, so increase the density can be greatly enhance system performance.

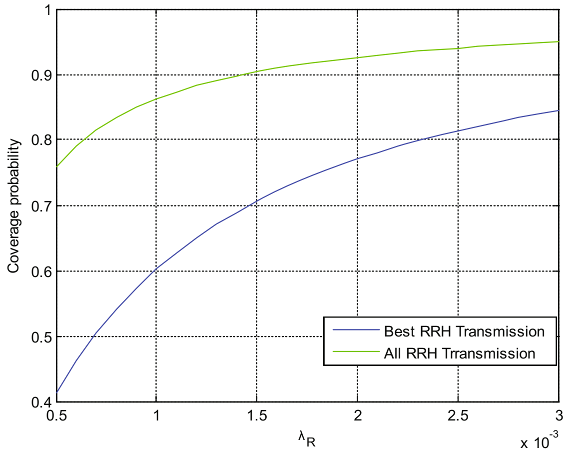

Fig. 3. Effects of density on coverage probability.

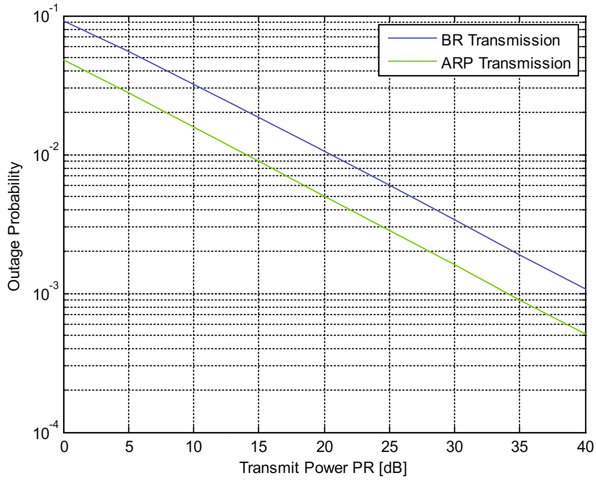

Fig. 4. Outage probability for BR and BRP scheme.

From the Fig. 4, we can see the tendency of outage probability of both transmission schemes with different transmission power. It reveals that the outage probability of both schemes show a decreasing trend with the increase transmission power. The outage probability of the ARP transmission scheme is lower compared to the BR scheme.

Figure 5 show the effect of RRHs density on outage probability. It is obvious that with more RRHs are deployed, there is a substantial decrease in the outage probability and the ARP scheme has a lower outage probability compared to BR scheme.

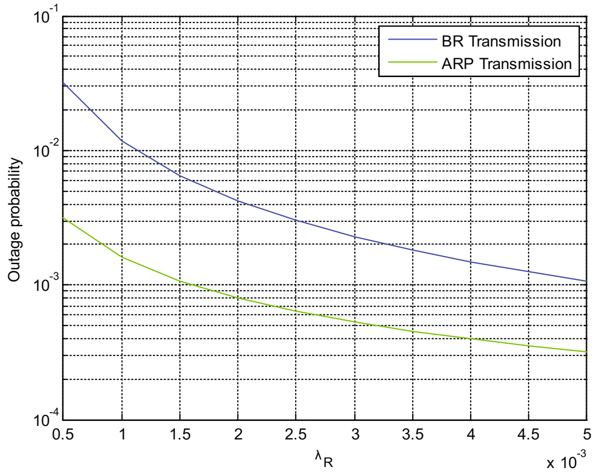

Fig. 5. Effects of density on outage probability.

5 Conclusions

In this paper, the downlink performance of mm-Wave C-RAN with different transmission schemes was investigated. We used a LOS circle concept that only consider the RRHs in the region transmission the information to a user. In this system, the performance of BP and ARP schemes were analyzed. We also derived the analytical expressions for the coverage probability and outage probability and it were validated through numerical simulation. As the result showed, that ignored the interference between the RRHs, the performance of the system will be highly increased and the ARP scheme was outperformed the BR scheme.

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