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Base Station Clustering in mmWave Cellular Networks with Self-Body Blocking

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ABSTRACT

This letter considers base station (BS) clustering in a downlink mmWave cellular system to overcome the self-body blocking. If the communication link is lost due to the body blocking, a user quickly reselects the BS whose signal power is strongest in the cluster to continue the communication. In this scenario, a network model built upon stochastic geometry is put forth to analyze the signal-to-noise (SNR) complementary cumulative distribution function (CCDF). The obtained expression is verified via simulation.

Key Words : Stochastic geometry, mmWave cellular networks, self-body blocking

Ⅰ. Introduction

Although the positive measurement results promise the feasibility of millimeter wave (mmWave) cellular networks, system-level performance evaluation is also required to investigate the potential of mmWave cellular networks rigorously. The performance evaluations based on numerical simulations[1], however, are often time-consuming and do not provide general insights regarding the effects of various system parameters. For this reason, stochastic geometry has been widely exploited as a tool for analyzing the system-level performance mathematically[2,3]. One missing point that has not been considered is the human body blocking, which occurs when a user blocks the signal by its body. In the measurements, it was shown that a human body heavily attenuates the mmWave signal power[4]. In addition to that, to cope with the body blocking is harder than other blockages since it occurs more frequently and in an unpredictable way.

In this letter, we consider BS clustering to overcome the self-body blocking in mmWave cellular networks. In the considered strategy, the BSs are included in the cluster if they located within a predefined range from a user. If the signal from the initially associated BS is lost due to the body blocking, a user quickly reselects the BS whose signal power is strongest in the cluster and continues the communication with it. In this scenario, a downlink mmWave cellular network model based on stochastic geometry is put forth to analyze the network performance. Specifically, the SNR CCDF of the considered clustering strategy is derived as a function of the relevant system parameters, e.g., line-of-sight (LoS) parameters, the BS density, and the cluster radius. The obtained analytical result is verifed via simulation. Our main finding is that the considered BS clustering can be a promising solution for the body blocking in mmWave cellular networks, while increasing the cluster size over a certain threshold is not efficient.

Ⅱ. System Model

A downlink mmWave cellular network is considered. The BSs are distributed according to a homogeneous Poisson point process, $\Phi = \{\mathrm{d}_k\}$ with density λ. Per Slivnyak's theorem, we focus on the typical user located at the origin. For modeling directionality of mmWave propagation, it is assumed that each BS and user have a single sectored antenna model.

To incorporate the peculiar propagation characteristic of mmWave signals, we adopt the LoS model used in [3]. In this model, a link of distance r is LoS with probability P_{L} if $r \leq D$ and 0

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otherwise. In addition to that, we also adopt the cone blocking model used in [4] for modeling the self-body blocking. In this model, a user's body blocks the signals coming within a certain angle θ_{BB}. For example, a user is at a direction ψ, the signals coming from $(\psi-\theta_{BB}/2, \psi+\theta_{BB}/2)$ are blocked. If the self-body blocking occurs, the signals are totally blocked, so that the user receives no signal. Unfortunately, the exact behavior of the self-body blocking may be hard to capture due to its time dynamics. To simplify this, we only focus on a network environment after the body blocking occurs, so that a user loses the signal of the initially associated BS. For analytical tractability, we assume the independence between networks before and after the body blocking occurs.

We consider the log-normal shadowing as mid scale fading and do not consider small scale fading. Denoting the power variation of an arbitrary link as H, the following is defined:

$$H=\begin{cases}10^{-\delta\xi_{\mathrm{L}}/10} \text{ if LoS} \\ 10^{-\delta\xi_{\mathrm{N}}/10} \text{ if NLoS}\end{cases} \qquad (1)$$

where δ follows the normal distribution. The path-loss exponent is defined as

$$L_{\alpha}(r)=\begin{cases}\alpha_{\mathrm{L}} \text{ if LoS} \\ \alpha_{\mathrm{N}} \text{ if NLoS}\end{cases} \qquad (2)$$

Combining (1) and (2), the channel of the link with the distance r is $Hr^{-L_{\alpha}(r)}$.

For BS clustering, the typical user forms a circle whose a radius is R_0 and a center is the origin. Then, the user connects to the BSs inside this circle; thereby the BS cluster is defined as $A=\{\mathrm{d_k} \mid \|\mathrm{d_k}\| \leq \mathrm{R_0}\}$. When the body blocking occurs so that the signal of the initially associated BS is lost, the user performs fast transition to another BS in the cluster A. Specifically, the user reselects the BS whose received power is strongest among the not blocked BSs in A, and continues the communication with the reselected BS. It is assumed that the user and the reselected BS match their beam directions by using beam alignment.

In [2,3], it was shown that the noise-limited approximation is accurate enough to evaluate the coverage performance of mmWave cellular systems. Motivated by these results, we also focus on the SNR of the typical user. Assuming that the user reselects the strongest BS in A, the SNR of the typical user is

$$SNR=\frac{H_0 \|d_0\|^{-L_{\alpha}(\|d_0\|)}}{\sigma^{2_{eff}}} \qquad (3)$$

where d_0 is the location of the reselected BS and $\sigma^{2_{eff}}$ means the effective noise that normalizes the reference path-loss, the transmit power and the antenna gain. The CCDF of (3) is defined as

$$F^c_{SNR}(\gamma)=P[SNR>\gamma] \qquad (4)$$

Ⅲ. Performance Analysis and Simulation Result

In this section, we present the main analytical results. The following analytical result is the main result of this section: When the body blocking angle is $(\psi-\theta_{BB}/2, \psi+\theta_{BB}/2)$, the SNR CCDF is obtained as

$$F^c_{SNR}(\gamma)=1-\exp(-\lambda\pi R_0^2 F^c_{SNR,Random}(\gamma)) \qquad (5)$$

where $F^c_{SNR,Random}(\gamma)$ is derived as

$$F^c_{SNR,Random}(\gamma)= \frac{2\pi-\theta_{BB}}{2\pi}\sum_{s=\mathrm{L,N}}\left(P_s\frac{1}{2}\mathrm{Erf}\left(\frac{-\frac{10}{\xi_s}\log_{10}\gamma\sigma^{2_{eff}}-10\frac{\alpha_s}{\xi_s}\log_{10}\mathrm{R}_0}{\sqrt{2}}\right)+1\right)+\frac{1}{\mathrm{T_s R_0^2}}\cdot 10^{\frac{10\log_{10}(\gamma\sigma^{2_{eff}})^{-1}}{5\alpha_s}} e^{\frac{(\xi_s\ln 10)^2}{50\alpha_s^2}}\mathrm{Erfc}\left(\frac{5\alpha_s\left(10\log_{10}(\gamma\sigma^{2_{eff}})^{-1}\right)+\xi_s^2\ln 10-50\alpha_s^2\log_{10}R_0}{5\sqrt{2}\,\xi_s\alpha_s}\right) \qquad (6)$$

where $T_s=1$ when $s=\mathrm{L}$ and $T_s=2$ otherwise. Due to space limitation, we provide a proof sketch for (5). We first consider the SNR CCDF for a randomly selected BS in the cluster under the assumption that $|A|=K$. If the selected BS has a LoS path, the SNR CCDF is derived as

$$F^{c}_{SNR,Random}(\gamma|\mathrm{LoS}) = \frac{2\pi-\theta_{BB}}{2\pi}\frac{1}{\sqrt{2\pi}}\int_{-\infty}^{-\frac{10}{\xi_{\mathrm{L}}}log_{10}\gamma\sigma^{2}_{\mathrm{eff}}}\int_{0}^{R_0} e^{-\frac{(x-10\log_{10}r^{\frac{\alpha_{\mathrm{L}}}{\xi_{\mathrm{L}}}})^2}{2}}\frac{2r}{R_0^2}\,\mathrm{d}r\,\mathrm{d}x \tag{7}$$

The SNR CCDF conditioned on that the selected BS has a NLoS path can be obtained in the similar fashion with (7). Combining the LoS and NLoS case, we have

$$F^{c}_{SNR,Random}(\gamma) = P_{\mathrm{L}}F^{c}_{SNR,Random}(\gamma|\ \mathrm{LoS}) + P_{\mathrm{N}}F^{c}_{SNR,Random}(\gamma|\ \mathrm{NLoS}) \tag{8}$$

Now we obtain $F^{c}_{SNR}(\gamma)$ by leveraging $F^{c}_{SNR,Random}(\gamma)$. Since the user connects to the BS whose link power is strongest, when there are K number of BS in th cluster, the corresponding SNR CCDF is obtained as

$$F^{c}_{SNR}(\gamma) = 1-(1-F^{c}_{SNR,Random}(\gamma))^{K} \tag{9}$$

Marginalizing (9) with K, we have

$$\begin{aligned} F^{c}_{SNR}(\gamma) &= 1-E_K[(1-F^{c}_{SNR,Random}(\gamma))^{K}] \\ &= 1-e^{-\lambda\pi R_0^2 F^{c}_{SNR,Random}(\gamma)} \end{aligned} \tag{10}$$

where the expectation is regarding a Poisson random variable with mean $\lambda\pi R_0^2$. This completes the proof.

Now we verify the obtained expression by comparing with the numerical results. For system setups, we assume the followings: the bandwidth is $W = 2\mathrm{GHz}$, the path-loss at the reference distance is $L_0 = 70\mathrm{dB}$, and the main lob gain is $M = 10\mathrm{dB}$. Incorporating these, the effective noise is calculated as follows.

$$\sigma^{2}_{\mathrm{eff}} = -204\mathrm{dB/Hz} + 10\log_{10}W + \mathrm{NoiseFig}(10\mathrm{dB}) - L_0 - P - M \tag{11}$$

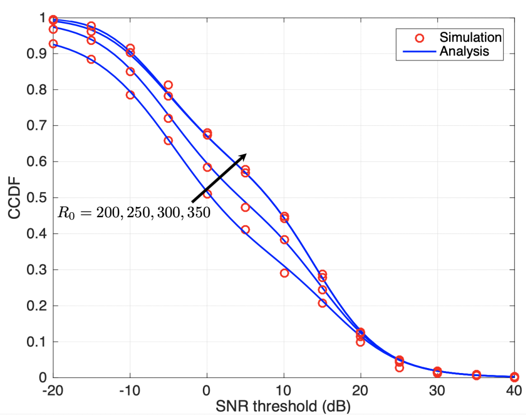

Fig. 1. Comparison of the SNR CCDF obtained by the analysis and the numerical simulations. The simulation paramters are: $\alpha_{\mathrm{L}} = 2, \alpha_{\mathrm{N}} = 3.3$, $\xi_{\mathrm{L}} = 5.2, \xi_{\mathrm{N}} = 7.6$, and also $D = 300, \theta_{BB} = 90°$. The density is $0.0001/\pi$.

As shown in Fig.1, the SNR CCDF obtained by the analysis and the numerical simulation are well matched. As the cluster radius increases, the SNR CCDF improves, while increasing the cluster radius over a certain threshold (e.g., 300 in this simulation) is not helpful.

Ⅳ. Conclusions

By modeling a downlink mmWave network with PPP, we obtained the SNR CCDF as a function of the relevant system parameters. As the cluster radius increases, the probability of finding a strong BS increases. Our major finding is that BS clustering is able to resolve the body-blocking in mmWave cellular networks, while increasing the cluster size over a certain threshold is not efficient.

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