3D 공간 전파 모델 기반 밀리미터파 통신채널 용량 분석

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Capacity Analysis for mmWave Communication Systems Based on 3D Spatial Propagation Models

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요 약

We present the capacity analysis of the millimeter Wave (mmWave) systems in a realistic 3-dimensional spatial channel model (3D-SCM) provided by the third-generation partnership project (3GPP). With the consideration of analog elevation beamforming in 3D Urban Micro Streat Canyon (UMi-Street Canyon) environment, capacity comparisons are performed considering mmWave frequencies. In particular, several factors such as rand and gas losses are analyzed, which have significant effects on channel capacity for high frequency communications.

I. 서론

Millimeter wave (mmWave) has proven to be a promising solution in meeting the capacity demands. However, these signals experience a significant path-loss in free space and cannot propagate longer distances with the conventional techniques.

This weakness can be overcome by deploying a large number of antennas. Due to the smaller size of antennas, many antennas can be compensated in a small area. However, one cannot use simply conventional digital beamforming techniques for multilayer communication due to increase in hardware complexity. To obtain efficient multi-stream performances, hybrid beamforming structures have been introduced [1], [2].

One such type is full-dimensional MIMO (FD-MIMO) that provides a practical solution to the space limitation issue in very large scale uniform linear arrays used in earlier base stations (BS) [3]. Hence, the mmWave can be combined with FD-MIMO that utilizes uniform rectangular array (URA) instead of uniform linear arrays (ULA) [4]. Therefore, mmWave based FD-MIMO systems will be able to efficiently meet the demands of future sixth generation (6G) services.

In this paper, we introduce mmWave systems based on FD-MIMO and analyze the sum rate performances by introducing the several additional loss components that become significant under high frequency regime. Also, the effect of increasing the elevation dimension elements is analyzed and the feasibility of FD-MIMO is discussed for future mmWave systems.

II. 본론

A downlink single user multiple input multiple output (MIMO) system is considered in which a base station (BS) equipped with $\mathrm{M}=\mathrm{M_Y}\mathrm{M_Z}$ active antenna system (AAS) is serving a user equipment (UE) with $\mathrm{N}=\mathrm{N_Y}\mathrm{N_Z}$ antenna array system (AAS) placed along yz-plane. The BS performs hybrid beamforming with $\mathrm{M_Z}$ antennas forming a ULA in the vertical direction forming a single RF chain. The UE on the other end is based on one element per RF chain. It is assumed that the channel is unknown to the BS transmitter.

The signal received at the UE is given by

$$\mathbf{y}=\sqrt{\rho}\,\mathbf{F_D}\mathbf{H}\mathbf{F_A}\mathbf{s}+\mathbf{F_D}\mathbf{n} \qquad (2.1)$$

where $\mathbf{y}\in\mathbb{C}^{\mathrm{N}\times 1}$ and $\mathbf{H}\in\mathbb{C}^{\mathrm{N}\times\mathrm{M}}$ is the channel, $\mathbf{s}\in\mathbb{C}^{\mathrm{M_Z}\times 1}$ is the transmitted symbol vector taken from i.i.d. source which follows $\mathcal{CN}(0,\mathbf{I}_{\mathrm{M_Z}})$ and $\mathbf{n}\in\mathbb{C}^{\mathrm{N}\times 1}$ is the circularly symmetric complex Gaussian (CSCG) noise vector with mean $\mathbf{0}$ and covariance matrix $\sigma_n^2\mathbf{I}_\mathrm{N}$. $\mathbf{F_D}\in\mathbb{C}^{\mathrm{N}\times\mathrm{N}}$ and $\mathbf{F_A}\in\mathbb{C}^{\mathrm{M}\times\mathrm{M_Z}}$ are the digital and analog beamforming matrices respectively. ρ is the transmit power divided equally among N streams such that $\rho = \frac{\mathrm{P}}{\mathrm{N}}$. The analog beamforming is performed at the transmitter and can be defined as

$$\mathbf{F}_{\mathrm{A}} = \mathbf{I}_{\mathrm{M_Z}} \otimes \mathbf{w}_{\mathrm{tilt}} \qquad (2.2)$$

where $\mathbf{I}_{\mathrm{M_Z}} \in \mathbb{C}^{\mathrm{M_Z \times M_Z}}$ is the identity matrix and $\mathbf{w}_{\mathrm{tilt}} \in \mathbb{C}^{\mathrm{M_Y \times 1}}$ is the common beamsteering vector of each of the stacked ULA along y-axis and each entry of this vector can be defined as

$$w_m = \exp\left(\frac{2\pi}{\lambda} \mathrm{d_v}(\mathrm{m}-1)\cos(\theta_{\mathrm{tilt}})\right),$$
$$m = 1,2,\dots,\mathrm{M_Z}.$$

θ_{tilt} is the elevation angle that can be steered in the desired direction. As there is no channel state information at transmitter, so digital zeroforcing beamforming is implemented at the receiver denoted by $\mathbf{F}_{\mathrm{D}}$ end that is defined as

$$\mathbf{F}_{\mathrm{D}} = \widetilde{\mathbf{H}}^{\mathbf{H}}\left(\widetilde{\mathbf{H}}\widetilde{\mathbf{H}}^{\mathbf{H}}\right)^{-1} \qquad (2.3)$$

where $\widetilde{\mathbf{H}} = \mathbf{H}\mathbf{F}_{\mathbf{A}} \in \mathbb{C}^{\mathrm{N \times M_Z}}$ is the effective channel matrix.The sumrate can be calculated as

$$\mathrm{C} = \sum_{\mathrm{i}=1}^{\mathbf{N}} \log\left(1 + \frac{\mathrm{P}}{\mathrm{N}\sigma_n^2 \|\mathbf{f}_{\mathrm{i}}\|^2}\right) \qquad (2.4)$$

where $\mathbf{f}_{\mathrm{i}}$ is the ith row vector of $\mathbf{F}_{\mathrm{D}}$.

We consider a urban Micro (UMi) street canyon scenario with a clustering based ray tracing 3D channel model defined by third-generation partnership project (3GPP) document TR38.901 [5]. The extensive simulations are performed for various frequencies considering the path-loss models defined by [6], [7], [8]. For the sake of comparison, the bandwidth is fixed as 100MHz in all cases. Fig. 1 shows the variation on sum rate with UE distance from the BS under certain path-loss conditions. The elevation is assumed to be pointing towards the UE. One can see that while increasing the element size along the individual ULA increases the sumrate when moving away from the BS. Also, at higher frequencies, the effect of rain and gases becomes prominent that must be considered while designing the mmWave based systems.

Fig. 2 shows the average sum rate when the UE is deployed randomly in a cell considering the fixed elevation angle of 100^{o}. Here, the effects of rain and gases are analyzed. It can be seen that the effect of rain is more prominent than the gas effect that affect significantly average sum rate of the overall system.

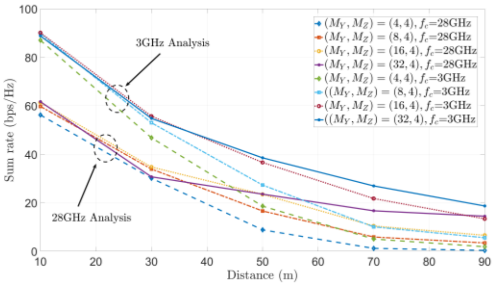

Fig. 1 Sum rate comparison for 3GHz and 28Ghz frequencies with the UE distance.

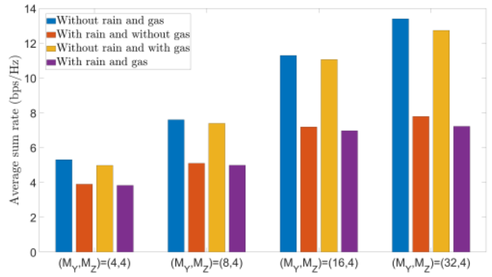

Fig. 2 Effects of rain and gas losses for 28GHz frequency on average sum rate performance.

ACKNOWLEDGMENT

This work was supported by the Institute of Information & Communications Technology Planning & Evaluation (IITP) grant funded by the Korean government (MSIT) (2021-0-00749, RF Performance Verification Platform Development for 5G+ Communication System).

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