Hybrid Beamforming-based Beam Tracking using Angular speed in Massive MIMO Systems

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***Abstract*— This paper proposes an angular speed 3D-based beam tracking method using hybrid beamforming. We propose a new beam tracking algorithm that enables dynamic pilot insertion based on closed loop feedback control by utilizing the Line of Sight (LoS) path of the channel between T-BS and UAV-UE. Simulations show that the proposed beam tracking method has improved overall performance in terms of beamforming gain and spectral efficiency (SE).**

***Keywords*— 3D beam tracking; hybrid beamforming; multiple-input multiple-output; orthogonal frequency division multiplexing.**

I. INTRODUCTION

Unmanned Aerial Vehicle (UAV) is attracting attention as one of the key elements of 5G New Radio (NR) systems because it can overcome the limitations of ground networks due to its high altitude, flexibility, and mobility. In addition, multiple-input multiple-output (MIMO) technology, which uses multiple antennas to increase data transmission and reception efficiency, is also one of the promising technologies that support high data rates in NR MIMO-OFDM systems [1], [2]. However, short wavelengths due to high frequencies of millimeter waves cause problems such as signal attenuation and path loss, and interest in research on high-directional beamforming technology is growing to compensate for this, and when considering the full beamforming gain and high mobility of UAVs, it is essential to obtain an accurate beam angle. The composition of the paper is as follows. Chapter II defines the system model and introduces the applied channel model. Chapter III introduces a 3D-based beam tracking method using hybrid beamforming, and Chapter IV evaluates performance through simulation environments and simulation results. Finally, we conclude in Chapter V.

II. SYSTEM MODEL AND CHANNEL MODEL

In this paper, we consider a downlink NR MIMO-OFDM system where one Terrestrial-Base Station (T-BS) serves a number of Unmanned Aerial Vehicle-User Equipment (UAV-UE) as shown in Fig. 1.

The proposed algorithm can be applied to UPA in any direction. At time t, if the coordinate of UAV-UE is represented by $[X(t), Y(t), Z(t)]$, the distance between UAV-UE and the z-axis can be represented by $[X(t)^2, Y(t)^2, Z(t)^2]$, and the distance between UAV-UE and T-BS can be represented by $D(t) = \sqrt{X(t)^2 + Y(t)^2 + Z(t)^2}$. The angular velocities of the UAV-UE are then given as $v_\theta(t) = \frac{d\theta(t)}{dt}$ and $v_\phi(t) = \frac{d\phi(t)}{dt}$, respectively, which can be characterized by the instantaneous rate of change of the zenith and azimuth angles.

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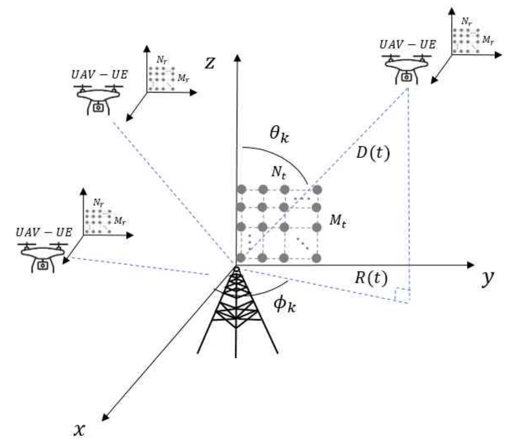

Fig. 1. UAV-UE communication with UPA for 3D beamforming on T-BS and UAV-UEs.

In this study, most of the millimeter wave frequency signals are signal loss caused by obstacles such as buildings and people. As a result, most of the signal power from T-BS to UAV-UE reaches the LoS path [3], [4]. In the NR MIMO-OFDM communication system of this paper, we consider a Rician fading channel model for communication between UAV-UE and service T-BS, assuming that UAV-UE is serviced by T-BS with LoS paths by utilizing macro diversity. When the antenna array response vector $a(\theta, \phi)$ is applied, the channel may be expressed as follows (1).

$$h_l = \sqrt{\frac{\rho_0}{d_l^{\alpha}}}\left(\sqrt{\frac{K}{K+1}}h_l^{bs} + \sqrt{\frac{1}{K+1}}h_l^{nbs}\right),$$
$$l = 0, \ldots, L-1 \quad (1)$$

III. 3D-BASED BEAM TRACKING METHOD USING HYBRID BEAMFORMING

Beamforming technology is divided into analog beamforming and fully digital beamforming, and hybrid beamforming using these two [5]. the beamforming configuration is divided into two parts, analog and electronic, and hybrid beamforming, which applies the advantages of the two methods, is applied to the system. The hybrid precoding structure applied in this paper is shown in Fig. 2.

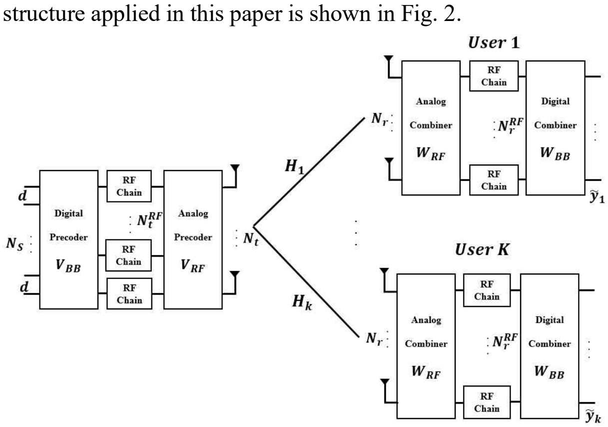

Fig. 2. Hybrid precoding structure.

After estimating $(\theta_{l_1}^t, \phi_{l_1}^t, \theta_{l_1}^r, \phi_{l_1}^r)$ and $(\theta_{l_2}^t, \phi_{l_2}^t, \theta_{l_2}^r, \phi_{l_2}^r)$, the predicted values of AOD and AOA are $\hat{v}_\theta = \frac{\hat{\theta}_{l_2} - \hat{\theta}_{l_1}}{(l_2 - l_1)T_v}$ and $\hat{v}_\phi = \frac{\hat{\phi}_{l_2} - \hat{\phi}_{l_1}}{(l_2 - l_1)T_v}$, respectively. On the basis of these values, $\hat{\theta}_l = \theta_{l_2} + (l - l_2)\hat{v}_\theta$ and $\hat{\phi}_l = \phi_{l_2} + (l - l_2)\hat{v}_\phi$ can be obtained by using a linear variation model in the period where $l > l_2$. However, because the direction and speed of movement of the UAV-UE can change after T_v , $(\theta_l^t, \phi_l^t \theta_l^r, \phi_l^r)$ becomes increasingly inaccurate over time, which can reduce beamforming gains. To solve this problem, we propose a closed-loop feedback control method based on power measurements received from the UAV-UE.

A flowchart of the proposed 3D beam tracking algorithm is presented in Fig. 3.

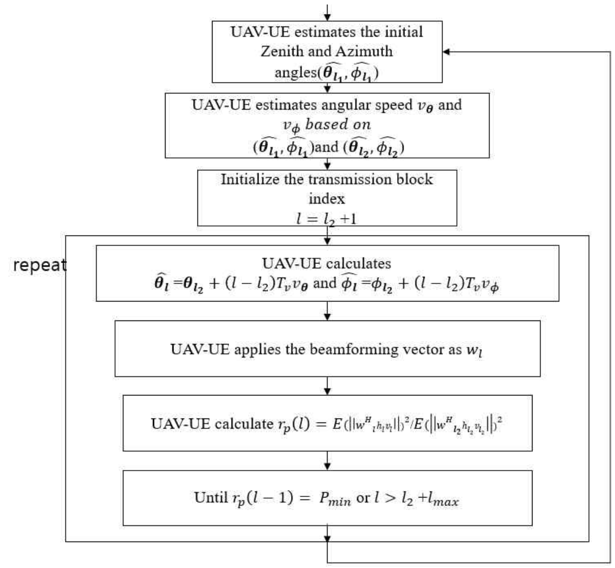

Fig. 3. Hybrid Beamforming-based Beam Tracking algorithm using Angular speed.

IV. SIMULATION RESULTS

Table I. Simulation parameter.

Parameter	Value
Carrier frequency (GHz)	30
Bandwidth (MHz)	100
Sub-Carrier Spacing (kHz)	60
Cyclic Prefix	Normal CP
Modulation	QPSK
T-BS Antenna array	$UPA : 8 \times 8$
UAV-UE Antenna array	$UPA : 4 \times 4$
Transmitter RF chain number	4
Receiver RF chain number	4
Antenna Spacing (λ)	0.5
Number of UAV-UE	2
P_{min}	0.8
$l_{max} (ms)$	1000

A. Simulation setup

In this simulation, we consider a quasi-static mobility model for UAV-UE, where UAV-UE randomly changes the direction and speed of movement every second. The maximum speed of the UAV-UE is assumed to be 160 km/h, and the minimum speed is assumed to be 40 km/h. The initial coordinate of the UAV-UE proceeds in (r_0, 0, 100) m. In addition, K = 15 dB is set, and the time interval between and proceeds to 100 (ms). Table. 1 shows the simulation system parameters and simulations are conducted based on the NR MIMO-OFDM system that supports NR downlink UAV. The system was configured to have a system bandwidth of 100 MHz in a frequency band of 30 GHz.

B. Performance Evaluation

The case of using analog beamforming and the case of using hybrid beamforming are compared and analyzed to evaluate the performance improvement of the proposed technique. Average normalized beamforming gain G_{BF} and spectral efficiency (SE) are used as performance indicators. Also, in case G_{BF}, it is calculated as shown in (2).

$$G_{BF} = E\left(\frac{\left\|w_l^H h_l v_l\right\|^2}{\left\|h_l v_l\right\|^2}\right) \tag{2}$$

Fig. 4 presents the simulation results and compares the performances of the beamforming techniques used herein. When 3D beam tracking was performed using the hybrid beamforming technique proposed herein, the G_{BF} performance improved compared to that when using analog beamforming. In addition, as r_0 increased, the pilot reception SNR of the UAV-UE worsened. This implies that when analog beamforming was applied, performance decreased greatly, while with hybrid beamforming, the degradation was not considerable.

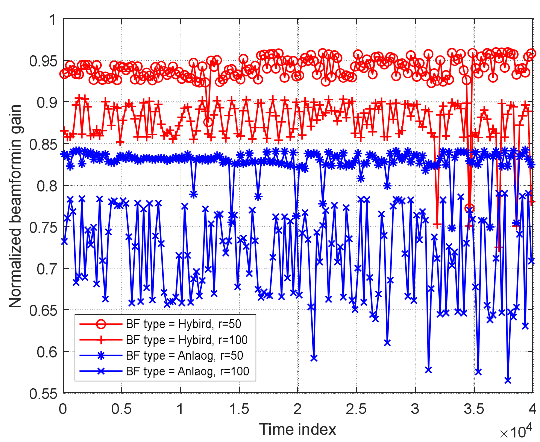

Fig. 4. Comparison of 3D beam tracking performance according to Beamforming Type ($\mathbf{G_{BF}}$).

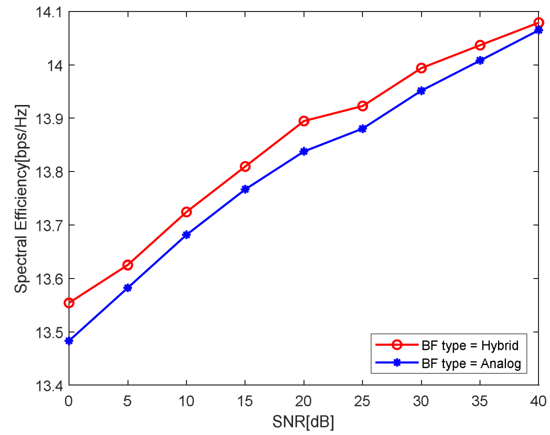

Fig. 5. Comparison of 3D beam tracking performance according to beamforming type (Spectral Efficiency).

Fig. 5 show the spectral efficiency according to analog beamforming and hybrid beamforming techniques, and the performance of hybrid beamforming is improved compared to that of analog beamforming.

V. Conclusion

This paper proposed a 3D beam tracking method using hybrid beamforming in a UAV-enabled NR MIMO-OFDM system. The proposed algorithm is an efficient beam tracking method that reduces pilot overhead using feedback loops using received power. In addition, by utilizing hybrid beamforming, existing algorithms limited to single users, single streams can be applied to multi-user, multi-stream environments, increasing data capacity and increasing utilization in 5G systems. Simulation results confirm that the proposed algorithm can reduce pilot overhead and track accurate channel angles with high spectral efficiency in transceivers.

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