

Network Parameter Evaluations for Cellular-Connected UAV Communications

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Abstract—This paper investigates the performance of unmanned aerial vehicle (UAV) communication systems served by cellular base station (BS). In particular, we analyze the impact of network parameters such as inter-site distance (ISD) and the mechanical tilt angle of BS antenna panels. A standards-based system-level simulator (SLS) is used to evaluate the performance while considering inter-cell interference (ICI), which becomes more significant at higher UAV altitudes due to the dominant line-of-sight (LoS) links. Experiment results show that the optimal ISD and tilt angle vary depending on the UAV altitude, indicating the need for joint optimization of ISD and tilt angle to enhance communication performance.

Index Terms—Unmanned aerial vehicle (UAV), system-level simulator (SLS), inter-cell interference (ICI), network parameter.

I. INTRODUCTION

Unmanned aerial vehicles (UAVs), commonly called drones, play a crucial role in enabling three dimensional (3D) connectivity and have gained significant attention in the 5G and 6G eras. UAVs serve important functions in various use cases and scenarios, which has led to active research on UAV communication systems. In wireless communications, UAV based communication where UAVs act as communication nodes makes it possible to achieve 3D coverage in the millimeter wave (mmWave) frequency band [1].

Among different deployment methods, using existing cellular infrastructure is regarded as one of the most promising approaches due to its cost efficiency, high reliability, and provision of high-speed backhaul links [2]. This scenario is known as cellular-connected UAVs, where mission driven UAVs are integrated into current cellular networks and operate as aerial user terminals.

Unlike conventional ground terminals, UAVs can operate at altitudes of several kilometers [3]. Accordingly, while antenna panels of existing base station (BSs) are typically down-tilted toward the ground, UAV communication systems require up-tilted antenna panels. In addition, the inter-site distance (ISD) between BSs must be adjusted based on the UAV altitude. Both the antenna panel angle and the ISD jointly

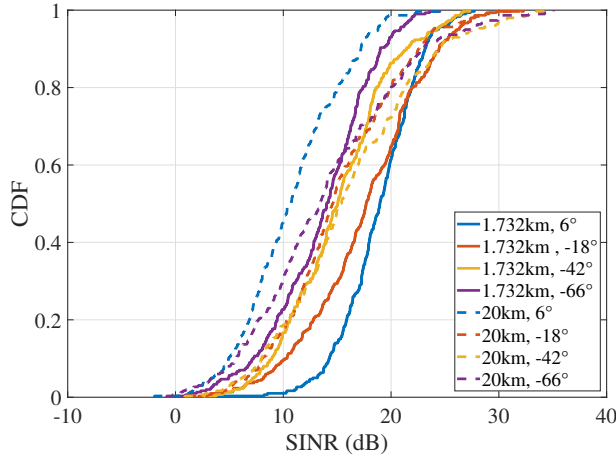
affect the inter-cell interference (ICI) pattern. Therefore, this paper aims to analyze how these network parameters impact UAV communication performance through a standard-based calibrated system-level simulation.

II. SYSTEM MODEL

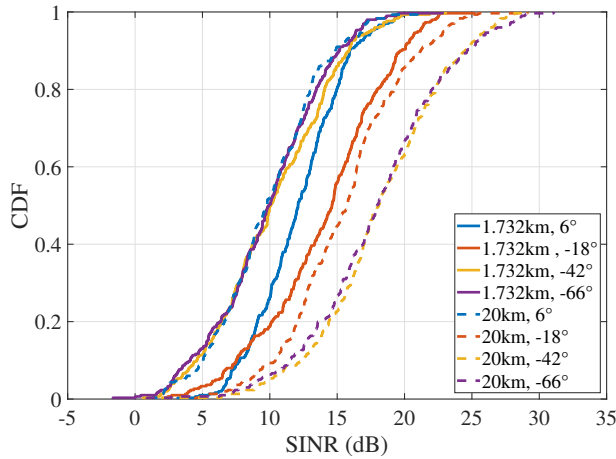
Given the strong line-of-sight (LoS) conditions typical in UAV networks, which are much more dominant than in terrestrial systems, ICI from neighboring BSs becomes a critical factor in the performance. In particular, changes in network parameters significantly impact performance by altering the ICI pattern. Therefore, a system-level simulator (SLS) is used to evaluate the performance of large-scale networks composed of BSs and UAV. We employ a SLS developed based on the 3GPP standard. The performance is evaluated across various UAV altitudes, considering changes in the BS antenna panel tilt angle and ISD.

The channel between the BSs and UAV is modeled based on 3GPP TR 36.777 and TR 38.901 [4], [5], which specify the channel parameters for UAV and New Radio (NR) scenarios, respectively. We consider a scenario in which a network composed of hexagonally arranged terrestrial BSs on a two-dimensional plane supports UAVs at a specific altitude. The network consists of a total of 57 BSs, where one site is divided into three sectors and is surrounded by two tiers of neighboring sites. Each UAV communicates with the serving BS that provides the strongest received signal power and, as a result, receives interference from a total of 56 neighboring BSs. We assume a rural macro aerial vehicle (RMa-AV) scenario. Specific parameters are as follows. The carrier frequency and bandwidth are set to 28 GHz and 100 MHz, respectively. The BS antenna is configured as a uniform planar array (UPA) with $(M, N, P) = (16, 16, 2)$, where M and N represent the antenna number of rows and columns, and P denotes the number of polarizations. Directional antennas with 8 dBi gain are used. The UAV antenna configuration is $(M, N, P) = (2, 2, 2)$. The UAV's antenna panel is oriented toward the ground. All BSs are equipped with antenna panels with the same angle. In the existing TR 36.777, a 6° down-tilted antenna panel and an ISD of 1.732 km are configured to support both ground user terminal and UAVs simultaneously. We evaluate the performance of high-altitude UAV communi-

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(a)



(b)

Fig. 1. SINR performance with respect to ISD and mechanical tilt angle; (a) UAV at 5 km. (b) UAV at 10 km.

cation by employing up-tilted antenna panels and increasing the ISD.

III. NUMERICAL RESULTS

Fig. 1 illustrates the SINR performance for ISDs of 1.732 km and 20 km, and mechanical tilt angles of 6° , -18° , -42° , and -66° . In Fig. 1 (a) and Fig. 1 (b), the UAV altitude is fixed at 5 km and 10 km, respectively. A mechanical tilt angle closer to -66° indicates that the BS antenna panel is more up-tilted, pointing toward the sky. As shown in the figure, when the UAV altitude is 5 km, the configuration defined in 3GPP TR 36.777, which uses an ISD of 1.732 km and a tilt angle of 6° , provides high SINR performance. However, when the UAV altitude increases to 10 km, a different configuration yields better performance. Specifically, at an altitude of 10 km, the highest average SINR is achieved when the ISD is 20 km and the tilt angle is -42° . This implies that a larger up-tilt angle is not always optimal, since excessively up-tilted

antennas can increase ICI. Furthermore, even with the same ISD, SINR performance varies depending on the BS antenna tilt angle, and performance also changes across different ISD values under a fixed tilt angle. These findings highlight the need for joint optimization of ISD and mechanical tilt angle in UAV communication systems.

IV. CONCLUSION

This paper has evaluated the SINR performance of UAVs based on ISD and the mechanical tilt angle of BS antenna panels using a standard-based SLS that has considered ICI. Simulation results have shown that the optimal ISD and tilt angle vary depending on the UAV's altitude. Additionally, it has been observed that high-altitude UAVs experience performance degradation when served by BS configurations originally designed for ground terminals. These findings have highlighted the necessity of jointly optimizing ISD and mechanical tilt angles for UAV communication systems.

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