Performance Analysis of Multiple High Altitude Platform Stations Cellular Network Coverage

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***Abstract*—The High Altitude Platform Station (HAPS) provides communication services within the stratosphere at an altitude ranging between 20 - 50 km. Utilizing the stable atmospheric conditions of the stratosphere, HAPS offers communication services over extensive areas while facilitating effective communication in line-of-sight (LoS) environments. This paper focuses on the analysis of HAPS cell coverage in a 3GPP standard based cellular communication network where multiple HAPS served as base stations based on the signal-to-interference-plus-noise ratio (SINR). Specifically, the study concentrates on whether user equipment (UE) positioned at the cell edge of the central HAPS maintains a downlink (DL) SINR above a certain threshold. Simulation results show that multiple HAPS 7-cell scenario coverage is achieved at 400 km^2 and multiple HAPS one-cell scenario coverage is achieved at 230 km^2.**

***Index Terms*—HAPS, SINR**

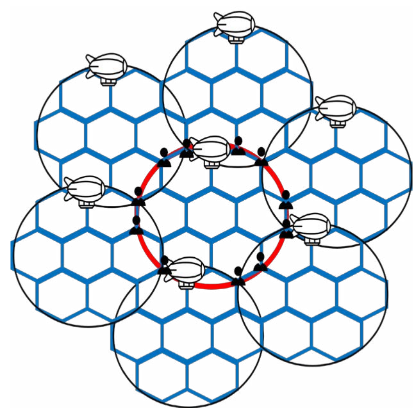

Fig. 1. Multi HAPS Cellular Network Scenario.

I. Introduction

The number of devices in cellular networks is continually increasing year by year. By 2050, networks are projected to expand to hundreds to thousands of exabytes (EB), facing the challenge of processing ever-larger volumes of data at faster speeds. Furthermore, despite the growing demand for mobile broadband connectivity, a significant portion of the global population still lacks access to available communication services. In response to these challenges, research is underway on the development of 6G communication networks [1]. High-altitude platform stations (HAPS), positioned in the stratosphere at altitudes between 20 - 50 km, offer the benefits of stable communication and flexible deployment. Due to these advantages, significant ongoing research into using HAPS as an alternative to terrestrial base stations, aiming to provide coverage to numerous devices [2] - [4]. In [2], the authors are to mitigate co-channel and adjacent channel interference (ACI) within the 2.6 GHz time division duplex (TDD) band. In [3], the authors analyze bent-pipe and regenerative HAPS architectures for both single-cell and multi-cell scenarios. The authors use genetic algorithms (GA) to efficiently determine the optimal combination within a feasible time frame. The authors of [4] analyze how to optimize cell configuration for HAPS mobile communication that can be adapted to any number of cells. However, since these studies are not based on the 3rd generation partnership project (3GPP) standard, a multitude of studies are considering the concurrent usage of HAPS and terrestrial base stations to efficiently handle the surge in traffic demands. Thus this paper delves into the performance analysis of cellular network coverage, harnessing the potential of multiple HAPS. Our analysis is centered on the achievement of a minimum SINR threshold by UE positioned at the edges of HAPS cells. We adopt the well-established 3GPP standard antenna patterns and channel models to assess HAPS coverage comprehensively. Additionally, the paper explores scenarios featuring single-cell and multi-cell HAPS configurations, to thoroughly evaluate and compare interference power levels.

II. System model

In this section, we define a system model as depicted in Fig. 1. We assume that the number of HAPS is $H = \{h_c, h_1, h_2, ...h_i\}$. Configuration involving HAPS, comprising a central HAPS referred to as h_c, and the HAPS surrounding the central HAPS is denoted as h_i. As depicted in Fig. 1, we examined two scenarios: the first scenario entails each HAPS covering a single cell, while the second scenario involves 7 cells being covered by each HAPS. These cells are denoted as $C = \{c_1, c_2, .., c_j\}$. In both of these scenarios, HAPS was positioned at an altitude of 20 km to ensure central deployment within the designated cell, while UEs, denoted as $u = \{u_1, u_2, ...u_k\}$, were strategically placed around the exterior periphery of the central HAPS cell at an elevation of 1.5 m. Cell coverage is determined through downlink (DL) calculations. Therefore, the primary focus of this study lies in

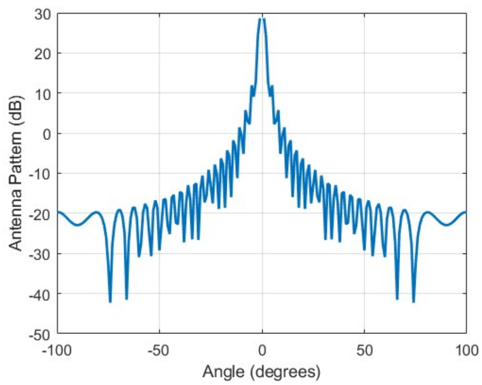

Fig. 2. 3GPP antenna pattern of HAPS

the DL scenario. The evaluation of coverage involved conducting measurements of the SINR. For the SINR analysis, mean SINR values were calculated for UEs associated with each HAPS, covering either a single cell or 7 cells. Additionally, the SINR of the UE located farthest from the central HAPS was scrutinized in cases where the HAPS covered 7 cells.

III. Antenna pattern

In this paper, the antenna patterns specified in 3GPP TR 38.811 [5] were employed. These patterns $G(\theta)$ are calculated as eq. (1).

$$G(\theta) = \begin{cases} 1 & \text{for } \theta = 0 \\ 4\left|\frac{J_1(ka\sin\theta)}{ka\sin\theta}\right|^2 & \text{for } 0^\circ < |\theta| \leq 90^\circ \end{cases} \quad (1)$$

where J_1 denotes the Bessel function of the first kind with an argument x. The parameter a corresponds to the radius of the circular aperture of the antenna, while k represents the wave number. The eq. (1) is given by $2\pi f/c$, where f represents the frequency of 2 GHz, and c denotes the speed of light. In this context, θ signifies the angle between the cell's boresight and the UE's direction. The normalized gain pattern is calculated for a equal to $10c/f$. Fig. 2 shows an example of an antenna pattern

IV. Channel model

In this paper, we consider the channel model between the HAPS and the UE based on the free space path loss (FSPL). Additionally, our analysis incorporates a range of LoS and NLoS probabilities, accounting for different environments like urban, suburban, and rural scenarios. Specifically, this study focuses on an urban environment. The path loss (PL_b) is calculated by eq. (2).

$$PL_b = FSPL(d, f_c) + CL(\alpha, f_c) + SF, \quad (2)$$

where f_c was set to a frequency of 2 GHz and d is the distance between the central HAPS and the i-th UE. To accurately calculate the associated path loss for each scenario, clutter loss, and shadow fading were determined by the angle between the central HAPS and the individual UE. The SNR of u_i in the cell C_j in the central HAPS can be calculated as eq. (3).

$$SNR_{h_c,C_j,u_i} = RSSI - \text{noise}, \quad (3)$$

The received signal strength indicator (RSSI) is calculated as eq. (4).

$$RSSI = \text{EIRP}{-}PL_b + G, \quad (4)$$

where G is denoted as an antenna gain.

The noise power in dB (σ^2) is calculated as follows eq. (5).

$$\sigma^2 = -174 + BW + NF, \quad (5)$$

where bandwidth (BW) is set to 18 MHz and a noise figure (NF) of -5 dB, we proceed to compute the SNR, which subsequently facilitates the calculation of the SINR. In the context of a single HAPS, the computation of interference encompasses considering interference originating from all cells apart from its cell. In the scenario with 7 HAPS and a cumulative total of 48 cells, interference assessment involves accounting for interference from all cells of the other HAPS, excluding the cell under consideration. The cumulative interference power for the k-th UE associated with the c_k-th cell of the h_k-th HAPS is calculated by eq. (6) as follows [4].

$$I_k = \sum_{j=1, j\neq c_k}^{N_{cell}} R_{k,c_j,h_k} + \sum_{i=1, i\neq h_k}^{N_{HAPS}} \sum_{j=1}^{N_{cell}} R_{k,c_j,h_i}, \quad (6)$$

where R_{k,c_j,h_k} is the received power from the k-th UE located in the c_j-th cell of the h_k-HAPS configuration, excluding its own cell. Additionally, the variable R_{k,c_j,h_i} denotes the received power from the k-th UE to the j-th cell of the i-th HAPS configuration, excluding the HAPS and cell to which the UE belongs. For the k-th UE, $N_{HAPS} \times N_{cell}$ values are computed, where N_{HAPS} represents the number of HAPSs and N_{cell} denotes the number of cells in a HAPS. The cell to which the k-th UE is connected is identified as the cell with the highest received level among $N_{HAPS} \times N_{cell}$ cells. The summation encompasses interference originating from all N_{cell} cells and N_{HAPS} HAPS, excluding the cell to which the UE is associated. The variables R_{k,c_j,h_k} and R_{k,c_j,h_i} pertain to DL signals. The SINR is determined by subtracting the interference received from all cells except the UE's cell from

TABLE I
Simulation Parameters

	HAPS	UE
Frequency	2 GHz	
Bandwidth	18 MHz	
Altitude	20 km	1.5 m
Transmission power	43 dB	-
Antenna gain	-	-3 dBi
Noise figure	-	5 dB
Propagation	Free space loss	

the SNR value, as described in the equation. The SINR is calculated as eq. (7).

$$SINR = \frac{R_{k,c_k,h_k}}{\sigma^2 + I_k}. \quad (7)$$

V. Performance Evaluation

In this paper, a configuration is considered where a total of 7 HAPS operate in a circular flight pattern at an altitude of 20 km, utilizing beamforming techniques to maintain a consistent distance between the HAPS and cellular cells. UEs are strategically positioned around the exterior periphery of the central HAPS cell at an elevation of 1.5 m, comprising a total of 6 UEs. To establish coverage, previously calculated SINR values are utilized. Within the hexagonal coverage area of the central HAPS, the 6 UEs are positioned at the cell edges. SINR measurements lead to the calculation of average SINR values for the UEs. Moreover, within the context of the 7-cell configuration, the SINR of the UE positioned farthest among the 7 HAPS placements is analyzed.

Through the simulation, we conducted SINR measurements by altering the coverage area of the HAPS in scenarios featuring both single and 7 cells. Additionally, we delved into the influence of coverage radius by examining the area where UEs near the cell encounter SINR levels nearing -7 dB. The antenna gain diminishes as the distance increases and path loss lessens with greater distances. With the expansion of coverage, interference reduces owing to the increased separation from neighboring cells. Fig. 3 shows that illustrate SINR variations based on coverage for UE, positioned both at the cell edge of the central HAPS in the 7-cell configuration and the UE farthest from the center. A noticeable drop in SINR occurs around 500 km^2, primarily attributed to the combined impact of interference and antenna gain. As coverage expands, interference diminishes, yet antenna gain also declines, leading to a gradual SINR reduction. Fig. 4 shows SINR based on coverage for the one-cell HAPS scenario. The antenna's radiation pattern, originating solely from the center, closely resembles the antenna gain graph. While specific setups fulfill SINR requirements before reaching around 240 km^2, SINR consistently decreases with increased distance. In the 7-cell HAPS scenario, the central UE's SINR is satisfied at approximately 900 km^2, while the farthest UE experiences a SINR drop below -7 dB at around 2,400 km^2. For the one-cell scenario, SINR is achieved within the range of 231 - 250 km^2.

VI. Conclusion

In this paper, we are analyzing coverage in the multiple HAPS cellular networks based on the 3GPP standard. We consider both the SINR values and the number of cells in the HAPS configuration for our coverage analysis. The simulation results show that the multiple HAPS 7-cell scenario coverage is achieved at 400 km^2 and the multiple HAPS one-cell scenario coverage is achieved at 230 km^2. For the future works, we will analyze multiple HAPS cellular coverage based on the movement of the HAPS.

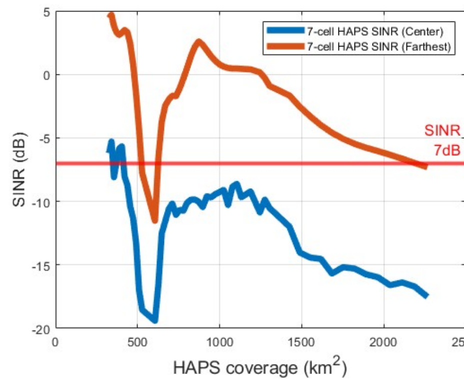

Fig. 3. Coverage according to SINR of 7-cell HAPS

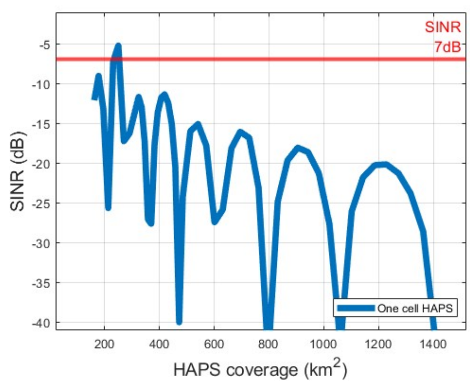

Fig. 4. Coverage according to SINR of one cell HAPS

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