UAV Deployment Optimization for ISAC in Aerial GPS Denied Environments

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***Abstract*—This paper presents an unmanned aerial vehicle (UAV) deployment optimization scheme for integrated sensing and communication (ISAC) in aerial GPS denied environments. We consider a scenario where a UAV-base station (UAV-BS) provides ISAC services to ground user equipments (UEs) whose locations are precisely known, while the UAV-BS position is uncertain. To address this, we propose an optimal UAV deployment scheme that employ UEs as reference anchor nodes for time difference of arrival (TDOA) localization of UAV-BS. Two positioning methods, center-based and centroid-based, are evaluated under both fixed optimal altitude and adaptive minimum altitude constraints. Numerical results demonstrate that the centroid-based method with altitude adjustment significantly reduces transmission power while maintaining reliable localization accuracy, particularly in highly clustered UE distributed environments.**

***Index Terms*—UAV, ISAC, optimal deployment, localization**

I. INTRODUCTION

Unmanned aerial vehicles (UAVs) are increasingly being utilized as aerial platforms in various sectors, with recent works particularly focusing on UAV-assisted integrated sensing and communication (ISAC) technology to significantly enhance next generation wireless communication systems [1]. In order for the UAV base station (BS) to provide efficient ISAC service to ground-based user equipments (UEs), it is essential that they are positioned at accurate positions. Global navigation satellite systems (GNSS) such as global positional system (GPS) are normally utilized for positioning. Nonetheless, in practice, UAVs are susceptible to GNSS-based attacks as their elevated positions make them more exposed to line-of-sight (LoS) connections from potential adversaries [2]. To tackle such problem, the study in [3] utilized ground based UEs as reference anchor nodes to perform localization of location uncertain UAV-BS to optimal position, aiming to jointly enhance communication and sensing performance. However, this work constrains the UAV's altitude to a fixed optimal altitude, which limits further improvement. Accordingly, in our study we propose an enhanced joint communication and localization scheme aiming to perform optimal placement of UAV-BS in GPS-denied environments to further maximize communication efficiency and localization accuracy.

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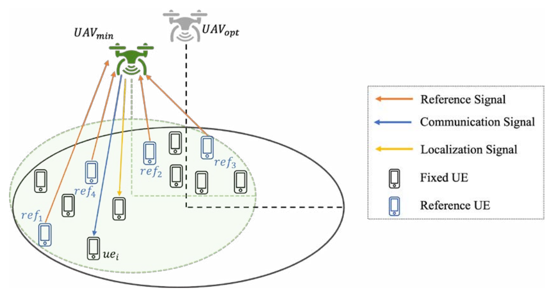


Fig. 1: Proposed system model.

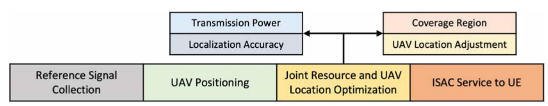


Fig. 2: Proposed scheme.

II. SYSTEM MODEL

As shown in Fig. 1, we consider a wireless communication network consisting of a single UAV-BS without GPS service and multiple UEs at fixed locations on ground. The UAV-BS is initially positioned at optimal position of $(0, 0, h_{\text{opt}})$, determined by the methodology presented in [4] which aims to maximize the coverage region. The set of N ground UEs, denoted as $\text{UE}_N = \{ue_i\}_{i=1}^{N}$, are spatially distributed following the clustering factor (CF) model defined in [3]. Among the N UEs, four are selected as reference anchor nodes responsible for transmitting reference signals to position UAV-BS to optimal location, denoted as $(x_c, y_c, h_{\text{min}})$. We assume that only the aerial based UAV-BS is impacted from GNSS signal degradation, while the UEs on ground maintain full and reliable GNSS service. Thus, only the UAV-BS position is unknown and UEs are precisely located. Upon receipt of reference signals, time difference of arrival (TDOA) localization is performed to estimate UAV-BS location.

III. PROPOSED SCHEME

In Fig. 2, we illustrate each phase of our proposed scheme. In the first phase, the UAV receives reference signals from selected UEs. The concept behind selecting reference nodes among the N UEs is based on the algorithm proposed in [3].

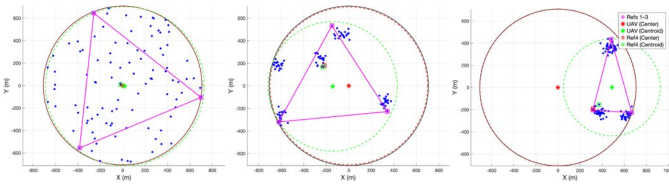
Initially, the first three reference nodes chosen form maximum triangle area, which is efficiently determined using convex hull principles [5]. The fourth node is then selected based on its proximity to either (0,0) or the centroid of triangle formed by the first three nodes, referred to as center and centroid methods, respectively. Next, UAV positioning is performed using TDOA localization method based on priorly selected reference UEs. We then adjust the UAV location to optimal location in the next phase to optimize transmission power and localization accuracy based on UE distribution. Transmission power is measured in terms of average power needed to communicate with all UEs, and position dilution of precision (PDOP) is used as performance metric for accuracy [6]. For center method, the UAV maintains its horizontal position at optimal location at $(0, 0)$ and for centroid method, we position the UAV to the centroid point, (x_c, y_c) formed by the first three reference nodes. Additionally, the UAV adjusts its altitude to the minimum allowable height $h_{\min}$, provided that full coverage of all users is ensured. Since a single UAV-BS is deployed to serve all N users simultaneously, the UAV's position and altitude are optimized such that the minimum required transmission power threshold requirements are satisfied for every user. Thus, the UAV descends to $h_{\min}$ only when this full-coverage condition is met. In the final stage, upon finding its optimal location for joint communication and localization service, the UAV provides ISAC service to all user devices at the optimally deployed location.

IV. Numerical Results

In this section, we present numerical results to evaluate the performance of our proposed scheme. Specifically, we assess the effectiveness of the center and centroid-based UAV positioning methods under both optimal and minimum altitude settings, across CF values ranging from 1 to 5, with higher CF values corresponding highly clustered environments.

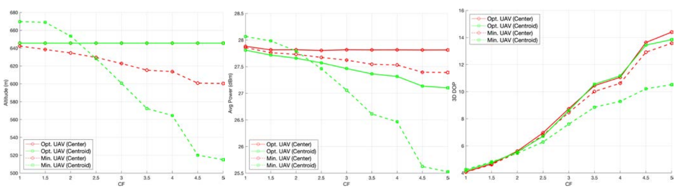
Fig. 3 illustrates representative scenarios for CF values of 1, 3, and 5, showing the spatial distribution of UEs, the resulting UAV-BS placement, and the corresponding coverage areas. The results indicate that the centroid-based method yields a more advantageous UAV-BS placement relative to the center-based approach, particularly as UE clustering increases. In highly clustered scenarios, the UAV-BS can operate at a lower altitude while maintaining full coverage of UEs, which in turn reduces the required transmission power to serve all UEs.

Fig. 4 shows numerical results of UAV altitude, UAV transmission power, and UAV DOP across different strategies. As shown in Fig. 4(a), the UAV altitude remains constant for both center and centroid methods when using the optimal altitude configuration. In contrast, out minimum altitude strategy allows the UAV to significantly lower its altitude as CF increases. Such trend is more pronounced for centroid based method, indicating higher potential for altitude saving as UEs are more tightly clustered. Accordingly, Fig. 4(b) illustrates that the minimum UAV centroid strategy achieves lowest average transmission power needed to communicate with all UEs. This highlights the efficiency of our algorithm



(a) CF = 1 (b) CF = 2 (c) CF = 3

Fig. 3: Sample scenario for different CF.



(a) CF vs Altitude (b) CF vs Avg. Power (c) CF vs PDOP

Fig. 4: Simulation results for proposed scheme.

particularly under highly clustered CF conditions. In Fig. 4(c), an increase in PDOP can be observed with CF across all methods, reflecting degradation in localization accuracy due to denser clustering and indicating a tradeoff between localization accuracy and transmission power. Nonetheless, the minimum altitude based centroid method consistently achieves lowest PDOP compared to other methods, demonstrating better performance.

V. Conclusion

In this work, we proposed a UAV deployment optimization framework for ISAC under location uncertainty caused by GNSS degradation. By leveraging reference UEs for localization and applying adaptive altitude adjustment, the UAV-BS is optimally positioned to balance communication performance and localization accuracy. Center-based and centroid-based methods were examined under both fixed optimal and minimum altitude settings. Through simulations, we demonstrated that the centroid-based approach with minimum altitude adjustment achieves superior performance in terms of reduced transmission power and improved localization metrics.

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