Randomized 3D Neighbor Discovery with Mechanically Steered FSO Transceivers

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***Abstract*—Free-space optical (FSO) communication has recently found credible mobile applications between high-altitude platforms (HAPs) and satellites. Success of these applications rely heavily on line-of-sight (LOS) beam discovery and alignment. Unlike millimeter-wave or Terahertz systems using antenna arrays with large electronic beam-steering capability, FSO systems utilize mechanical steering to scan angles more than a few degrees. In this paper, we design an LOS link discovery method for mechanically steered FSO transceivers attached to flying nodes. We assume that the nodes know each others' locations with an error significantly larger than the footprint of the FSO beam. The FSO transceivers are full-duplex and do not have access to out-of-band radio channels. We design an all-optical neighbor discovery and beam alignment method that randomly searches the space where the other node may be. Our design ensures uniform search of the search space to maximize the detection probability of the other node. 3D simulations show that our method significantly improves the beam discovery time in comparison to the baseline method of scanning the space linearly.**

I. Introduction

Unlike traditional radio frequency (RF) communication, FSO communication offers several distinct advantages, including extremely high bandwidth, low power consumption, and enhanced security due to its narrow beam divergence [1], [2]. The military leverages FSO systems for secure communication, where its narrow beam divergence and LOS requirements enhance security against interception and jamming [3], [4]. Furthermore, FSO is also being utilized in mobile nodes, such as unmanned aerial vehicles (UAVs), HAPs, and portable devices, to provide connectivity without the bandwidth limitations of conventional RF systems [5]. One of the primary challenges in FSO communication, particularly in mobile applications, is the requirement for LOS between transceivers. The FSO transceivers commonly use light-emitting diodes (LEDs), which offer data rates up to 100 Mbps, and laser diodes, which can easily achieve Gbps rates and even reach Tbps rates in controlled settings. However, laser diodes require more precise LOS links and are significantly affected by pointing error. Pointing error or jitter is the deviation between the anticipated antenna position and its actual position [6]. When the pointing error is very small (e.g., smaller than one degree) and the transceiver is not high powered (i.e., can only reach very short ranges such as a few meters), it can be corrected by micromirrors, also known as MEMS mirrors [7]. But, for an FSO transceiver system covering long ranges and transmitting high-power beams, mechanical steering is the only viable option. Such FSO systems are often mounted on mechanical heads or equipped with movable optical lens systems in order to steer the light beam.

Pointing, acquisition, and tracking (PAT) of the OWC link between mobile platforms necessitate fast neighbor discovery and beam alignment using mechanical steering methods. Effective communication is contingent upon the ability of the nodes to quickly discover each other and establish a stable link. Most of the existing methods utilize out-of-band RF channels to coordinate the PAT process at the mobile nodes [8]. However, RF channels are vulnerable to jamming. Hence, all-optical neighbor discovery and beam alignment methods are crucial for enabling rapid alignment and maintenance of optical links in challenged environments. Previous works have proposed various discovery algorithms, such as a exhaustive helical search pattern in 3D space [9], [10]. While these methods are effective for entirely oblivious settings, they are inefficient when there is a rough estimate of the other node's location, making an exhaustive search unnecessary.

We introduce a novel all-optical, randomized neighbor discovery algorithm designed for transceivers in FSO communication systems equipped with mechanical steering heads. This algorithm utilizes an optimized random Beta distribution to guide the mechanical steering head's movements within a defined 3D search space. Unlike traditional methods that scan the space linearly, our approach ensures that each point in the search space is traversed with equal probability, maximizing the detection probability of the other node. By uniformly and randomly searching the space where the other node may be, our method significantly reduces the beam discovery time. Full-duplex FSO transceivers, which do not have access to out-of-band radio channels and know each other's locations with an error larger than the beam's footprint, benefit from this approach. Random search techniques are well-regarded in the field of machine learning, often employed for their powerful prediction and search capabilities [11], [12]. Our intuition is that applying a random search algorithm and by optimizing the random movements, our algorithm can significantly reduce the time to discover the target node compared to traditional exhaustive search methods, thereby enhancing the overall efficiency of the FSO communication system.

This algorithm is especially useful when the general location of the target is known. In inter-satellite communication, where each satellite has an approximate position of the other, a random search can quickly establish the necessary FSO link. Similarly, in visually aided communication systems or with mobile nodes like UAVs, where GPS data may be unavailable or imprecise, our algorithm provides a robust solution for efficient space exploration. Its flexibility extends beyond traditional FSO systems to various mobile applications, such as establishing links between ground stations and UAVs or searching areas in rescue operations. In this paper, we show that, through comprehensive simulations and numerical evaluations, this innovation significantly enhances the performance and reliability of FSO communication systems, especially in dynamic and uncertain environments where quick and efficient node discovery is crucial. Our main contributions include: (i) formulation of the mechanical beam steering as an optimization problem, (ii) a randomized asynchronous algorithm for mechanical steering of FSO transceivers that does not require GPS support, (iii) a definitive procedure to apply the mechanical steering in 3D to ensure equal probability scanning a search space around a neighbor, and (iv) extensive simulation-based evaluation of our method against a traditional mechanical steering method.

II. Related Work

Previous studies have extensively explored neighbor discovery using directional transceivers. We only discuss the ones related to LOS link discovery and alignment. Several techniques have been proposed [13]–[15] for LOS beam alignment with single transceivers that rely on GPS clock synchronization or additional omni-directional RF channels. An et al. [15] proposed a handshake-based self-adaptive neighbor discovery protocol for ad-hoc networks with directional antennas, taking into consideration directional transmitters and omni-directional receivers for neighbor discovery with dynamic frequency operation. In [16], Ramanathan et al. introduced UDAAN, the first ad-hoc network to use directional antennas in a full system deployment. It employs omni-directional antennas to establish connections with new neighbors and GPS clock synchronization for neighbor detection. It uses heartbeat messages to exchange position information. Vasudevan et al. [17] introduced a neighbor discovery protocol for directional RF ad-hoc networks. The protocol makes use of an optimal probability for randomly transmitting beacon messages and a gossip-based algorithm for neighbor discovery that utilizes GPS data and neighbor information. In these efforts, either the transmitter or the receiver was omni-directional.

A neighbor discovery technique employing both directional transmitters and receivers was presented by Jakllari et al. [18]. When all nodes point in different directions, their polling-based MAC protocol synchronizes nodes in terms of polling slots, assigning particular slots for neighbor finding. Conversely, other techniques have investigated neighbor detection in the absence of clock synchronization. In Chen et al. [19] and Wang et al. [20], processes with only a single directional transceiver and no synchronization were shown; as a result, the absence of coordination led to prolonged discovery durations. Even while these techniques work well, they usually result in slower discovery times and worse efficiency in dynamic or highly populated contexts.

Significant progress has been achieved in improving communication and discovery methods in FSO LOS networks in recent research. In order to guarantee reliable and continuous connection, one such study, [21], focuses on the deployment of numerous transceivers in mobile nodes. This design is especially helpful in dynamic contexts where nodes move and reorient regularly since it improves spatial reuse and fault tolerance. However, it is only designed for a 2D plane and strictly assumes that every vehicular node is at the same height. Another important contribution is provided by [9], which offers a novel method of LOS neighbor finding for aerial nodes

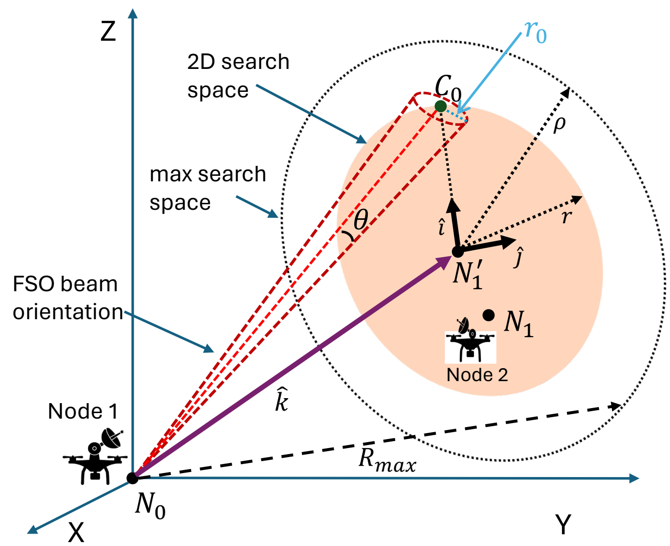


Fig. 1: System representation of two nodes in 3D space

without the need for extra RF links or synchronization. This technique dramatically lowers discovery times and improves network efficiency by using in-band full-duplex transceivers to transmit and receive messages simultaneously. On a similar vein, Khan et al. [10] introduced a sophisticated algorithm for 3D LOS neighbor discovery. This algorithm uses highly directional transceivers to scan the 3D environment in a modified helical shape in 3D space. In this case the two mobile nodes are synced by a helping RF beacon message that synchronizes the start of the neighbor discovery process. This ensures precise alignment and quick discovery of neighboring nodes in one helical scan as long as one of the nodes is starting from the up direction and the other from the down direction.

While these studies have developed comprehensive search mechanisms and provided robust solutions for neighbor discovery, our work builds upon these foundations by introducing a more refined and efficient discovery algorithm. Specifically, our algorithm extends the principles of FSO node discovery in 3D [10] and precise alignment, focusing on reducing discovery times and enhancing the accuracy of the search process. By integrating optimized random search algorithm, our approach promises to offer significant improvements in the application of OWC networks, particularly in scenarios requiring rapid and precise neighbor discovery.

III. System Model

We consider two nodes trying to find each other in 3D space, as shown in Fig. 1. The figure shows the perspective of Node 1, located at N_0. The nodes know each others' location with an error r, that is substantial in comparison to the footprint of their directional FSO beams r_0. In the figure, N_1' is the location of Node 2 known to Node 1 while actual location is N_1 which is within the shaded circular region centered around N_1' with radius r. By steering FSO transceivers, they search for each other by sending probes. We make the following assumptions:

- The FSO transceivers are full-duplex, has a range $R_{\max}$, and operate solely within the optical domain.
- The FSO beams are highly directional with a footprint radius r_0, much smaller than the communication range, i.e., $r_0 << R$.

- No RF channel is used and the nodes are asynchronously searching for each other by sending Beacon messages.
- The neighbor discovery is achieved only after a three-way handshake is completed, i.e., three message transfers must succeed: Beacon, Beacon-ACK, and ACK.
- The nodes use mechanical steering with a maximum angular speed $\omega_{\max}$ for navigating the 3D search space.
- Nodes have a rough estimate of each other's locations with an error margin r that is significantly larger than the FSO beam footprint, i.e., $r >> r_0$.

These assumptions hold in various real settings involving laser-based OWC. We particularly focus on two drones trying to find each other via lasers or narrowbeam LEDs.

A. Transceiver and Channel Properties

We assume that the nodes are outfitted with FSO transceivers which employ photo diodes as receivers and lasers or LEDs as transmitters. Inline with a typical laser-based FSO transceiver for low-flying drones, Table I details the key transceiver properties [1].

TABLE I: Transceiver properties

Symbol	Meaning	Value
P_t	Transmitter source power	-43 dBm
ξ	Transmitter radius	0.3 cm
ζ	Receiver radius	3.75 cm
σ	Attenuation coefficient	0.0508*

*For visibility of 20km and wavelength of 1,550nm.

Atmospheric attenuation, geometric attenuation, and Lambertian loss all affect an FSO transceiver's maximum communication range and received power. We calculate the received power P_r as [10]:

$$P_r = \cos\delta \left(P_t - 10\log e^{-\sigma d \cos\delta} - 20\log \frac{\zeta}{\xi + 200\theta d \cos\delta} \right), \quad (1)$$

where δ is the angle of incidence in Rad, $d \leq R_{\max}$ is the distance between the nodes in meters, θ is the divergence angle of the FSO beam in mRad, and the rest are shown in Table I. The values are kept the same as [10] for comparative purposes.

B. Search Protocol and Parameters

The nodes try to find each other obliviously and asynchronously. They rotate their transceivers while periodically sending Beacon messages. Since the transceivers are full-duplex (which is a reasonable assumption for FSO transceivers), they can send and receive simultaneously. Upon reception of a Beacon, the nodes send an acknowledgment (B-ACK) to the originator of the Beacon. If the Beacon originator successfully receives the B-ACK, it responds with an ACK. Successful reception of the ACK completes the three-way handshake. This process ensures the FSO link is established between two neighbors among potentially many neighbors.

Assuming there are only two nodes in the system, we can calculate the minimum time for required for establishing a link through this protocol, τ. It includes the transmission delay (t_{tran}), propagation delay (t_{prop}), and processing delay (t_{proc}) at both ends and can be calculated as $\tau = t_{\text{tran}} + 3 \times t_{\text{prop}} + 2 \times t_{\text{proc}}$.We assume the the packet processing delays are negligible and that the distance d is a few hundred meters,making t_{tran} the dominant component of τ. Considering a 1KB message size, the transmission time of the three messages (Beacon, B-ACK, and ACK) will take $t_{\text{tran}} = 0.3$ms for a link rate 100Mbps, which is well below feasible for FSO links using lasers or non-phosphorus (e.g., infrared) LEDs. The 3D geometry analysis in [10] showed that the nodes can complete the three-way handshake as long as $\omega \leq \theta/(\sqrt{2}\tau)$ holds. The smallest θ value we consider is 3°, which imposes a maximum angular speed of $\omega_{\max} = 7,071$°/s. In our study, we only consider ω values up to 1,800°/s, corresponding to 300RPM. This is a conservative assumption as higher ω would reduce the discovery times. However, given the complexity of the mechanical steering apparatus on drones, we think this is fair assumption.

C. Problem Formulation

The primary objective is to maximize the probability of discovering a neighboring node during the scanning process. This involves optimizing the trajectory of the beam in terms of its positional coordinates over time intervals while considering the movement constraints. Let the $C_t = (x_t, y_t, z_t)$ be the coordinate which the beam is point to at time t. ω_1 is the angular speed of rotation for the mechanical beam steering at interval t. Let $P(\omega_t, C_{t-1}, C_t)$ represent the probability of finding the neighbor if the beam scans the line segment between positions C_{t-1} and C_t at an angular speed ω. We can write the problem of optimal steering of the beam as maximization of the total probability of discovering the neighbor over T scanning intervals:

P1: $\textsc{OptimalSteeringTrajectory}(N_0, N_1', r, C_0)$

$$\arg\max_{\hat{\omega}, \hat{C}} \sum_{t=1}^{T} P(\omega_t, C_{t-1}, C_t) \quad (2)$$

such that

$$C_i \in \mathcal{H}(N_0, N_1', r), \forall i = 0..T, \text{ and} \quad (3)$$

$$\omega_j \leq \omega_{\max}, \forall j = 1..T, \quad (4)$$

where $\hat{\omega} = [\omega_1, .., \omega_T]$ is the vector of angular speeds and $\hat{C} = [C_1, .., C_T]$ is the vector of coordinates to be chosen by the scanning node. Further, N_0 is the position of the scanning node, $N_1' \pm r$ is the position of the neighbor being searched, and C_0 is the initial coordinate the beam is pointing to. $\mathcal{H}(N_0, N_1', r)$ is the circular hyperplane defined by the erroneous position of the node being searched. Hence, the constraint (3) limits the beam scanning trajectory to be within this hyperplane boundaries. Finally, the constraint (4) limits the mechanical steering speed.

The formulation in **P1** is generic and can be applied to different granularity of time and space. If, for instance, τ is significantly larger than the scanning time of a line segment (i.e., $\tau >> \left|\overrightarrow{C_{t-1}C_t}\right| / \omega$), then the objective function in (2) is a good representation of what needs to be maximized as it is possible to have a trajectory that has a high total probability of discovery even though $P(\omega_t, C_{t-1}, C_t)$ may be too low for some intervals t. However, since τ for an FSO link is very small (e.g., around 0.3ms for our case as detailed earlier), we can assume a simplified problem where we only care about finding the next point to steer to (i.e., C_t), instead of a vector of them. Hence, we solve the following problem:

$$\textbf{P2:}\quad \textsc{OptimalSteeringPoint}(N_0, N_1', r, C_0)$$

$$\arg\max_{\omega, C} \quad P(\omega, C_0, C) \tag{5}$$

such that

$$C \in \mathcal{H}(N_0, N_1', r), \text{ and} \tag{6}$$

$$\omega \leq \omega_{\max}, \tag{7}$$

where C_0 is the latest coordinate the beam is pointing to. Next, we focus on solving **P2** by designing a randomized heuristic.

IV. Randomized Discovery Algorithm

To solve OptimalSteeringPoint, we design an algorithm that attempts to maintain an equal probability of scanning each point in the search space $\mathcal{H}(N_0, N_1', r)$. The intuition behind this design is that (1) the neighbor's actual location N_1 has equal chance of being anywhere in the search space, and (2) random sampling of the search space achieves faster detection and reduce discovery time.

Algorithm 1 Scanning Algorithm for Neighbor Discovery

1: **Initialization:** Initialize the mechanical head to point to C_0, a random location on the circumference of search space on the plane. Define $\hat{\imath}$ as the unit vector from N_1' towards C_0 (shown in Fig. 1). Define ψ as the clockwise rotation angle from $\hat{\imath}$. Initialize *MaxRotationCount*. Set *RotationCount* to 0.

2: **Random Point Generation:**
- Generate a rotation angle $\psi = b \cdot 2\pi$ by sampling b from a probability distribution.
- Calculate the next point C on the circumference by $x = N_1' + r \cdot \cos(\psi), y = N_1' + r \cdot \sin(\psi)$.

3: **Movement:** Rotate the mechanical head from C_0 to C. Increment *RotationCount*. Check if the other node is aligned at every τ s. If yes, stop and report the neighbor is discovered.

4: **Finish Search:** If *MaxRotationCount* is greater than *RotationCount*, go to Step 2. Otherwise, stop and report the neighbor is not discovered.

We consider the circular 2D search space, defined by the hyperplane $\mathcal{H}(N_0, N_1', r)$, quantized into equal-sized small squares as shown in Fig. 2. We design the steering method such that the mechanical movements happen on straight line between points located on the perimeter of the circle, denoted by the dashed red light, around $\mathcal{H}(N_0, N_1', r)$. This simplifies the problem to selecting the next point to move to only from the circle. That is, given the current location C_0 on the circle, we focus on selecting the next point C on the circle such that the objective $P(\omega, C_0, C)$ for a constant ω. The detail of this process is clearly stated in Alg. 1.

Selecting C from the points on the circle using a Uniform distribution, however, yields an outcome that scans the center region of the search space more than its edges. This is illustrated in the Fig. 2(left) where the center has higher probability of traversal. To attain a uniform scanning likelihood of all the small squares in the search space, we need to design a non-uniform probability of selecting a point in the circle. To do so, we explore the Beta distribution to select C given the current location C_0.

A. Optimizing Beta Distribution Parameters

The Beta distribution is a family of continuous probability distributions defined on the interval $[0, 1]$ and parameterized by two positive shape parameters, denoted as α and β. These parameters control the shape of the distribution, influencing its behavior in modeling variability within a bounded interval [22]. The probability density function (PDF) of the Beta distribution for $0 \leq x \leq 1$ and shape parameters $\alpha, \beta > 0$ is given by:

$$f(x, \alpha, \beta) = \frac{1}{B(\alpha, \beta)} x^{\alpha-1} (1-x)^{\beta-1} \tag{8}$$

where $B(\alpha, \beta) = \int_0^1 u^{\alpha-1}(1-u)^{\beta-1}\, du$ is the Beta function. We use the shape parameters α and β to generate a non-uniform likelihood of selecting the next point C on the circle, which is part of the **Random Point Generation** step of Alg. 1. The outcome we would like to achieve is a uniform traversal likelihood across the search space similar to Fig. 2(right).

We consider the problem of finding the best shape parameters as an optimization. We use the coefficient of variation (CV) of the traversal probability across the circular search space as the metric to minimize. Minimizing the CV results in a more uniform distribution of search activity across the grid. We count the number of times each grid square is traversed/scanned by the beam when the next point C is picked via the PDF $f(x, \alpha, \beta)$. Then, we calculate the CV as the ratio of the standard deviation and the mean of these counts.

To obtain a symmetric PDF, we set the shape parameters equal to each other ($\alpha = \beta$) and use Simulated Annealing to optimize the shape of the PDF to minimize the CV. Fig. 3 illustrates the relationship between the CV and the α values tried during the optimization, which yielded $\alpha = \beta = 0.7616$, producing a U-shaped PDF. The resulting likelihood of traversal of the search space when the next point C is selected using the optimized Beta distribution is shown in Fig. 2(right). During the optimization, we also consider the maximum number of rotations (*MaxRotationCount*), before which the scanning process is stopped if no neighboring node is discovered. The Fig. 4 shows the relationship between the *MaxRotationCount* and the CV. As the *MaxRotationCount* is increased, the CV decreases and reaches a stable point after about 1,000 samples, with only slight variations thereafter. Thus, we set *MaxRotationCount* = 1000 as it is the smallest number of points necessary to attain this stability, ensuring that the search space is comprehensively covered in the shortest possible time during one complete scanning process.

B. Search Space in 3D Geometry

Given a method to optimally select the next point C on the circle around the 2D search space, denoted by $\mathcal{H}(N_0, N_1', r)$, we need to apply it in 3D geometry. Fig. 1 depicts the 3D setting, where $N_0 = (x_0, y_0, z_0)$ is the searching node's location and $N_1' = (x_1, y_1, z_1)$ is the center of the search space where

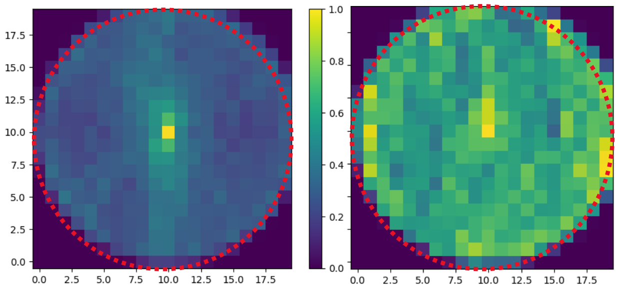


Fig. 2: Likelihood of beam traversal across the search space when the next point on the circle is picked from the Uniform distribution (left) and Beta distribution (right).

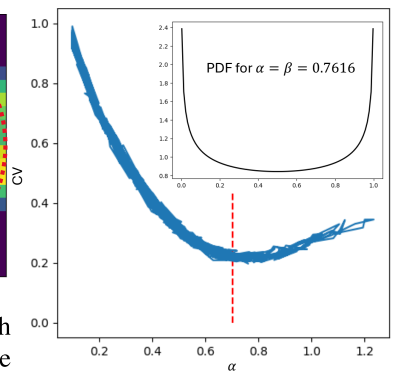


Fig. 3: CV vs. $\alpha = \beta$

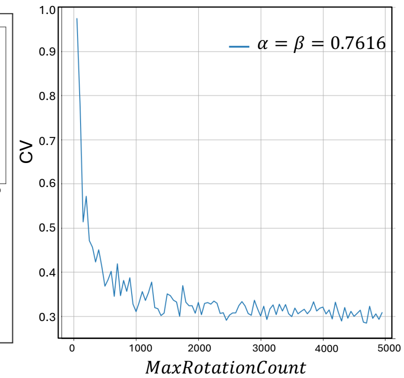


Fig. 4: Effect of *maxRotationCount*

the neighbor is predicted to be located. To mathematically define the search space $\mathcal{H}(N_0, N_1', r)$ (denoted as the 2D search space in Fig. 1) in 3D, we start with the equation of the hyperplane that is perpendicular to the vector $\hat{k} = \overrightarrow{N_0 N_1'}$:

$$a(x - x_1) + b(y - y_1) + c(z - z_1) = 0, \tag{9}$$

where a, b, and c are the hyperplane's slopes in the X, Y, and Z dimensions. Next, we define the sphere with radius $R_{\max}$ (i.e., the range of the FSO transceiver) centered at N_0:

$$x^2 + y^2 + z^2 = R_{\max}^2. \tag{10}$$

The intersection of the hyperplane (9) and the sphere (10) yields a 2D circular space (denoted as the max search space in Fig. 1), which is parameterized by:

$$N_1' + \rho \cos(\psi)\hat{i} + \rho \sin(\psi)\hat{j} \tag{11}$$

where $0 \leq \psi \leq 2\pi$ denotes the radial angle of the point on the circle, ρ is the radius of the circle, and **i** and **j** are orthogonal unit vectors in the plane of the circle. Finally, to obtain $\mathcal{H}(N_0, N_1', r)$, we restrict the search space to the error r from N_1' by replacing ρ in (11) with r. We adjusted the Alg. 1 to include this mathematical process after ψ is randomly picked (by the Beta distribution) in the **Random Point Generation** step.

V. Simulation Experiments

To understand the performance of our method, we evaluated our neighbor discovery method using simulations. We simulated the search process in Alg. 1, in Python, among two UAVs equipped with the FSO transceivers as described in Section III and Table I. We placed Node 1 at the origin N_0=(0,0,0) and randomly generated Node 2 position, N_1, within a cone that has radius r, slant height $R_{\max}$, and apex located at N_0. We generated 100 random such Node 2 positions and ran the algorithm 100 times in each case. We will be reporting the average of these runs.

1) Baseline Method: We compare our method to a baseline approach inspired by [10] that solved the neighbor discovery problem among two UAVs. Since the UAVs had no predicted locations of each other (i.e., they did not have N_1'), they searched each other via helical movement of FSO transceivers in their 3D vicinity. We adapted this approach to our case where the search space is a cone with center N_1' instead of the entire 3D vicinity. In this baseline approach, the nodes start from a C_0 location on the base of the cone and linearly scan the entire circular search space. A key favor the nodes have in the baseline method is that they start search synchronously via a beacon message sent through an RF channel. Similar to the method in [10], they start scanning starting from the opposite locations at the circumference of the circular search space. Fig. 5 shows the average discovery time of our randomized method against the baseline method as θ varies from 3° to 25°. As expected the discovery time reduces with a larger beam footprint (i.e., larger θ). The inner graph plot the discovery times in log-scale, clearly showing that the performance difference between the methods is consistent.

2) Effect of Radius of Search Space, r: We investigate the effect of smaller error margin, i.e., $r \leq \rho$, on the neighbor discovery time. Fig. 6 demonstrates that the average discovery time is almost halved, as the radius of the search space is halved i.e. $r = \rho/2$. This improvement is consistent for all beam footprint sizes, shown in the inner log-scale graph. Despite improvements in the discovery time, one of the challenges of our asynchronous randomized algorithm is that there is no guarantee of finding the neighbor within *MaxRotationCount* scans. Therefore, we measure the success probability of finding the neighbor as shown in Fig. 7. As expected, the the probability of discovery increases with larger beam footprint θ or smaller search space r. Furthermore, for particular combination of θ and r, we can guarantee discovery as probability is 1 for example when $\theta = 15$ and $r \leq \rho/7$.

3) Effect of Angular Speed, ω: We varied the angular speed, ω, of mechanical rotation with respect to the maximum that guarantees detection $\omega_0 = \theta/\sqrt{2}\tau$ (as explained in Section III-B). Fig. 8a shows a decreasing trend in the discovery time up to $\omega/\omega_0 = 1.75$, after which there it breaks. For some beam footprint the average discovery time further decreases while for other it increases. This indicates the potential for smaller discovery times if ω is tuned, which is a worthy future work.

4) Hovering UAVs: To observe the effect of positional errors due to hovering of UAVs, we evaluated our method under increasing hovering error on vertical and horizontal error. Fig. 8b shows the disvoery time against increasing beam footprint, larger θ, when the hovering error is randomly picked from (0,0.5]m, (0.5,1.5]m, and (1.5,3]m. The discovery time significantly increases as soon as we introduce the hovering error even though the extent of this displacement seems to have little effect. Also, smaller beam footprints r seem to more effected rather than larger ones.

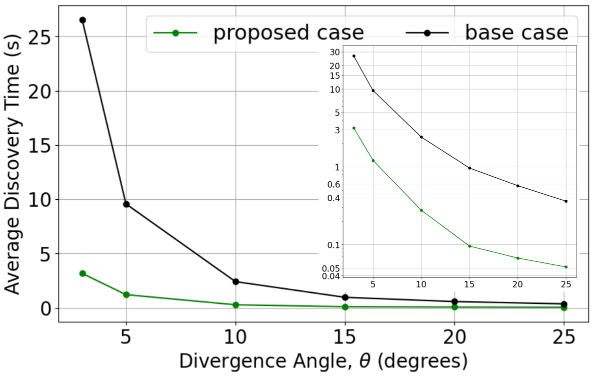


Fig. 5: Average discovery time vs. FSO beam footprint

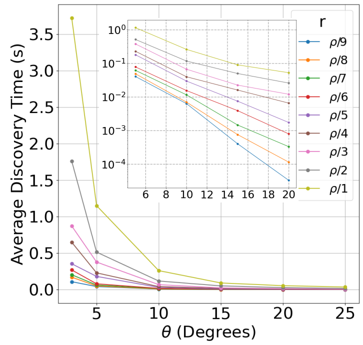


Fig. 6: Effect of r on average discovery time where ρ = 86m

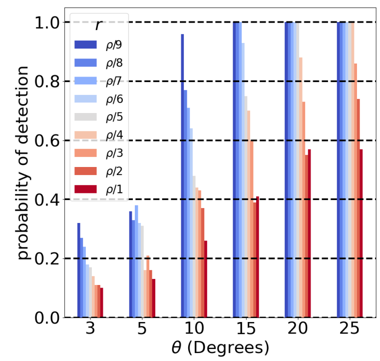
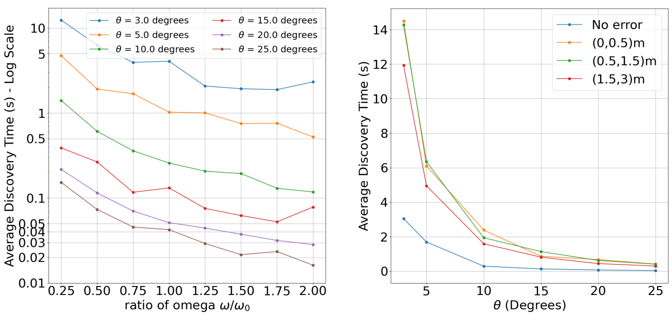


Fig. 7: Probability of discovery



(a) Effect of changing ω (b) Effect of UAV hovering error

Fig. 8: Average discovery time against ω and hovering error

VI. Conclusion

We addressed the challenges of PAT in OWC links between mobile platforms which require rapid neighbor discovery and precise beam alignment through mechanical steering methods. As as solution we introduced a novel randomized search algorithm for LOS transceivers equipped with mechanical steering heads. Our research aimed to maximize the probability of discovering neighboring nodes and optimize beam steering in a 3D search space, considering mechanical and networking constraints. We optimized a Beta distribution to guide the mechanical steering so as to minimize the coefficient of variation in the probability of being scanned across the 3D search space. In comparison to a baseline method, inspired from a similar study on synchronous neighbor discovery, our randomized asynchronous method achieved significantly smaller discovery times. We evaluated our method under varying search space size, angular speed of the steering head, and hovering error.

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