Trajectory and Power Optimization in sub-THz band for UAV Communications

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***Abstract*—Vapor loss and molecular absorption make the transmission distance in sub-Terahertz bands a challenge, especially in mobile statues such as UAVs communication. The molecular absorption element is an essential part of the path loss in THz communication channel modeling that cannot be neglected. Along this direction, we investigated ~~the~~ UAV trajectories in sub-THz band. To maximize the secrecy rate of the UAVs communication, an optimization problem has been proposed to jointly optimize the trajectory and transmit power. To enhance the obtained average secrecy rate, MIMO communication and a cooperative UAV jammer strategy were used in this paper. Also, analysis and simulations results were presented to show the performance of UAV-ground communication at THz communications. Finally, Secrecy Outage Probability was obtained for each UAV trajectories in different flight periods to examine the performance of physical layer security added to the UAV-ground communication at sub-THz communication.**

Keywords—Terahertz, Trajectory, MIMO, UAV.

I. Introduction

The traditional wireless systems are not capable to fill the gap of wireless communication systems such as the growth of interconnected devices, faster data rates, improved latency rate, and reliability. The new frequency bands (terahertz THz) communication is expected to provide a larger bandwidth and higher data rate [1-3]. In addition, it plays a big role in the drone networks which is considered as an important technology to enable many new applications, such as the distribution of edge computing and wireless security in malicious environments [4]. On the other hand, THz frequencies are suffering from severe path loss caused by water vapor and its vulnerability to blockage [5]. This issue can cost near 100 dB path loss in a few meters link which makes long-distance communication a real issue in THz [6]. Directional transmissions with narrow beams, Ultra-Massive MIMO, and Hyper intelligent surface -indoor and outdoor environments- have been used to overcome this communication distance problem [1][7].

Utilizing UAVs is a key in new wireless communication systems not only because of their convenient deployment and flexible mobility [8][9]. UAVs have the ability to generate a high wireless capacity, cover a wide area, and enhance energy efficiency [10]. Although, UAVs usually tend to communicate through robust line-of-sight (LoS) connections with ground users yet are vulnerable to eavesdropping and jamming threats that might cause confidential information leakage and decreasing ~~of~~ in communication quality. Consequently, ensuring transmission security in UAV networks must be considered. Due to their flexible flying trajectory, UAVs can choose their desirable transmission conditions over unwanted illegal ground communication. In addition, optimizing the UAV trajectory plays a significant role in improving the secrecy rates in UAV communications which have been shown its effectiveness for physical-layer security techniques [11] [12]. Several studies have shown that trajectory design is a challenge that must be solved in UAV Wireless communications. Optimizing the UAV trajectory jointly with transmitting power was studied in [13] to improve the secrecy rates. In [14] authors studied an approximate solution of the optimization equation of joint power control and trajectory design that achieve a minimum outage probability of an amplify-and-forward relay UAV [14]. In [15] a suboptimal solution to the optimization problem was obtained for multiple relay UAVs to improve the system's end-to-end throughput [15].

Authors in [16] solved the optimization problem that maximizes a number of users communicating with only one UAV. Authors in [17], the position of ~~a~~ UAV and its altitude were jointly optimized to minimize transmit power of the UAV while communicating with ground users. Minimizing transmit power in User-UAV association is introduced in [18, 30, 31]. Authors in [19] investigated the optimization problem of UAV trajectory design and its transmit power to maximize the data rate for all users under their gained energy constraints. In [20], authors studied multiple UAVs' optimal trajectory design to maximize the downlink data rate. UAV-Mobile edge computing network coverage was studied in [21]. In [22] introduced a solution that minimizes the energy consumption of UAV by optimizing its location and transmit power. In [23] Authors studied the impact of imperfect location information ~~of~~ for eavesdroppers while ground nodes are in mobility status [23]. In [24] authors consider the UAV as a user and introduce an approximate solution of the trajectory problem that maximizes the energy efficiency of the UAV. In [25], authors studied three-node secure UAV-enabled communication systems. Authors of [11]-[26], studied the trajectory of a UAV, however THz path loss for UAVs trajectory has not been considered. However, authors in [10], introduce an iterative algorithm to resolve the optimization problem of joint trajectory and transmitting power for down and uplinks that reduce the delay between UAV and ground users while considering sub-THz band path loss.

In this paper, unmanned aerial vehicles (UAVs) are used to support terahertz (THz) communications. Joint trajectory and power control parameters are optimized to maximize the data rate of users. Motivated by [26] we investigate a cooperative UAV jamming strategy and MIMO technique are used to further enhance the secrecy rate for UAV-ground communication. An iteration algorithm based on Successive Convex Approximation is used to determine UAV's trajectory in the sub-THz band. Experiment results support that the proposed algorithm can find the best trajectory that enhances the secrecy rate performance of the whole system. In this paper, we consider the scenario described in Fig.1 where a UAV S communicates with a ground-user U in the presence of an eavesdropper E.

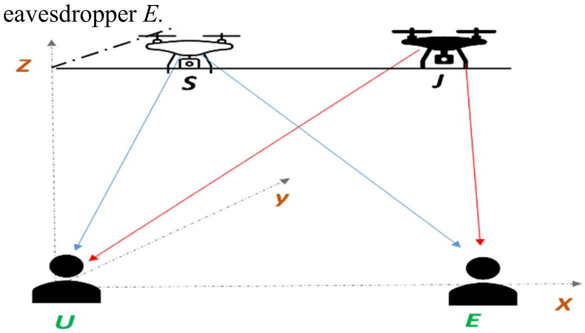

Fig1: Illustration of UAV communication

The remainder of the paper is organized as follows. We introduce the system model and format our problem in Sec. II. Details of analyzing the path loss over the THz-band and mathematical frame of converting our optimization problem to a convex problem were discussed in Sec. III. Sec. IV, we consider adding MIMO to the system. Sec. V presented Secrecy Outage Probability analysis. Simulation results and performance evaluation were discussed in Sec. VI. Finally, the paper is concluded in Sec. VII.

II. System Model

Based on the scenario given in figure, we consider the UAV S as a source that communicates with a ground node U in the presence of an eavesdropper E. We assume that the user node and eavesdropper node are located on the ground at $w_d = (0,0,0)$ and $w_e = (10,0,0)$ note that all measures are in meter (m). A friendly jammer UAV was considered to enhance the secrecy rate of the UAV-ground communication system, The purpose of the friendly jammer UAV is to travel as close as possible to the eavesdropper to weaken the eavesdropper signal, and therefore enhance the overall secrecy rate of the UAV communication.

We assumed both UAVs fly horizontally at a fixed H and their initial and final location donated as (q_{s0}, q_{sf}) (q_{j0}, q_{jf}).In this paper, we assumed the trajectory of the cooperative jammer UAV is given. the UAV flight time is given as N slots with equal length ($T * \delta$), to assume the location of our UAV within each time slot is equal, δ has to be very small. In this paper, the trajectory of our UAVs is given as:

$$q_s(n) = [x_s(n), y_s(n), H] \quad (1)$$

$$q_j(n) = [x_j(n), y_j(n), H] \quad (2)$$

$$n \in \mathbb{N} = \{1, \dots, N\}$$

Also, the trajectory must satisfy the following constraints:

$$\|q_s(n+1) - q_s(n)\|^2 \leq (V\delta)^2 \quad (3\text{-a})$$

$$\|q_j(n+1) - q_j(n)\| \leq (V\delta)^2 \quad (3\text{-b})$$

$$q_{s0} = q_s(0) \quad (3\text{-c})$$

$$q_{sf} = q_s(N) \quad (3\text{-d})$$

$$q_{j0} = q_j(0) \quad (3\text{-e})$$

$$q_{jf} = q_j(N) \quad (3\text{-f})$$

$$n \in \mathbb{N} = \{1, \dots, N\}$$

Due to week NLoS links in the outdoor environment of THz communication, LoS link between UAVs and ground nodes is the only channel we consider for our UAV-Users communication. Gain between the UAV and user at THz LoS channel can be written as [10] $h = p_0 ds^{-2} e^{-k(f)ds}$ where ds is the distance between source and user and p_0 is the channel gain at reference distance = 1 m. thus, we can assume channel gain for UAV-Users:

$$h_{s-d\ los}(n) = p_0 * \|(qs(n) - w_d)\|^{-2} e^{-k(f)\|(qs(n)-w_d)\|} \quad (4\text{-a})$$

$$h_{s-e\ los}(n) = p_0 * \|(qs(n) - w_e)\|^{-2} e^{-k(f)\|(qs(n)-w_e)\|} \quad (4\text{-b})$$

$$h_{j-d\ los}(n) = p_0 * \|(qj(n) - w_d)\|^{-2} e^{-k(f)\|(qj(n)-w_d)\|} \quad (4\text{-c})$$

$$h_{j-e\ los}(n) = p_0 * \|(qj(n) - w_e)\|^{-2} e^{-k(f)\|(qj(n)-w_e)\|} \quad (4\text{-d})$$

$$n \in \mathbb{N} = \{1, \dots, N\}$$

Where $e^{-k(f)d}$ is the molecular absorption path loss, and $k(f)$ is the water vapor molecules absorption coefficient operating at frequency f.From now on, we will use k to represent $k(f)$ in this paper. Let $P_s(n)$ denoted by the transmit power of the source UAV and $P_j(n)$ the transmit power of jammer UAV. Both of them are under average and peak constraints:

$$0 \leq P_s(n) \leq P_{Smax} \quad (5\text{-a})$$

$$0 \leq P_j(n) \leq P_{Jmax} \quad (5\text{-b})$$

$$\frac{1}{N}\sum_{1}^{N} P_s(n) \leq \overline{P_s} \quad (5\text{-c})$$

$$\frac{1}{N}\sum_{1}^{N} P_j(n) \leq \overline{P_j} \quad (5\text{-d})$$

$$n \in \mathbb{N} = \{1, \dots, N\}$$

If we assume there is only one cooperative jamming UAV the secrecy data rate of the system is given by:

$$C_u = \max\left\{\frac{1}{N}\sum_{1}^{N} log_2\left(1 + \frac{P_s(n)h_{sd}(n)}{P_j(n)h_{jd}(n) + \sigma^2}\right) - log_2\left(1 + \frac{P_s(n)h_{se}(n)}{P_j(n)h_{je}(n) + \sigma^2}\right), 0\right\} \quad (6)$$

Where σ^2 is the additive white Gaussian noise power We assume:

$$\boldsymbol{Q_s} = \{q_s(1), \dots, q_s(N)\} \quad (7)$$

$$\boldsymbol{P_s} = \{P_s(1), \dots, P_s(N)\} \quad (8)$$

$$n \in \mathbb{N} = \{1, \dots, N\}$$

our problem can be written as:

$$P1: max_{\boldsymbol{Q_s},\boldsymbol{P_s}} log_2\left(1 + \frac{P_s(n)h_{sd}(n)}{P_j(n)h_{jd}(n) + \sigma^2}\right) - log_2\left(1 + \frac{P_s(n)h_{se}(n)}{P_j(n)h_{je}(n) + \sigma^2}\right) \quad (9)$$

s.t. (3),(5)

$$\|q_s(n+1) - q_s(n)\|^2 \leq (V\delta)^2$$
$$q_{s0} = q_s(0)$$
$$q_{sf} = q_s(N)$$
$$0 \leq P_s(n) \leq P_{Smax}$$
$$0 \leq P_j(n) \leq P_{Jmax}$$
$$\frac{1}{N}\sum_{1}^{N} P_s(n) \leq \overline{P}_s$$
$$\frac{1}{N}\sum_{1}^{N} P_j(n) \leq \overline{P}_J$$
$$n \in \mathbb{N} = \{1, \dots, N\}$$

III. Proposed Soultion

In this section, we consider solving $P1$ by dividing it into two subproblems that can be solved by an iterative algorithm that optimize both UAV transmit power $\boldsymbol{P_s}$ and the UAV trajectory $\boldsymbol{Q_s}$.

A. Optimizing Transmit Power $\boldsymbol{P_s}$

From $P1$, we assume Q_s is known, then we write $P2$ as:

$$P2: max_{\boldsymbol{P_s}} log_2\left(1 + \frac{P_s(n)h_{sd}}{P_j(n)h_{jd} + \sigma^2}\right) - log_2\left(1 + \frac{P_s(n)h_{se}}{P_j(n)h_{je} + \sigma^2}\right) \quad (10)$$

s.t.

$$\frac{1}{N}\sum_{1}^{N} P_s(n) \leq \overline{P}_s$$
$$0 \leq P_s(n) \leq P_{Smax} \quad \text{(5-a, c)}$$

Let

$$a_n = \frac{h_{sd}(n)}{P_j(n)h_{jd}(n) + \sigma^2} \quad , \quad b_n = \frac{P_s(n)h_{se}(n)}{P_j(n)h_{je}(n) + \sigma^2} \quad (11)$$

Thus, P2 converted to:

$$P2': max_{Ps(n)} \; log_2(1 + a_nP_s(n)) - log_2(1 + b_nP_s(n)) \quad (12)$$

s.t.

$$\frac{1}{N}\sum_{1}^{N} P_s(n) \leq \overline{P}_s$$
$$0 \leq P_s(n) \leq P_{Smax} \quad \text{(5-a, c)}$$

The optimal solution for such problem was obtained in [27] as:

$$P^*{}_s(n) = \begin{Bmatrix} \min([\hat{P}_s(n)]^+, \tilde{P}_s & a_n > b_n \\ 0 & a_n \leq b_n \end{Bmatrix} \quad (13)$$

$$\hat{P}_s(n) = \sqrt{(\frac{1}{2b_n} - \frac{1}{2a_n})^2 + \frac{1}{\lambda In(2)}(\frac{1}{b_n} - \frac{1}{a_n})} - \frac{1}{2a_n} - \frac{1}{2b_n} \quad (14)$$

where λ is a Positive parameter to ensures $\sum_1^N P^*{}_s(n) \leq N\overline{P}_s$.

B. Optinizing Transmit Power $\boldsymbol{Q_s}$

From $P1$, we assume $\boldsymbol{P_s}$ is known, then we write $P3$ as:

$$P3: max_{\boldsymbol{Q_s}} log_2\left(1 + \frac{P_s(n)h_{sd}(n)}{P_j(n)h_{jd}(n) + \sigma^2}\right) - log_2\left(1 + \frac{P_s(n)h_{se}(n)}{P_j(n)h_{je}(n) + \sigma^2}\right) \quad (15)$$

s.t.

$$\|q_s(n+1) - q_s(n)\|^2 \leq (V\delta)^2$$
$$q_{s0} = q_s(0)$$
$$q_{sf} = q_s(N)$$
$$n \in \mathbb{N} = \{1, \dots, N\} \quad \text{(3-a, b, c)}$$

Let

$$c_n = \frac{\rho_0 P_s}{P_j h_{jd} + \sigma}, \quad d_n = \frac{\rho_0 P_s}{P_j h_{je} + \sigma} \quad (16)$$

by introducing two variables $\boldsymbol{S}$ and $\boldsymbol{G}$ where:

$$\boldsymbol{S} = \left\{s(n) = \|q_{sd} - w_d\|^2 e^{k\|q_{sd} - w_d\|}\right\} \quad (17)$$

$$\boldsymbol{G} = \left\{g(n) = \|q_s - w_e\|^2 e^{k\|q_{sd} - w_e\|}\right\} \quad (18)$$

Our Optimization problem can be rewritten as:

$$P3: max_{\boldsymbol{Qs},\boldsymbol{S},\boldsymbol{G}} \; \{log_2\left(1 + \frac{c_n}{s(n)}\right) - log_2\left(1 + \frac{d_n}{g(n)}\right)\} \quad (19)$$

s.t

$$\|q_s(n) - w_d\|^2 e^{k\|q_s(n) - w_d\|} - s(n) \leq 0 \quad (20)$$

$$g(n) - \|q_s(n) - w_e\|^2 e^{k\|q_s(n) - w_e\|} \leq 0 \quad (21)$$

$$g(n) \geq 0 \quad (22)$$

$s(n)$ is approximated by its first order Taylor Series around local point ${q_s}^i(n)$ which is updated every iteration i.

$$s(n) \approx s^i(n) + \frac{d\,s(n)}{dq_s}(q_s(n) - {q_s}^i(n)) \quad (23)$$

Where:

$$s^i(n) = \left\|{q_s}^i(n) - w_d\right\|^2 e^{k\|{q_s}^i(n) - w_d\|} \quad (24)$$

Let

$${q_{sd}}^i(n) = \left\|{q_s}^i(n) - w_d\right\| \quad (25)$$

then

$$\acute{x}^k(n) = \frac{d}{dq_s}\|q_s(n) - w_d\| = \frac{{q_s}^i(n) - w_d}{\|{q_s}^i(n) - w_d\|} \quad (26)$$

$$\frac{d\,s(n)}{dq_s} = 2kq_{sd}{}^i(n)(\acute{x}^k(n))e^{q_{sd}{}^i(n)} + s^i(n)\,\acute{x}^k(n) \quad (27)$$

Substituting (26) (27) into (23)

$$s(n) \approx s^i(n) + [2k\|q_s{}^i(n) - w_d\| \left(\frac{q_s{}^i(n)-w_d}{\|q_s{}^i(n)-w_d\|}\right) e^{k\|q_s{}^i(n)-w_d\|} + s^i(n)\left(\frac{q_s{}^i(n)-w_d}{\|q_s{}^i(n)-w_d\|}\right)](q_s(n) - q_s{}^i(n)) \quad (28)$$

Also, $g(n)$ is approximated by its first order Taylor Series

$$g(n) \approx g^i(n) + \frac{d\,g(n)}{dq_s}(q_s(n) - q_s{}^i(n)) \quad (29)$$

$$\text{Let } q_{se}{}^i(n) = \|q_s{}^i(n) - w_e\| \quad (30)$$

$$\acute{y}^k(n) = \frac{d}{dq_s}\|q_s(n) - w_e\| = \frac{q_s{}^i(n)-w_e}{\|q_s{}^i(n)-w_e\|} \quad (31)$$

$$\frac{d\,g(n)}{dq_s} = 2kq_{se}{}^i(n)(\acute{y}^k(n))e^{q_{se}{}^i(n)} + g^i(n)\,\acute{y}^k(n) \quad (32)$$

Substituting (32) (31) into (29)

$$g(n) \approx g^i(n) + [2k\|q_s{}^i(n) - w_e\| \left(\frac{q_s{}^i(n)-w_e}{\|q_s{}^i(n)-w_e\|}\right) e^{k\|q_s{}^i(n)-w_e\|} + g^i(n)\left(\frac{q_s{}^i(n)-w_e}{\|q_s{}^i(n)-w_e\|}\right)](q_s(n) - q_s{}^i(n)) \quad (33)$$

The first term of P3 ($log_2\left(1+\frac{c_n}{s(n)}\right)$) can be replaced by its convex lower bound

$$log_2\left(1+\frac{c_n}{s(n)}\right) \geq log_2\left(1+\frac{c_n}{s^i(n)}\right) - \frac{c_n}{In(2)s^i(n)(s^i(n)+c_n)}\,(s(n) - s^i(n)) \quad (34)$$

and the second term $log_2\left(1+\frac{d_n}{g(n)}\right)$can be replaced by its convex first-order Taylor series

$$log_2\left(1+\frac{d_n}{g(n)}\right) \approx log_2\left(1+\frac{d_n}{g^i(n)}\right) - \frac{d_n}{In(2)g^i(n)(g^i(n)+d_n)}\,(g(n) - g^i(n)) \quad (35)$$

Thus, the optimization problem is approximated as:

$$P4: max \sum_{1}^{N} - \frac{c_n}{In(2)s^i(n)(s^i(n)+c_n)}(s(n) - s^i(n)) - [log_2\left(1+\frac{d_n}{g^i(n)}\right) - \frac{d_n}{In(2)g^i(n)(g^i(n)+d_n)}\left(g(n) - g^i(n)\right) \quad (36)$$

s.t

$$s^i(n) + [2k\|q_s{}^i(n) - w_d\| \left(\frac{q_s{}^i(n)-w_d}{\|q_s{}^i(n)-w_d\|}\right) e^{k\|q_s{}^i(n)-w_d\|} + s^i(n)\left(\frac{q_s{}^i(n)-w_d}{\|q_s{}^i(n)-w_d\|}\right)](q_s(n) - q_s{}^i(n)) - s(n) \leq 0 \quad (37)$$

$$g(n) - g^i(n) + [2k\|q_s{}^i(n) - w_e\| \left(\frac{q_s{}^i(n)-w_e}{\|q_s{}^i(n)-w_e\|}\right) e^{k\|q_s{}^i(n)-w_e\|} + g^i(n)\left(\frac{q_s{}^i(n)-w_e}{\|q_s{}^i(n)-w_e\|}\right)](q_s(n) - q_s{}^i(n)) \leq 0 \quad (38)$$

$$g(n) \geq 0 \quad (39)$$

Since $(P4)$ is a convex problem, it can be solved using CVX tool.[28]

IV. Overall Algorithm

To summarize our approach, our algorithm solves $P1$ by alternately optimizing variables $\boldsymbol{P_s}$ and $\boldsymbol{Q_s}$ in an iterative way. The detailed steps of solving problem $P1$is concluded in Algorithm 1

Algorithm 1: Proposed algorithm for P1

1: **Initialize** $q_s{}^0(n)$, $P_s{}^0(n)$ Let $i = 0$.
2: **repeat**
3: With given $P_s{}^i$ and $q_s{}^i$ **update** source UAV's transmit powerP_s^{i+1};
4: With the given P_s^{i+1} **update** source UAV's trajectory q_s^{i+1}
5:**Update** $k = k + 1$.
6: **Until** the fractional increase of the objective value is below a small threshold ϵ

V. MIMO And Secrecy Outage Probability Analysis

Deploying MIMO technique to increase the communication distance at sub-THz frequencies was discussed in [1]. The purpose of using this technique is to reduce the impact of the severe THz frequencies path loss in UAV communication. Also, this technique has shown its effectiveness in UAV communication at sub-THz too as we demonstrated in our previous work [7]. In this paper, MIMO was used for UAVs and ground nodes. the communication of both UAVs and ground nodes. To evaluate the performance of physical layer security of the trajectory of UAVs at sub-THz communication, Secrecy outage capacity is calculated in this section. We assume that the secrecy outage can be written as:

$$Pr_{out}(R_s) = \Pr\{C_u < R_s\} \quad (40)$$

where R_s is the threshold secrecy rate for our communications. Assuming $\overline{\gamma_k}$ is the average SNR of the users and $\overline{\gamma_e}$ is the average SNR of the eavesdropper, respectably. As proven in [29], the secrecy outage probability can be written as:

$$Pr_{out}(R_s) = 1 - \frac{\overline{\gamma_u}}{\overline{\gamma_u}+\overline{\gamma_e}(2^{R_s})} exp\left(-\frac{2^{R_s}-1}{\overline{\gamma_u}}\right) \quad (41)$$

VI. Performance Evaluation

In this section, we present our simulation results to show that our proposed joint transmit power control and UAV trajectory optimization TP is effective for improving the secrecy rate performance. Also, we consider a benchmark algorithm TnoP. Our simulation result TP is compared to a UAV trajectory optimized without power optimization (TnoP). The UAV trajectory in TNoP is calculated by solving problems (P4) iteratively until algorithms converge with $P_s(n) = \overline{P_s}, P_j(n) = \overline{P_J}$. over the whole duration. While our approach is calculated by solving P2 and P4 iteratively until algorithms converge $P_j(n) = \overline{P_J}$ Our simulation parameters are presented in Table 1.

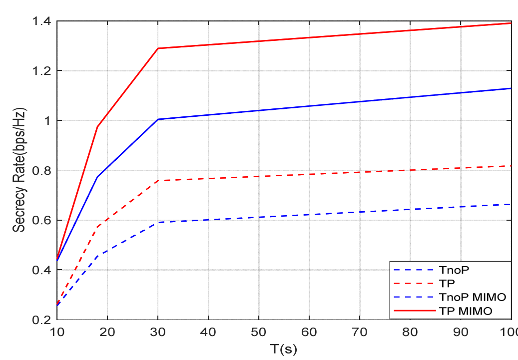

Fig.2: Secrecy Rate(bps/Hz) versus Time(s)

Table 1. Simulation parameters.

Simulation parameter	*Value*
location of w_d	(0,0,0)
location of w_e	(10,0,0)
q_{s0}	(5,-10,0)
q_{sf}	(5,10,0)
H	3
V	2
$\overline{P_J}$	0 dBm
$\overline{P_s}$	10 dBm
P_{s-max}	$4\overline{P_s}$
P_{s-max}	$4\overline{P_J}$
δ	1
ρ_0	-60 dBm
σ^2	-110 dBm
ϵ	10^{-4}
k	0.005 m^{-1}

We assumed both UAVs start and end at the same location as $q_{s0} = q_{j0}$ and $q_{sf} = q_{jf}$ .In this paper, we assume the friendly jammer UAV trajectory is given as a straight line from the initial point to the eavesdropper node and then to the final point in a straight-line. Fig.3 shows the trajectories of the UAV for different flight periods T and the transmit power was set as 10 dBm for all flights. We notice that at the minimum time required for the UAV to fly from the initial point to the final point T = 10s, the trajectory of the UAV performed as a straight line at maximum speed as seen in Fig.3. When the time-of-flight increases, the trajectories by our proposed algorithm TP and the benchmark algorithm TnoP fly as close as possible to the ground node and as far away as possible from the eavesdropper at the same time. When T is sufficiently large, T = 100s, it can be seen both TP and TnoP UAVs fly at maximum speed to reach the nearest point to the ground node for as long as possible, and then fly to the final point at maximum speed and reaches there by the end of the flight period.

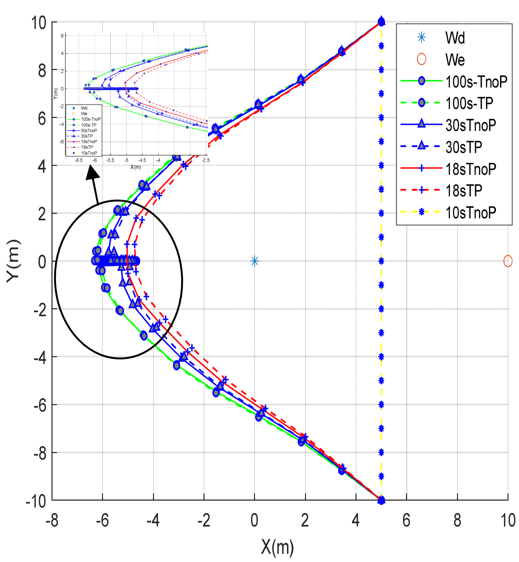

Fig.2: Trajectories of the UAV for different values of flight time

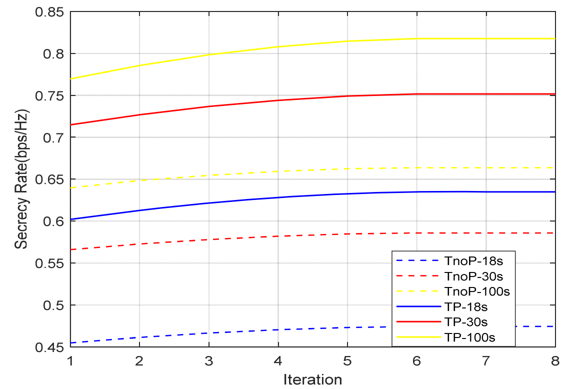

Fig.4: Convergence plot of Algorithm1

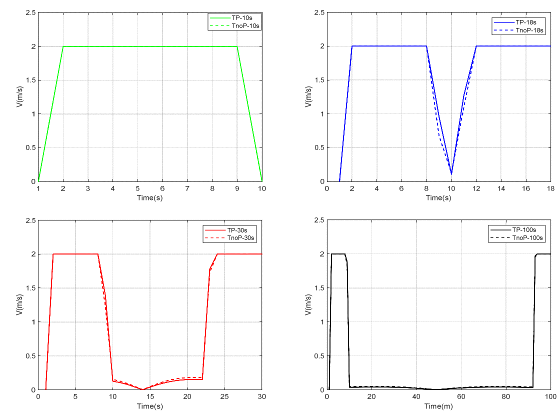
Fig.5: speed of UAV vs Time (s)

Fig.2 shows the average secrecy rate versus Time for TP and TnoP. It is shown that the average secrecy rate for both algorithms increase with T because that the UAV can stay longer at the best location near the user location. We can see that the proposed TP algorithm achieves better secrecy rate performance than the TNoP achieves. Also, both algorithms achieve a better secrecy data rate when MIMO technique is used for all different time flights as seen in Fig.2. Fig .4 demonstrates the convergence of both Algorithms TP and TnoP. As seen the secrecy rate improves from one iteration to the next one until converges at 6 iterations for different time flights. Notably, the secrecy data rate at T=10 is not affectable due to the lack of sufficient flying time for the UAV which prevents the UAV from improving its secrecy data rate in different trajectories.

Moreover, the secrecy outage probability's variation vs Time of the flight was obtained as seen in Fig.6 for three flight periods (18s, 30s, 100s). We considered the value of threshold Rs = 1bps in the presence of eavesdroppers. User’s and eavesdropper’s SNR were taken from the best location obtained by our algorithm. We conclude that as time flight increase, the UAV enjoy the best secrecy outage probability value near the user location. Notably, the secrecy outage probability at T=10 is not affected by the optimized trajectory due to the lack of sufficient flying time for the UAV.

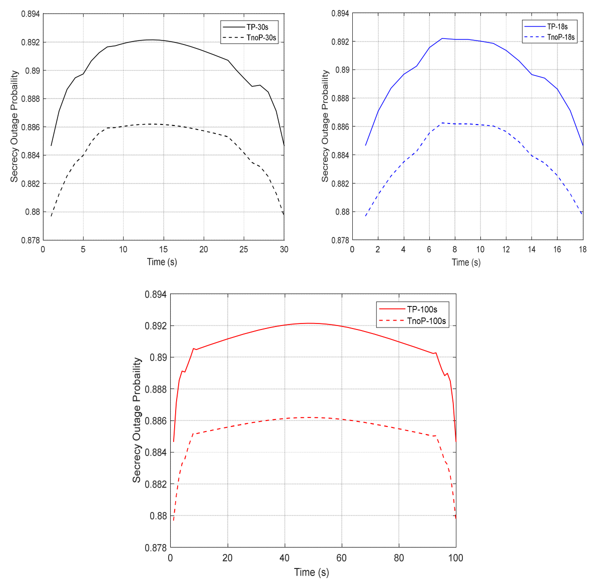

Fig6: Secrecy Outage Probability for T=18s,30s, and 100s vs time

VII. Conclusion

The severe path loss parameter is an essential part of THz channel modeling that cannot be neglected. In this paper, we studied the trajectories of UAV in the sub-THz band, and we proposed an optimization equation that maximizes the secrecy rate by optimizing the trajectories and transmit power of the UAV jointly. To further enhance the achievable average secrecy rate for UAV-ground communications, MIMO technique and a cooperative UAV jamming strategy were used. Analysis and simulations are presented for UAV-ground communication. Finally, an analysis for Secrecy Outage Probability is presented to demonstrate the performance of physical layer security of our proposed algorithm in sub-THz UAV communication

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