# Wireless Communication-UAVs

Jyothi R[1], Sona Sara Thomas[2], Kumari Priya[3], Rajala Tejashwini[4], Sayantani Sarkar[5]

Assistant Professor, Dept. of C.S.E, R.R Institute of Technology, Bengaluru, India[1]

UG Students, Dept. of C.S.E, R.R Institute of Technology, Bengaluru, India [2,3,4,5]

**ABSTRACT**: The use of flying platforms such as unmanned aerial vehicles (UAVs), popularly known as drones, is rapidly growing. In particular, with their inherent attributes such as mobility, flexibility, and adaptive altitude, UAVs admit several key potential applications in wireless systems. On the one hand, UAVs can be used as aerial base stations to enhance coverage, capacity, reliability, and energy efficiency of wireless networks. On the other hand, UAVs can operate as flying mobile terminals within a cellular network. Such cellular-connected UAVs can enable several applications ranging from real-time video streaming to item delivery. In this paper, a comprehensive tutorial on the potential benefits and applications of UAVs in wireless communications is presented. Moreover, the important challenges and the fundamental tradeoffs in UAV-enabled wireless networks are thoroughly investigated. In particular, the key UAV challenges such as three-dimensional deployment, performance analysis, channel modeling, and energy efficiency are explored along with representative results. Then, open problems and potential research directions pertaining to UAV communications are introduced. Finally, various analytical frameworks and mathematical tools such as optimization theory, machine learning, stochastic geometry, transport theory, and game theory are described. The use of such tools for addressing unique UAV problems is also presented. In a nutshell, this tutorial provides key guidelines on how to analyse, optimize, and design UAV-based wireless communication systems.

**KEYWORDS**: Millimeter wave (mmWave) communications, unmanned aerial vehicle (UAV), mmWave UAV communications, UAV-assisted wireless networks, 5G and beyond.

## I. INTRODUCTION

Unmanned aerial vehicles (UAVs), commonly known as drones, have been the subject of concerted research over the past few years [1]–[5], owing to their autonomy, flexibility, and broad range of application domains. Indeed, UAVs have been considered as enablers of various applications that include military, surveillance and monitoring, telecommunications, delivery of medical supplies, and rescue operations [1], [3], and [6]–[17]. However, such conventional UAV-centric research has typically focused on issues of navigation, control, and autonomy, as the motivating applications were typically robotics or military oriented. In contrast, the communication challenges of UAVs have typically been either neglected or considered as part of the control and autonomy components.Cellular connections in our everyday life are about to be ubiquitously reliable in 5G cellular systems [1]–[3].

The remaining cellular coverage holes would then come from disaster scenarios, which significantly disrupt the search and rescue operations [4]. To fill these holes quickly and efficiently, it is envisaged to utilize unmanned aerial vehicles (UAVs) that support air-to-ground cellular communications [5]–[9]. In this work, we focus particularly on an urban disaster scenario requiring a large number of emergency connections that are enabled by a massive number of UAVs. The major technical challenge is the real-time movement control of the massively deployed UAVs. To elaborate, when the ground users are crowded around a disaster hotspot as shown in Fig. 1, the optimal UAV locations for the air-toground communication are also likely to be concentrated. The resulting inter-UAV distances may be too short, leading to the inter-UAV collisions caused by their swaying in the wind. To keep their collision-safe distances stable under time-varying wind dynamics, it is thus necessary to adjust the UAV locations continuously. At the same time, due to the limited battery capacity, UAVs need to maximize their energy efficiency, which is difficult to be optimized per se even for a single UAV under a given constant wind velocity [7].

## II. RELATED WORK

Trajectory optimization for UAVs has been studied primarily from a robotics/control perspective. Most of the current UAV literature is focused on solving air-to-ground wireless communication problems in sparse deployment scenarios [5], [6], [8], [9]. These include power control, altitude optimization, UAV location, and so forth. Nevertheless these works overlook specifics of UAV in terms of energy efficiency, collision avoidance and massive UAV deployments. Fewer works study the interplay between UAV's trajectory (control) and the wireless communication performance such as [7], [13], [14]. However while interesting these works do not consider the challenging scenario involving a massive deployment of UAVs. To the best of our knowledge this is the first work to fill that void.

## III. PROPOSED ALGORITHM

### A. *Design Considerations:*

- Locomotion, the vehicle must have a flexible drive system
- Communication, Control and Power
- GSM technology would be used in the prototype
- GPS to show the position and orientation of the robot
- Additional features to assist in search and rescue applications, including cameras, audio systems and sensors

### B. *Description of the Proposed Algorithm:*

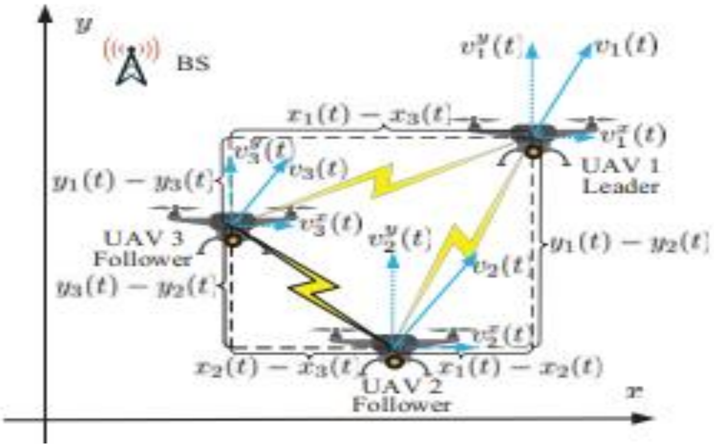

Figure 1. A swarm of three UAVs where each UAV can communicate with the BS. UAV 1 is the leader, and UAVs 2 and 3 are followers.

Consider a swarm of three UAVs flying at the same altitude. In this swarm, two UAVs are following a third, leading UAV to form and maintain a triangle formation, as shown in Fig. 1. In this model, we assume that UAV 1 is the leading UAV that always flies with a target velocity and heading direction, while UAVs 2 and 3 are followers. Note that, when following the leading UAV, UAVs 2 and 3 will also need to keep a certain target distance with each other and with the leader. For each UAV, an embedded radar sensor can sense the distance to the nearby UAVs. Moreover, each following UAV can communicate with the two other UAVs in the swarm, via wireless cellular links, to obtain information of the velocity and heading angle. In addition, each UAV will communicate with the BSs through cellular links to report its movement and location or to complete tasks, like sending the collected surveillance information back to the BSs.

A. Control System

Model As shown in Fig. 1, we consider a Cartesian coordinate system centered on an arbitrarily selected point, and the location of each UAV at time t is denoted by (xi(t), yi(t)), i ∈ {1, 2, 3}. Also, by using the coordinate system, we can decompose the velocity of each UAV into two components: one on the x-axis and the other one on the y-axis. Moreover, we assume that the control laws of each following UAV over the x-axis and y-axis depend on the difference between the actual distance to the UAVs in the swarm and the target distance. For example, if the actual distance between a following UAV and other UAVs in the swarm exceeds the corresponding target spacing, the following UAV needs to accelerate in order to reduce the spacing and reach the target distance. To determine the control law on each axis, we first take the component on the x-axis as an example. In particular, we define the x-axis distance difference by using the following spacing errors:

$$\delta_{1,2}^{x}(t)=x_1(t)-x_2(t)-\bar{x}_{1,2},\delta_{1,3}^{x}(t)=x_1(t)-x_3(t)-\bar{x}_{1,3}, \quad (1)$$

$$\delta_{2,3}^{x}(t)=x_2(t)-x_3(t)-\bar{x}_{2,3},\delta_{3,2}^{x}(t)=x_3(t)-x_2(t)-\bar{x}_{3,2}, \quad (2)$$

where x¯1,2, x¯1,3, x¯2,3, and x¯3,2 are the target x-axis spacing between the corresponding UAVs. Note that xi(t) − xj (t) is usually considered as the x-axis headway distance between UAVs i and j with i, j ∈ {1, 2, 3}, at time t. Also, we can define the x-axis velocity errors for following UAVs 2 and 3 as

$$z_2^x(t) = v_2^x(t) - \bar{v}_x, z_3^x(t) = v_3^x(t) - \bar{v}_x, \qquad (3)$$

where v¯x is the x-axis component of the target operating velocity for the swarm of UAVs. Note that the spacing errors and velocity errors on the y-axis can be derived as done in (1)–(3) and are omitted due to space limitations. Similar to the dynamical system model introduced in [13], the acceleration and deceleration of each UAV will depend on the spacing errors and velocity errors. In particular, the x-axis control law for each following UAV can be given by:

$$\begin{aligned} u_i^x(t) = {} & a_i\delta_{1,i}^x + b_i[v_1^x(t-\tau_{1,i}(t)) - v_i(t)] + \hat{a}_i\delta_{j,i}^x + \\ & \hat{b}_i[v_j(t-\tau_{j,i}(t)) - v_i(t)], i \neq j, i, j \in \{2,3\}, \qquad (4) \end{aligned}$$

where ai, bi, aˆi, and ˆbi are the associated gains for each corresponding term, while τj,i captures the delay for the wireless link from UAV j to UAV i. Note that the associated gains essentially capture the sensibility of the control system to changes in distance and velocity. Also, since the leading UAV always flies with the target velocity and heading angle, then the solution to vx 1 (t − τ1,i(t)) = ¯vx always exists. Similarly, we can also derive the control law over the y-axis for each following UAV. Therefore, based on the x-axis and y-axis control laws for the velocity components, we can determine how the velocity and heading angle of each following UAV should change.

## B. Wireless Communication

System For the wireless communication links between UAVs inside the swarm, we consider an orthogonal frequency-division multiple access (OFDMA) scheme where each communication link does not share the frequencyinterference from each other. However, the wireless links in one swarm can experience interference when other UAVs at the same altitude that are using the same frequency resource to transmit information with each other or with BSs via cellular links. To have a general interference model, we assume that the distribution of interfering UAVs at the same altitude with the swarm follows a 2-dimensional Poisson point process (2-D PPP) with density λ. Also, similar to [14], we consider the wireless communication channels inside the swarm as independent Nakagami channels with parameter β, and we also model the wireless channels from interfering UAVs to UAVs inside the swarm as independent Rayleigh fading channels. Thus, the channel gain between a receiving UAV i and a transmitter j at time t will be gj,i(t) = hj,i(t)(dj,i(t))−α, where hj,i(t) captures the fading gain, dj,i(t) is the distance between UAVs j and i, and α is the path loss exponent. Moreover, we can obtain the received signal at UAV i as Pj,i(t) = Ptgj,i(t), where Pt is the transmission power. Also, the signal-to-interference-plusnoise-ratio (SINR) can be given by γj,i(t) = Pj,i(t) σ2+Ii(t) , where σ2 is the variance of the Gaussian noise, and Ii(t) captures the interference experienced by UAV i. Then, the data rate will be: Rj,i(t) = ω log2(1 + γj,i(t)), where ω is the bandwidth of the frequency resource. Whenever all packets are of equal size S bits, the transmission delay of the wireless link between UAVs j and i can be derived as τj,i(t) = S ω log2(1 + γj,i(t)). (5) In the following section, we take into account the time-varying wireless transmission delay in (5) and analyze its effect on the stability of the control system in the swarm of UAVs.

## IV. PSEUDO CODE

**Algorithm for image processing**

```
Step 1: Clear all
Step 2: Activate the camera and start a video.
Step 3:Take the images from the video and store the image in x.
Step 4:Subplot the image in rows and columns and display it on the screen.
Step 5:Crop this image into 40*40 pixel and check for a human face.
Step 6:Face is detected using the protocol Cascadeobject detection and displayed it on screen.
Step 7: Once the face is detected control is send to the controller.
Step 8: End.
```

**Algorithm for the k−opt algorithm Notations**

Let cost(T) denote the sum of the cost of traveling all the edges in the tour T.

Let n denote the search span of a segment.

```
Step 1: T∗ ← Initial feasible tour.
Step 2: T ← T∗.
Step 3: loop
Step 4: Nd ← Number of visits to the depots in T.
Step 5: for i = 1, · · · , Nd do
Step 6: S(i, n) ← segment of T centered at the i th depot visited in T.
Step 7: Find a tour R such that for 2 ≤ k� ≤ k,
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Step 8: R is obtained by replacing k� edges in the segment S(i, n) with k� new edges;
Step 9: R is the best improving k� −exchange of T.
Step 10: If cost(R) < cost(T), T ← R.
Step 11: end for
Step 12: if cost(T∗) ≤ cost(T) then
Step 13: break;
Step 14: else
Step 15: T∗ ← T.
Step 16: end if
Step 17: end loop
Step 18: Output T∗ as the solution.
```
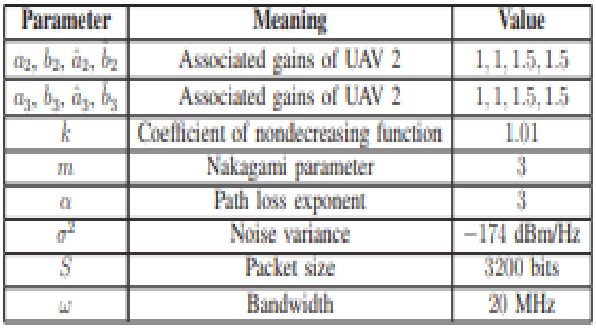
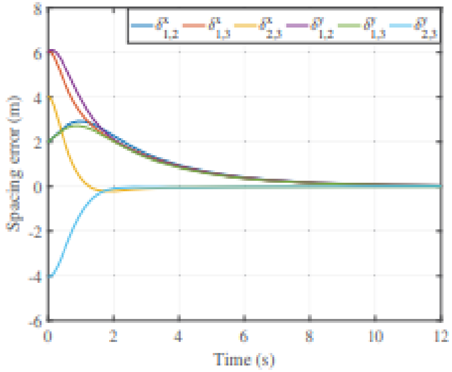

## V. SIMULATION RESULTS

For our simulations, we first validate the results derived in Corollary 1. Based on Lemma 1, we then study the impact of interference on the reliability performance of the wireless network and finally obtain the design guideline of formulating a stable triangle formation for a swarm of three UAVs. All simulation parameters are summarized in Table I. Without loss of generality, we assume that the two following UAVs have the same control gains, given in Table I. Using the parameter settings in Table I for Corollary 1, we can find that the maximum allowable transmission delay to avoid the instability of the control system is 18.2 ms. We first corroborate the analytical result in Corollary 1 on the stability of the control system under the derived transmission delay threshold. In particular, we model the uncertainty of the wireless channel pertaining to the wireless communication links in the swarm of UAVs as a time-varying delay in the range (0, 18.2 ms). The following UAVs are initially assigned with different velocities from the target velocity and random locations. Here, the leading UAV flies with speed components v¯x = 5 m/s and v¯y = 5 m/s, and the target spacing between UAVs are x¯1,2 = 3 m, x¯1,3 = 4 m, x¯2,3 = 1 m, y¯1,2 = 4 m, y¯1,3 = 3 m, and y¯2,3 = −1 m.

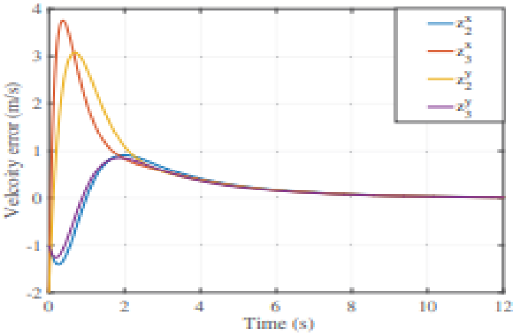
TABLE I
SIMULATION PARAMETERS.



| Parameter | Meaning | Value |
|---|---|---|
| $a_2, b_2, \hat{a}_2, \hat{b}_2$ | Associated gains of UAV 2 | 1, 1, 1.5, 1.5 |
| $a_3, b_3, \hat{a}_3, \hat{b}_3$ | Associated gains of UAV 2 | 1, 1, 1.5, 1.5 |
| $k$ | Coefficient of nondecreasing function | 1.01 |
| $m$ | Nakagami parameter | 3 |
| $\alpha$ | Path loss exponent | 3 |
| $\sigma^2$ | Noise variance | −174 dBm/Hz |
| $S$ | Packet size | 3200 bits |
| $\omega$ | Bandwidth | 20 MHz |



(a) Spacing errors over time.



(b) Velocity errors over time

Fig. 2. Stability validation for a swarm of three UAVs when using the maximum allowable transmission delay derived in Corollary 1.

Fig. 2(a) shows the time evolution of the spacing errors. We can observe that the spacing errors at x-axis and y-axis for both following UAVs will eventually converge to 0. Also, in Fig. 2(b), we can observe that the velocity errors will converge to 0 when time passes by. Thus, by choosing the maximum delay derived in Corollary 1, we can ensure that the stability of the swarm of UAVs is guaranteed and the target formation can be formulated.

Fig. 3 shows the reliability performance of the wireless network with different densities of interfering UAVs when the spacing target increases. As observed from Fig. 3, when the spacing target between two following UAVs increases, the reliability of the wireless network will decrease. For example, for a system with density of interfering UAVs λ = 5×10−2 UAV/m2, the reliability is around 35% when the spacing target is 10 m. However, when the spacing target is 4 m, the reliability is 90.1%. Moreover, we can obtain a design guideline on how to guarantee a stable UAV formation from the results shown in Fig. 3. In particular, to guarantee that the reliability of the wireless system exceeds a threshold, we need to properly choose the target spacing between two following UAVs in the swarm. As shown in Fig. 3, for a system with λ = 10×10−2 UAV/m2, the target spacing should be chosen a smaller value than 2.8 m so that the reliability performance can exceed 90%. Also, for a system with λ = 5 × 10−2 UAV/m2, the corresponding target spacing value should be smaller than 4 m to reach a reliability of 90%. Moreover, when the density is chosen as λ = 1×10−2 UAV/m2, the spacing target should be smaller than 9 m. This is due to the fact that the strength of the receiving signal will decrease and the delay of the communication link will increase when the spacing increases.

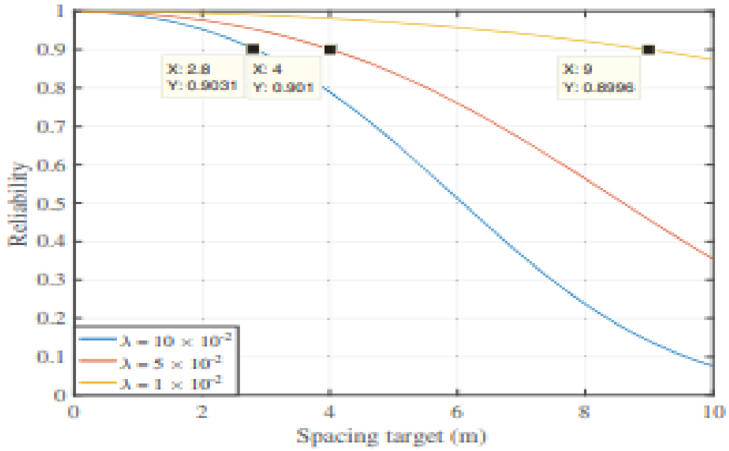


Fig. 3. Reliability performance of systems with different densities of interfering UAV when spacing target increases.

## VI. CONCLUSION AND FUTURE WORK

In this, we have provided a comprehensive study on the use of UAVs in wireless networks. We have investigated two main use cases of UAVs, namely, aerial base stations and cellular-connected users, i.e., UAV-UEs. For each use case of UAVs, we have explored key challenges, applications, and fundamental open problems. Moreover, we have presented the major state of the art pertaining to challenges in UAVenabled wireless networks, along with insightful representative results. Meanwhile, we have described mathematical tools and techniques needed for meeting UAV challenges as well as analyzing UAV-enabled wireless networks. Such an in-depthfurther improvements the microcontroller could also be modified to monitor the voltage across each arm rotation motor to determine when the motor has stalled (and by extension, when the arm has made contact with the ground or an obstacle). These contacts would be communicated to the laptop via the Wi-Fi router on the robot. The arms would flash a different color when they confirm contact with an obstacle. In addition, the two processors used by the team would be replaced by a single, more powerful processor with more input and output pins, which would eliminate the communication delays experienced by the prototype.

## REFERENCES

[1] N. Zhao, et al., “UAV-assisted emergency networks in disasters,” IEEE Wireless Commun., vol. 26, no. 1, pp. 45–51, Feb. 2019.

2]F. Cheng et al., “UAV relaying assisted secure transmission with caching,” IEEE Trans. Commun., 2019, doi:10.1109/TCOMM.2019.2895088.

[3] J. Xu, Y. Zeng, and R. Zhang, “UAV-enabled wireless power transfer: Trajectory design and energy optimization,” IEEE Trans. Wireless Commun., vol. 17, no. 8, pp. 5092–5106, Aug. 2019.

[4] Q. Wu, Y. Zeng, and R. Zhang, “Joint trajectory and communication design for multi-UAV enabled wireless networks,” IEEE Trans. Wireless Commun., vol. 17, no. 3, pp. 2109–2121, Mar. 2018.

[5] F. Cheng et al., “UAV trajectory optimization for data offloading at the edge of multiple cells,” IEEE Trans. Veh. Technol., vol. 67, no. 7, pp. 6732–6736, Jul. 2018.

[6] D. Kim, J. Lee, and T. Q. S. Quek, ‘‘Multi-layer unmanned aerial vehicle networks: Modeling and performance analysis,’’ Apr. 2019.

[7] Y. Zeng, Q. Wu, and R. Zhang, ‘‘Accessing from the sky: A tutorial on UAV communications for 5G and beyond,’’ Mar. 2019.

[8] M. Mozaffari, W. Saad, M. Bennis, Y.-H. Nam, and M. Debbah, ‘‘A tutorial on UAVs for wireless networks: Applications, challenges, and open problems,’’ IEEE Commun. Surveys Tuts., to be published. doi: 10.1109/ COMST.2019.2902862.

[9] A. Fotouhi, H. Qiang, M. Ding, M. Hassan, L. G. Giordano, and A. García-Rodríguez, and J. Yuan, ‘‘Survey on uav cellular communications: Practical aspects, standardization advancements, regulation, and security challenges,’’ IEEE Commun. Surveys Tuts., to be published. doi: 10.1109/COMST.2019.2906228.

[10] E. Vinogradov, H. Sallouha, S. D. Bast, M. M. Azari, and S. Pollin, ‘‘Tutorial on UAV: A blue sky view on wireless communication,’’ Jan. 2019, arXiv:1901.02306. [Online]. Available: http://arxiv.org/abs/1901.02306.

## BIOGRAPHY

**Prof. Jyothi R** is an Assistant Professor in the Computer Science & Engineering Department, R.R Institute of Technology, Visvesvaraya Technological University. She Received Master of Technologydegree in 2015 in computer Science branch from Visvesvaraya Technological University. Belgaum. Her area of interest are Software Engineering, Network Security andAlgorithms.