

# AI-Based Unmanned Aerial Vehicles Networks

Subjects: Computer Science, Artificial Intelligence

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To enhance the overall performance of the unmanned aerial vehicles (UAVs) networks and to address some specific problems, new features in the network are being designed as autonomous features. This approach not only provides optimum solutions for the targeted problems but also supports the dynamic properties of a UAV network.

Keywords: artificial intelligence ; autonomous UAV ; AI-based UAV networks

## 1. Resource Management and Network Planning

Optimal management and planning of network resources are very crucial for the success of any network. This is particularly true when it comes to networks where human intervention is minimal. For unmanned aerial vehicles (UAVs), this feature is being focused on by many researchers, and various challenges are being identified and addressed. **Table 1** provides a summary of related surveys on UAV network resource management and planning.

**Table 1.** Summary of related survey: UAV network resource management and planning.

Scope	Autonomous Features	Computational Intelligence	Channel Modeling	Interference Management	Security and Safety	Reference
Cooperative path planning, collisions	Path planning	√	Non-convex modeling	-	-	[1]
Cooperative path planning, resource allocation	Path planning	√	-	-	-	[2]
Cooperative UAVs, trajectory conflicts	Conflict detection and resolution	√	-	-	-	[3]
Channel modeling		√	Shadowing channel	√	-	[4]
Interference management	Path planning	√	Rician distribution	√	-	[5]
Interference-aware path planning	Path planning	√	Free-space path loss with 6 GHz	√	-	[5]
Interference management	Spatial configuration	√	Customized	√	-	[6]
Interference management	Transmission power, trajectory planning	√	Large-scale path loss	√	-	[7]
Interference management	Transmission power	√	Free-space path loss	√	-	[8]
Resource management	Energy consumption, transmission power	√	Various	√	-	[9]
Collision free navigation	Trajectory planning	√	-	-	-	[10]
Risk-aware path planning	Path planning	√	-	-	-	[11]
Mobility challenges		-	-	-	√	[12]

Scope	Autonomous Features	Computational Intelligence	Channel Modeling	Interference Management	Security and Safety	Reference
Resource management	User association	✓	Free-space path loss	✓	-	[13]
Delay-aware throughput maximization	Trajectory planning	✓	Free-space path loss	-	-	[14]
UAV placement	Energy efficiency and optimization	✓	Path loss outdoor/indoor penetration	-	-	[15]
Collision free navigation	Trajectory planning	✓	-	✓	-	[16]
Swarm-based UAV	Path planning	✓	-	-	-	[17]
Physical layer security	security and cooperation	✓	Free-space path loss	✓	✓	[18]
Secure UAV communication	Cooperative scheduling	✓	Free-space path loss	-	✓	[19]
Physical layer security	Cooperative trajectory and optimization	✓	Free-space path loss	✓	✓	[20]
Physical layer security	Cooperative resource allocation	✓	Free-space path loss	-	✓	[21]
Quality of Experience (QoE)	Cooperative resource allocation	✓	LOS and Non-LOS	-	-	[22]
Secure UAV communication	UAV defense	✓	-	-	✓	[23]
Software-defined radio (SRD)	Localization of unwelcomed UAVs	✓	-	✓	✓	[24]

In [9], the autonomous distribution of resource management for UAV networks is being discussed. The authors have used the concept of game theory and highlighted various game models that may be used for optimal resource management among UAVs. In specific, five-game theory models were discussed, including coalition, potential, graphical, mean-field, and Stackelberg. Each model is explained based on its goals, design of utility function, and strategies, which implies their application areas.

Reference [10] focused on real-time planning for UAV's path under dynamic conditions. A discrete algorithm, along with a probabilistic graph, is being used to achieve a path with no collisions. Another similar study to explore path planning for UAVs is conducted in [11]. In this study, the information from both static and dynamic paths is utilized to provide a path. A step-by-step adaptive path planning technique is proposed to achieve optimal results. Another interesting idea is that UAVs are considered additional users in the 5G cellular networks [12]. The study highlights various challenges that are encountered by service providers to facilitate new users.

## 2. Multiple Access and Routing Protocols

Multiple access and routing protocols are another challenging domain for UAV networks. As UAVs are supposed to be co-located with other networks, the natural choice for multiple access for UAVs was initially space division multiple access techniques [25][26][27]. However, as time passes, many researchers have started exploring other techniques that prove to be more efficient in the case of UAV networks. Most of these include orthogonal, non-orthogonal, or rate-splitting techniques. **Table 2** provides a summary of related surveys on UAV multiple access and routing protocols.

In orthogonal multiple access techniques, the interference is reduced by ensuring that the simultaneous communications are orthogonal to one another. Multiple research studies [13][28] have been conducted to achieve this goal. Some propose to use time division multiple access (TDMA) and frequency division multiple access (FDMA) in their system models. Another group of researchers focused on using code division multiple access (CDMA) [29][30][31]. On the other hand,

orthogonal frequency division multiple access (OFDMA) is explored by some researchers [14][32][33], while some other research studies are conducted exploring space division multiple access (SDMA) [34][35][36][37][38][39].

To overcome the above-stated limitation of orthogonal multiple access techniques, much work is being performed using non-orthogonal techniques, mainly using joint optimization of the base stations (BSs), including power [40][41][42], trajectory [43][44][45], and placement [46][47]. Although non-orthogonal multiple access techniques can perform better by covering many users with non-orthogonal yet correlated channels, however, there is a case when its performance can degrade exponentially, i.e., when the number of antennas is greater than the number of users scheduled. To avoid such circumstances, another effective technique is explored.

Rate-splitting multiple access techniques for UAVs seem to overcome the problems of both orthogonal and non-orthogonal multiple access.

### 3. Power Control and Energy Efficiency

For drones and unmanned aerial vehicles (UAVs), power control and energy efficiency are other very critical realms. As these network nodes are not on the ground, an uninterrupted supply of power and efficient utilization of energy become very crucial. Many research studies have addressed this area and proposed several solutions, some targeting multiple power sources, including battery [48][49], hydrogen fuel [50][51], solar [52][53], and hybrid [54][55], that can be utilized by the UAVs. While others focus on how efficiently energy can be consumed. Energy efficiency affects all the operations of a UAV. Many studies have been conducted to explore UAV placement for optimal energy efficiency [15][56].

Another aspect explored in this domain is path planning. Various approaches are being used to explore this area, including sample-based [16][57], space search [17], and biological searching techniques [58][59][60].

**Table 2.** Summary of related survey: UAV multiple access and routing protocols.

Scope	Autonomous Features	Computational Intelligence	Channel Modeling	Interference Management	Security and Safety	Reference
Channel access	Cyclic multiple channel access	√	Free-space path loss with LOS	-	-	[28]
MAC protocol	Energy consumption, Packet-error-rate (PER)	√	Free-space path loss with LOS	-	-	[29][30]
Performance evaluation of MAC	PER	√	Rician fading	-	-	[31]
Trajectory optimization	Trajectory planning	√	Free-space path loss with LOS, correlated Rician fading, Rayleigh fading, Rician K-factor	√	-	[34]
mm wave UAV cellular network	Beam forming	√	Quasi-static, Rayleigh fading	√	-	[35]
Channel access with time-modulated array (TDM)	Beam forming, performance	√	Free-space path loss with LOS	√	-	[37]
Trajectory optimization	Trajectory planning, power control	√	Additive white Gaussian noise (AWGN)	√	-	[41]
MAC protocol	Power optimization	√	Rician fading	√	-	[42]
MAC protocol	Throughput optimization	√	Free-space path loss	-	-	[43]
MAC protocol	Power optimization	√	Free-space path loss with LOS	√	-	[44]

Scope	Autonomous Features	Computational Intelligence	Channel Modeling	Interference Management	Security and Safety	Reference
MAC protocol	Trajectory planning, resource management	√	LOS and Non-LOS (NLOS)	√	-	[45]
MAC protocol	Power optimization	√	LOS, NLOS	√	-	[46]
MAC protocol	Power and placement optimization	√	Additive white Gaussian noise (AWGN)	√	-	[47]
Rate-splitting	Beam forming	√	Additive white Gaussian noise (AWGN)	√	-	[61]
Rate-splitting	Spectral efficiency	√	Additive white Gaussian noise (AWGN)	√	-	[62]

## References

- Richards, A.; How, J. Decentralized model predictive control of cooperating UAVs. In Proceedings of the 43rd IEEE Conference on Decision and Control (CDC) (IEEE Cat. No. 04CH37601), Nassau, Bahamas, 14–17 December 2004; pp. 4286–4291.
- Bellingham, J.; Tillerson, M.; Richards, A.; How, J.P. Multi-Task Allocation and Path Planning for Cooperating UAVs; Springer: Boston, MA, USA, 2003.
- Conde, R.; Alejo, D.; Cobano, J.A.; Viguria, A.; Ollero, A. Conflict detection and resolution method for cooperating unmanned aerial vehicles. *J. Intell. Robot. Syst.* 2012, 65, 495–505.
- Bithas, P.S.; Nikolaidis, V.; Kanatas, A.G.; Karagiannidis, G.K. UAV-to-ground communications: Channel modeling and UAV selection. *IEEE Trans. Commun.* 2020, 68, 5135–5144.
- Challita, U.; Saad, W.; Bettstetter, C. Interference management for cellular-connected UAVs: A deep reinforcement learning approach. *IEEE Trans. Wirel. Commun.* 2019, 18, 2125–2140.
- Fouda, A.; Ibrahim, A.S.; Güvenç, İ.; Ghosh, M. Interference management in UAV-assisted integrated access and backhaul cellular networks. *IEEE Access* 2019, 7, 104553–104566.
- Zhang, S.; Shi, S.; Gu, S.; Gu, X. Power control and trajectory planning based interference management for UAV-assisted wireless sensor networks. *IEEE Access* 2019, 8, 3453–3464.
- Zhang, J.; Chuai, G.; Gao, W. Power control and clustering-based interference management for UAV-assisted networks. *Sensors* 2020, 20, 3864.
- Chen, J.; Chen, P.; Wu, Q.; Xu, Y.; Qi, N.; Fang, T. A game-theoretic perspective on resource management for large-scale UAV communication networks. *China Commun.* 2021, 18, 70–87.
- Sanchez-Lopez, J.L.; Wang, M.; Olivares-Mendez, M.A.; Molina, M.; Voos, H. A real-time 3d path planning solution for collision-free navigation of multirotor aerial robots in dynamic environments. *J. Intell. Robot. Syst.* 2019, 93, 33–53.
- Primatesta, S.; Guglieri, G.; Rizzo, A. A risk-aware path planning strategy for UAVs in urban environments. *J. Intell. Robot. Syst.* 2019, 95, 629–643.
- Fonseca, E.; Galkin, B.; Kelly, M.; DaSilva, L.A.; Dusparic, I. Mobility for cellular-connected UAVs: Challenges for the network provider. In Proceedings of the 2021 Joint European Conference on Networks and Communications & 6G Summit (EuCNC/6G Summit), Porto, Portugal, 8–11 June 2021; pp. 136–141.
- Yin, S.; Li, L.; Yu, F.R. Resource allocation and basestation placement in downlink cellular networks assisted by multiple wireless powered UAVs. *IEEE Trans. Veh. Technol.* 2019, 69, 2171–2184.
- Wu, Q.; Zhang, R. Delay-constrained throughput maximization in UAV-enabled OFDM systems. In Proceedings of the 2017 23rd Asia-Pacific Conference on Communications (APCC), Perth, Australia, 11–13 December 2017; pp. 1–6.
- Pandey, A.; Kushwaha, D.; Kumar, S. Energy efficient UAV placement for multiple users in IoT networks. In Proceedings of the 2019 IEEE Global Communications Conference (GLOBECOM), Waikoloa, HI, USA, 9–13

16. Lupascu, M.; Hustiu, S.; Burlacu, A.; Kloetzer, M. Path planning for autonomous drones using 3d rectangular cuboid decomposition. In Proceedings of the 2019 the 23rd International Conference on System Theory, Control and Computing (ICSTCC), Sinaia, Romania, 9–11 October 2019; pp. 119–124.
17. Wu, Y.; Low, K.H.; Pang, B.; Tan, Q. Swarm-based 4D path planning for drone operations in urban environments. *IEEE Trans. Veh. Technol.* 2021, 70, 7464–7479.
18. Wu, Q.; Mei, W.; Zhang, R. Safeguarding wireless network with UAVs: A physical layer security perspective. *IEEE Wirel. Commun.* 2019, 26, 12–18.
19. Cai, Y.; Cui, F.; Shi, Q.; Zhao, M.; Li, G.Y. Dual-UAV-enabled secure communications: Joint trajectory design and user scheduling. *IEEE J. Sel. Areas Commun.* 2018, 36, 1972–1985.
20. Li, A.; Wu, Q.; Zhang, R. UAV-enabled cooperative jamming for improving secrecy of ground wiretap channel. *IEEE Wirel. Commun. Lett.* 2018, 8, 181–184.
21. Sun, X.; Shen, C.; Chang, T.-H.; Zhong, Z. Joint resource allocation and trajectory design for UAV-aided wireless physical layer security. In Proceedings of the 2018 IEEE Globecom Workshops (GC Wkshps), Abu Dhabi, United Arab Emirates, 9–13 December 2018; pp. 1–6.
22. Zeng, F.; Hu, Z.; Xiao, Z.; Jiang, H.; Zhou, S.; Liu, W.; Liu, D. Resource allocation and trajectory optimization for QoE provisioning in energy-efficient UAV-enabled wireless networks. *IEEE Trans. Veh. Technol.* 2020, 69, 7634–7647.
23. Min, M.; Xiao, L.; Xu, D.; Huang, L.; Peng, M. Learning-based defense against malicious unmanned aerial vehicles. In Proceedings of the 2018 IEEE 87th Vehicular Technology Conference (VTC Spring), Porto, Portugal, 3–6 June 2018; pp. 1–5.
24. Yue, X.; Liu, Y.; Wang, J.; Song, H.; Cao, H. Software defined radio and wireless acoustic networking for amateur drone surveillance. *IEEE Commun. Mag.* 2018, 56, 90–97.
25. Amphawan, A.; Chaudhary, S.; Neo, T.-K.; Kakavand, M.; Dabbagh, M. Radio-over-free space optical space division multiplexing system using 3-core photonic crystal fiber mode group multiplexers. *Wirel. Netw.* 2021, 27, 211–225.
26. Yang, Y.; Ma, Z.; Wang, Y. SDM Technology based on Spot-beam Antenna. In Proceedings of the 3rd International Conference on Mechatronics Engineering and Information Technology (ICMEIT 2019), Dalian, China, 29–30 March 2019; pp. 788–794.
27. Konstantinou, D.; Rommel, S.; Morales, A.; Raddo, T.R.; Johannsen, U.; Tafur Monroy, I. An ehealth-care driven perspective on 5g networks and infrastructure. In Proceedings of the Interactive Mobile Communication, Technologies and Learning, Thessaloniki, Greece, 29 November–1 December 2017; pp. 1076–1088.
28. Lyu, J.; Zeng, Y.; Zhang, R. Cyclical multiple access in UAV-aided communications: A throughput-delay tradeoff. *IEEE Wirel. Commun. Lett.* 2016, 5, 600–603.
29. Ho, T.D.; Park, J.; Shimamoto, S. Novel multiple access scheme for wireless sensor network employing unmanned aerial vehicle. In Proceedings of the 29th Digital Avionics Systems Conference, Salt Lake City, UT, USA, 3–7 October 2010; pp. 5. C. 5-1–5. C. 5-8.
30. Ho, T.D.; Park, J.; Shimamoto, S. QoS constraint with prioritized frame selection CDMA MAC protocol for WSN employing UAV. In Proceedings of the 2010 IEEE Globecom Workshops, Miami, FL, USA, 6 December 2010; pp. 1826–1830.
31. Ho, D.-T.; Park, J.; Shimamoto, S. Performance evaluation of the pfsc based mac protocol for wsn employing uav in rician fading. In Proceedings of the 2011 IEEE Wireless Communications and Networking Conference, Cancun, Mexico, 28–31 March 2011; pp. 55–60.
32. Xue, S.; Bi, S.; Lin, X. Energy minimization in UAV-aided wireless sensor networks with OFDMA. In Proceedings of the 2019 11th International Conference on Wireless Communications and Signal Processing (WCSP), Xi'an, China, 23–25 October 2019; pp. 1–7.
33. Zhou, F.; Wu, Y.; Hu, R.Q.; Qian, Y. Computation rate maximization in UAV-enabled wireless-powered mobile-edge computing systems. *IEEE J. Sel. Areas Commun.* 2018, 36, 1927–1941.
34. Jiang, F.; Swindlehurst, A.L. Optimization of UAV heading for the ground-to-air uplink. *IEEE J. Sel. Areas Commun.* 2012, 30, 993–1005.
35. Xiao, Z.; Xia, P.; Xia, X.-G. Enabling UAV cellular with millimeter-wave communication: Potentials and approaches. *IEEE Commun. Mag.* 2016, 54, 66–73.
36. Xie, J.; Zhang, J.; Zhang, T. An efficient transmission of 4D trajectory short messages on LDACS1. In Proceedings of the 2014 Integrated Communications, Navigation and Surveillance Conference (ICNS) Conference Proceedings,

Herndon, VA, USA, 8–10 April 2014; pp. W3-1–W3-11.

37. Chen, Q.; He, C.; Bai, L.; Zhang, X. A novel SDMA uplink method based on time-modulated array for UAV communications. In Proceedings of the 2018 IEEE International Conference on Communication Systems (ICCS), Chengdu, China, 19–21 December 2018; pp. 19–24.
38. Ren, H.; Li, L.; Xu, W.; Chen, W.; Han, Z. Machine learning-based hybrid precoding with robust error for UAV mmWave massive MIMO. In Proceedings of the ICC 2019-2019 IEEE International Conference on Communications (ICC), Shanghai, China, 20–24 May 2019; pp. 1–6.
39. Tan, W.; Li, S.; He, C.; Tan, W.; Gu, X.; Shi, Z. Achievable rate of UAV-based communication with uniform circular arrays in Ricean fading. *Phys. Commun.* 2019, 32, 185–191.
40. Liu, Y.; Qin, Z.; Cai, Y.; Gao, Y.; Li, G.Y.; Nallanathan, A. UAV communications based on non-orthogonal multiple access. *IEEE Wirel. Commun.* 2019, 26, 52–57.
41. Abbasi, O.; Yanikomeroglu, H.; Ebrahimi, A.; Yamchi, N.M. Trajectory design and power allocation for drone-assisted NR-V2X network with dynamic NOMA/OMA. *IEEE Trans. Wirel. Commun.* 2020, 19, 7153–7168.
42. Nasir, A.A.; Tuan, H.D.; Duong, T.Q.; Poor, H.V. UAV-enabled communication using NOMA. *IEEE Trans. Commun.* 2019, 67, 5126–5138.
43. Sun, J.; Wang, Z.; Huang, Q. Cyclical NOMA based UAV-enabled wireless network. *IEEE Access* 2018, 7, 4248–4259.
44. Nguyen, M.T.; Le, L.B. NOMA user pairing and UAV placement in UAV-based wireless networks. In Proceedings of the ICC 2019-2019 IEEE International Conference on Communications (ICC), Shanghai, China, 20–24 May 2019; pp. 1–6.
45. Cui, F.; Cai, Y.; Qin, Z.; Zhao, M.; Li, G.Y. Multiple access for mobile-UAV enabled networks: Joint trajectory design and resource allocation. *IEEE Trans. Commun.* 2019, 67, 4980–4994.
46. Sohail, M.F.; Leow, C.Y.; Won, S. Non-orthogonal multiple access for unmanned aerial vehicle assisted communication. *IEEE Access* 2018, 6, 22716–22727.
47. Liu, X.; Wang, J.; Zhao, N.; Chen, Y.; Zhang, S.; Ding, Z.; Yu, F.R. Placement and power allocation for NOMA-UAV networks. *IEEE Wirel. Commun. Lett.* 2019, 8, 965–968.
48. Zhai, Q. Modelling of Energy Storage System in the Australian Electricity Market; UNSW Sydney: Sydney, Australia, 2018.
49. Zhang, X.; Liu, L.; Dai, Y. Fuzzy state machine energy management strategy for hybrid electric UAVs with PV/fuel cell/battery power system. *Int. J. Aerosp. Eng.* 2018, 2018, 1–16.
50. Dutczak, J. Compressed hydrogen storage in contemporary fuel cell propulsion systems of small drones. In IOP Conference Series: Materials Science and Engineering; IOP Publishing: Bristol, UK, 2018; p. 042013.
51. Cho, S.M.; Kim, C.; Kim, K.S.; Kim, D.K. Lightweight hydrogen storage cylinder for fuel cell propulsion systems to be applied in drones. *Int. J. Press. Vessel. Pip.* 2021, 194, 104428.
52. Geertjes, M.; Spijkstra, J. Solar Powered Drones: Power Electronics. 2020. Available online: <https://repository.tudelft.nl/islandora/object/uuid%3A664f1b4e-da14-4a16-8e02-c0230e68872d> (accessed on 14 May 2023).
53. El-Atab, N.; Mishra, R.B.; Alshanbari, R.; Hussain, M.M. Solar Powered Small Unmanned Aerial Vehicles: A Review. *Energy Technol.* 2021, 9, 2100587.
54. Suewatanakul, S.; Porcarelli, A.; Olsson, A.; Grimler, H.; Chiche, A.; Mariani, R.; Lindbergh, G. Conceptual Design of a Hybrid Hydrogen Fuel Cell/Battery Blended-Wing-Body Unmanned Aerial Vehicle—An Overview. *Aerospace* 2022, 9, 275.
55. Boukoberine, M.N.; Zia, M.F.; Benbouzid, M.; Zhou, Z.; Donato, T. Hybrid fuel cell powered drones energy management strategy improvement and hydrogen saving using real flight test data. *Energy Convers. Manag.* 2021, 236, 113987.
56. Shehzad, M.K.; Hassan, S.A.; Luque-Nieto, M.; Poncela, J.; Jung, H. Energy efficient placement of UAVs in wireless backhaul networks. In Proceedings of the 2nd ACM MobiCom Workshop on Drone Assisted Wireless Communications for 5G and Beyond, London, UK, 25 September 2020; pp. 1–6.
57. Kiani, F.; Seyyedabbasi, A.; Aliyev, R.; Gulle, M.U.; Basyildiz, H.; Shah, M.A. Adapted-RRT: Novel hybrid method to solve three-dimensional path planning problem using sampling and metaheuristic-based algorithms. *Neural Comput. Appl.* 2021, 33, 15569–15599.
58. Cabreira, T.M.; Brisolara, L.B.; Ferreira, P.R., Jr. Survey on coverage path planning with unmanned aerial vehicles. *Drones* 2019, 3, 4.

59. Shivgan, R.; Dong, Z. Energy-efficient drone coverage path planning using genetic algorithm. In Proceedings of the 2020 IEEE 21st International Conference on High Performance Switching and Routing (HPSR), Newark, NJ, USA, 11–14 May 2020; pp. 1–6.
  60. Peng, K.; Du, J.; Lu, F.; Sun, Q.; Dong, Y.; Zhou, P.; Hu, M. A hybrid genetic algorithm on routing and scheduling for vehicle-assisted multi-drone parcel delivery. *IEEE Access* 2019, 7, 49191–49200.
  61. Joudeh, H.; Clerckx, B. Rate-splitting for max-min fair multigroup multicast beamforming in overloaded systems. *IEEE Trans. Wirel. Commun.* 2017, 16, 7276–7289.
  62. Bansal, A.; Agrawal, N.; Singh, K. Rate-Splitting Multiple Access for UAV-Based RIS-Enabled Interference-Limited Vehicular Communication System. *IEEE Trans. Intell. Veh.* 2022, 8, 936–948.
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