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AUTONOMOUS FLYING ROBOTS for INTELLIGENT IOT DATA HARVESTING

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This presentation reports on fascinating results obtained within the PERFUME project, which is an "Advanced ERC" (European Research Council) funded project that develops algorithms and prototypes for autonomous aerial robots (drones or "UAV – Unmanned Aerial Vehicles") that provide wireless connectivity to users and devices. Our work finds applications in **intelligent data harvesting** in future IoT networks and ultra-flexible deployment radio access networks to provide on-demand connectivity in **post-disaster** wireless networks. The uniqueness of PERFUME lies in the requirement of a cross-disciplinary research among **three important fields:** (1) Future wireless networks and **IoT**, (2) **Artificial intelligence**, and (3) **Robotics**. The key idea is to insert autonomous robots at the edge of the wireless networks as flying base stations (BSs) in order to make network deployment **ultra-flexible**. The drone's trajectory is optimized using machine learning algorithms as to maximize the IoT network's performance under navigation and limited on-board energy constraints of the drone. Practical prototypes of our autonomous flying robots have been designed, tested, and recorded on videos.

Potential Applications

The potential associated with the use of **flying radio access networks** is multi-fold. In the area of post-disaster relief, mission critical services, an autonomous 5G/6G base station will be able to position itself exactly ***when*** and ***where*** it is most needed, to quickly provide connectivity to ground users thereby complementing an insufficient or broken mobile infrastructure.

In the context of IoT, we proposed another application as "**smart data harvesting**". IoT devices are known to be limited by coverage and battery life of the sensors and other low-cost user equipment. An AI-driven drone is developed which is capable of sensing and exploiting radio measurements from the ground nodes and autonomously design a flight trajectory which collects the largest amount of sensed data from ground nodes while minimizing flying time and energy. The drone's trajectory gives the unique advantage that the data receiver on board the drone comes optimally close to the ground nodes hence allows for minimal radio power to be consumed by the ground node, thereby **extending the IoT network's performance and lifetime**.

Methodologies

The trajectory design problems of UAV as flying radios has been studied in the past in order to optimize various network performance metrics. In many cases, it is assumed a pilot is used. In the case of automatic placement, a common trait behind existing works is that they use simplified radio propagation models with either deterministic or statistical models to make the solution calculable from conventional optimization programs (NEC Labs, Nokia Bell Labs and AT&T prototypes). In reality, propagation is much more complex and may be line-of-sight or non-line of sight or a mix. Hence in order to obtain performance guarantees, the robots must be able to combine **radio measurements** and **complex propagation models** that depend on **terrain maps**. We believe our project was **world's first** to exploit machine learning to design an **autonomous flying radio** that is capable of **self-optimizing it's trajectory in a complex propagation environment.**

Results

Our work followed two main inter-related tracks: (i) **A theoretical track** to produce new ML-based algorithms capable of optimizing the drone trajectory as as to maximize some communication metric (like **maximizing user or sensor throughput**) while **minimizing flying and communication energy**. (2) **A prototyping track** that enabled the development of **real-life robotic flying base stations**, fully **4G compliant** for their communications (based on OpenAir Interface) and with on-board running of the ML-driven trajectory design algorithms. Along the way, we pioneered a number of new concepts, such as the *map-compression* approach that exploits the 3D terrain map of an environment in designing UAV placement problems. We have also shown it is possible estimate the ground **user/sensor locations** along the flight and learn the channel parameters, all based on radio measurements collected during the drone flight.

Our real-world experiments have validated the performance improvements promised by the theoretical trajectory designs of drone BSs. Our main video as attracted over 20 000 views over our linkedIn account. The project recently obtained the Pole SCS Award for Best Project in the Fundamental Sciences category. One of the papers [2] obtained a best paper award.

[1] O. Esrafilian, R. Gangula and D. Gesbert, "Learning to Communicate in UAV-Aided Wireless Networks: Map-Based Approaches," in *IEEE Internet of Things Journal*, vol. 6, no. 2, pp. 1791-1802, April 2019.

[2] Z. Becvar, M. Vondra, P. Mach, J. Plachy, D. Gesbert "Performance of mobile networks with UAVs: Can flying base stations substitute ultra-dense small cells" Proceedings of 23th European Wireless 2017. **Best Paper Award.**

[3] J. Chen, U. Yatnalli, D. Gesbert, "Optimal Positioning of Flying Relays for Wireless Networks: A LOS Map Approach" in Proc. of the International Conference on Communications (ICC), Paris, May 2017.

Videos of demonstrations visible at

https://youtu.be/7e0hmd_xiDQ (for Intelligent Data Harvestinf for IoT)

and

https://youtu.be/GI_lOsg_qmQ (for broadband coverage extension)

Figure 1 Photo our our robot prototype, carrying a fully functional 4G base station.