# Energy-optimal control in mobile aerial relay-assisted networks

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***Abstract*— Robotic networks, particularly of unmanned aerial vehicles (UAVs), are benefiting from increased on-board computing capabilities. The aim of our work is to minimize the total communication energy required by a UAV-assisted network to achieve certain mobility and data throughput objectives. We capture the full cost of communication by defining communication energy as the sum of transmission energy and propulsion energy used for the purpose of facilitating transmission. Simulation results show how joint optimization of mobility and transmission schemes results in significant energy savings and increased network capacity.**

## I. EXTENDED ABSTRACT

UAVs are usually deployed in objective-based missions, where inter-UAV and UAV-to-ground communication links are necessary for completion of real-time goals. Trajectories are designed in [1] for a cellular-enabled UAV, while [2], [3] consider the reciprocal problem of optimal cell association for a UAV-enabled wireless network. These works largely neglect the use of UAV mobility dynamics. Employing a similar system model to [4], the work in [5] considers optimally trading off locomotion and transmission energy for only a single UAV with various trajectory constraints.

In previous work [4] we developed continuous-time communication-theoretic and Newtonian dynamic models to relate transmission and locomotion energy. These models were used to formulate a nonlinear optimal control problem to compute the minimum energy expenditure of the network. We extend [4] by simulating a UAV-assisted terrestrial network, representative of an Internet of Things (IoT) network. This is the first work to combine multiple access channel (MACs) communication with agent mobility, and exhibits both significant energy savings as well as increased network capacity.

Nodes cooperatively perform data aggregation based on an energy-optimal control policy. For simulation purposes, we consider two stationary sources uploading data to a UAV through a MAC link. Energy expenditures are shown in Table I and compared to more naive protocols, e.g. where the bandwidth is partitioned into two single access links and/or transmission optimization is subject to constant UAV speed. Compared to the simplest feasible policy, joint optimization of transmission and propulsion yields a transmission energy saving of 60%.

TABLE I: Transmission energy of source $i$ ($\epsilon_i$) and total network communication energy ($\epsilon_C$) for different communication policies in kJ for the UAV uplink.

| | Separate BW | | Shared BW (MAC) | |
|---|---|---|---|---|
| | $v = v_{\text{avg}}$ | $v = v^*$ | $v = v_{\text{avg}}$ | $v = v^*$ |
| $\epsilon_C$ (kJ) | NA | 296.7 | 191.4 | 183.4 |
| $\epsilon_1$ (kJ) | NA | 54.04 | 16.70 | 11.04 |
| $\epsilon_2$ (kJ) | NA | 54.25 | 18.64 | 11.57 |

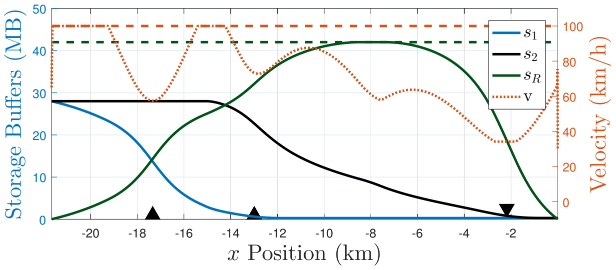

Fig. 1: Open-loop UAV relay-assisted IoT network simulation, with UAV memory constraint. Sources $s_1, s_2$ (triangles) must transmit data to the AP (inverted triangle) via UAV relay $s_R$. Solid lines show data held at each node against relay position. The dotted line shows relay velocity against relay position. Dashed lines show constraint bounds.

Now assume the UAV has finite memory and hence must relay collected data to a destination access point (AP) to ensure feasibility of the optimization problem. The open-loop trajectory, shown in Figure 1, exhibits not only energy savings and increased network capacity available, but also the complexity of the coupling between transmission and mobility policies. Future work could explore this further by simulating the closed-loop system, subject to uncertainty in the data transmission and UAV trajectory.

## REFERENCES

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