Representative use cases and performance trade-offs

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Half-day Tutorial Session at ICUAS 2026 (09:00 – 13:00), 15th June 2026
Room Calypso A – Divani Corfu Palace

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Case 1: Energy efficiency

A quadrotor must go from a starting point to a goal point while transmitting as much data as possible to a base station, using as little energy as possible. This must be done in a finite time T.

Problem Formulation

$$
\begin{aligned}
\underset{\mathcal{C},\mathcal{T}}{\text{minimize}} \quad & J(\mathcal{C},\mathcal{T}) \\
\text{s.t.} \quad & \text{Motion model}, \\
& \text{Channel model}, \\
& \text{Trajectory constraints}, \\
& \text{Communication constraints}.
\end{aligned}
$$

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$$\begin{aligned} \underset{\mathcal{C},\mathcal{T}}{\text{minimize}} \quad & J(\mathcal{C},\mathcal{T}) \\ \text{s.t.} \quad & \dot{\mathbf{x}} = f(\mathbf{x},\mathbf{u}), \\ & \text{Channel model}, \\ & \mathbf{x}(T) = \mathbf{x}_g, \\ & \text{Communication constraints}. \end{aligned}$$

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Should we consider:

- ONLY the energy spent by the motors?
- ALSO the energy spent by the transmitter?

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In this example, we take $E(0,T) = f_{\text{mech}}(\mathcal{T})$.

How to include $E(0,T)$ into the optimization problem?

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Depending on prior information:

- STOCHASTIC model. (almost none)
- MEASURMENT based model. (RF measurements at some positions)
- RAY TRACING model. (3D map)

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Problem Formulation

$$\begin{aligned} \underset{\mathcal{C},\mathcal{T}}{\text{minimize}} \quad & J(\mathcal{C}, \mathcal{T}) \\ \text{s.t.} \quad & \dot{\mathbf{x}} = f(\mathbf{x}, \mathbf{u}), \\ & y(t) = \frac{h(\mathbf{p})s(t)}{\|\mathbf{p}_{rx} - \mathbf{p}_{tx}\|} + n_{rx}(t), \\ & \mathbf{x}(T) = \mathbf{x}_g, \\ & \text{Communication constraints.} \end{aligned}$$

Stochastic model with shadowing.

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Does the transmitter use:

- Power control?
- Constant power?

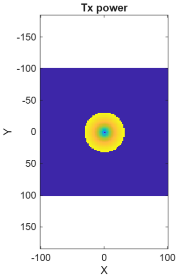
Case 1: Energy efficiency

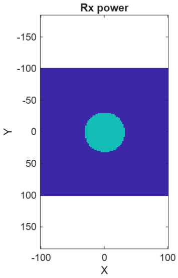
Power control

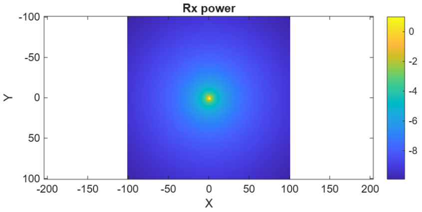
- P_{ref} at the receiver whenever possible.
- Requires feedback for channel estimation.
- Transmitted data depends on time spent in connected regions.

Constant power

- Transmits with constant power, received power depends on transmitter position.
- No feedback required.
- Transmitted data depends on trajectory.







BOTH MECHANISMS LEAD TO DIFFERENT PROBLEMS

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For constant tx power the tx rate is

$$r(t) = B\log_2\left(1 + \frac{h^2(\mathbf{p})P}{\|\mathbf{p}_{rx}-\mathbf{p}_{tx}\|^2\sigma_n^2}\right)$$

Case 1: Energy efficiency

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$E(0,T) = f_{\text{mech}}(\mathcal{T})$

$r(t)$

Problem Formulation

$$\begin{aligned} \underset{\mathcal{C},\mathcal{T}}{\text{minimize}} \quad & J(\mathcal{C},\mathcal{T}) \\ \text{s.t.} \quad & \dot{\mathbf{x}} = f(\mathbf{x},\mathbf{u}), \\ & y(t) = \frac{h(\mathbf{p})s(t)}{\|\mathbf{p}_{rx} - \mathbf{p}_{tx}\|} + n_{rx}(t), \\ & \mathbf{x}(T) = \mathbf{x}_g, \\ & \text{Communication constraints.} \end{aligned}$$

- How to include $E(0,T)$?
- How to include $r(t)$?
- How to combine $E(0,T)$ and $r(t)$?

Case 1: Energy efficiency

OP 1

$$\begin{aligned}\underset{\mathbf{u}}{\text{maximize}} \quad & \frac{\int_0^T r(t)\mathrm{d}t}{E(0,T)} \\ \text{s.t.} \quad & \dot{\mathbf{x}} = f(\mathbf{x},\mathbf{u}), \\ & y(t) = \frac{h(\mathbf{p})s(t)}{\|\mathbf{p}_{rx} - \mathbf{p}_{tx}\|} + n_{rx}(t), \\ & \mathbf{x}(T) = \mathbf{x}_g,\end{aligned}$$

OP 2

$$\begin{aligned}\underset{\mathbf{u},E_{max}}{\text{maximize}} \quad & \int_0^T r(t)\mathrm{d}t - E_{\max} \\ \text{s.t.} \quad & \dot{\mathbf{x}} = f(\mathbf{x},\mathbf{u}), \\ & y(t) = \frac{h(\mathbf{p})s(t)}{\|\mathbf{p}_{rx} - \mathbf{p}_{tx}\|} + n_{rx}(t), \\ & \mathbf{x}(T) = \mathbf{x}_g, \\ & E(0,T) < E_{\max}.\end{aligned}$$

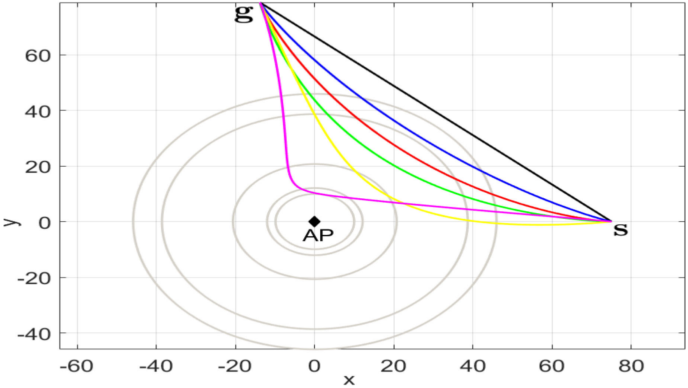
OP 3

$$\begin{aligned}\underset{\mathbf{u}}{\text{minimize}} \quad & \vartheta E(0,T) + (1-\vartheta)\left(\int_0^T r(t)\mathrm{d}t\right)^{-1} \\ \text{s.t.} \quad & \dot{\mathbf{x}} = f(\mathbf{x},\mathbf{u}), \\ & y(t) = \frac{h(\mathbf{p})s(t)}{\|\mathbf{p}_{rx} - \mathbf{p}_{tx}\|} + n_{rx}(t), \\ & \mathbf{x}(T) = \mathbf{x}_g,\end{aligned}$$

OP 4

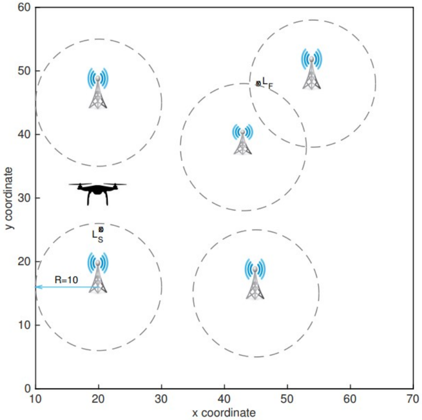
$$\begin{aligned}\underset{\mathbf{u},D}{\text{minimize}} \quad & E(0,T) + D^{-1} \\ \text{s.t.} \quad & \dot{\mathbf{x}} = f(\mathbf{x},\mathbf{u}), \\ & y(t) = \frac{h(\mathbf{p})s(t)}{\|\mathbf{p}_{rx} - \mathbf{p}_{tx}\|} + n_{rx}(t), \\ & \mathbf{x}(T) = \mathbf{x}_g, \\ & \int_0^T r(t)\mathrm{d}t > D.\end{aligned}$$

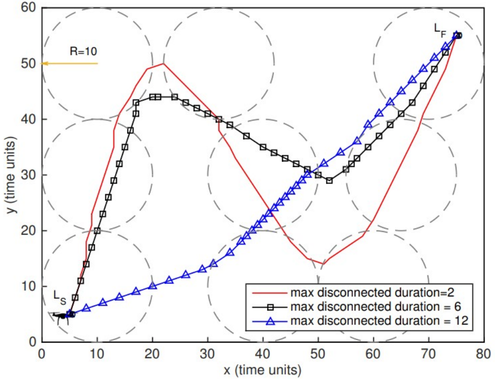
Case 1: Energy efficiency



D. Bonilla Licea, et al., "*Communication-Aware Energy Efficient Trajectory Planning With Limited Channel Knowledge*," in IEEE Transactions on Robotics, 2020

Case 2: Disconnectity





E. Bulut et al, "*Trajectory Optimization for Cellular-Connected UAVs with Disconnectivity Constraint*," in IEEE International Conference on Communications Workshops, 2018.

Thank you

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