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Southeast University

Energy-efficient Trajectory Planning and Speed Scheduling for UAV-assisted Data Collection

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Outline

- Background
- Problem Formulation
- Solutions
- Simulation
- Conclusion

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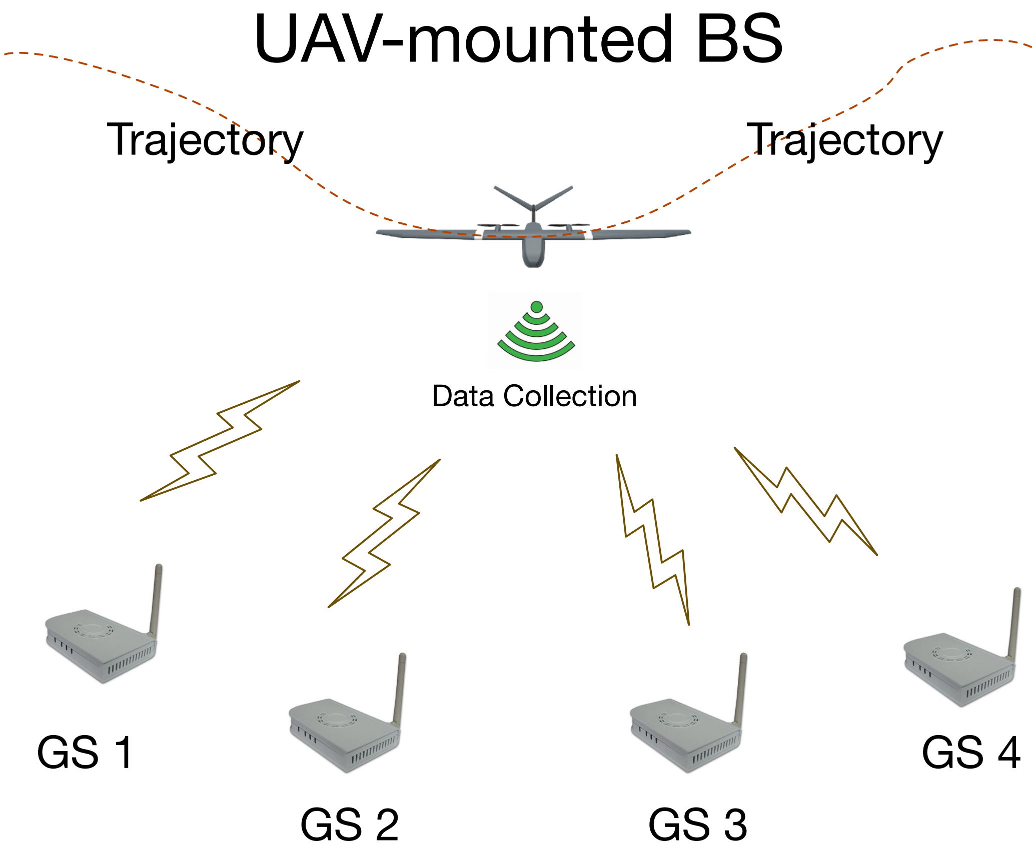
- **Background**
- **Problem Formulation**
- **Solutions**
- **Simulation**
- **Conclusion**

UAV-assisted Data Collection Scenario

A UAV collects data from ground sensors (GSs) deployed in an open area



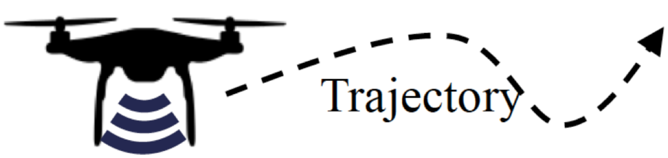
Motivation

- Key issues: Limited on-board energy for UAV
- Flight power occupies nearly 1000 times than that of communication power

We focus on minimizing propulsion energy of UAV

Motivation

- Most work does not consider a fine-grained energy consumption model
- Most of them only consider a distance-related model or duration-related energy consumption models



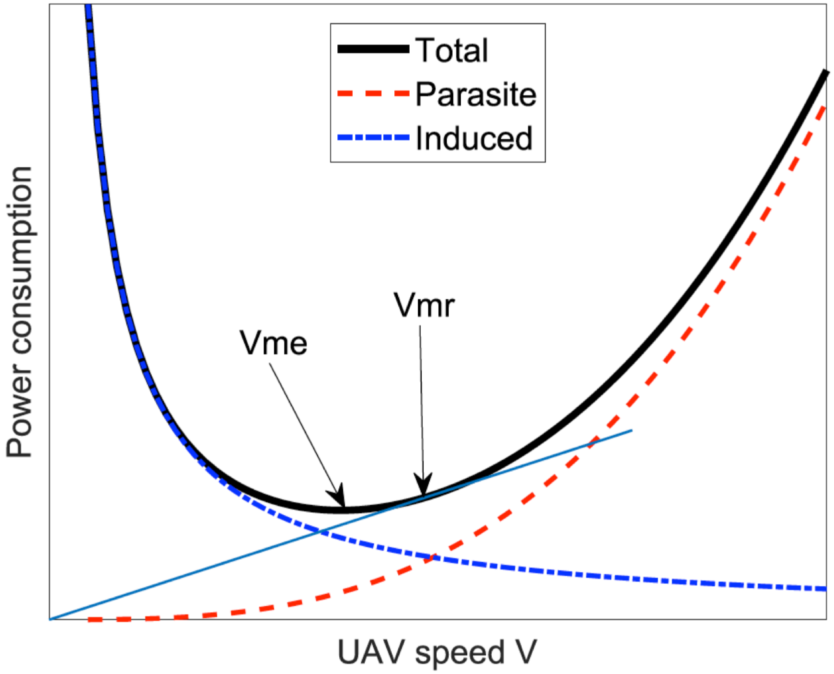
distance-related energy model

duration-related energy model

A sophisticated energy model

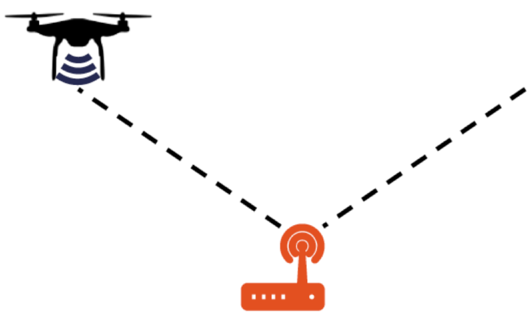
$$E\big(q(t)\big) = \int_0^T \left[c_1 ||v(t)||^3 + \frac{c_2}{||v(t)||} \left(1 + \frac{||a(t)||^2 - \frac{(a^T(t)v(t))^2}{||v(t)||^2}}{g^2}\right) \right] dt$$

Zeng Y , Zhang R . Energy-Efficient UAV Communication With Trajectory Optimization[J]. IEEE Transactions on Wireless Communications, 2017:3747-3760.



Challenges to our problem

1. Minimizing flight energy to collect all data



Slow speed

Sufficient time to collect data

Cost more flight energy

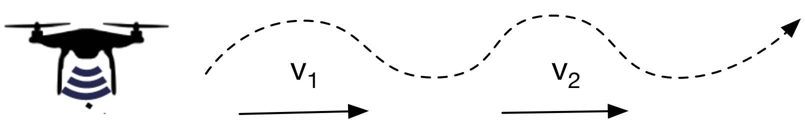
Faster speed

Less time to collect data

Save more flight energy

Best trade-off must be found

2. Trajectory & speed must be considered together



Longer trajectory may save energy

Lower speed may consume more energy

Proper trajectory and speed design must be found

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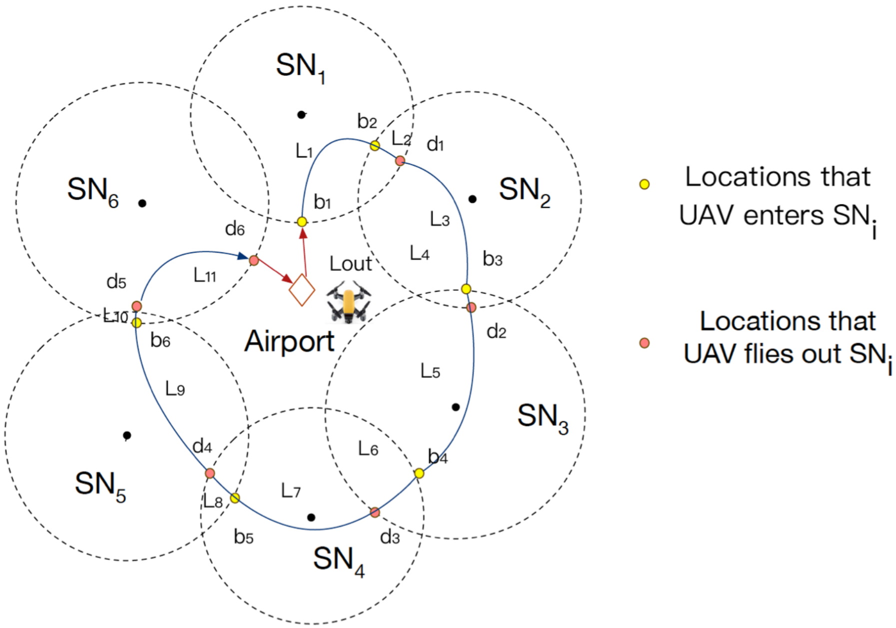
GSs and UAV



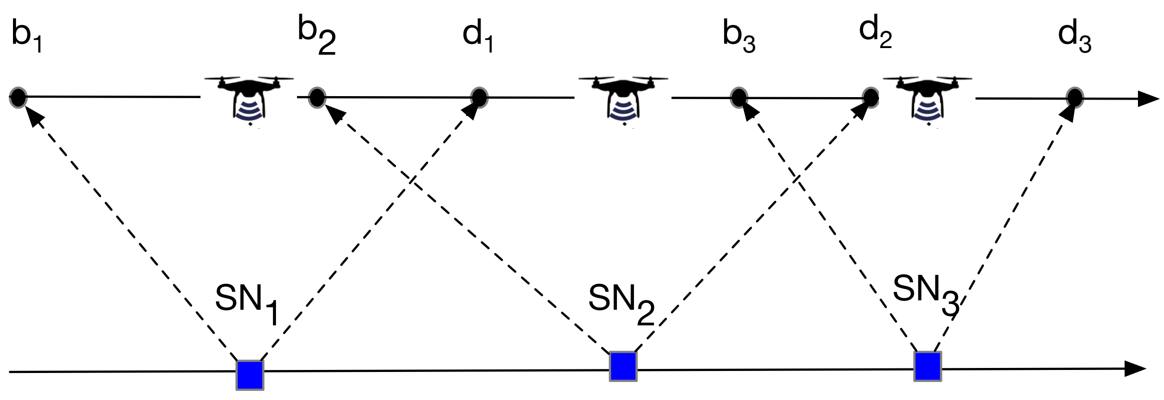
- m Ground Sensors (GSs), 1 UAV
- The UAV collects data from GSs when flying in communication range of them

We aim to minimizing UAV's energy consumption by finding a proper trajectory and flight speed, under constraints of data collection and UAV's trajectory

Transmission range and required time

- GS has a transmission range (b_i, d_i)
- Within range, GS i requires t_i time to upload data
- We allow the transmission ranges of GSs are different but they must be adjacent

$0 = b_1 < b_2 < b_3 < \cdots < b_m$ $\quad$ $d_1 < d_2 < d_3 < \cdots < d_m$



Key points $\quad D = b \cup d = \{b_1, \ldots, b_m, d_1, \ldots d_m\}$

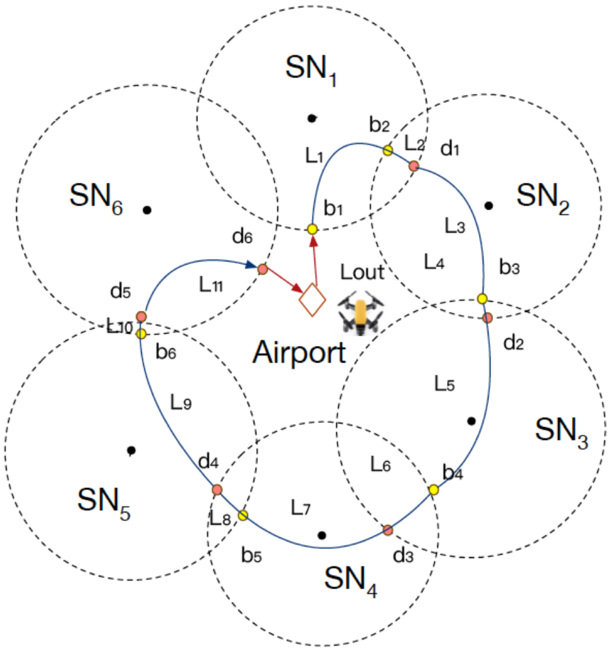
Trajectory

- Key points D divide the trajectory into 2m+1 parts:

$$L=\{L_1, L_2, \ldots L_n\}$$

- Length of curve L_i is l_i, denoted as:

$$l_i = \int_{L_{i-1}}^{L_i} dl$$



Distance / location constraint

- Length of trajectory between two key points must be larger than their straight distance

$$\int_{L(D_i, D_{i+1})} \mathrm{d}l \geq dis(D_i, D_{i+1}).$$

- All key points must be located on the range circle of each sensor

$$dis(b_i, SN_i) = dis(d_i, SN_i) = Cr_i, i \in \{1, 2, ..., m\}$$

Service time/Deadline constraint

- Service time constraint

$$\int_{L(b_i,d_i)} \frac{\mathrm{d}l}{v(l)} \geq t_i, i \in \{1, 2, ..., m\}$$

- Deadline constraint

$$\int_{L(b_1,d_m)} \frac{dl}{v(l)} \leq T.$$

ETPSS problem

•ETPSS problem: Find the proper speed and trajectory to

1. minimize UAV energy consumption
2. satisfy distance / location constraint
3. satisfy service time / deadline constraint

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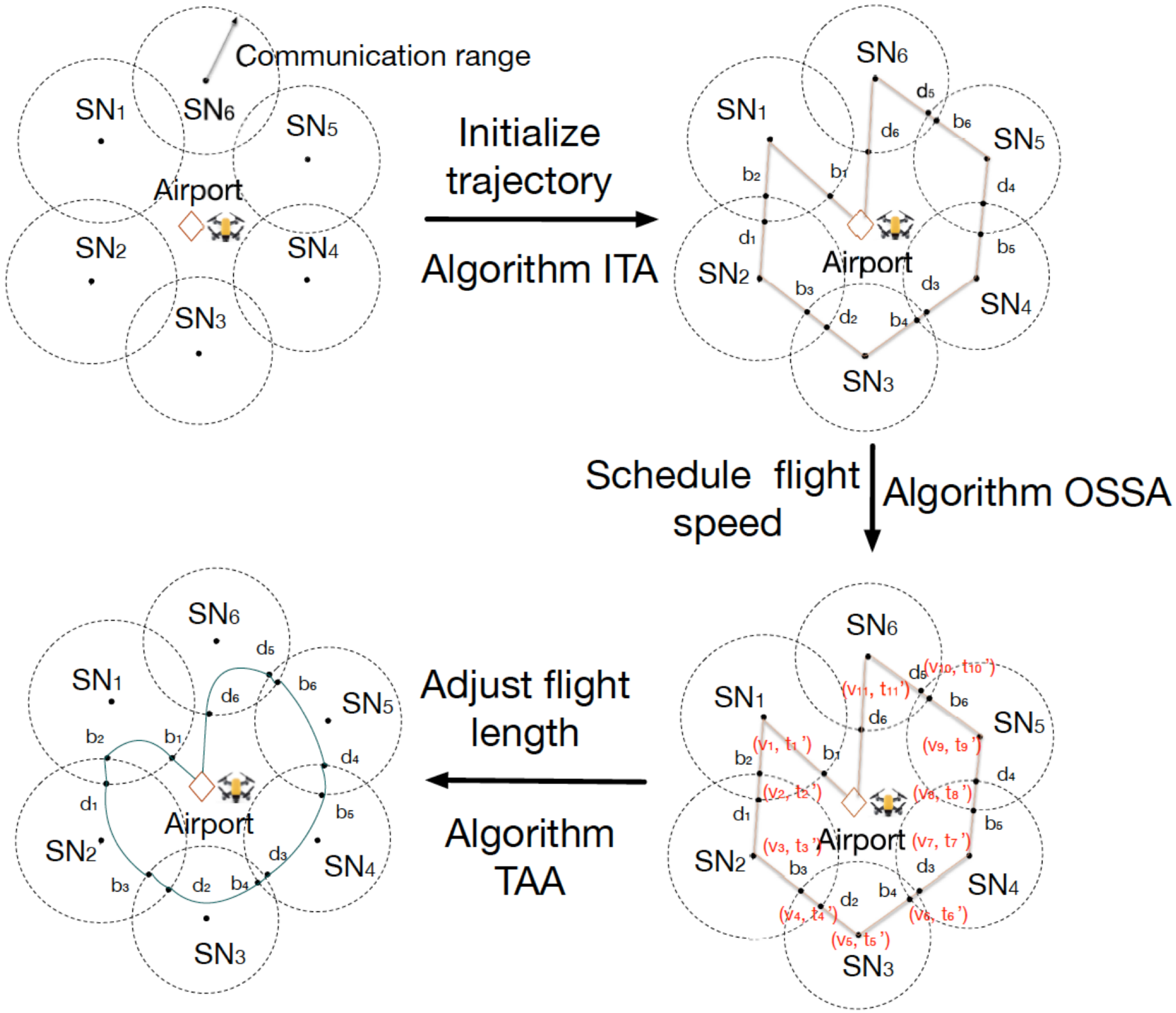
Framework for ETSO solution



Step 1: Initialize trajectory

Step 2: Schedule flight speed

Step 3: Adjust flight length

Step 1: Initialize trajectory

- Construct the initial graph

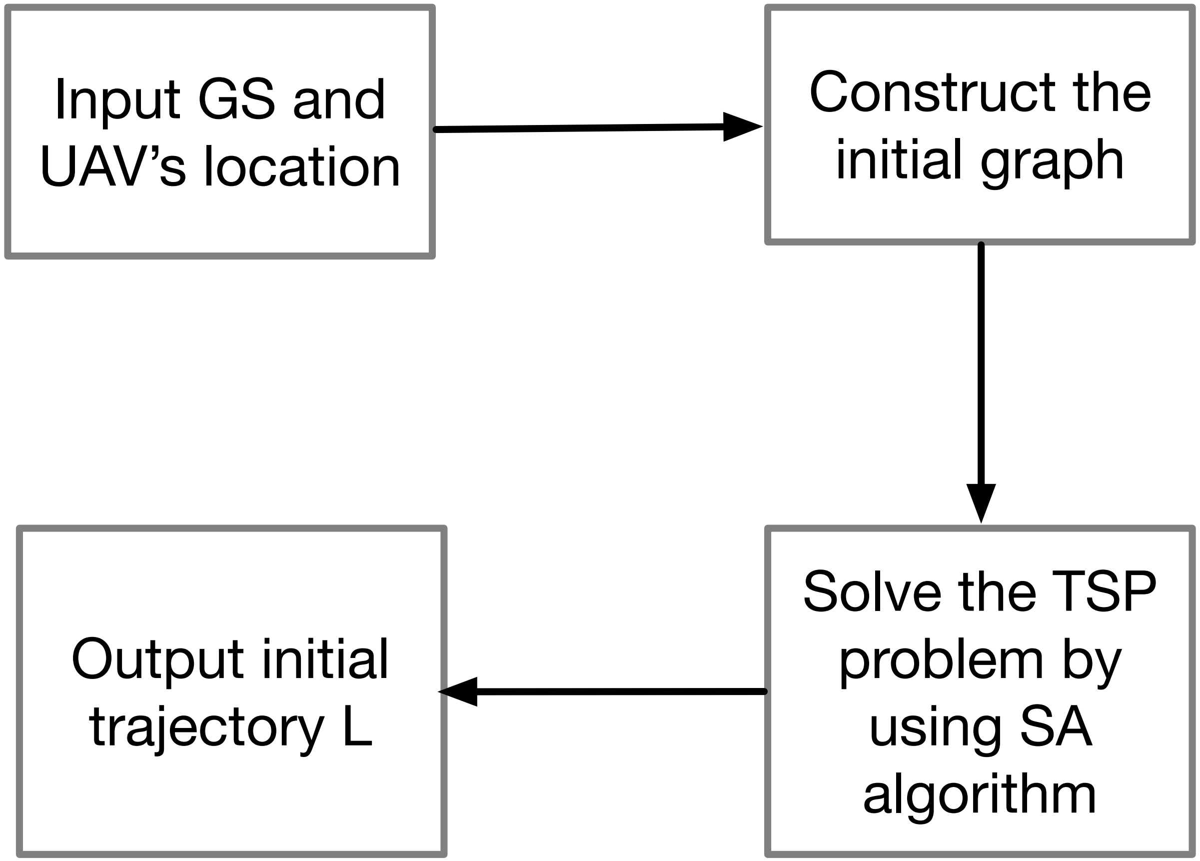
$$G = (V, E)$$

$V = M \cup \{u\}$ Vertexes: airport and all key points

$e_{ij} \in \mathrm{E}, \{i, \mathrm{j}\} \in M$ Edges: lines between two neighboring vertexes

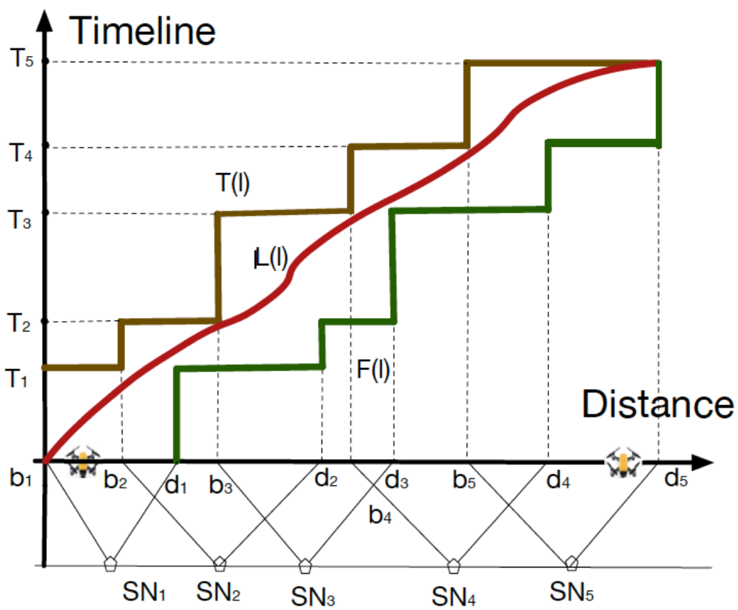
- Use travelling salesman problem (TSP) to initialize the trajectory

Step 1: Initialize trajectory



Step 2: Schedule flight speed

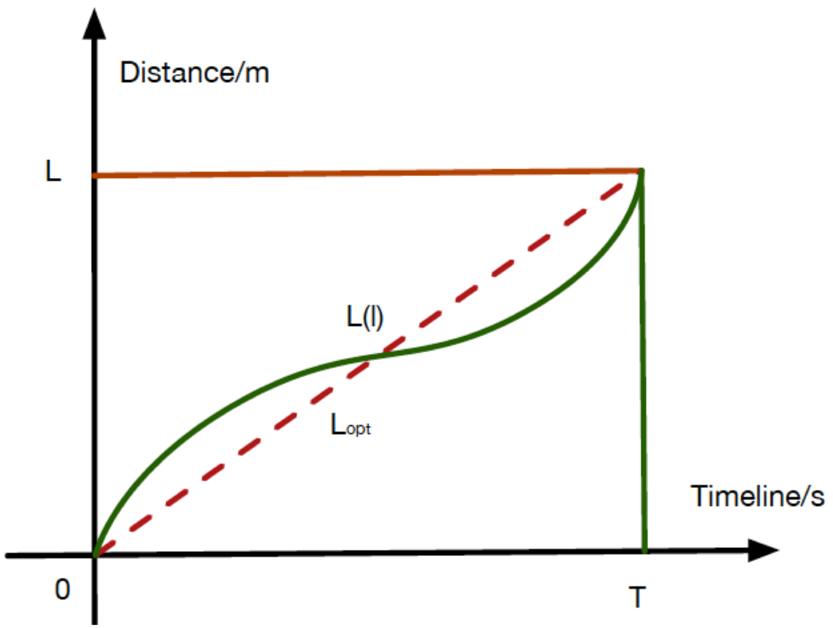
- Construct a time-distance diagram
- Satisfying service time / deadline constraints



- $T(l)$: Service time constraints
- $F(l)$: Deadline constraints
- $L(l)$: Optimal curve whose slope is reciprocal of speed

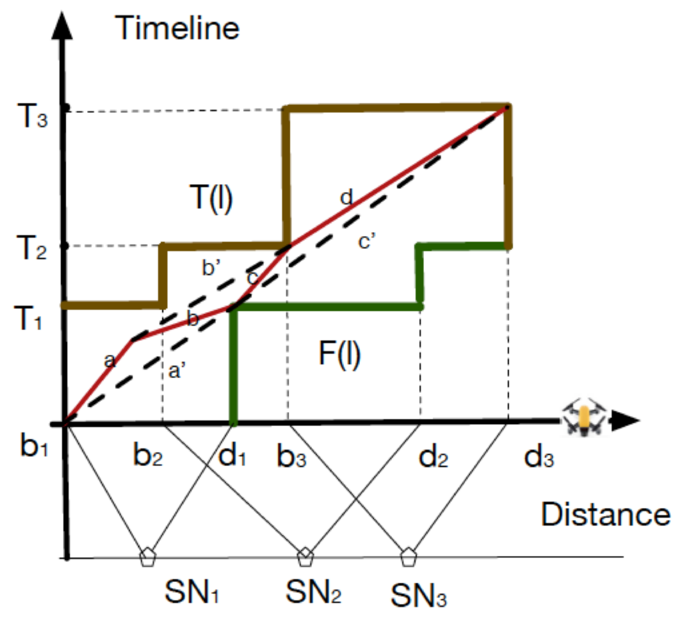
Step 2: Schedule flight speed

Theorem 1: UAV flying in a constant speed consumes less energy than flying in a changing speed.



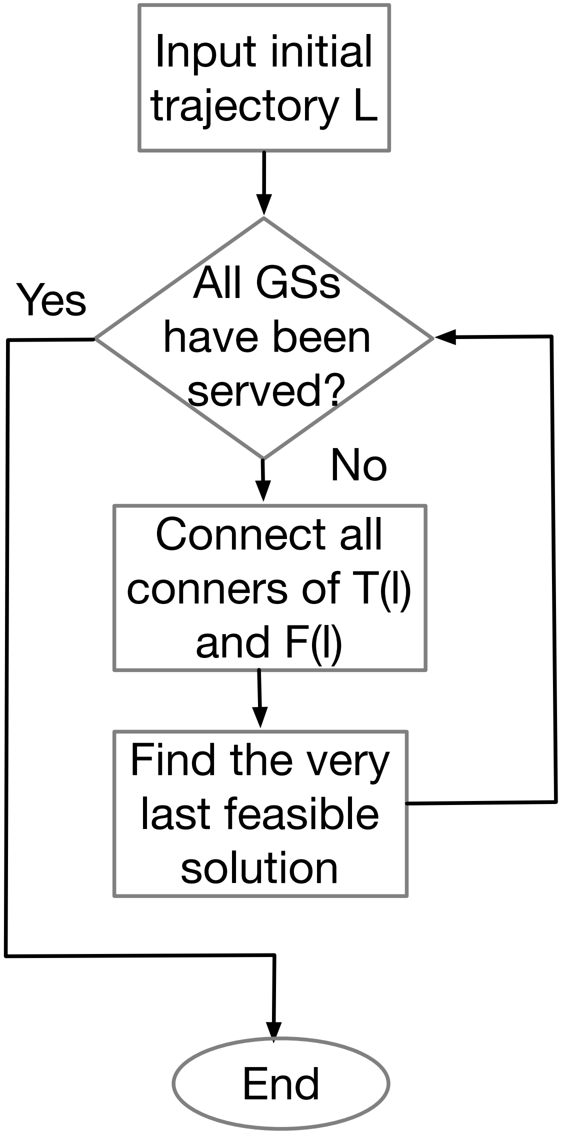
Step 2: Schedule flight speed

Theorem 2: Optimal curve property



- $L(l)$ must intersect with corner of upper bound $T(l)$ or lower bound $F(l)$
- Assume in point d_i, we have $L(d_i) = T(d_i)$, the slope change must be negative
- Assume in point b_i, we have $L(b_i) = T(b_i)$, the slope change must be positive

Step 2: Schedule flight speed



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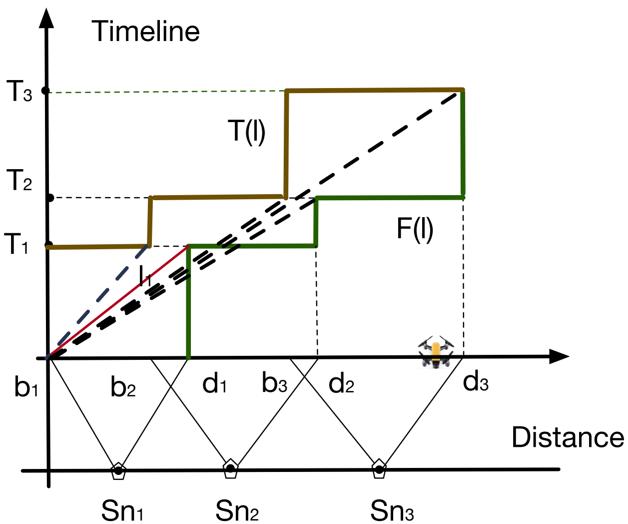
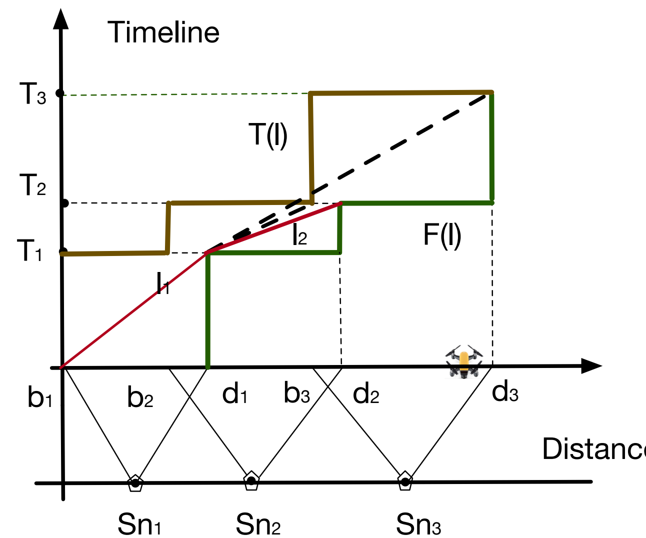
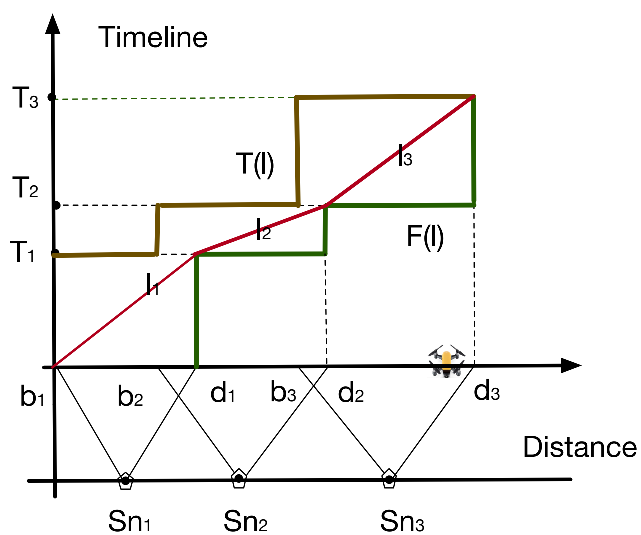


Step 1

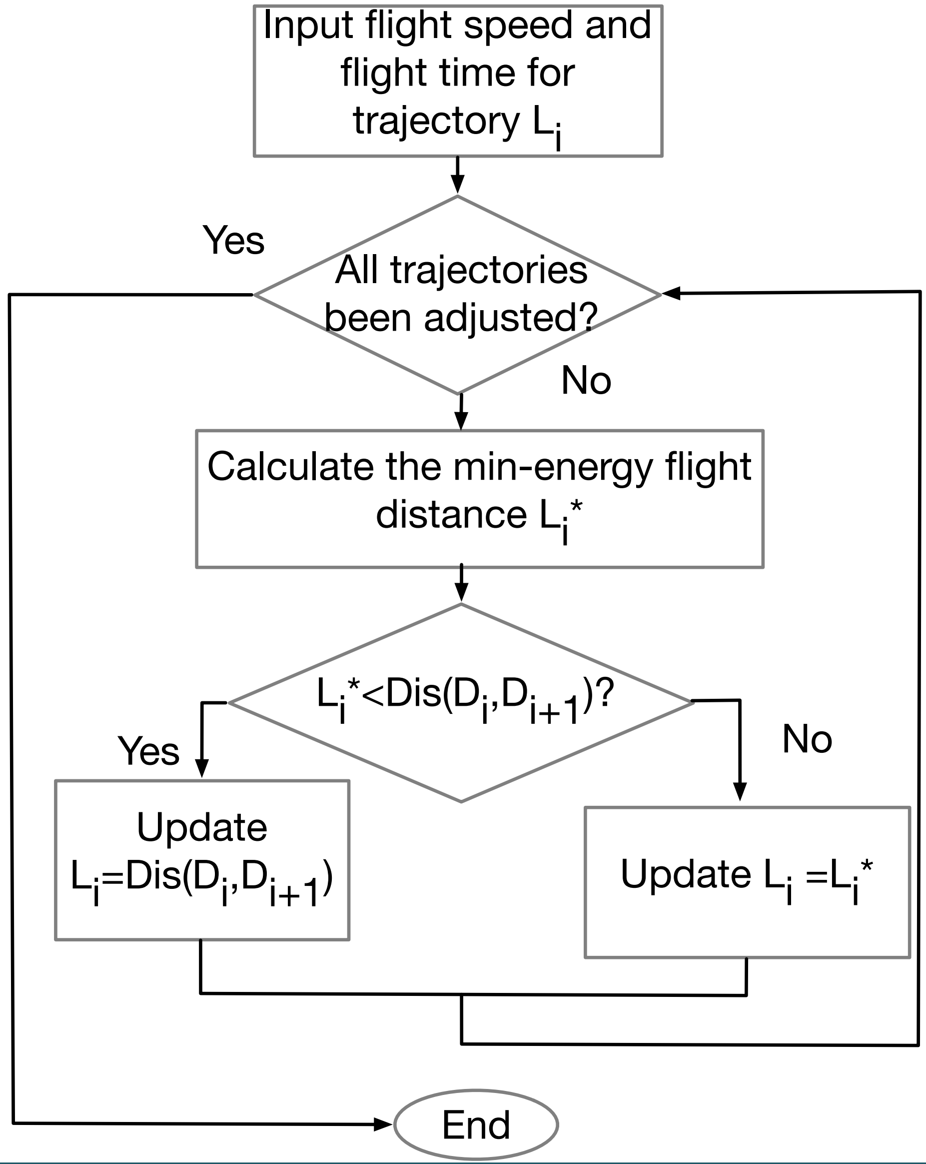


Step 2



Step 3

Step 3: Adjust flight length



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Simulation parameters

- GSs are randomly deployed in 2km×2km area
- We evaluate propulsion energy consumption of UAV with compared algorithms

Table 1: Simulation Parameters

Parameters	Values	Meaning
t_i	[0.5, 2]s	Service time for SN_i
m	[10,1000]	Number of GSs
v	[5,100]	Flight speed of UAV
H	100m	Flight altitude of UAV
c_1	$9.26 * 10^{-4}$	Parameter of energy model
c_2	2250	Parameter of energy model
Cr	[30,50]m	Communication range for GSs

Compared algorithms

- Task Completion Speed (TCS): UAV reaches departing key point d_i at time $t = \sum_{j=1}^{i} t_j$
- NoTAA: The ETSO scheme without Algorithm TAA
- TAA-ALG: The UAV flies along the trajectory worked out by TAA and speed scheduling algorithm using online Algorithm ALG proposed in previous work

Simulation Results

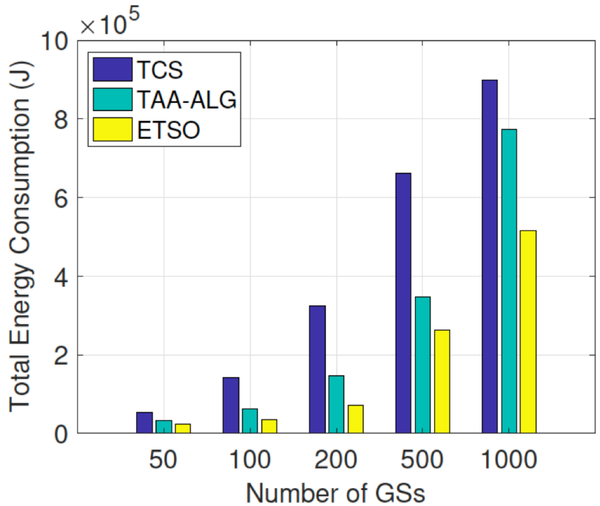

Fig. 7: The impact of GS number on energy consumption with different speed scheduling algorithms

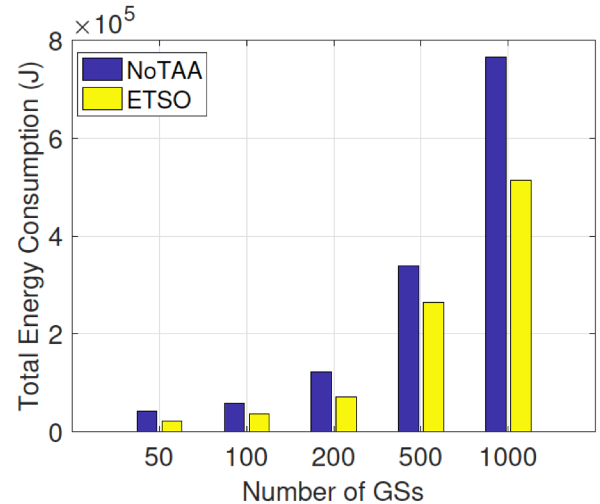

Fig. 8: The impact of GS number on energy consumption with different trajectory design algorithms

Our proposed algorithm ETSO costs less propulsion energy consumption than compared algorithms

Simulation Results

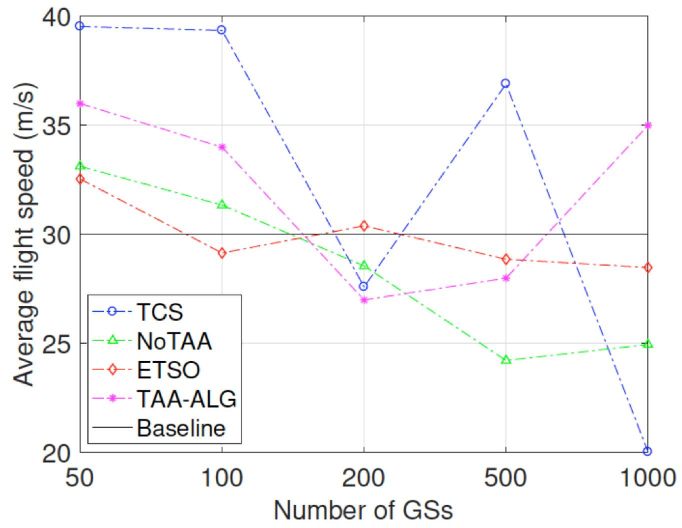

Fig. 9: The impact of GS number on average flight speed

Flight speed in Algorithm ETSO are more stable than that of compared algorithms

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Conclusion

- We investigate a UAV data collection problem from GSs deployed in an open area.
- We use a sophisticated energy consumption model to illustrate propulsion consumption of UAV.
- We propose a three-step algorithm to jointly design trajectory and schedule flight speed for UAV, in which the second step is proved to be an optimal offline algorithm.
- Simulation results show that our algorithm preforms well in energy-efficiency.

Thank You!

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