Unmanned Aerial System Traffic Management

Challenges and Design Ideas

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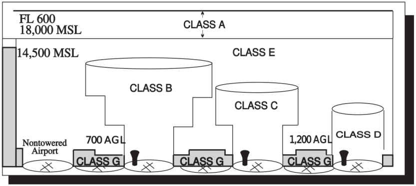
Joint work with P.R. Kumar's group at Texas A&M

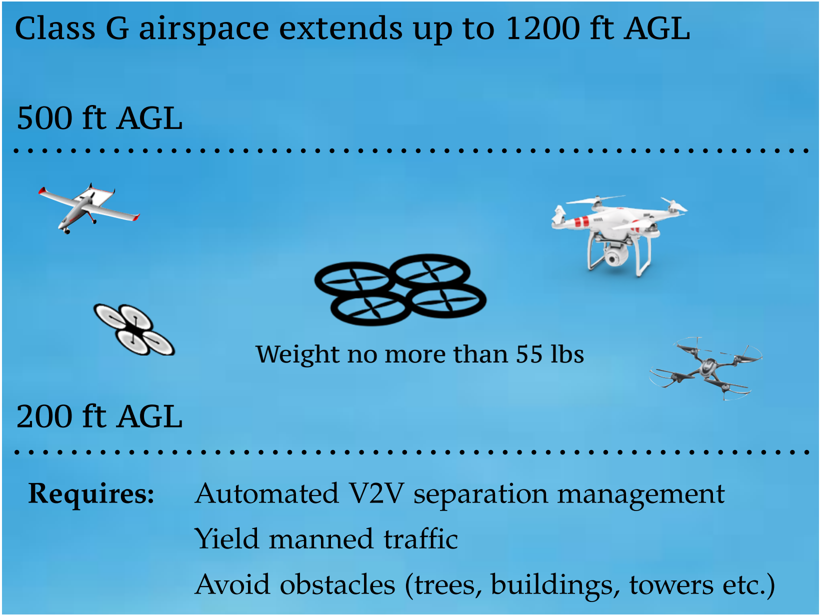
Today's Manned Air Traffic Management

- Managed by humans
- Voice based system
- Separation management for each aircraft
- For controlled airspace (A,B,C,D,E)



MSL - mean sea level
AGL - above ground level
FL - flight level

Vision for UAS Traffic Management (UTM)



Enabler for Many Potential Services

- Package delivery
- News coverage
- Precision agriculture
- Firefighting
- Law enforcement
- Infrastructure inspection

Technical Challenges

Dynamic Geofencing

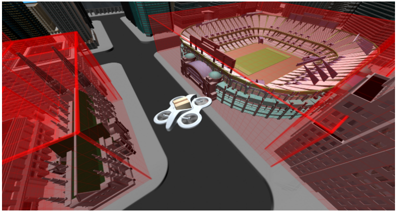
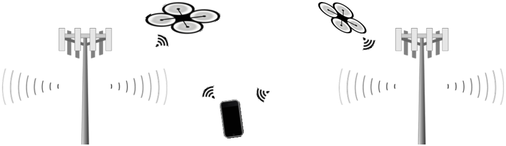
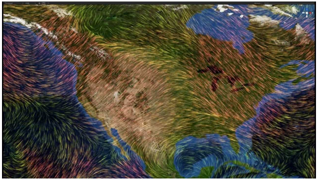


Image credit: NASA Ames Research Center

Control over LTE



Wind Uncertainty



Provable Safety

Protocols $\equiv$ Laws of the Sky

Offline Protocol

– How FAA approves a flight path request?

Motion Protocol

– What does an individual drone do in real time?

Communication Protocol

– What and how should a drone in flight talk?

Database Protocol

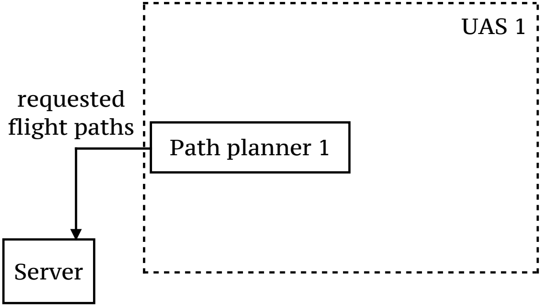
– Which other drones to talk with and when?

Offline Protocol

How FAA approves a flight path request?

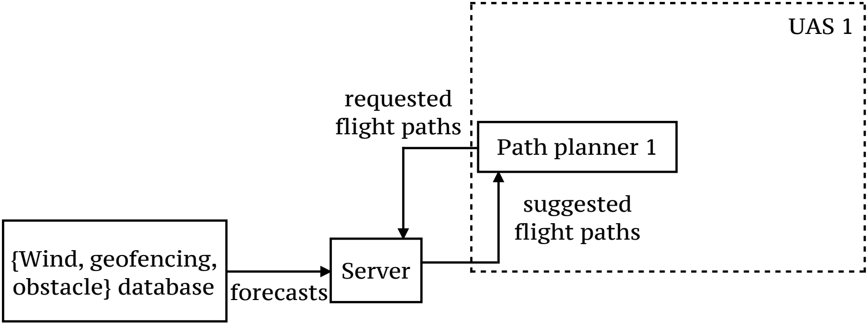
Offline Protocol

Path Planning and Deconfliction



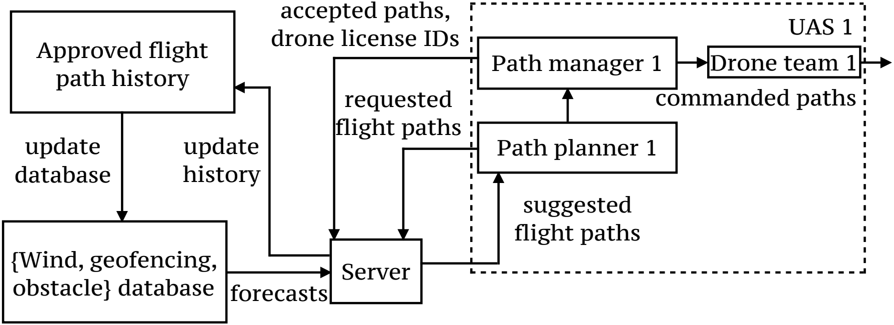
Offline Protocol

Path Planning and Deconfliction



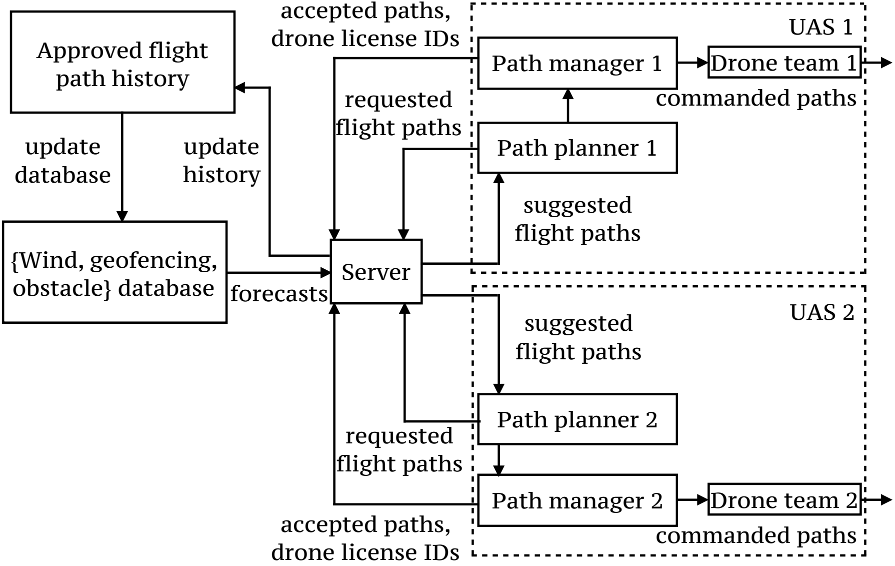
Offline Protocol

Path Planning and Deconfliction



Offline Protocol

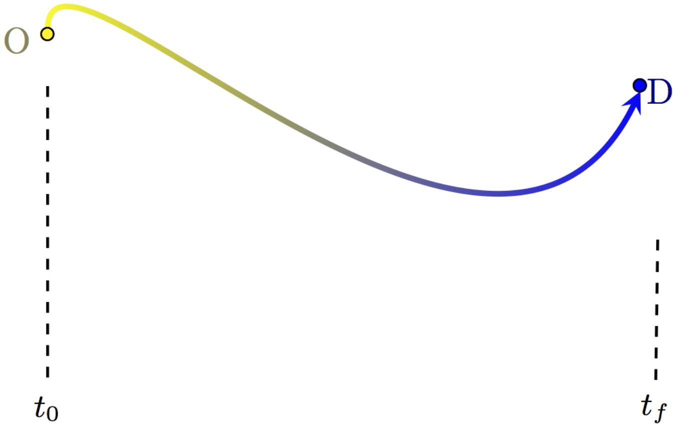
Path Planning and Deconfliction



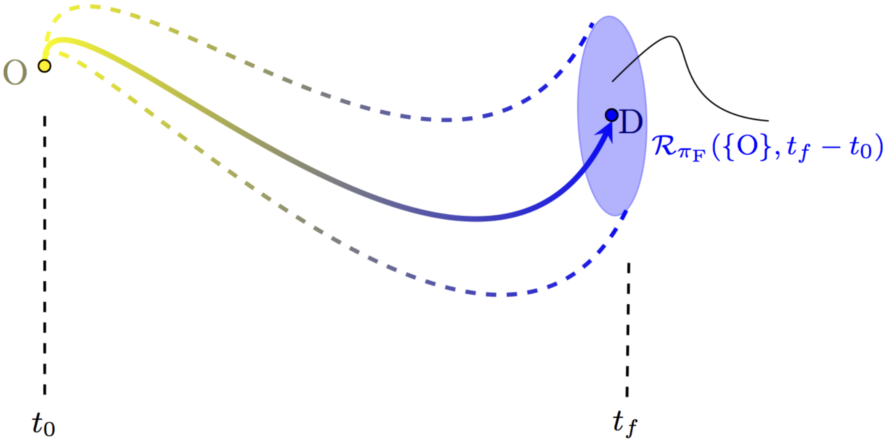
Motion Protocol

What does an individual drone do in real time?

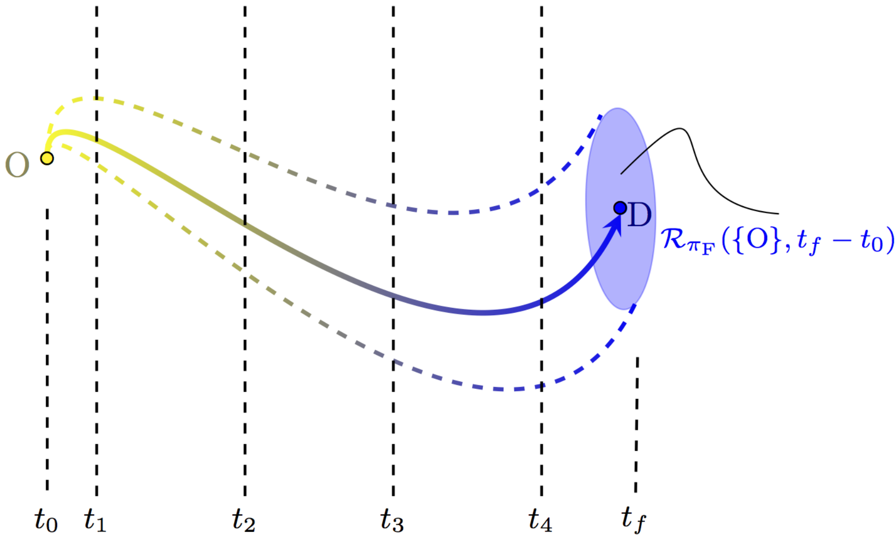
Input: Approved Flight Path



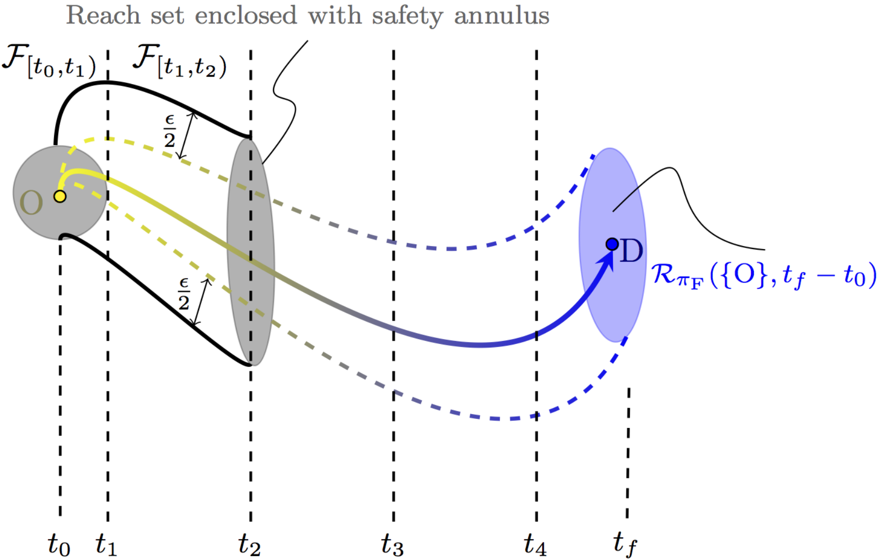
Reach Set Evolution due to Wind Uncertainty



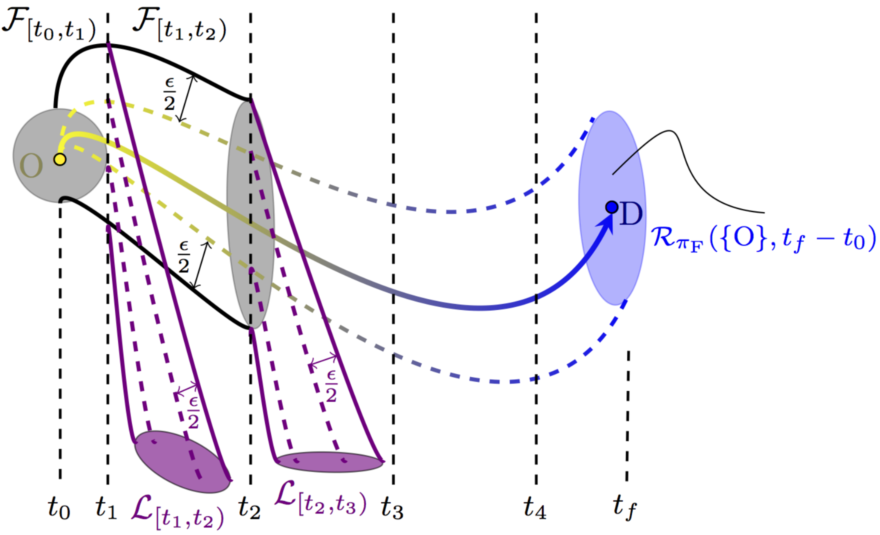
Discrete Decision Making Instances



4D Flight Tubes $\mathcal{F}_{[t_j, t_{j+1})}$

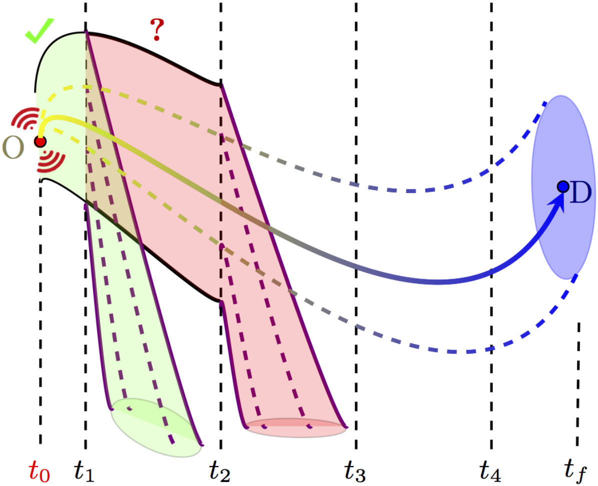


4D Flight + Landing Tubes $\{\mathcal{F}_{[t_j,t_{j+1})}, \mathcal{L}_{[t_{j+1},t_{j+2})}\}$



Motion Protocol: $t = t_0$

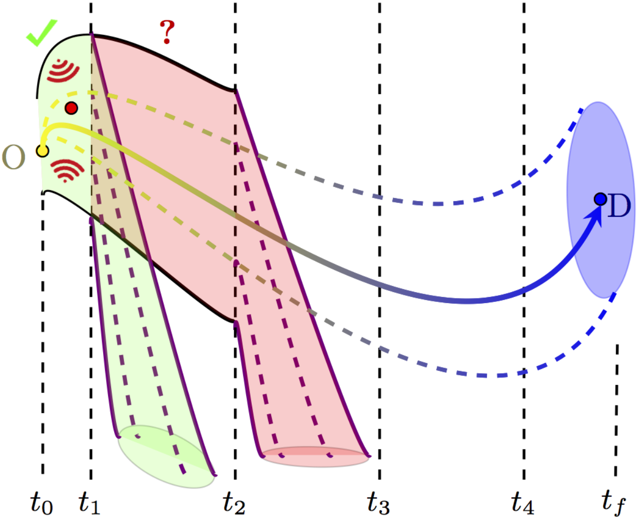
IF: Have all + ACKs for $\{\mathcal{F}_{[t_0,t_1)}, \mathcal{L}_{[t_1,t_2)}\}$ **AND** D $\in \mathcal{R}_{\pi_F}\left(\{O\}, t_f - t_0\right)$



THEN: Take-off **AND** broadcast req. for $\{\mathcal{F}_{[t_1,t_2)}, \mathcal{L}_{[t_2,t_3)}\}$

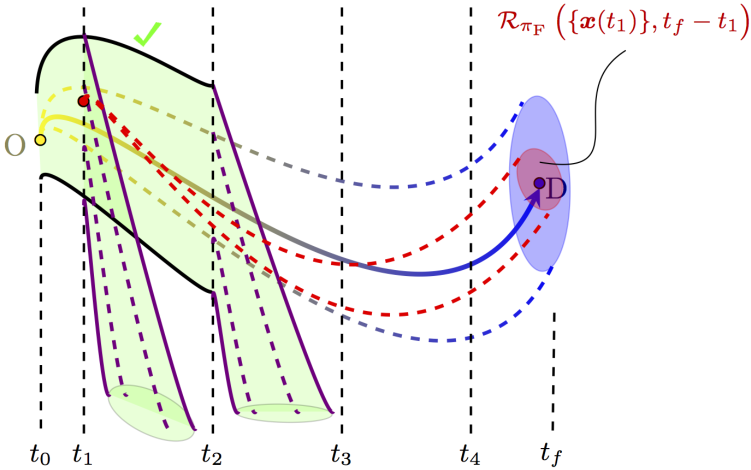
Motion Protocol: $t \in [t_0, t_1)$

Listening for $\pm$ ACKs, $\boldsymbol{x}(t) \in \mathcal{F}_{[t_0,t_1)}$



Motion Protocol: $t = t_1$

IF: All + ACKs **AND** D $\in \mathcal{R}_{\pi_F}\left(\{\boldsymbol{x}(t_1)\}, t_f - t_1\right)$

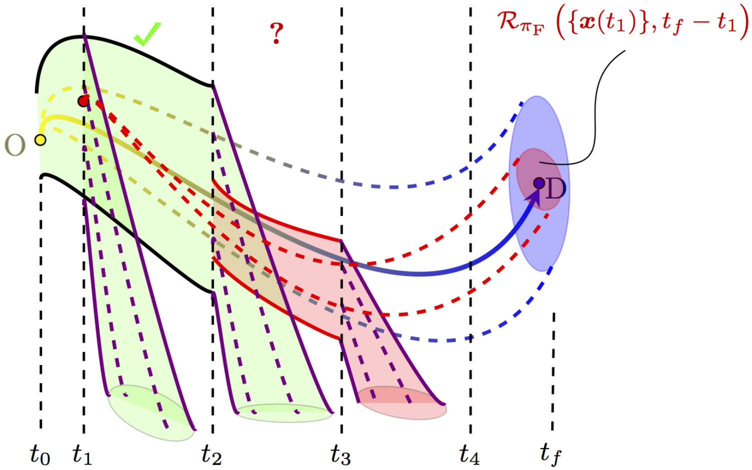


THEN: Continue in $\mathcal{F}_{[t_1,t_2)}$ **AND** broadcast req. for $\{\mathcal{F}_{[t_2,t_3)}, \mathcal{L}_{[t_3,t_4)}\}$

ELSE: Abort mission via $\mathcal{L}_{[t_1,t_2)}$

Motion Protocol: $t = t_1$

IF: All + ACKs **AND** D $\in \mathcal{R}_{\pi_{\mathrm{F}}}\left(\{\boldsymbol{x}(t_1)\}, t_f - t_1\right)$

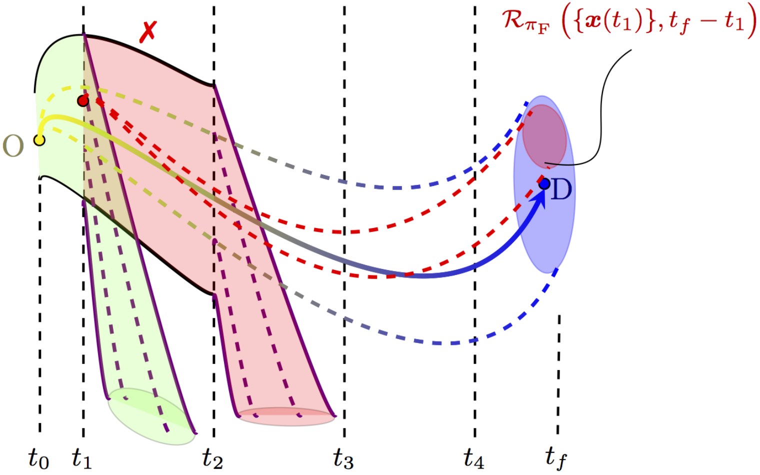


THEN: Continue in $\mathcal{F}_{[t_1,t_2)}$ **AND** broadcast req. for $\{\mathcal{F}_{[t_2,t_3)}, \mathcal{L}_{[t_3,t_4)}\}$

ELSE: Abort mission via $\mathcal{L}_{[t_1,t_2)}$

Motion Protocol: $t = t_1$

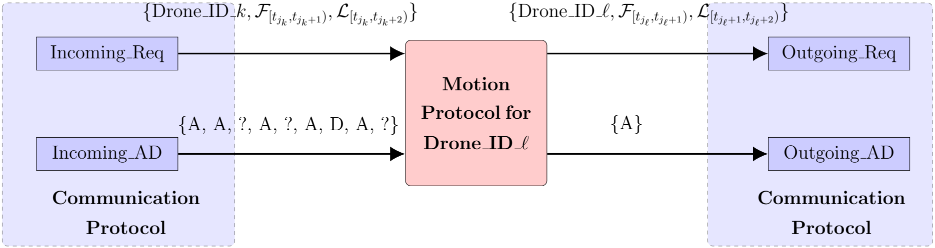
IF: All + ACKs **AND** D $\notin \mathcal{R}_{\pi_F}\left(\{\boldsymbol{x}(t_1)\}, t_f - t_1\right)$



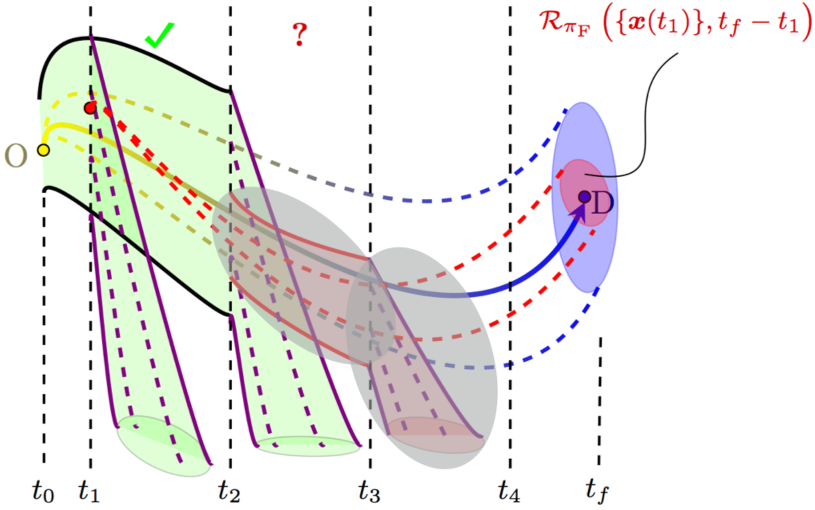
THEN: Continue in $\mathcal{F}_{[t_1,t_2)}$ **AND** broadcast req. for $\{\mathcal{F}_{[t_2,t_3)}, \mathcal{L}_{[t_3,t_4)}\}$

ELSE: Abort mission via $\mathcal{L}_{[t_1,t_2)}$

Input-Output for Motion Protocol

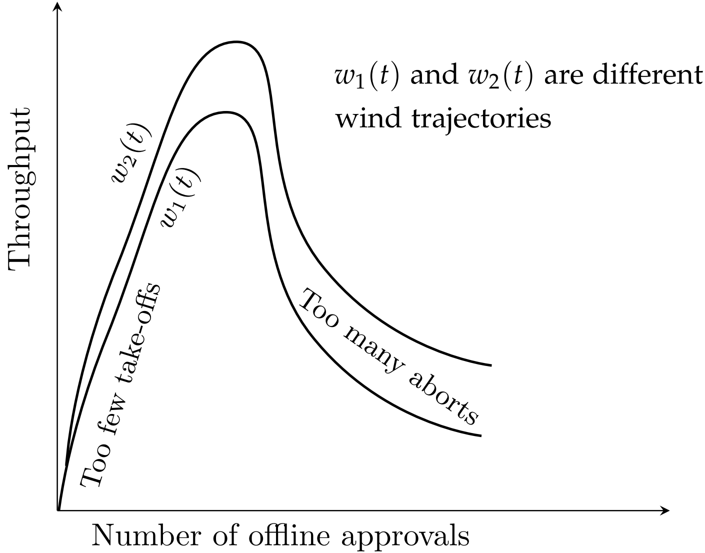


Algorithms for Motion Protocol



Compute minimum bit-length parameterizations: ellipsoids

Proposed Architecture: Performance



Thank You