Autonomy Architecture for Low-Altitude UAS Operations in UTM TCL-4+

Session: Drone Detection, Tracking and Neutralization

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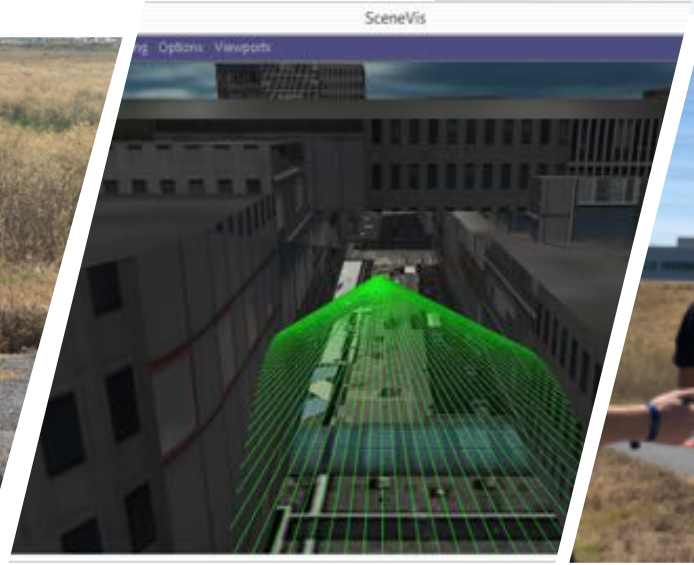
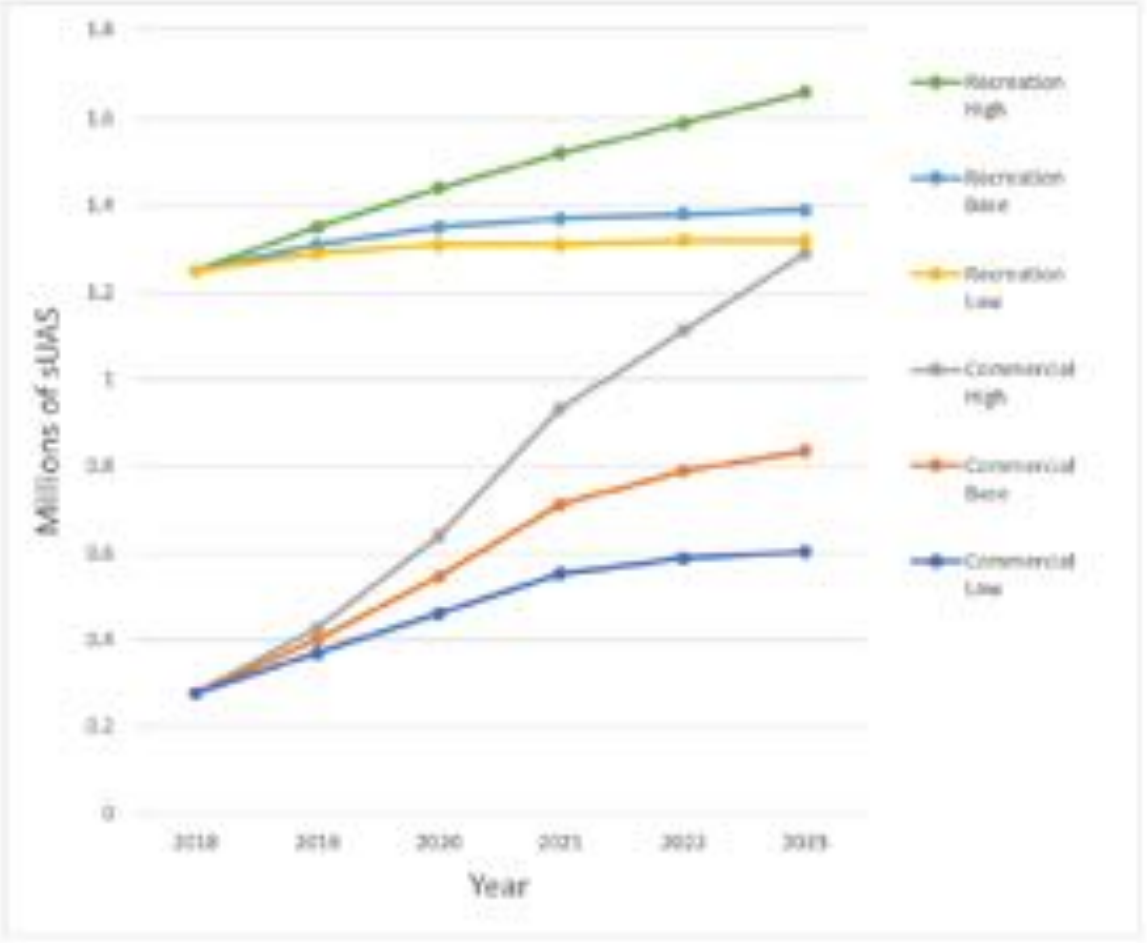


Need for Regulation

- **Operating Requirements**
  Just as there are rules of the road when driving a car, there are rules of the sky when operating a drone.
- **Registration**
- **Pilot Certification**
- **Drone Certification**
- **Airspace Authorizations**
- **FAA DroneZone**

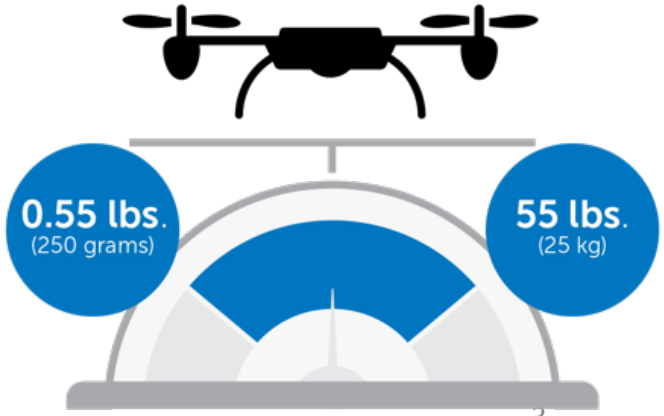


Projected UAS Growth (FAA Aerospace forecast, 2019-2013

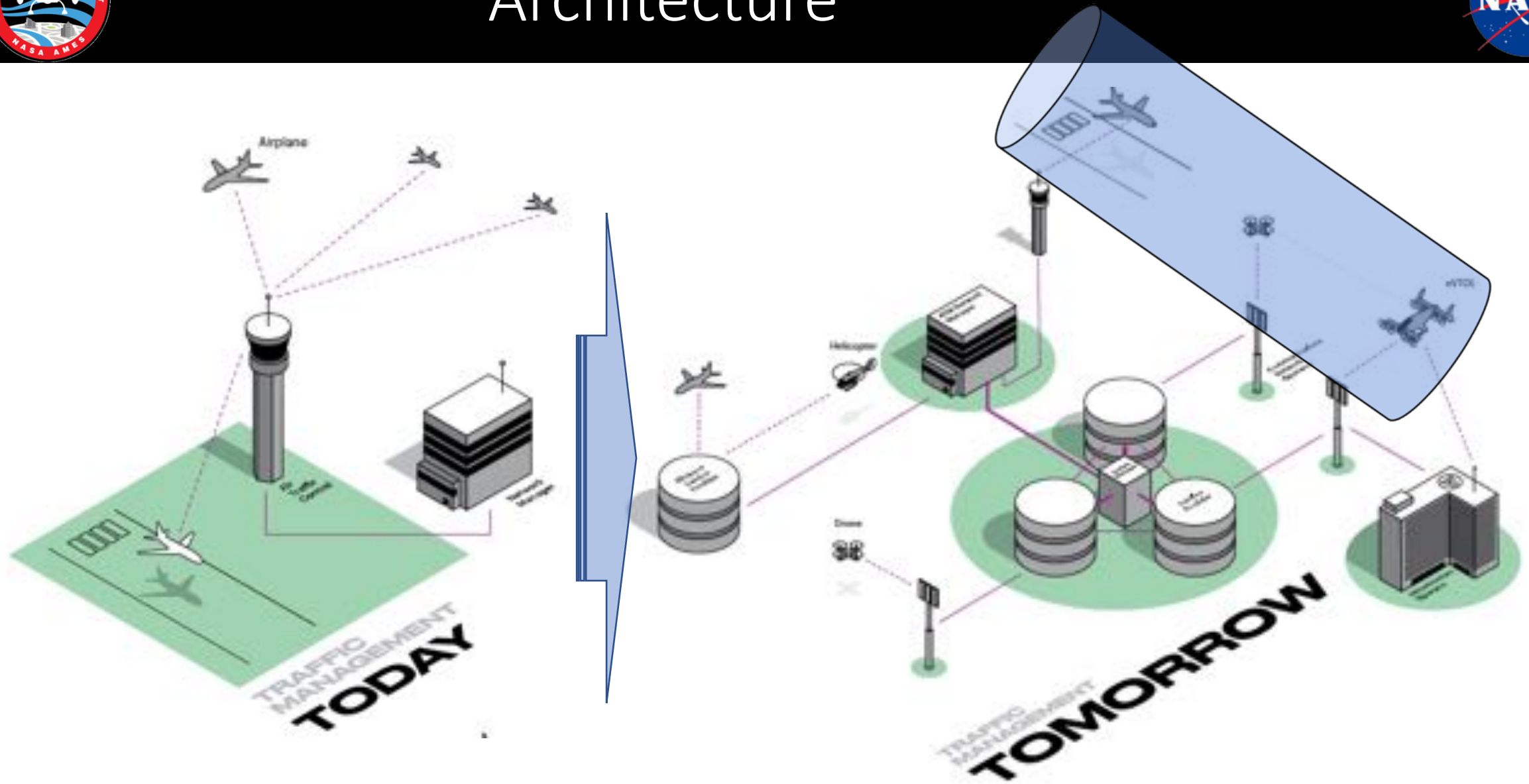
FAA – Small Unmanned Aircraft Systems (UAS) Regulations (Part 107)

Need for Regulation

- Unmanned Aircraft System (UAS) Traffic Management System (UTM)
- Remote ID (Digital License Plate)
- Part 107
- Recreational Flight
- Drone Registration

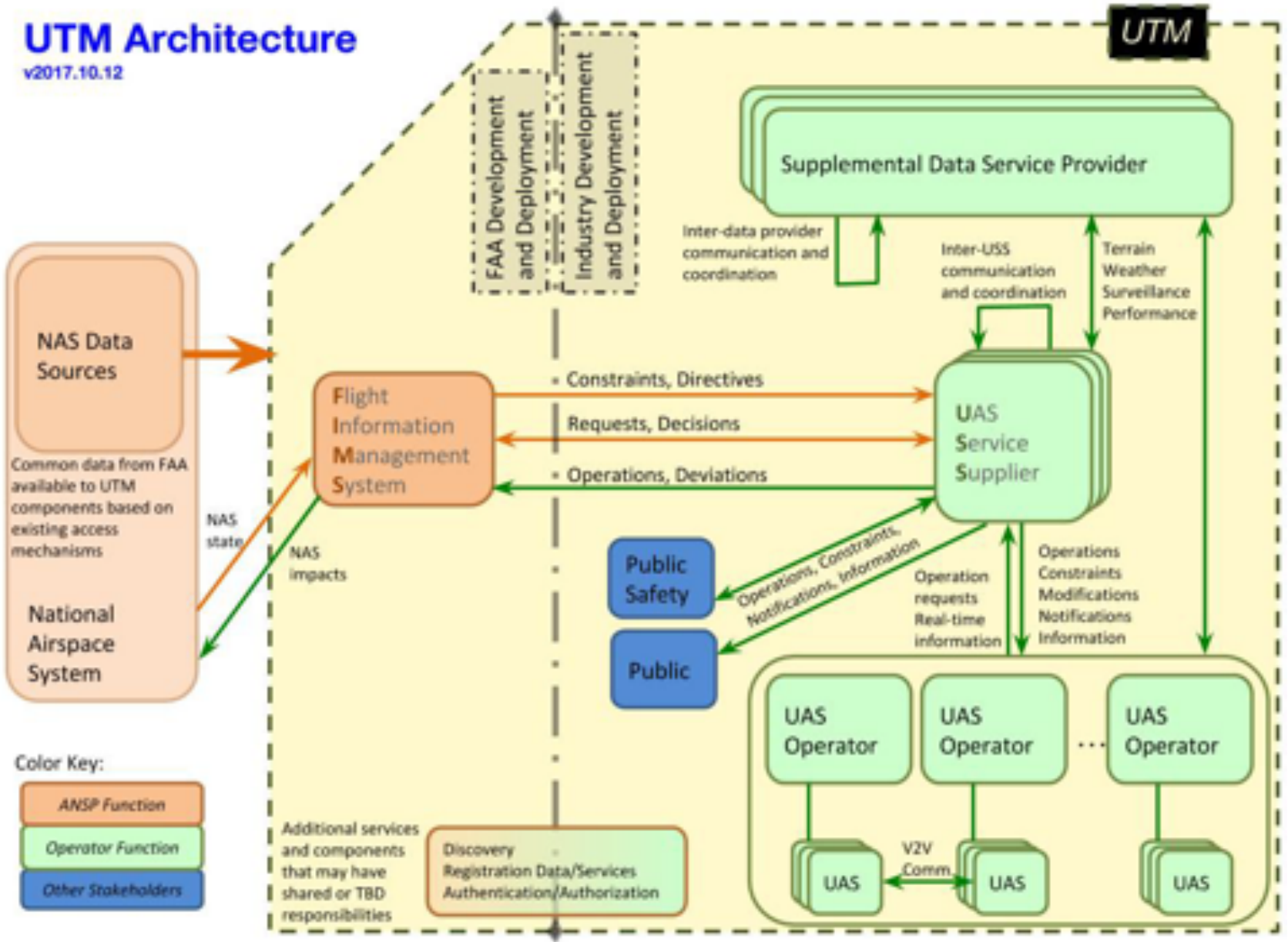


Architecture



Airbus Traffic management Con-ops

UTM



UTM Concepts of operations
FAA

TCL-4 requirements

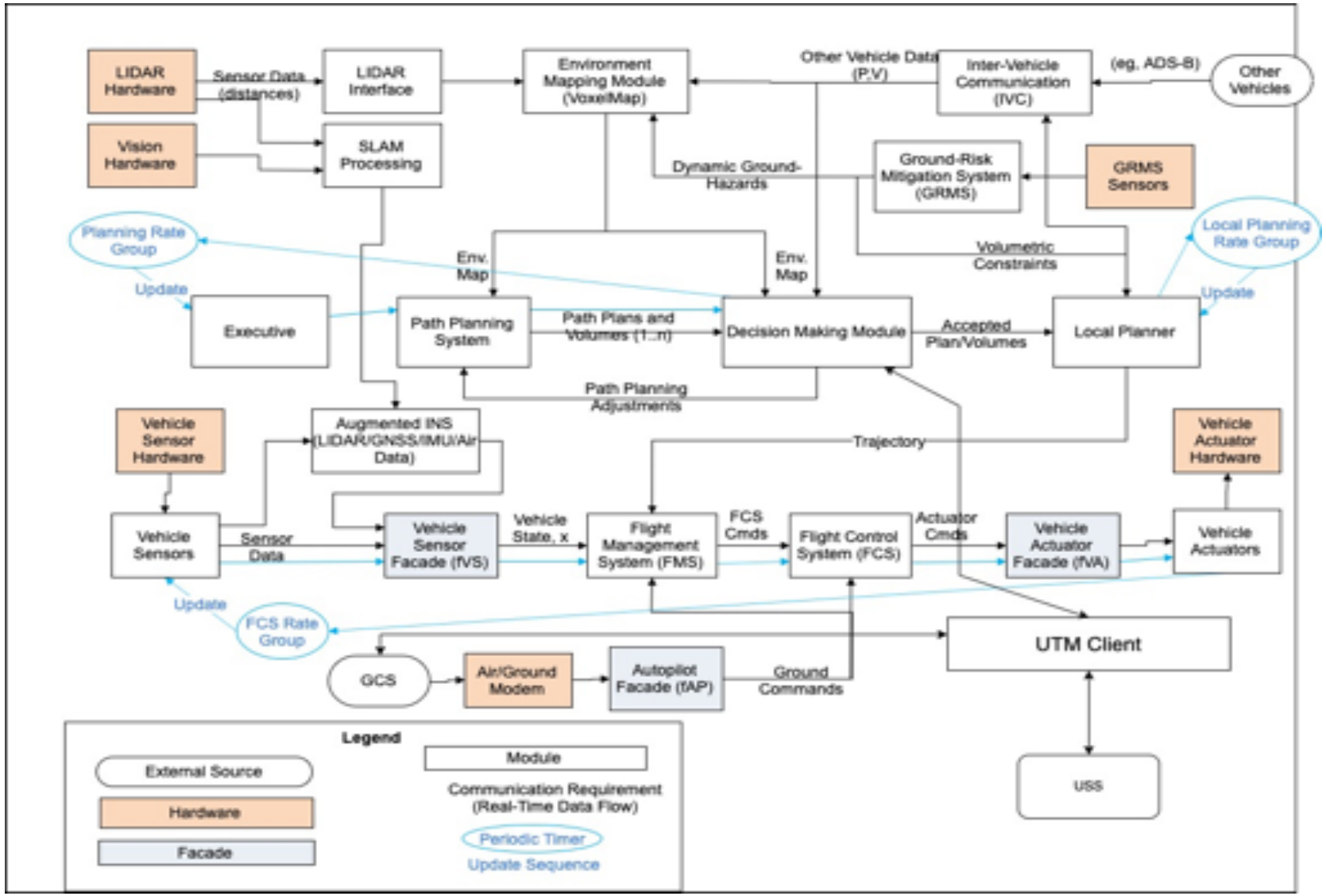
- high density environments
- large-scale off-nominal conditions
- vehicle-to-vehicle communications
- detect-and-avoid technologies communication requirements
- public safety operations
- airspace restrictions,

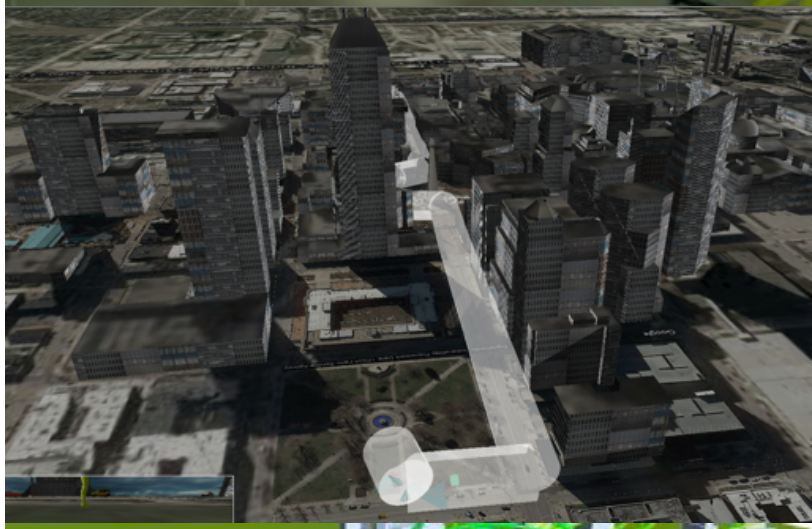
Goals

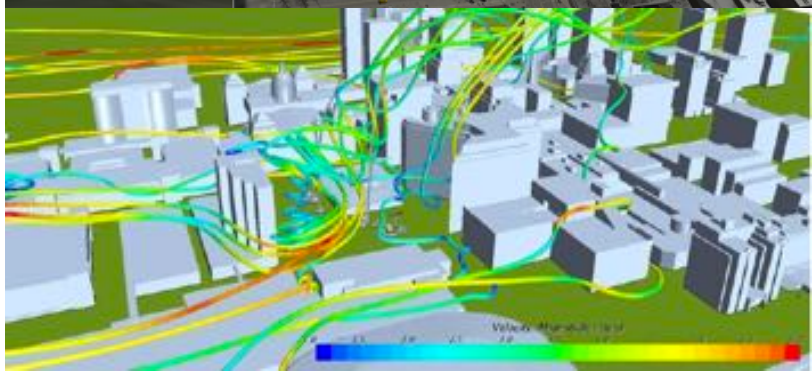
- Operational Autonomy Architecture for UTM TCL4+
- Integration with UAS service provider (USS)
  - Develop flight plan
  - Authorize flight plan
  - Adhere to UTM rules.
- Simulating UTM TCL4 architecture
  - On-board autonomy
  - V2V/V2X communication
  - On-board path planning and decision making
  - Demonstrable via flight testing.

- Compatible with the current state of the art
- Decentralized and layered design for future expansion.

Reflection Simulation Architecture – SAFE50

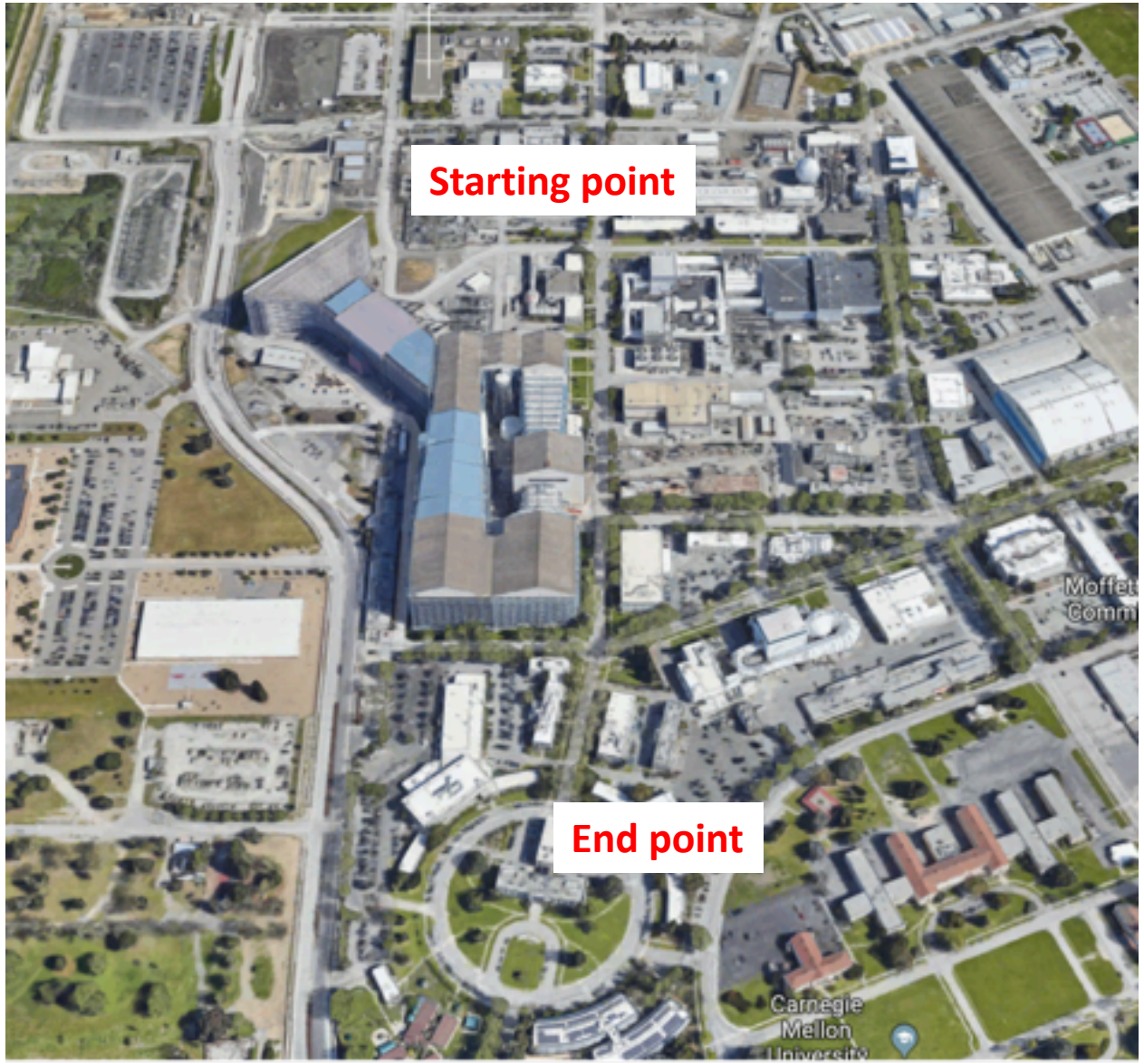






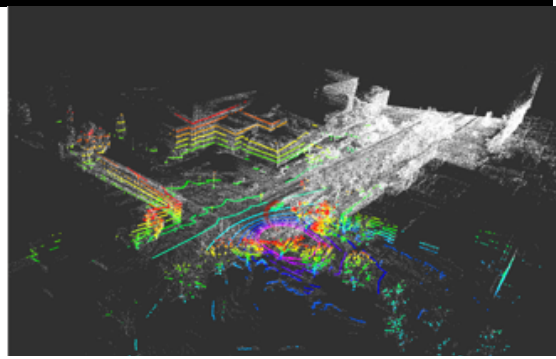
Scenario

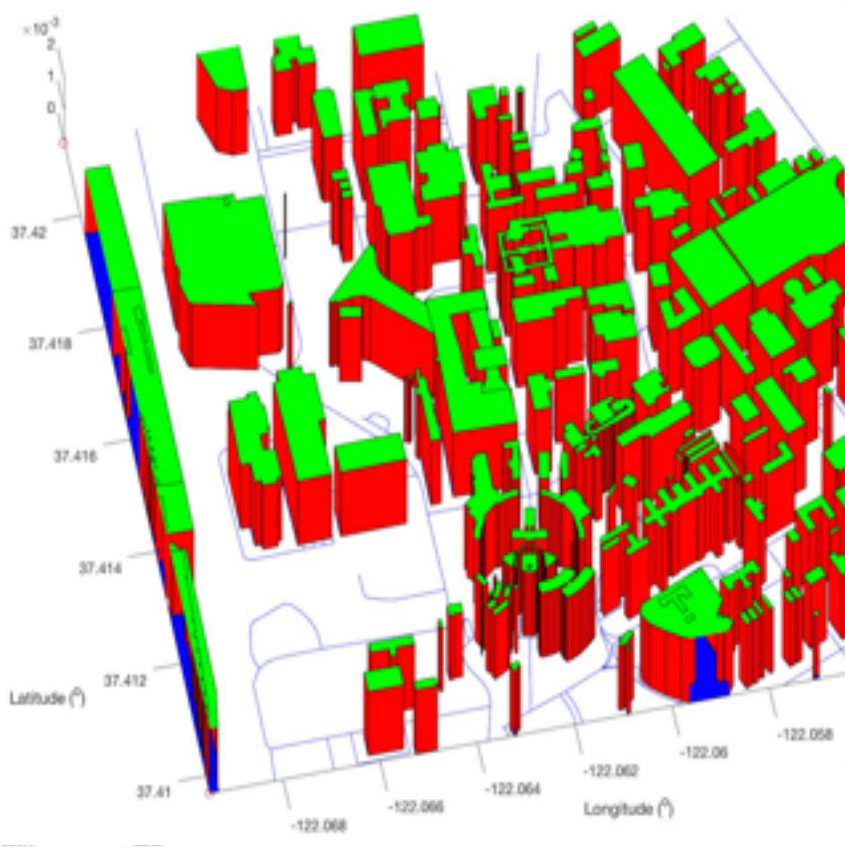
- Example flight Scenario
- Test all the components of SAFE50 Architecture
  - Onboard autonomy
  - UTM
  - Contingency plans
- Rules and regulations



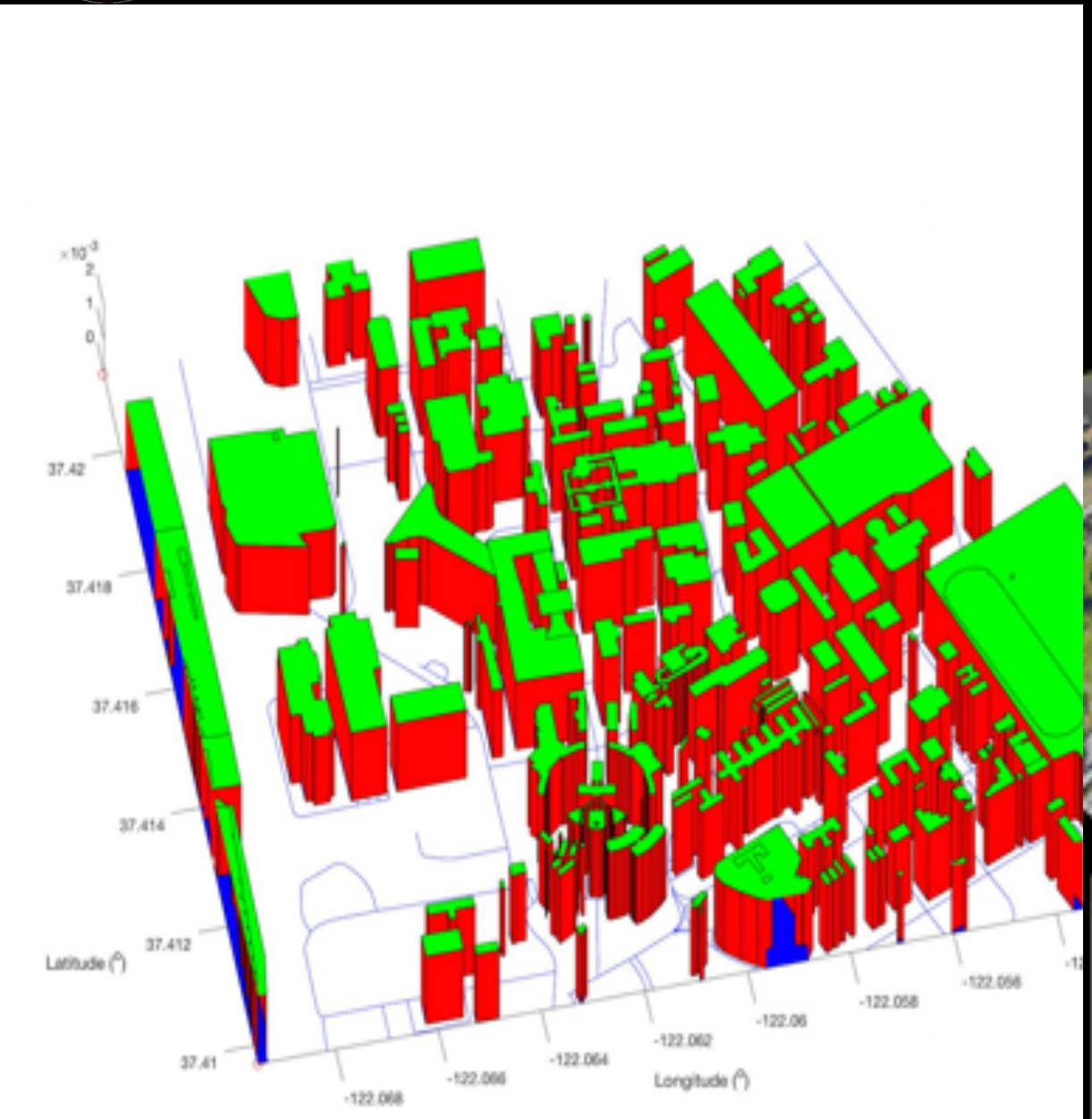
NASA Ames- Digital Map

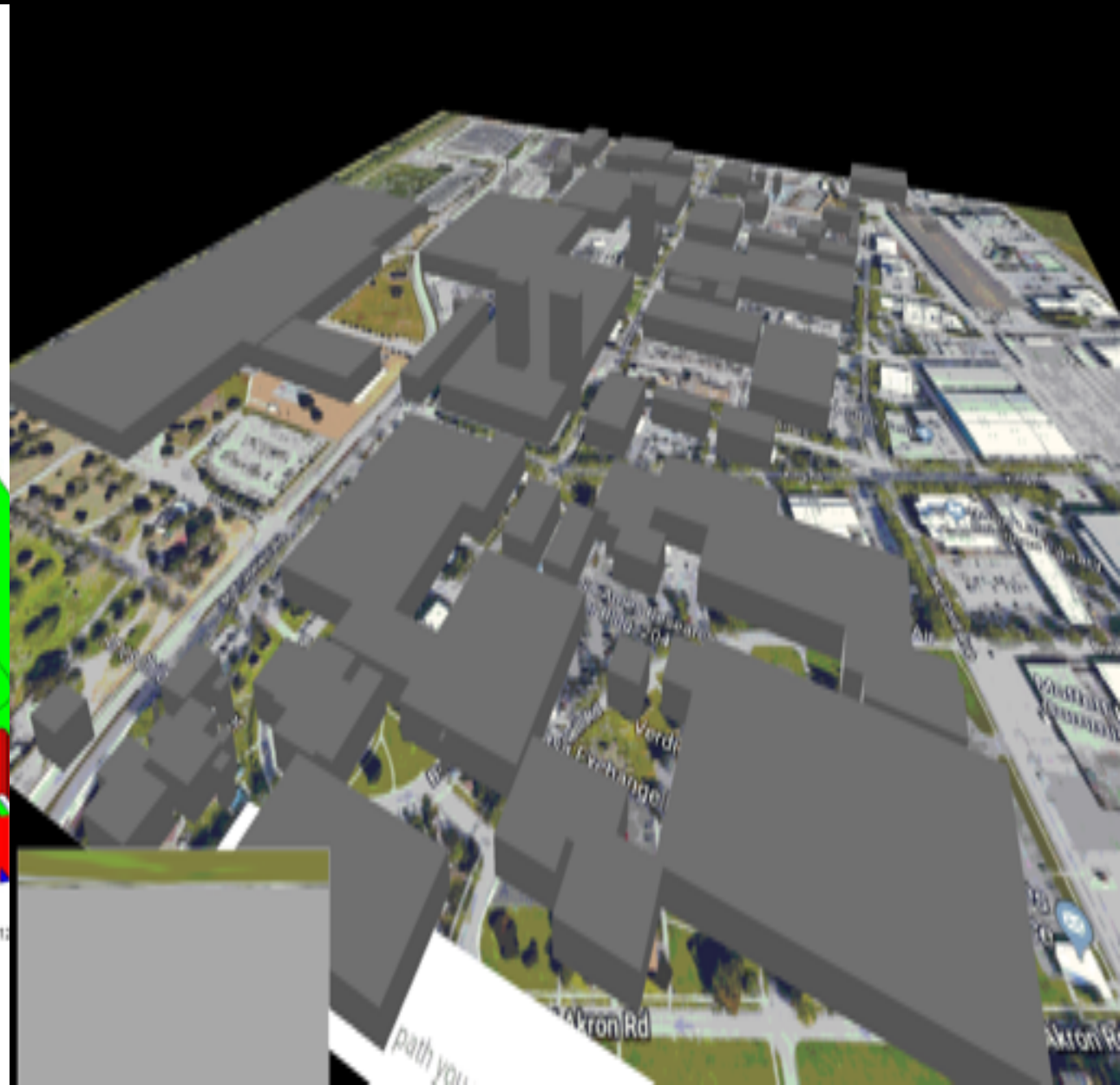
- Generate planning domain





NASA Ames- Digital Map





Global Path Planning RRT*

Algorithm 1: $\texttt{RRT}^*((V, E), N)$

```
for i = 1, ..., N do
    x_rand ← Sample;
    X_near ← Near(V, x_rand);
    (x_min, σ_min) ← ChooseParent(X_near, x_rand);
    if CollisionFree(σ) then
        V ← V ∪ {x_rand};
        E ← E ∪ {(x_min, x_rand)};
        (V, E) ← Rewire((V, E), X_near, x_rand);
return G = (V, E);
```

Algorithm 2: $\texttt{ChooseParent}(X_{near}, x_{rand})$

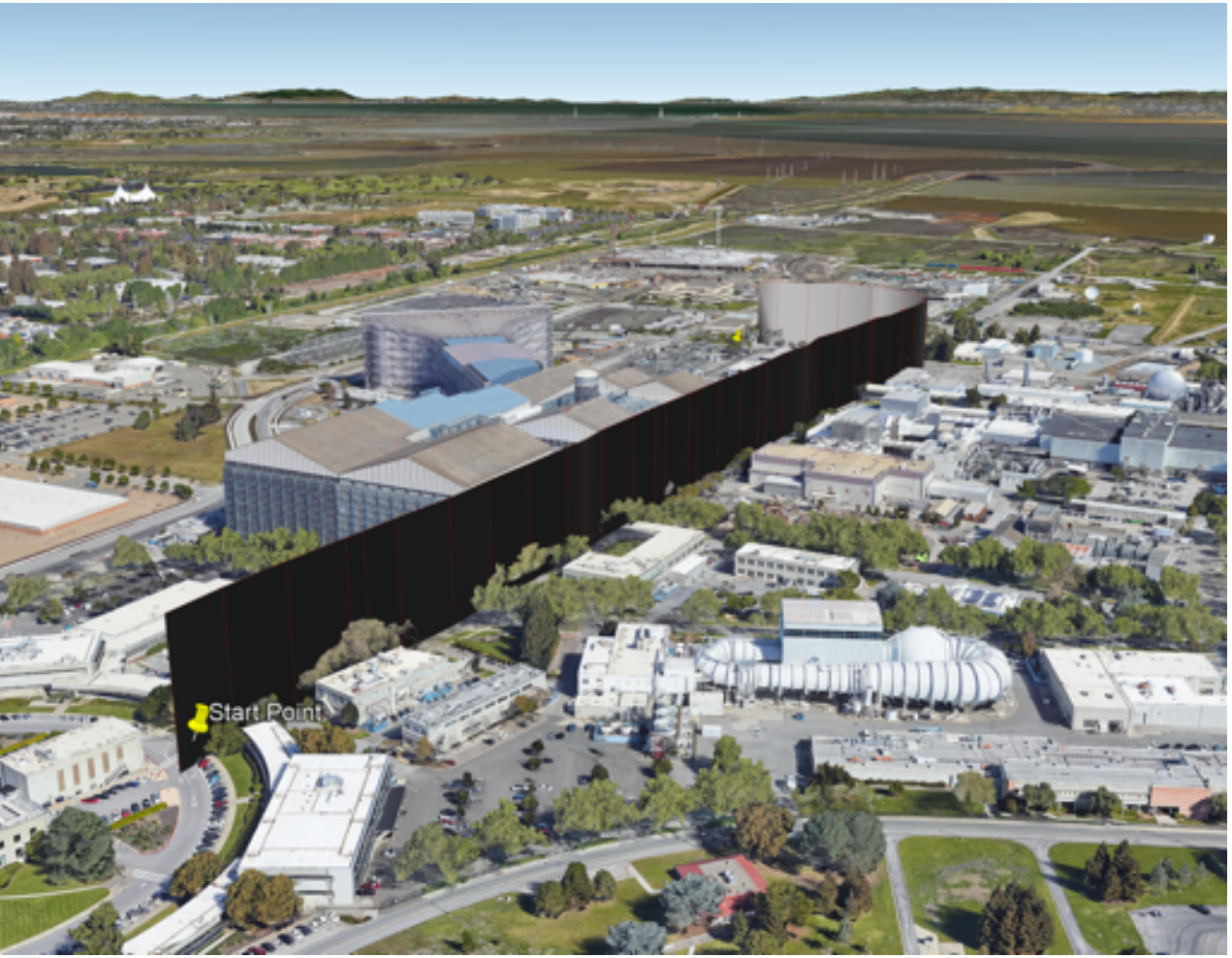
```
minCost ← ∞; x_min ← NULL; σ_min ← NULL;
for x_near ∈ X_near do
    σ ← Steer(x_near, x_rand);
    if Cost(x_near) + Cost(σ) < minCost then
        minCost ← Cost(x_near) + Cost(σ);
        x_min ← x_near; σ_min ← σ;
return (x_min, σ_min);
```

Algorithm 3: $\texttt{Rewire}((V, E), X_{near}, x_{rand})$

```
for x_near ∈ X_near do
    σ ← Steer(x_rand, x_near);
    if Cost(x_rand) + Cost(σ) < Cost(x_near) then
        if CollisionFree(σ) then
            x_parent ← Parent(x_near);
            E ← E \ {x_parent, x_near};
            E ← E ∪ {x_rand, x_near};
return (V, E);
```

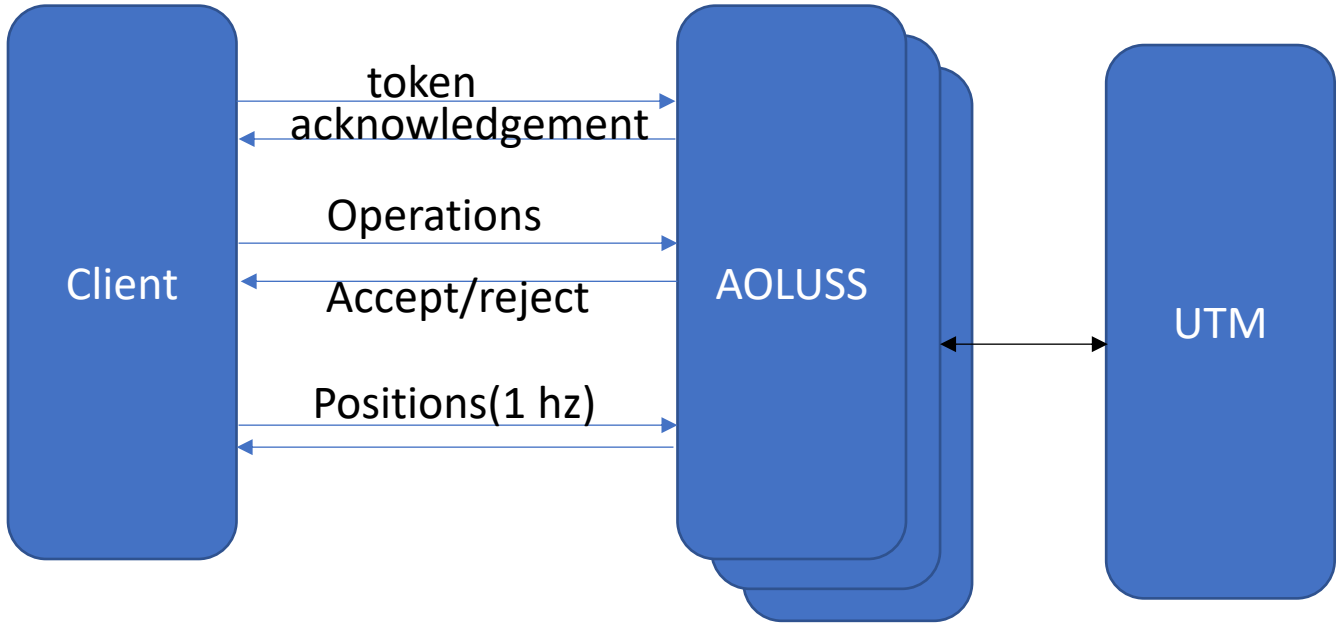
S. Karaman and E. Frazzoli, "Sampling-based algorithms for optimal motion planning," International Journal of Robotics Research June 2011.

Path and Volume



UTM- USS client

- AOL USS (Airspace Operations Lab)
- Other USS connections
- UTM connected
- GeoJason file

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....
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.......
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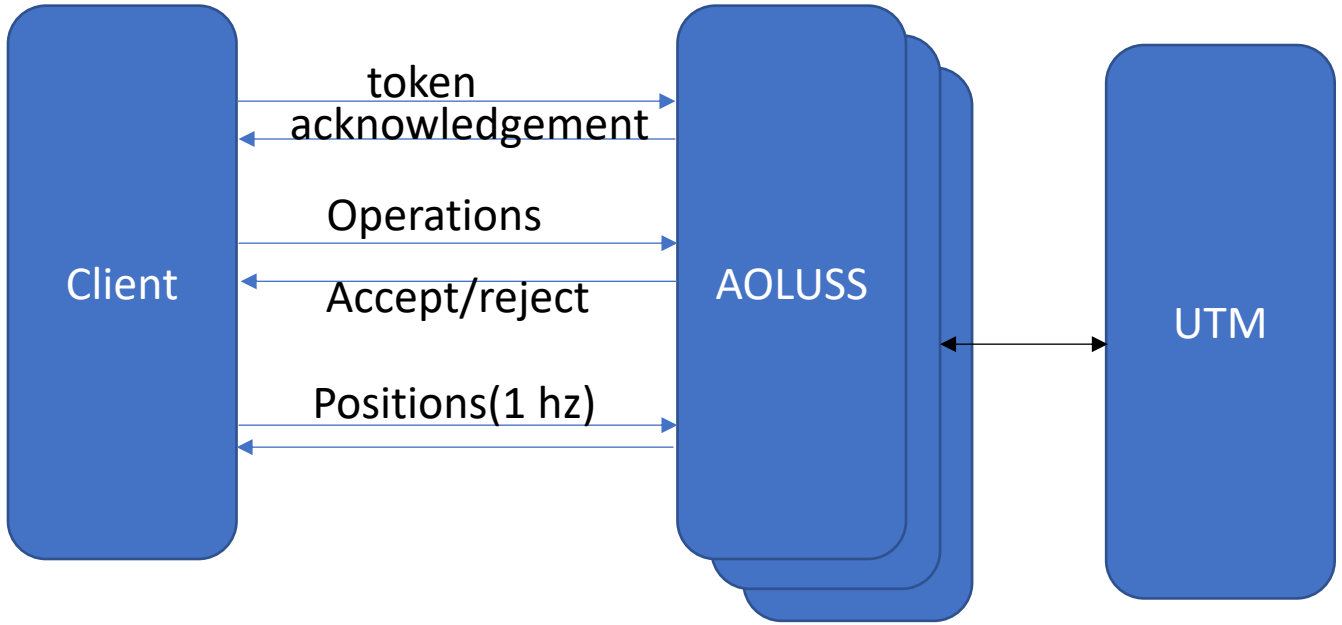
.......
          ]
.....
```

AOL USS (Airspace Operations Lab)

- UTM TCL-4+
  - In-flight plan modification
  - Multiple vehicles allowed inside same operating volume

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.......
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```
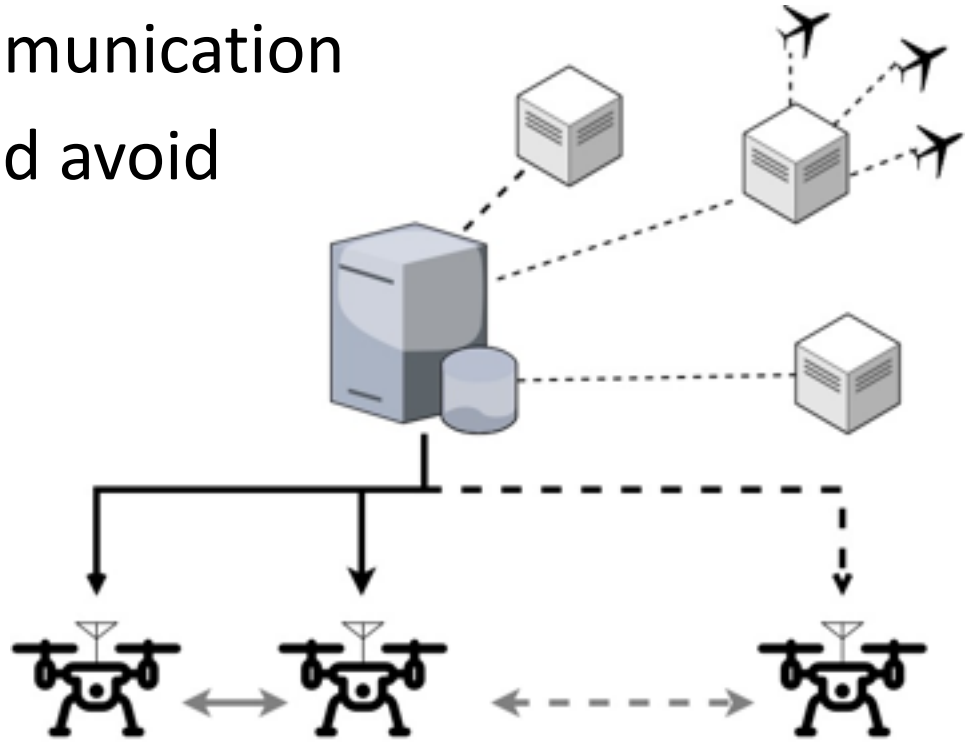
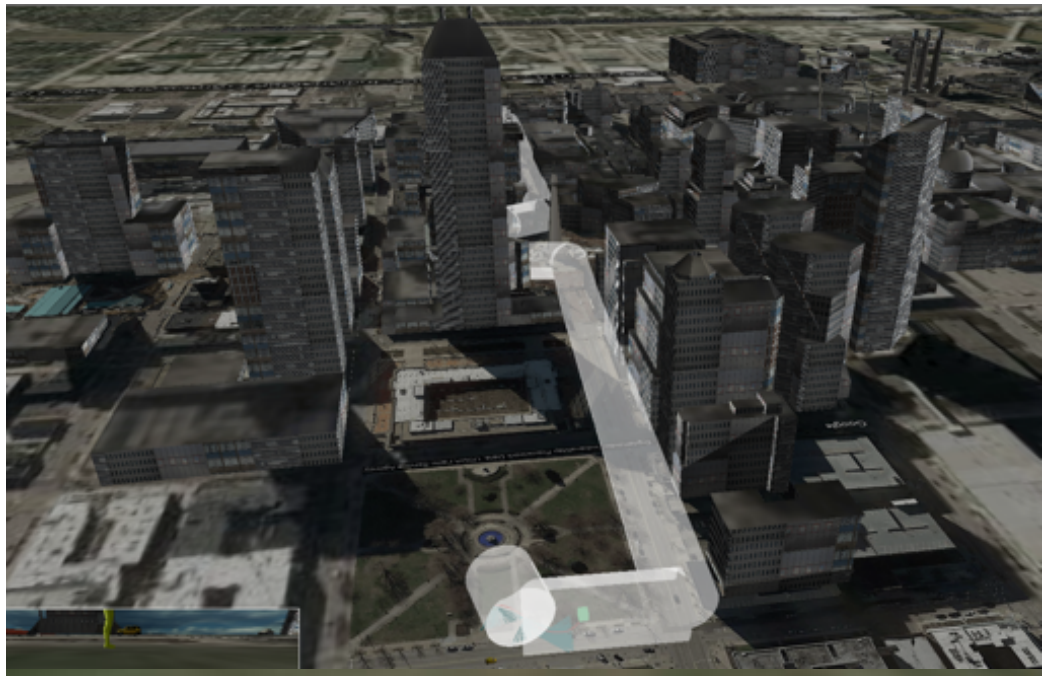

Local Planner and V2V communication

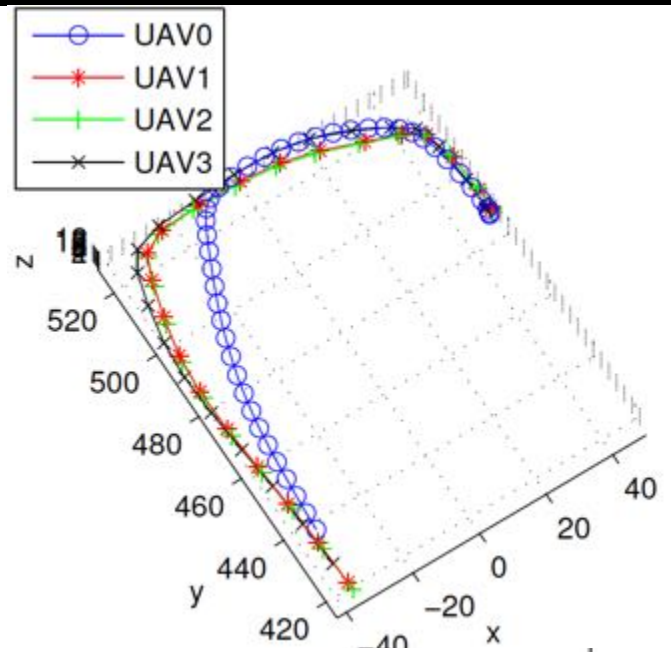
- Local Planner – driving on the highway
- Online decision making
- CAA & SA
- V2V communication
- Sense and avoid

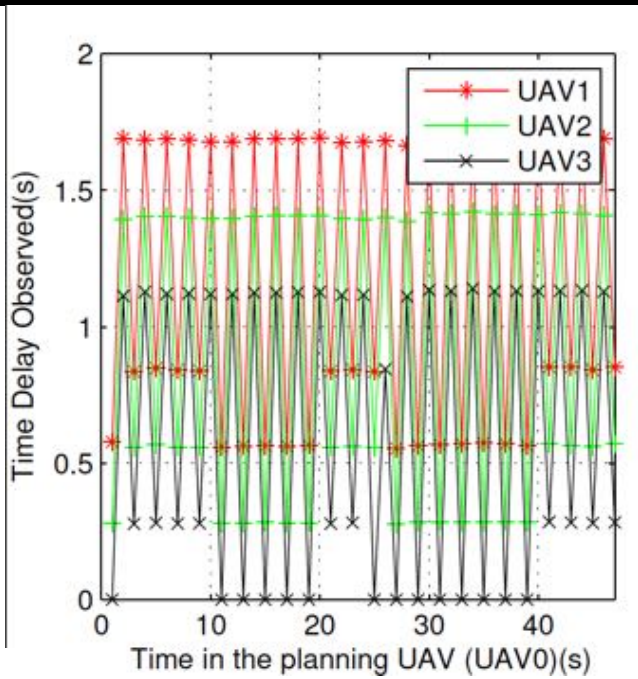


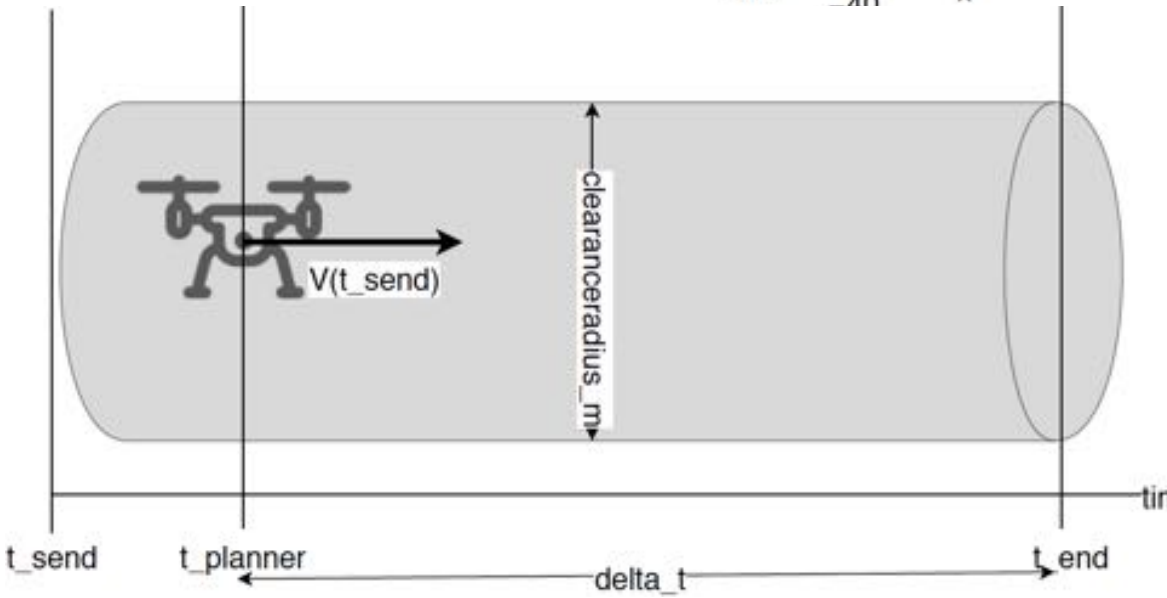


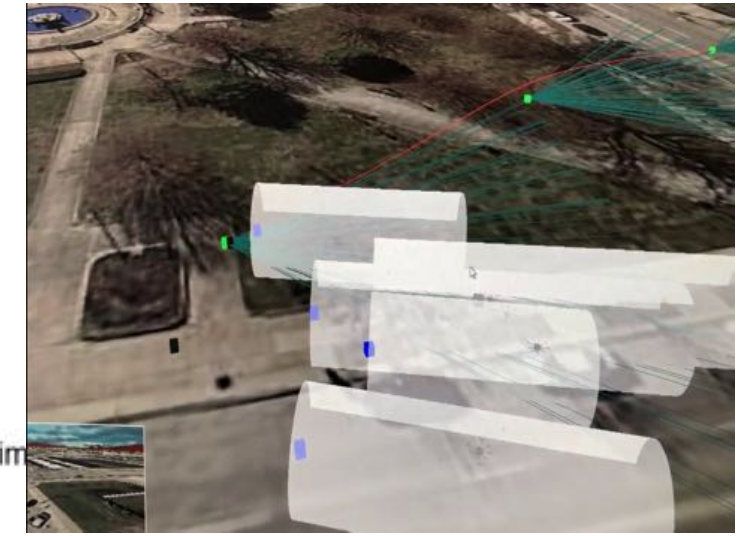
V2V Communication

- Unique vehicle id
- V2V and V2X setup
- Position and velocity updates
- Time delay









Local Planner

- Optimal Trajectory Generation using Recursive Tree algorithm

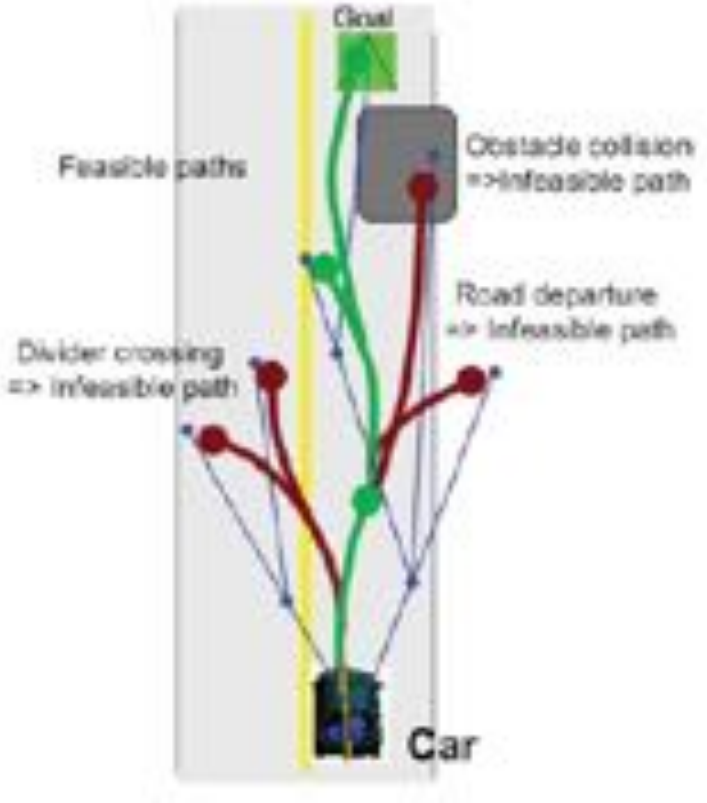
➢Fly inside approved volume

➢Generate collision free Trajectories

  ➢Within approved volume

  ➢Handles all constraints (energy/wind/)

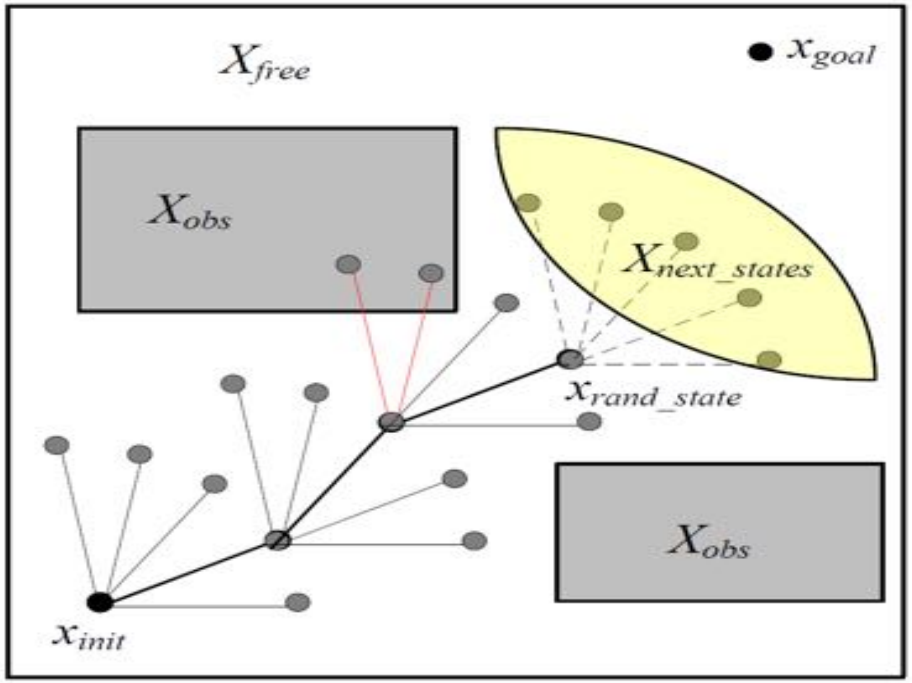
  ➢Real-time planning



"A Perception-Driven Autonomous Urban Vehicle" John Leonard, Jonathan How, Seth Teller, Mitch Berger, Stefan Campbell, Gaston Fiore, Luke Fletcher, Emilio Frazzoli, Albert Huang, Sertac Karaman, Olivier Koch, Yoshiaki Kuwata, David Moore, Edwin Olson, Steve Peters, Justin Teo, Robert Truax, and Matthew Walter Massachusetts Institute of Technology Cambridge, Massachusetts 02139, Journal of Field Robotics.

Local Planner – Tree based Path Planning

- Assumption:
- Cost Function is admissible (i.e you don't overestimate the cost)
- Total cost :f(x)=g(x)+h(x)

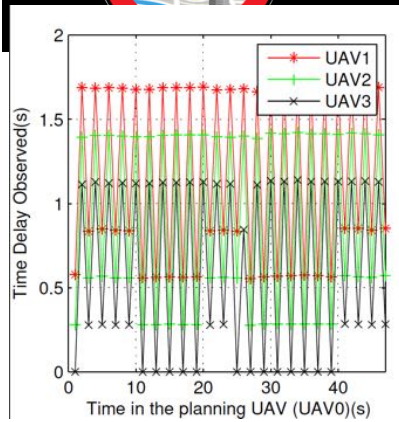


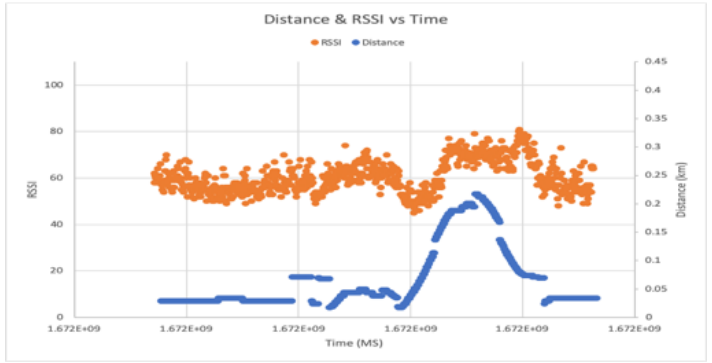
Function :$Kinematic\_Tree^*(x_{init})$;
G.init(x_{init});
G.extend $\leftarrow x_{init}$;
G.not_extend $\leftarrow \phi$
for $i=1$ *to* K **do**
  $x_{rand\_state} \leftarrow choose\_state(G)$;
  Extend(G,x_{rand_state})
end
Return
Function :Extend(G,x_{rand_state});
$X_{next\_states} \leftarrow Steer(x_{rand\_state}, U, \Delta t)$;
for *all* $x_{state} \in X_{next\_states}$ **do**
  if $collision\_free\_path(x_{random\_state}, x_{state})$ **then**
    $G.add\_node(x_{state})$;
    $G.add\_edges(x_{rand\_state}, x_{state}, u))$
    $G.extended(x_{rand\_state}))$
    $G.not\_extended \leftarrow G/G.extended$;
    $G.cost \leftarrow$
    $cost(x_{rand\_state}) + g(x_{rand\_state}, x_{state}) + h(x_{state}))$
  end
end
Return G
Function :Choose_State(G,x_{rand_state});
$x\_lowest\_cost \leftarrow find\_min\_cost(G)$
Return x_lowest_cost;

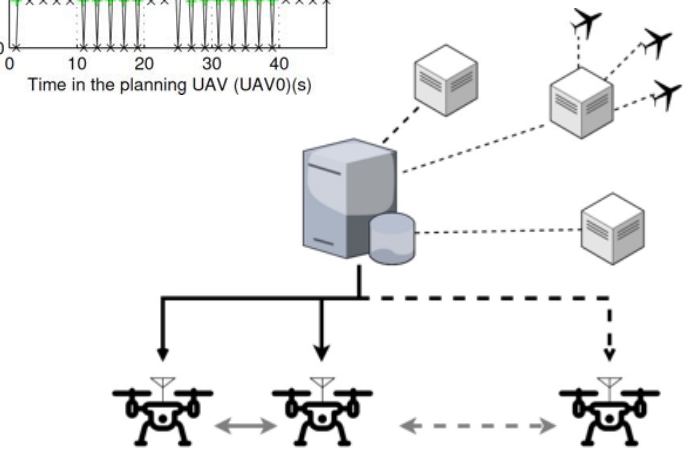
Algorithm 2: $KinematicTree^*Algorithm$

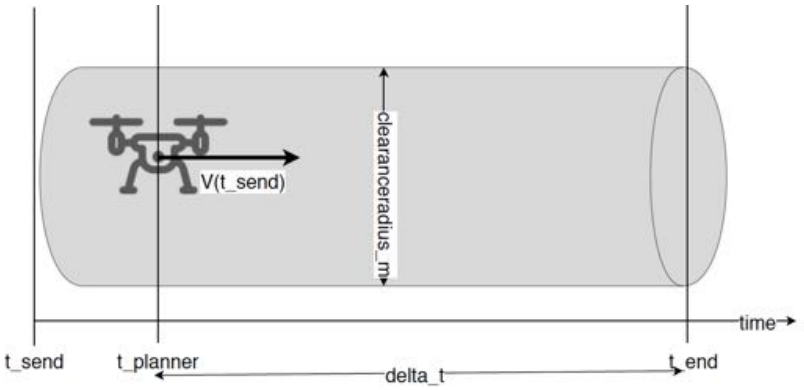
Local planning and V2V communication

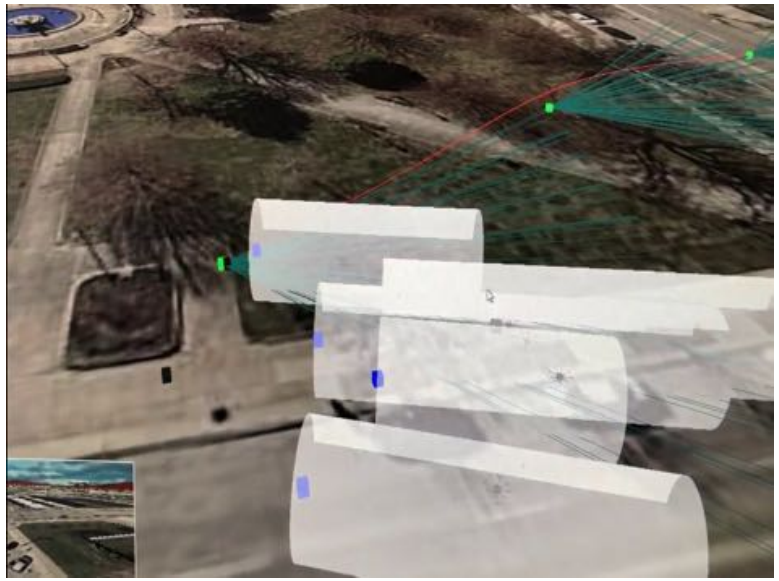
V2V Communication – Path Planning



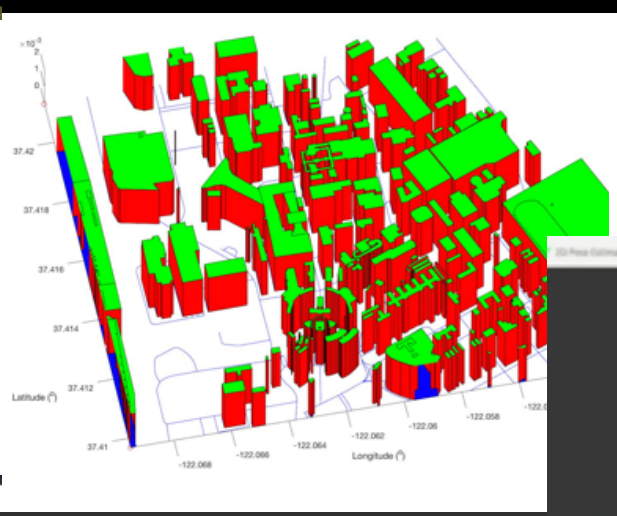


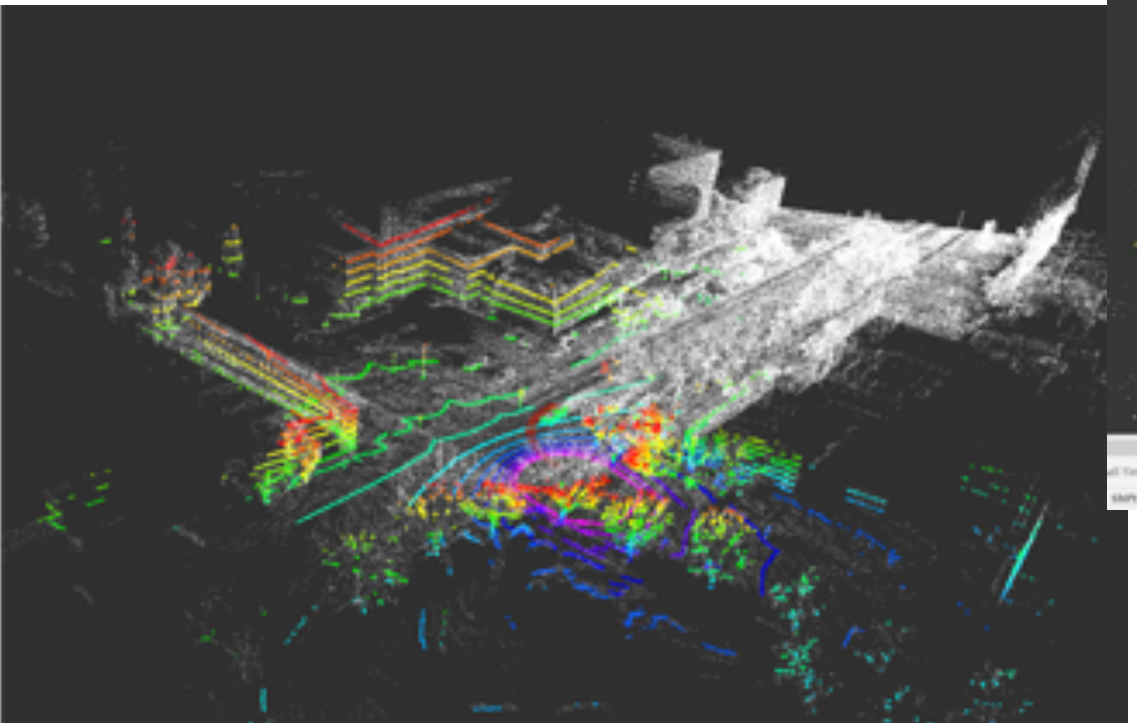


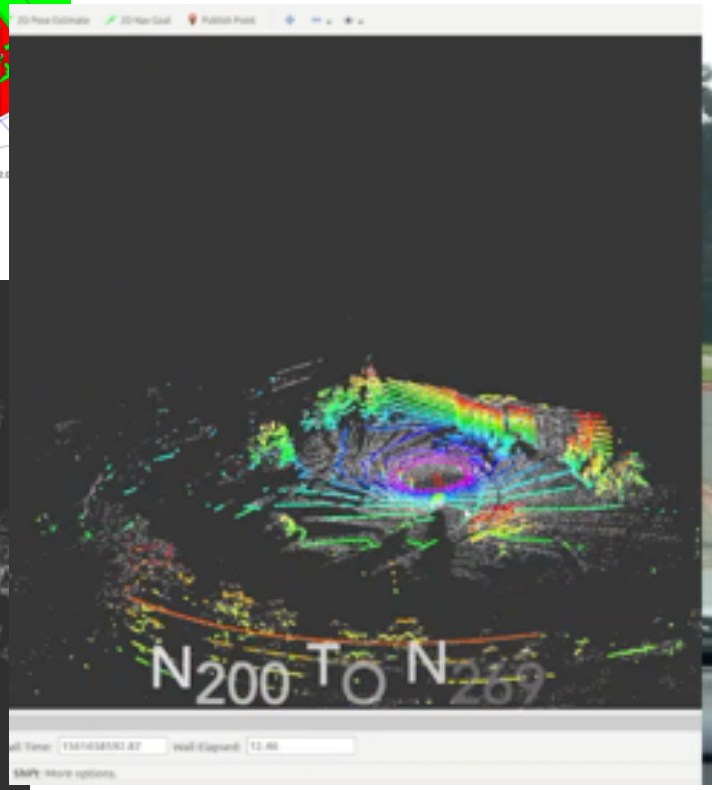




Initial Flight Tests

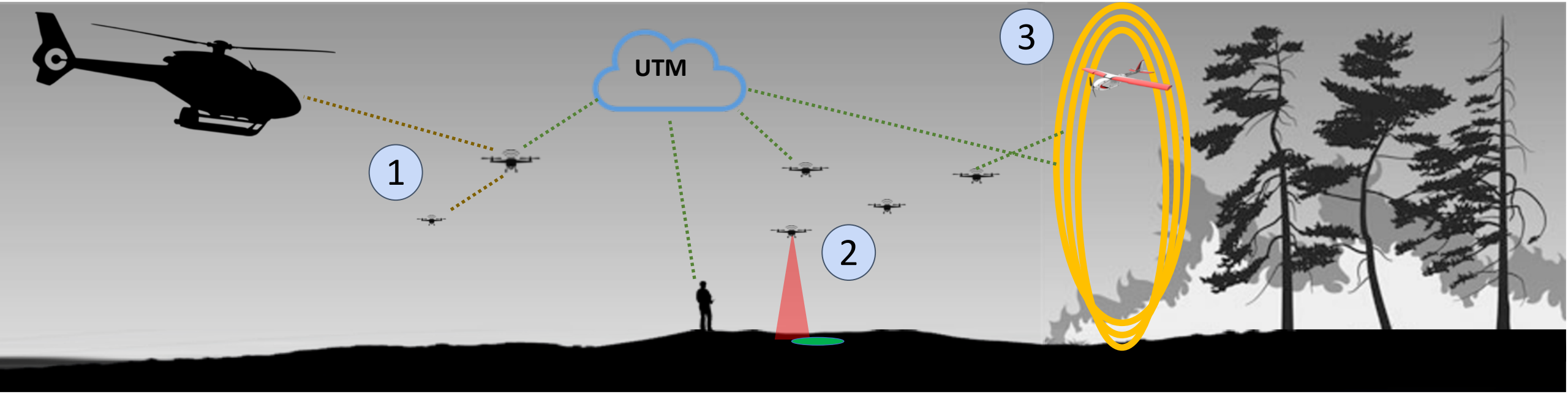




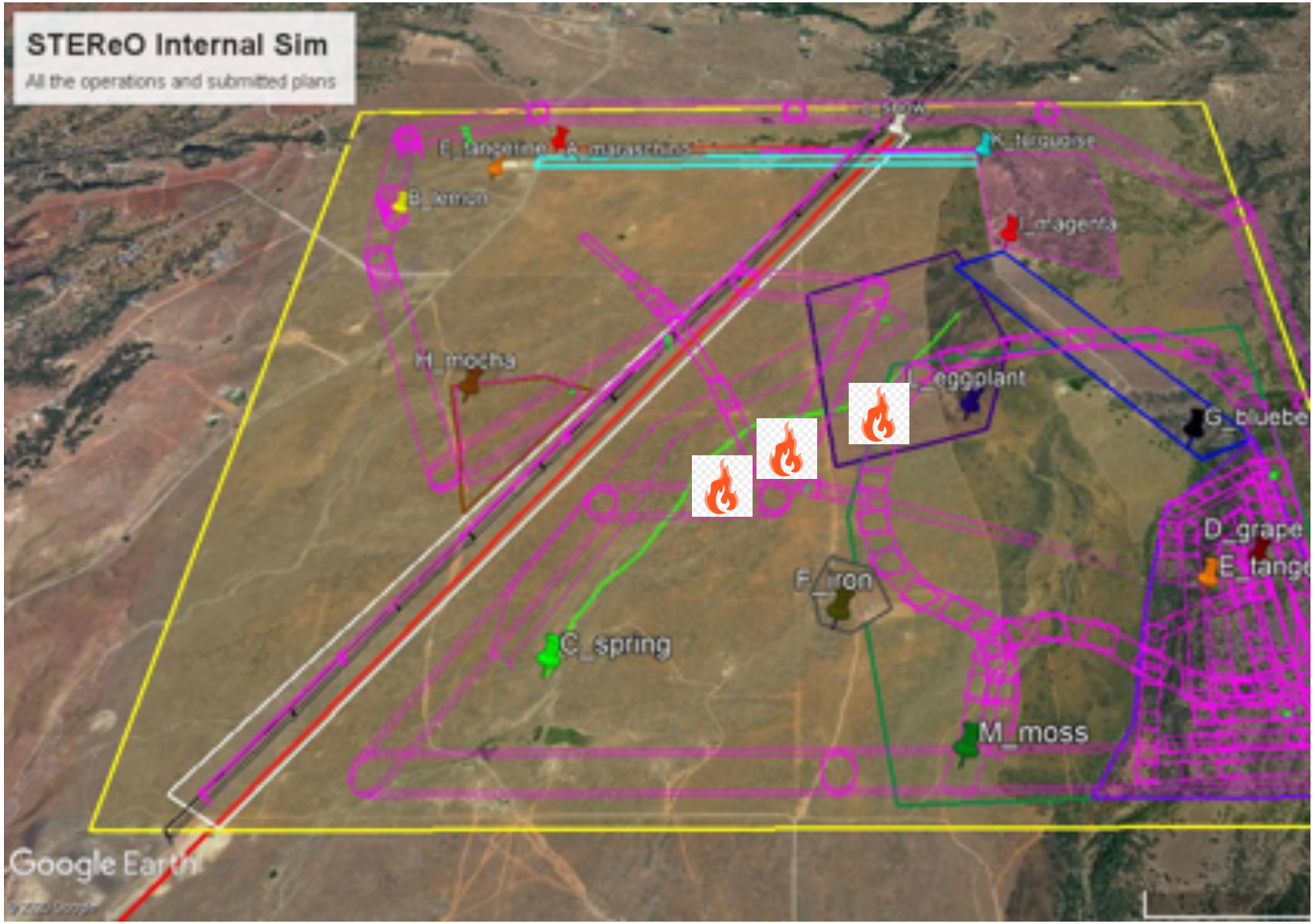


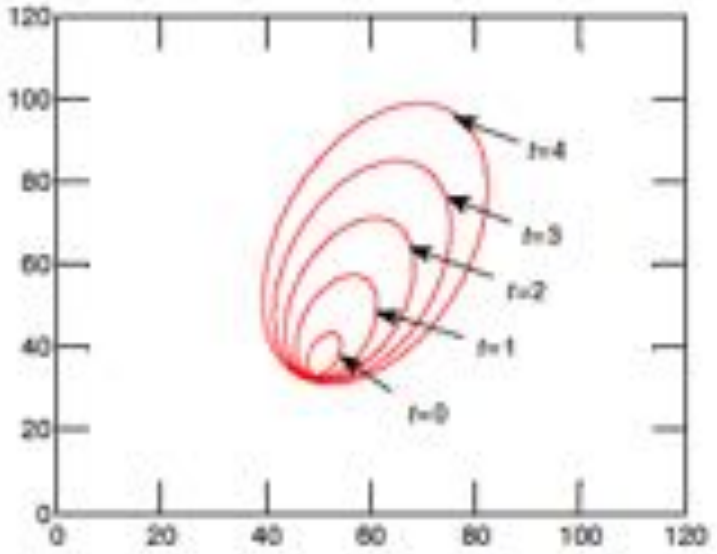
STEReO

- STEReO (**S**calable **T**raffic Management for **E**mergency **Re**sponse **O**perations) –
- collaboration with fire agencies, (CalFire, LA, SF)
- Communication(AT&T, Verizon)
- Regulations (TFR, Manned unmanned)



STEReO


STEReO Internal Sim
All the operations and submitted plans
K_turquoise
L_magenta
B_green
H_mocha
I_eggplant
G_blueberry
D_grape
E_tangerine
F_iron
C_spring
M_moss
Google Earth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80
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40
20
0
0
20
40
60
80
100
120
t=4
t=3
t=2
t=1
t=0

Conclusion

- Operational architecture for flying multiple vehicles in UTM TCL4+
- Develop autonomous flight plans and approval from UTM
- USS connectivity
- On-board path planning and decision making
- Testing individual components through bench tests and flight tests
- A road map for future complete autonomous operations in urban airspace.

Autonomy Architecture for Low-Altitude UAS Operations in UTM TCL-4+

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