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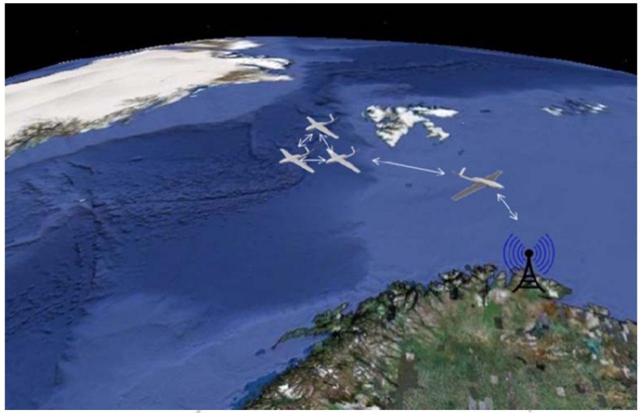

Path- and data transmission planning for cooperating UAVs in delay tolerant network

Esten Ingar Grøtli, Tor Arne Johansen

Outline

- Related work
- Applications of UAVs
- Motivation for our path planning approach
- Algorithm overview
- Introduction to SPLAT! and MILP
- Objective of MILP problem
- Simulations
- Conclusion and future work

Related work

- *Frew, Brown, «Networking Issues for Small Unmanned Aircraft Systems», 2008*
- *Beard, McLain,«Multiple UAV cooperative search under collision avoidance and limited range communication constraints»*, 2003

- Shengxiang, Hailong *«Real-time optimal trajectory planning with terrain avoidance using MILP»*, 2008
- Richards, How, “Mixed integer programming for control”, 2005
- Schouwenaars et. al., *«Mixed integer programming for multi-vehicle path planning», 2001*

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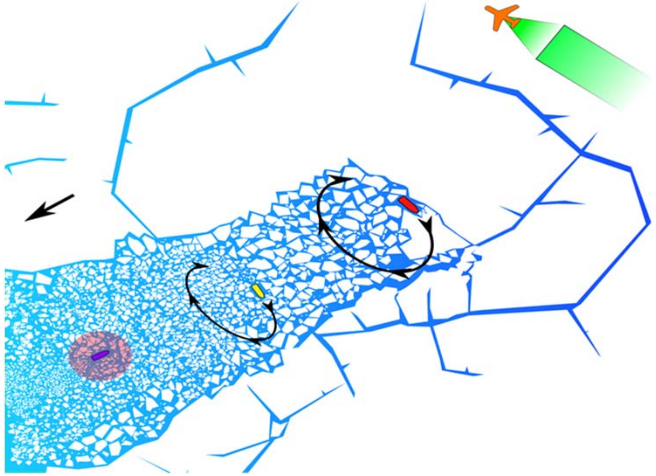
Applications of UAVs

- Environmental surveillance
    - Polar climatology
    - Wildfire management
    - Agricultural management
    - Offshore oil spill recovery
    - Ice management
    - Terrain mapping
    - Storm (ash cloud) chasers
- Border surveillance
- Military applications
    - Enemy surveillance
    - Radar detection
    - Weapon carriers
- Temporary and mobile communication relay or network node

Courtesy: Centre for Autonomous Marine Operations and Systems



Courtesy: Joakim Haugen et al, State Estimation of Ice Thickness Distribution Using Mobile Sensors

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Basic communication strategies*

- •Direct link
  - •Simple, low latency, reliable
  - •Only for LOS communication
- •Satellite
  - •'Good' coverage - although not for polar regions
  - •Poor data delivery, expensive
- •Cellular
  - •As for direct link, better coverage
  - •Expensive (not for transient demands)
- •Mesh
  - •Requires no permanent infrastructure, good coverage, 'good' data delivery, some redundancy
  - •Complex

Courtesy: www.wikipedia.org

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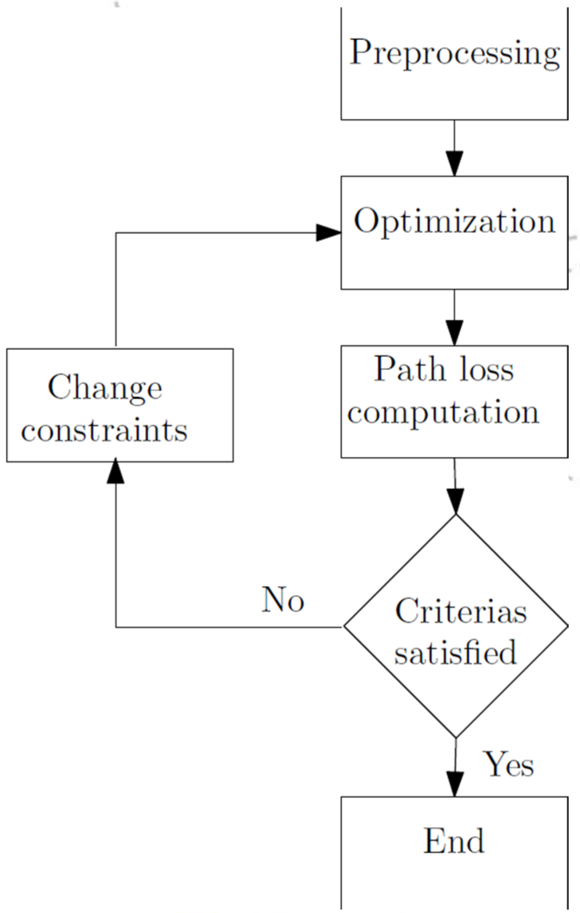
*Frew et. Al., «*Networking Issues for Small Unmanned Aircraft Systems*», 2008

Algorithm overview

Our goal is to do *coarse offline path planning* for a communication constrained mission:

•Preprocessing
•Solve MILP
•Analyse signal-to-noise ratio (SNR) based on pathloss calculations using SPLAT!
•If required SNR is not achieved, the constraints of the MILP are changed – otherwise we are done!

The planned path serves as a starting point *online* re-planning methods*.



*Grancharova et. al., «*Distributed path planning for a UAV communication chain by dual decomposition*, 2012

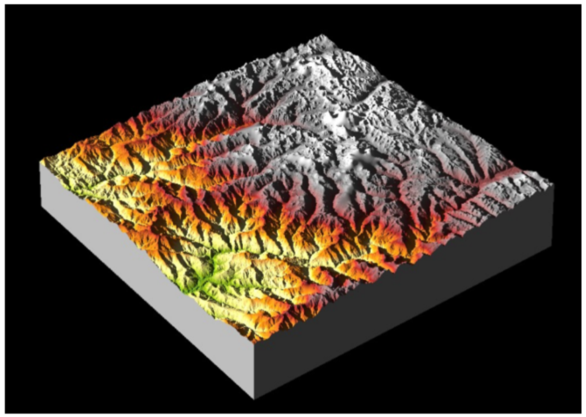
SPLAT! – Because the world isn't flat

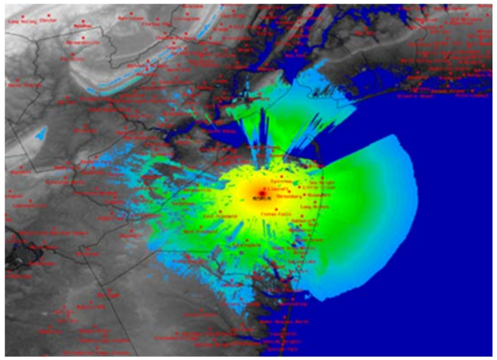
•SPLAT! is an RF Signal Propagation, Loss, And Terrain analysis tool for the spectrum between 20 MHz and 20 GHz*

•Computes path loss, field strength, etc, based elevation data, and the Longley-Rice irregular terrain model

•Pros: Free, command based, open-source

•Cons: Interfaces with cmd, much of input and output via textfiles





Courtesy: http://www.qsl.net/kd2bd/splat.html

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*Maglicane, «SPLAT!, An RF Signal Propagation, Loss, And Terrain analysis tool», 2010

Mixed-integer linear programming

- Special case of Linear programming in which some of the decision variables are constrained to take only integer values
- Attractive because*:

–Can be applied to resource allocation problems (which are not solvable using linear programming)

–Efficient in scheduling problems

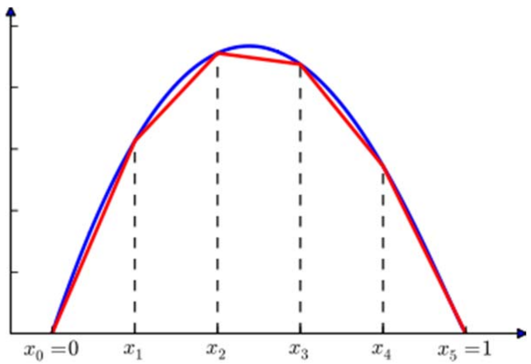
–Piecewise affine functions (approximations of continuous nonlinear functions) can be encoded using MILP

–Disjuction and non-convex sets can be handled by MILP

–Global optimal solutions can be guaranteed

–Possible to handle logic (if, else,…)

Courtesy: www.wikipedia.org

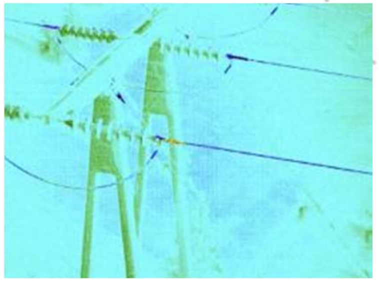


*Richards & How, «*Mixed integer programming for control*», 2005

Mission objective

- The mission objective: perform inspection along sequences of waypoints, called tasks, using UAVs.
- The task can represent road, railway, gas pipe or power line segments.
- During the servicing of a task, a large amount of sensor data is accumulated to be transmitted to the base station.
- Waypoints are not necessarily within communication range for direct transmission: Allow for one or more UAVs to function as relay links *or* data may be stored onboard the UAV for later transmission.
- Assume there is an upper limit for how long data can be stored onboard.

Courtesy: Håkon Bonafede



Courtesy: Trygve Ruud

Courtesy: www.kpsf.no

MILP cost function

The cost function consists of two terms: The first represents the total mission time, where as the second limits the acceleration of all vehicles:

$$J = J^{\text{finish}} + J^{\text{acc}}$$

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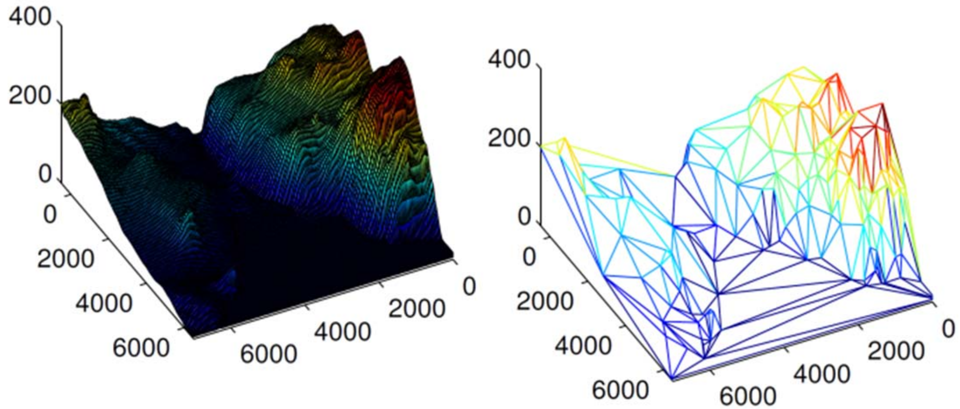
Constraints we consider

- Vehicle constraints
  - Anti-collision, anti-grounding, restricted airspace, speed, acceleration
- Network constraints
  - Communication radius, bandwidth, time delay, storage capacity
- Task constraint

Courtesy: Maritime Robotics



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*Shengxiang et al, «Real-time optimal trajectory planning with terrain avoidance using MILP», 2008

Task and network constraints

- A task consist of one or more waypoints to be visited.
- Each waypoint of a task is visited once.
- All vehicles have to return to the base station.
- Waypoints within a specific task has to be visited in a specific order and all by the same vehicle.

Task	Waypoint Coordinates
$\mathcal{W}_1$	{(4100,2150,200),(4000,2250,200),(3900,2350,200)}
$\mathcal{W}_2$	{(2800,1850,300),(2900,1950,300),(3000,2050,300)}
$\mathcal{W}_3$	{(3500,1000,250)}
$\mathcal{W}_4$	{(4000,1200,250),(4000,1300,250),(4000,1400,250)}
$\mathcal{W}_5$	{(3700,1850,250)}

Task and network constraints

•The vehicles must finish servicing one task before they can start another.

•There has to be a minimum temporal seperation at the final waypoint for safety reasons.

•During the servicing of a task, sensor data is accumulated.

•Sensor data can be transmitted directly to the basestation, *or* relayed by some other vehicle, *or* stored for later transmission.

Vehicle model

- We use a point mass model for each vehicle p, given by

$$\boldsymbol{p}_{p(i+1)} = I_3 \boldsymbol{p}_{pi} + \Delta t I_3 \boldsymbol{v}_{pi}$$

where $\boldsymbol{p}_{pi} := (x_{pi}, y_{pi}, z_{pi})^\top$ is the position vector, $\boldsymbol{v}_{pi} := (v_{1pi}, v_{2pi}, v_{3pi})^\top$ is the velocity vector and Δt is the time step.

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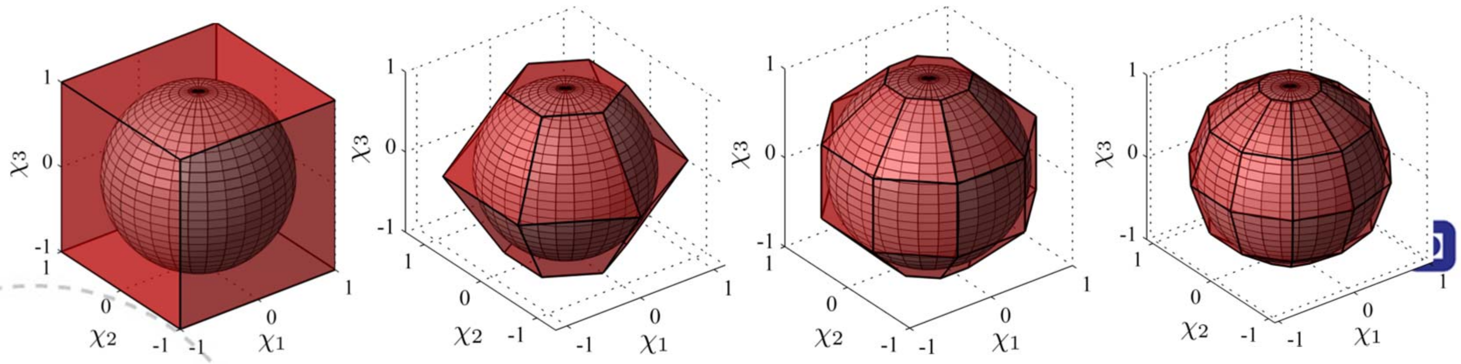
Communication constraints

•The vehicles and base station can communicate with eachother if they are within communication distance:

$$\boldsymbol{\chi}_{pqi}^{\top}\boldsymbol{\xi}_{kl} - R_{pqi} \leq 0$$

•The communication distance R_{pqi} is reduced between iterations if desired SNR is not achieved.



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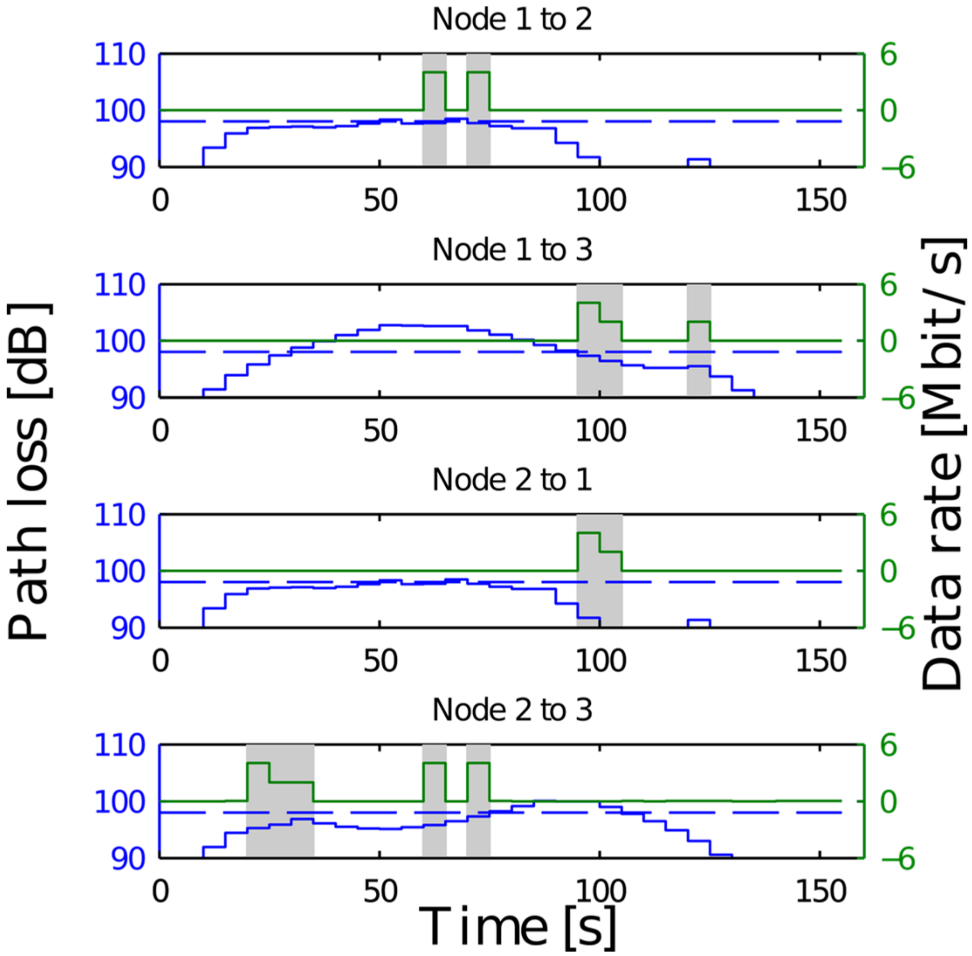
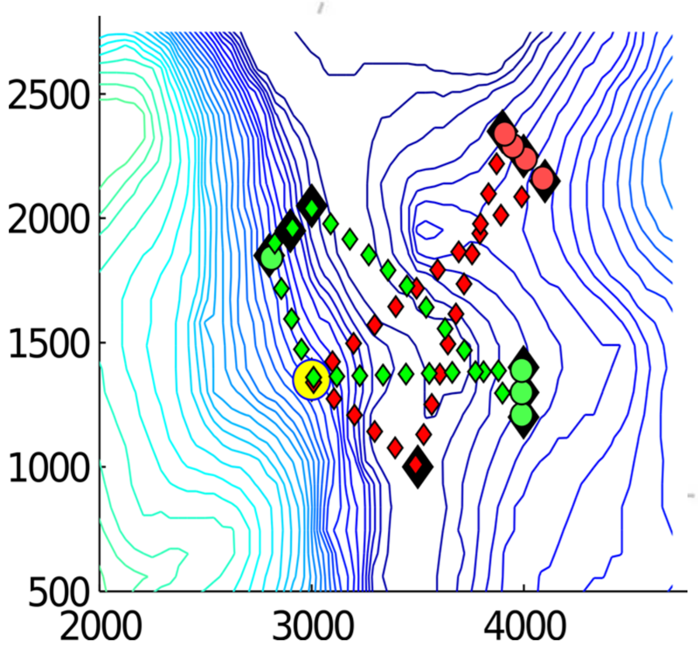
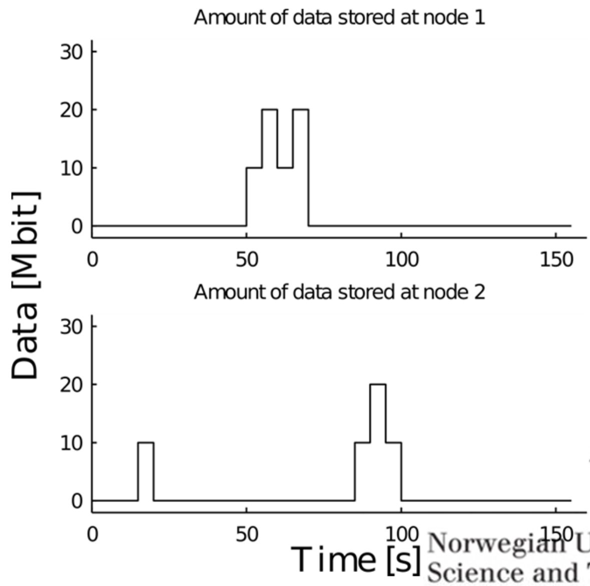
Simulations







Conclusion

•We have addressed the problem of path- and communication planning for multiple UAVs, which builds on the baseline approach for relaying agents in two key ways:

- Post-process resulting paths in a radio path loss simulator, and decrease allowable transmission distance if the loss is too large.
- Allow for ferrying of data, which introduces the complexity of tracking data as it is stored and passed through the network. Our algorithm is a novel framework where a network flow is being optimized on a dynamic network, which itself is optimized for task allocation and path planning.