Experimental Validation of RSS Driven UAV Mobility Behaviors in IEEE 802.11s Networks

07.12.2012

Niklas Goddemeier, Sebastian Rohde and Christian Wietfeld

Faculty of Electrical Engineering & Information Technology
Communication Networks Institute
Prof. Dr.-Ing. Christian Wietfeld
Content

- Motivation

- From Simulation to Experiment
  - Software in the Loop
  - Hardware in the Loop
  - Experimental validation

- Evaluation Results
  - Evaluation scenarios
  - Communication-aware mobility

- Conclusion
Motivation

- Research on varying and wide spread topics:
  - Reliable, fault-tolerant, high bandwidth communication in harsh or hazardous environments
  - Communication sensitive mobility
  - Multi robot coordination and corporation

→ Need for a versatile, flexible development methodology including:
  - Multiscale simulations
  - Modular and flexible simulation environments
  - Ability to include real soft- / hardware
  - Experimental validation
Goals for Development Process

- Algorithm and communication evaluation in realistic environment
- Reduce gap between development and experimental system
- Reduce development time
- Reduce failures during experiments

Development Process

- UAV system is evaluated in multiple steps at various stages
- Knowledge gained at each step is used as feedback to improve algorithms and strategies
## Development Methodology - Overview

<table>
<thead>
<tr>
<th>Mobility Simulation</th>
<th>Software in the Loop</th>
<th>Hardware in the Loop</th>
<th>Outdoor Experiment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simulation of:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- UAV kinematics</td>
<td>Ethernet Link</td>
<td>UAV Simulation</td>
<td></td>
</tr>
<tr>
<td>- Mobility behavior</td>
<td>UAV simulation +</td>
<td>Rotary step</td>
<td></td>
</tr>
<tr>
<td>- Communication</td>
<td>SCA impl.</td>
<td>attenuator</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>RF shield box</td>
<td></td>
</tr>
</tbody>
</table>

**Efficient to evaluate concepts & strategies**
- No real hardware
- Assumptions & uncertainty
- Minimalistic SCA / comm. implementations

**Full implementation of SCA**
- Comm. Protocols evaluation
- Assumptions & uncertainty e.g. comm. & channel model

**Impl. on target hardw.**
- Wireless communication
- Manual adjustment of attenuation
- Effort to set up for large simulations

**Complete system evaluation**
- Reproducibility due to dynamic env. Effects
- Complex setup (tech. & req.)

- Incremental substitution of simulated components
- Detailed evaluation of each component possible
- Increasing evaluation depth with every substitution

SCA: Service Control Air
Experimental Platforms & Setups

GPS Antenna

RC Antenna

Secondary telemetry link (868 MHz)

Autopilot
Embedded PC running SCA

Primary telemetry link (2.4 GHz)

Hardware in the Loop

Flight Dynamics Simulation

Experimental Flights

Stationary Mesh Unit

UAV
Communication-aware Mobility

- Movement composed of two components:
  - Macroscopic movement - Ensures mission goals are reached
  - Microscopic movement – responsible to maintain connectivity among agents

⇒ Main focus: Evaluation communication-aware movement

- **Micro mobility:**
  - Communication-Aware Potential Fields (CAPF) based on:
    - Communication links KPI between UAVs in swarm:
    - Assigned relay and articulation point UAVs ($\vec{F}_{ap}$)
    - Macro target ($\vec{F}_{mt}$) & collision avoidance ($\vec{F}_{ca}$)

  - Superposition of forces results determines direction of travel:
    $\vec{F}_{dir} = \vec{F}_{conn} + \vec{F}_{ap} + \vec{F}_{mt} + \vec{F}_{ca}$

\[ \vec{F}_{conn} = \sum_{k=1}^{d} \vec{F}_{conn_k} \]
\[ \vec{F}_{conn_k} = q \cdot |\Delta RSS| \cdot \vec{d}_{0k} \]

\[ q = \begin{cases} 
+1, & RSS_{loss} < RSS_{curr} < RSS_{min} \\
0, & RSS_{min} \leq RSS_{curr} \leq RSS_{max} \\
-1, & RSS_{curr} > RSS_{max} 
\end{cases} \]

RSS: Received Signal Strength
Validation of mobility behavior

- Phase I: UAV increases distance until desired RSS threshold is reached
- Phase II: Within the RF shadow of the build the UAV has to decrease its distance
- Phase III: UAV increases distance after shadowing area of build is passed

Desired RSS threshold of -63 dBm

Increase of distance until threshold is reached

Decrease of distance to maintain desired RSS value

-10 dB attenuation due to shadowing

Software in the Loop

Desired RSS threshold of -63 dBm

Distance between agents

Average RSS

RSS measurements

Target RSS reached

Reduction of tx power by 10 dB

Holding position

Mesh-AP

UAV

RSS max

RSS min

-100

-80

-60

-40

-20

0

1

2

3

4

5

Distance [m]

Time [min]
Comparison HiL and Experimental Validation

- Mobility algorithm enables UAV to maintain predefined parameter for communication system
- Micro steering shows equal behavior in all steps of the development process
CAPF in a cluttered environment (SiL)

<table>
<thead>
<tr>
<th>Connection</th>
<th>Log</th>
<th>Settings</th>
</tr>
</thead>
<tbody>
<tr>
<td>MCG</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ip port</td>
<td></td>
<td>127.0.0.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Base station

Articulation Point

Scout

<table>
<thead>
<tr>
<th>Color</th>
<th>Type</th>
<th>Name</th>
<th>UAV ID</th>
<th>Swarm ID</th>
<th>Payload</th>
<th>Role</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>EmbedSim</td>
<td>uav-sim-01</td>
<td>1</td>
<td>1</td>
<td>ROLE_Scout</td>
<td></td>
</tr>
<tr>
<td></td>
<td>EmbedSim</td>
<td>uav-sim-03</td>
<td>3</td>
<td>1</td>
<td>ROLE_NONE</td>
<td></td>
</tr>
</tbody>
</table>

CAPF in a cluttered environment (SiL)
CAPF in a cluttered environment (SiL)

- Complex shadowing attenuation
- CAPF maintain desired RSS threshold between AP and BS
- CAPF keep RSS between Scout and AP stable
- Response time depends on physical constraints of the UAV and weighting of forces
Conclusion

- Previous work evaluated using validation flights

- Reliably determination of communication link properties
  → capable to support future work in this area

- Experimental validation still requires a lot of effort but can be reduced with proposed methodology

- Lessons learned:
  - Low level validation of interfaces and protocols (e.g. alignment and bit representation issues)
  - Environmental influences have been underestimated in the past (e.g. wind)
Thank you for your attention

Selected Publications:

Contact Information

Head of Institute
Prof. Dr.-Ing. Christian Wietfeld

Point of Contact (POC):
Niklas Goddemeier
fon.: +49 231 755 4235
fax: +49 231 755 6136
e-mail: niklas.goddemeier@tu-dortmund.de
Internet: http://www.cni.tu-dortmund.de
Internet: http://www.avigle.de

Address:
TU Dortmund
Communication Networks Institute
Otto-Hahn-Str. 6
44227 Dortmund

Germany