Animal Monitoring with Unmanned Aerial Vehicle-Aided Wireless Sensor Networks

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Outline

1 Introduction
   - Motivation & problem statement

2 Problem analysis
   - Clustering
   - Network modeling
   - Value of information

3 Proposed path planning approach
   - Markov decision process
   - Path planning process for UAV

4 Simulation study
   - Simulation setup and metrics
   - Demo display
   - Performance results

5 Conclusion

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Motivation

Animal monitoring have various goals:

- Tracking their migration paths
- Predict if specific endangered species exist

Goal of this application:

- Providing reliable animal appearance information in large-scale areas
- Do not using mounting devices & not affecting animal activities
Problem statement

How to find these animals?
- Sensors can not directly send data to remote base station
- How the sink (UAV) knows which sensors have the relevant information

How to use those sensed information?
- Latency between animal appearance and information being gathered
- How to quantify this information
Clustering

Real movement trajectories of 4 zebras in 3 days †
Wildlife animals are more likely to having activities in a small area

Clustering

Real movement trajectories of 4 zebras in 3 days

Wildlife animals are more likely to having activities in a small area


Network model

<table>
<thead>
<tr>
<th>$s_0$</th>
<th>$s_1$</th>
<th>$s_2$</th>
<th>$s_3$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>UAV</td>
<td></td>
</tr>
<tr>
<td>$s_4$</td>
<td>$s_5$</td>
<td>$s_6$</td>
<td>$s_7$</td>
</tr>
<tr>
<td>Sensors</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$s_8$</td>
<td>$s_9$</td>
<td>$s_{10}$</td>
<td>$s_{11}$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$s_{12}$</td>
<td>$s_{13}$</td>
<td>$s_{14}$</td>
<td>$s_{15}$</td>
</tr>
</tbody>
</table>

- Cluster-heads are responsible for receiving data from other sensors and submitting data to the UAV.
- Single UAV communicates with cluster-heads.
Value of information

The value of information (VoI)†

- Sensed information has the highest value when event occurs
- Our goal is maximizing the VoI in the whole network

\[ F_{\text{Vol}}(t) = Ae^{-Bt} \]

A: the initial value of the information
B: the decay speed of the VoI

Markov decision process model

5-tuple \( \{ S, A, P, R, \gamma \} \):

- \( S \) is the set of states (grids) in the network
- \( A \) is the set of possible actions that UAV can do
- \( P \) is the state transition probabilities
- \( R \) is the instant reward when the UAV enters one grid
- \( \gamma \in [0, 1) \) is the discount parameter
Markov decision process model

- Solved this MDP model by Q-learning
- 9 possible actions of $S_4$: 8 neighbors and staying itself
- $Q(s, a) = R(s) + \gamma \max_{a'} Q(s', a')$
- Instant reward $R(s)$, future potential reward $Q(s', a')$

Possible actions of $S_4$: {Northwest, North, Northeast, West, Stay, East, Southwest, South, Southeast}
Path planning flow chart

- **Exploitation**: deterministic grid selection by $Q(s, a)$
- **Exploration**: random grid selection
- $\epsilon$: random selection probability

Start at $s_i$

- **Stochastic selection**
- **$\epsilon$-Greedy policy**
- **Deterministic selection by Q value**

Exploitation

- Move to the selected $s_{next}$
- Updating information
Simulation setup

- **Movement traces of zebras:**
  - ZebraNet project †
  - 5 zebras in June 2005 at a $10km \times 10km$ area near Nanyuki, Kenya
  - 5682 GPS records in total
  - GPS sampling time interval: 1 minute

- **Definition of sensing events:**
  - If zebra switches grid, record the event
  - If zebra always stays in one grid, record every $\Delta t$ time

Simulation setup

- Simulator:
  - Java-based discrete time simulator

- Performance metrics:
  - Value of information
  - Average message delay
  - Number of zebras encountered

- Approaches for comparison:
  - Greedy
  - Traveling salesman problem
  - Random
Simulation setup

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Network size</td>
<td>10 km x 10 km</td>
</tr>
<tr>
<td>Number of grids (states)</td>
<td>16</td>
</tr>
<tr>
<td>Grid size</td>
<td>2500 m x 2500 m</td>
</tr>
<tr>
<td>Unit experimental time (round)</td>
<td>10 s</td>
</tr>
<tr>
<td>UAV speed</td>
<td>100 m/round</td>
</tr>
<tr>
<td>Decay speed of VoI (parameter B)</td>
<td>0.05</td>
</tr>
<tr>
<td>Radius $r$ for direct observation</td>
<td>200 m</td>
</tr>
<tr>
<td>Initial reward $IR (\sigma, C_i, I_{dist}, I_{duration})$</td>
<td>10.0 (10.0, 1.0, 1.0, 1.0)</td>
</tr>
</tbody>
</table>
Demo display
Value of information

- MDP (Markov decision process)
- Greedy (Greedy total number of previous events)
- TSP (Traveling salesman problem)
- Random (Random selection from all grids)
Average message delays

- **TSP**: 0 deviation because fixed route
Number of zebras encountered

- MDP (Markov decision process)
- Greedy (Greedy total number of previous events)
- TSP (Traveling salesman problem)
- Random (Random selection from all grids)

Direct observation radius ($r$)
Performance stability

Results from 4 time experiments

Same parameters
Impact of exploration
Conclusion

- We focused on the animal monitoring in large area
- We proposed a MDP-based approach for UAV path planning
- The evaluation indicated significant improvement compared to Greedy, TSP and Random
- Future work:
  - Other species, other dataset
  - Multi-UAVs