Joint Deployment of Unmanned Aerial Vehicles and Wireless Sensor Networks

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Wireless Sensor Networks

- Sensors interface physical places and processes with the virtual world
- Empower us to monitor and control our environment.
- Wireless sensors offer much flexible sensing so that we can monitor remote, extensive, inaccessible, and dangerous areas.
Wireless Sensor Networks

- Wireless sensor networks consist of a large number of wireless sensor nodes.
- The nodes integrate one or more sensors, wireless transceivers, and processors, among others.
- This combination enable them to carry out high spatio-temporal sensing, in-network processing, and multi-hop communication.
Wireless Sensor Networks

- The requirement is that there has to be a wireless link connecting us with the sensor networks.
- The joint deployment of wireless sensor networks and unmanned aerial vehicles enables to monitor extensive, dangerous, inaccessible, or remote locations.
Joint Deployment

Courtesy of NASA, 2020
Joint Deployment

Courtesy of IMARC Group, 2020
Research Challenge

- Nodes operate with exhaustible batteries
  - Replacing or recharging batteries is not feasible.
  - The networks should have a long lifetime
- Low-bandwidth radio.
- UAV trajectory is uncertain.
  - Wind and other environmental factors affect flight route and time.
- High cross technology interference (CTI).
Research Areas

- Energy-efficient self-organisation (clustering) algorithms
- Energy-efficient communication protocols (routing and MAC protocols)
- Energy-efficient data collection/aggregation strategy
## Topology


$$
\mathbf{C} = \begin{bmatrix}
N1 & N2 & N3 & N4 & N5 & N6 & N7 & \ldots \\
N1 & 0 & 1 & 0 & 1 & 0 & 0 & 0 & \ldots \\
N2 & 1 & 0 & 1 & 0 & 1 & 0 & 0 & \ldots \\
N3 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & \ldots \\
N4 & 1 & 0 & 0 & 0 & 0 & 1 & 0 & \ldots \\
N5 & 0 & 1 & 0 & 0 & 0 & 0 & 1 & \ldots \\
N6 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & \ldots \\
N7 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & \ldots \\
N8 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & \ldots \\
\vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\
\end{bmatrix}
$$
Node Relevance

\[ H = \frac{C}{(n-1)} \]

\[ H^k = \frac{C^k}{(n-1)^k} \]

\[ \sum_{k=0}^{\infty} a^k = \frac{1}{1-a}, \quad a < 1 \]

\[ T \approx \sum_{k=1}^{\infty} (pH)^k = pH (I - pH)^{-1} \]
Packet Transmission Scheduling
Reliable Communication

Link Quality Metrics
Packet Loss
Estimation
void
scheduler ( char *link_history,
            struct schedule_performance *channel,
            short *mean,
            short *cmean)
{
    char ACK;
    unsigned short current_slot_id = 0, sending = 1;
    channel->link_performance[current_slot_id] =
    link_history[current_slot_id];
    unsigned short lost = 0, sleep = 0;

    while (sending)
    {
        if (current_slot_id >= SLOTS - 1)
        {
            break;
        }

        current_slot_id = current_slot_id + 1;
        if (lost < floor (*mean / 2))
        {
            channel->link_performance[current_slot_id] =
            link_history[current_slot_id];
            ACK = link_history[current_slot_id];
            if (!ACK)
            {
                lost = lost + 1;
            }
        }
        current_slot_id = current_slot_id + *cmean + 1;
        sleep = sleep + *cmean;
        lost = 0;
    }
    channel->total_slots_slept = sleep;
Evaluation

![Graph showing energy consumption across different channels (CH26, CH25, CH23, CH22, CH10). The chart is color-coded with bars representing 'Lost', 'Sleep', and 'Transmitted'.]
Data Aggregation
Application

- Toxic Gas Monitoring

Sensor Array

Diagram showing a sensor array setup with various components including:

- 16 CH MUX ADG706
- 16 CH MUX ADG706
- 16 CH MUX ADG706
- 16 CH MUX ADG706
- 8 CH MUX ADG708
- TIA LMP91000
- ADC ADS122C04
- Microcontroller ESP32

Connections to other components labeled ADG706 and 1-OF-16 DECODER.
Sensor Node
Zero-Offset
Zero-Offset
Data Aggregation/Link Quality
Indoor Localisation
Sensing
Sensing
Reference
Process Error
Process Error
Measurement Error
Estimation

\[ x_p(t) \quad x_m(t) \quad x_p(t + 1) = f(\tilde{x}(t)) \]

\[ \tilde{x}(t) = f(x_m(t), x_p(t)) \]
## Estimation Errors

<table>
<thead>
<tr>
<th>Type</th>
<th>Source</th>
<th>Time invariant?</th>
</tr>
</thead>
<tbody>
<tr>
<td>$e_r$</td>
<td>Driving setup error</td>
<td>No</td>
</tr>
<tr>
<td>$e_m$</td>
<td>Measurement setup error</td>
<td>No</td>
</tr>
<tr>
<td>$e_p(t)$</td>
<td>Prediction error</td>
<td>Yes</td>
</tr>
<tr>
<td>$e(t)$</td>
<td>Overall estimation error</td>
<td>Yes</td>
</tr>
</tbody>
</table>

**TABLE 1**

**Summary of the Estimation Errors**
Kalman Filter

\[ \hat{x}(t) = x_p(t) + K [x_m(t) - x_p(t)] \]

\[ K(t) = \frac{P(t)}{P(t) + R} \]
Particle Filter

\[
p(X_{0:t} \mid D_t) = \frac{p(z_t \mid x_t) p(x_t \mid x_{t-1})}{p(z_t \mid D_{t-1})} p(X_{0:t-1} \mid D_{t-1})
\]

\[
p(x_t \mid D_t) = \sum_{i=1}^{N} w_i^t \delta(x_t - x_t^i)
\]

\[
w_t^i = w_{t-1}^i p(z_t \mid x_t)
\]
Particle Filter

\[
p(X_{0:t}\mid D_t) = \frac{p(z_t\mid x_t)p(x_t\mid x_{t-1})}{p(z_t\mid D_{t-1})} p(X_{0:t-1}\mid D_{t-1})
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w_t^i = w_{t-1}^i p(z_t\mid x_t)
\]
Experiment
THANK YOU