A Reliability-Aware Medium Access Control for Unidirectional Time-Constrained WSNs

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Introduction

Wireless Sensor Networks:

- Networks of spatially distributed independent sensors to monitor physical or environmental conditions, e.g. temperature, moisture, sound, etc.
- Pass their information to a central location, e.g. a monitor that displays temperature, server, etc.
- Uses all kind of wireless communication technologies, e.g. RFID, WIFI, ZigBee, etc.
Uni- vs Bidirectional

- All Systems use either uni- or bidirectional transmission

<table>
<thead>
<tr>
<th>Unidirectional</th>
<th>Bidirectional</th>
</tr>
</thead>
<tbody>
<tr>
<td>sender <em>or</em> receiver</td>
<td>transceiver</td>
</tr>
<tr>
<td>no acknowledgement</td>
<td>acknowledgement</td>
</tr>
<tr>
<td>no synchronization</td>
<td>synchronization</td>
</tr>
<tr>
<td>cheap &amp; energy efficient</td>
<td>expensive</td>
</tr>
<tr>
<td></td>
<td>routing</td>
</tr>
<tr>
<td></td>
<td>retransmission</td>
</tr>
</tbody>
</table>

→ Unidirectional communication is error-prone
→ Hence most systems are bidirectional
Our Goal

• **Our Goal:** Develop a Medium Access Control to guarantee specified reliability requirements in unidirectional WSNs

• **Motivation:** Substantial cost saving, in particular, for networks with a large number of nodes

Intertechno Set  ~12€  KNX RF Switch  ~100€
Comparison with similar approaches

- Most existing approaches have major disadvantages:
  - Use hybrid systems, i.e. only partly unidirectional [1]
  - Increase reliability, but do not allow quantifying it [1]
  - Allow reliable communication, but are very pessimistic, i.e. sending more data than necessary → low energy-efficiency, high maximum delay [2][3]

- Our approach specifies:
  - Bounded delay, i.e. time from activation to reception
  - Reduced energy consumption
  - Modeling worst-case probability of packet loss
Design considerations

- Nodes send packets multiple times (sequence) with random inter-packet times (periods).
- Each sequence starts with a random transmission break (pause).
- Data length of a packet is minimal (6 byte packet size) to reduce transmission duration.

![Diagram showing node transmission times and periods](image)
Design considerations

• Given parameters:
  • Reliability $\rho$
  • Deadline $d_{max}$
  • Packet length $l_{max}$
  • Number of nodes $n$

• Missing parameters:
  • Inter-packet-times $[t_{min}, t_{max}]$
  • Number of packets per node $\kappa$
Probability of loosing single packets

- Packets can be lost due to interference from other nodes or external sources
- WC scenario: periods \([t_{\text{min}}, t_{\text{max}}]\) overlap completely
Probability of loosing single packets

• Collision interval

\[ \Delta_{coll} = 2(n - 1)l_{max} \]
Probability of loosing single packets

- Probability of loosing a single packet

\[ q = \frac{2(n - 1)l_{max}}{t_{max} - t_{min}} \]
Probability of loosing single packets

- Generalization: $m$

$$\Delta_{coll} = 2m(n - 1)l_{max} \quad q = \frac{2m(n - 1)l_{max}}{t_{max} - t_{min}}$$
Reliability

- Since \( n, l_{max}, t_{min}, t_{max} \) and \( m \) are system parameters, they are independent of nodes and packets

  → we can model packet transmission as binomial distribution

- Probability of receiving at least one out of \( \kappa \) consecutive packets (reliability)

\[
p = 1 - \left( \frac{2m(n - 1)l_{max}}{t_{max} - t_{min}} \right)^k
\]
Inter-packet-times: $t_{\text{max}}$

- We have to send $\kappa_i$ packets before $d_{\text{max}}$

$$t_{\text{max}} \leq \frac{d_{\text{max}} - l_{\text{max}}}{\kappa}$$
Inter-packet-times: $t_{\text{min}}$

- Rearranging the reliability formula:

$$t_{\text{min}} \leq t_{\text{max}} - \frac{2m(n - 1)l_{\text{max}}}{\sqrt{k(1 - p)}}$$

- The higher the reliability, the larger the difference between $t_{\text{max}} - t_{\text{min}}$

- The more packets we send, the smaller the difference between $t_{\text{max}} - t_{\text{min}}$

→ A reliability of 100% is not possible with this method
Results and simulations

- Theory has been validated by simulation using the framework OMNet++ and its extension MiXim.
  - **Proposed**: The presented Algorithm \(d_{max} = 0.5\text{s}, \kappa = 2, \rho = 0.95\)
  - **Simplistic**: 4 consecutive packets are transmitted followed by a pause of 500ms
  - **Periodic**: sends \(n\) packets with constant inter-packet-times followed by a transmission pause. [3]
  - **Optimized**: Same as periodic, except inter-packet-times are shorter (ILP optimization). [2]
Results and simulations

- proposed
- simplistic
- periodic
- optimized

lost packet sequences [%]

n
Results and simulations

![Graph showing energy consumption vs. n]

- simplistic
- proposed
- periodic
- optimized
Summary

- We presented a transmission scheme in which each node sends a sequence of $\kappa$ packets in randomly chosen time intervals $[t_{\text{min}}, t_{\text{max}}]$ within a deadline $d_{\text{max}}$

- This allows us to:
  - Design unidirectional WSNs with a specified reliability $\rho$ and deadline $d_{\text{max}}$
  - Find lowest packet number $\kappa$ that has to be sent
  - High energy efficiency
  - Paper covers external interferences and clock drift
Thank you for your attention

Thank you. Questions?
References

