Reliable and time-constrained communications in Wireless Sensor Networks

Fei YANG
SWING/ INRIA
CITI Laboratory, INSA-Lyon
January 25, 2011

Supervisors: Isabelle Augé-Blum
Tanguy Risset
Wireless sensor network

Sensor node

- Battery-powered
- Limited memory and process capability
- Low transmission power

Crossbow MICAz
Wireless sensor network

Network characteristics

- Large-scale
- Self-organization
- Application related

Volcano monitoring architecture of Harvard sensor networks lab
--- http://fiji.eecs.harvard.edu/Volcano
Wireless sensor network

Applications
- Target detection and tracking
- Monitoring
- Assisted-living

Common constraints
- longer lifetime
- real-time
- reliability
- robustness

Difficulties
- new/died nodes
- unreliable links
- duty-cycle
One difficulty: unreliable links

[Woo et al., 2003]
Another difficulty: duty-cycle

- Parameters of MicaZ node
  [MicaZ, 2005]

<table>
<thead>
<tr>
<th></th>
<th>Current</th>
</tr>
</thead>
<tbody>
<tr>
<td>Processor active mode</td>
<td>8mA</td>
</tr>
<tr>
<td>Processor sleep mode</td>
<td>&lt;15μA</td>
</tr>
<tr>
<td>Radio transmit at 0 dBm</td>
<td>17.4mA</td>
</tr>
<tr>
<td>Radio receive</td>
<td>19.7mA</td>
</tr>
<tr>
<td>Radio listen</td>
<td>19.7mA</td>
</tr>
<tr>
<td>Radio sleep</td>
<td>1μA</td>
</tr>
</tbody>
</table>

- Definition of duty-cycle

\[
\text{Duty-cycle} = \frac{T_{\text{listen}}}{T_{\text{listen}} + T_{\text{sleep}}}
\]

- Synchronous
- Asynchronous

Sender: [Diagram]
Receiver: [Diagram]
Challenge

- **Real-time**
- **Reliability**
- **Robustness**
- **Duty-cycle**
- **Unreliable links**
- **New/died nodes**

Node that detects the event
Node that reports the event
Normal sensor nodes
Outline

- Context and problematics
- Reliability of routing protocols under unreliable links
- Real-time and reliable forwarding protocol
- Robustness problems
- Conclusion and perspectives
Related work

- Geography based (GPSR [Karp and Kung, 2000], GFG [Bose et al., 2001])
- Simple and scalable
- Inaccurate location algorithms
Related work

- Virtual coordinate based
  - Relative position (LCR [Cao and Abdelzaher, 2004], BVR [Fonseca et al., 2005])

Four anchor nodes: A, B, C, D

A(0,1,2,1)  B(1,0,1,2)  E(1,1,1,1)  D(1,2,1,0)  C(2,1,0,1)
Related work

- Virtual coordinate based
- Estimated position (NoGeo [Rao et al., 2003])

Iteration process:

\[
\begin{align*}
    x_D &= \frac{x_A + x_B + x_C}{3} \\
    y_D &= \frac{y_A + y_B + y_C}{3}
\end{align*}
\]

Do not pay enough attention to the impacts of unreliable links
Impacts of unreliable links
--- simulation results with WSNet

![Graph showing the delivery ratio over the number of iterations for NoGeo and Real position. The graph indicates a higher delivery ratio for Real position compared to NoGeo.]
Three proposed solutions

- “Average-new”
- “Average-new-threshold”
- “Average-new-RSSI”

\[
\begin{align*}
    x_E &= \frac{x_A \times RSSI_{AE} + x_B \times RSSI_{BE}}{RSSI_{AE} + RSSI_{BE}} \\
    y_E &= \frac{y_A \times RSSI_{AE} + y_B \times RSSI_{BE}}{RSSI_{AE} + RSSI_{BE}}
\end{align*}
\]

Node E’s neighbor information:

```
<table>
<thead>
<tr>
<th></th>
<th>A</th>
<th>B</th>
<th>B</th>
<th>D</th>
<th>2/4</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st iteration</td>
<td>B</td>
<td>B</td>
<td>B</td>
<td>B</td>
<td>4/4</td>
</tr>
<tr>
<td>2nd iteration</td>
<td>C</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3rd iteration</td>
<td>D</td>
<td>D</td>
<td>D</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
```

Comparison between different protocols
Conclusion about routing under unreliable links

- Show the impacts of unreliable links on virtual coordinate based routing protocol
- Propose three schemes to construct virtual coordinate under unreliable links
- Better performances in terms of average delivery ratio
- Efficient for virtual coordinate based routing protocols to take the link quality into account
Outline

- Context and problems
- Reliability of routing protocols under unreliable links
- Real-time and reliable forwarding protocol
- Robustness problems
- Conclusion and perspectives
## Related work

<table>
<thead>
<tr>
<th></th>
<th>Real-time</th>
<th>Duty-cycle</th>
<th>Unreliable links</th>
</tr>
</thead>
<tbody>
<tr>
<td>I-EDF [Caccamo et al., 2002]</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PEDAMACS [Ergen and Varaiya, 2006]</td>
<td>✓</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>SPEED [He et al., 2003]</td>
<td>✓</td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>RPAR [Chipara et al., 2006]</td>
<td>✓</td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>THVR [Li et al., 2009]</td>
<td>✓</td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>DSF [Gu and He, 2007]</td>
<td></td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>SGF [Huang et al., 2009]</td>
<td></td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>? -&gt; WSEDR</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
</tbody>
</table>
Example that inspires us

\[
P_{AB} : \text{ Round-trip success ratio between A and B}
\]

\[
EDR_A : \text{ Expected delivery ratio of node A}
\]

Case 1:

\[
EDR_A^1 = P_{AB} \times P_{BD} + (1 - P_{AB}) \times P_{AC} \times P_{CD}
\]

\[
= 0.6 \times 0.7 + 0.4 \times 0.8 \times 0.4 = 0.548
\]

Case 2:

\[
EDR_A^2 = P_{AC} \times P_{CD} + (1 - P_{AC}) \times P_{AB} \times P_{BD}
\]

\[
= 0.8 \times 0.4 + 0.2 \times 0.6 \times 0.7 = 0.404
\]
Wakeup scheduling algorithm (WSEDR) --- basic idea

Nodes are synchronized

Maximum transmission delay = T

Sink
1 hop
2 hop
3 hop
4 hop
5 hop
Wakeup scheduling algorithm (WSEDR) --- a five nodes scenario

**EDR**: Expected Delivery Ratio  
**HC**: Hop Count  
**WS**: Wakeup Slot

- EDR = 0.48, HC = 2, WS = 70
- EDR = 0.4, HC = 2, WS = 72
- EDR = 0.67, HC = 2, WS = 66
- EDR = 0.57, HC = 2, WS = 69
- EDR = 0.8, HC = 1, WS = 84
- EDR = 0.7, HC = 1, WS = 86
- EDR = 1, HC = 0
Wakeup scheduling algorithm (WSEDR) --- assign the hop count

Threshold is set to 0.5 in this example
Wakeup scheduling algorithm (WSEDR) --- calculate the EDR

The EDR of node A:

\[0.8 \times 0.9 + (1 - 0.8) \times 0.7 \times 0.8\]

\[= 0.832\]
Wakeup scheduling algorithm (WSEDR) --- calculate the wakeup slot

\[ WS_i = (T - SR \times HC_i) + SR \times (1 - EDR_i) \]

\[ T = 100 \quad SR = 20 \quad HC = 3 \quad EDR = 0.832 \]

Mathematically proved optimal delivery ratio

Efficiency of WSEDR
--- in terms of average delivery ratio

WSEDR has an increment of about 50%.
Efficiency of WSEDR
--- in terms of the hop count distribution of the received packets

- WSEDR transmits 4 times more DATA packets than Random when the hop count is greater than 5.
Conclusion about WSEDR

- WSEDR
  - unreliable links and low duty-cycle (energy-efficient)
  - real-time (bounded delay)
  - mathematically proved optimal delivery ratio
  - better performances shown by simulation results

- Problem
  - difficult to update EDR when the network topology changes
Outline

- Context and problems
- Reliability of routing protocols under unreliable links
- Real-time and reliable forwarding protocol
- Robustness problems
- Conclusion and perspectives
## Related work

<table>
<thead>
<tr>
<th></th>
<th>Low duty-cycle</th>
<th>Unreliable links</th>
<th>Update</th>
</tr>
</thead>
<tbody>
<tr>
<td>SOFA [Lee et al., 2006]</td>
<td>✓</td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>SGF [Huang et al., 2009]</td>
<td></td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>WSEDR/RTCF</td>
<td>✓</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>?-&gt;RF</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
</tbody>
</table>
Asynchronous forwarding protocols
--- Basic idea

- RTCF (Real-Time Constrained Forwarding):
  backoff sleep time = f(EDR)

- RF (Robust Forwarding):
  backoff sleep time = f(COST)
Comparison between different protocols
Comparison between different protocols

![Graph showing average transmitted packets and average delay vs radius](image)

- **RF**
- **SOFA**
- **RTCF**

Legend:
- RF (Red Circles)
- SOFA (Blue Triangles)
- RTCF (Green Squares)
Conclusion about asynchronous forwarding

- **RTCF**
  - Mathematically proved optimal scheduling
  - Better performances shown by simulations
  - EDR is difficult to update

- **RF**
  - COST is easy to update
  - Proved loopless property
  - Better robustness performances shown by simulations
Outline

- Context and problems
- Reliability of routing protocols under unreliable links
- Real-time and reliable forwarding protocol
- Robustness problems
- Conclusion and perspectives
Conclusion and perspectives

--- conclusion

- Analyze the impacts of the difficulties on routing protocols
  - Duty-cycle (not presented here)
  - Unreliable links
    - Three new schemes to construct virtual coordinate
    - Improved performances shown by simulations

- Real-time and reliable forwarding protocols
  - Duty-cycle, unreliable links and virtual coordinate
  - Bounded delay
  - Mathematically proved maximized delivery ratio
  - Better performances than existing solutions by simulations
  - Extend to the robust version which can adapt to topology changes (node appearance and disappearance)
Conclusion and perspectives

--- perspectives

- Experiment our proposed protocols on a real platform
- Real-time and reliability properties of our distributed implementations have to be validated with formal methods
- To design a real-time aggregation algorithm which can aggregate event report packets into one alarm packet within a given deadline
- To broadcast a control message to the whole network with real time constraint
Publications

International journal
- Fei Yang and Isabelle Augé-Blum, Delivery ratio-maximized wakeup scheduling for ultra-low duty-cycled WSNs under real-time constraints, Computer Networks, 2011.

Book chapter

International conference

Under submission
- Fei Yang and Isabelle Augé-Blum, Robust forwarding in low duty-cycle wireless sensor networks.

Thank you for your attention!