Tiny Web Services: Design and Implementation of Interoperable and Evolvable Sensor Networks
(Priyantha, Kansal, Goraczko, Zhao, 2008)

Dominique Im Obersteg
Distributed Systems Seminar 2011, ETH Zurich
Evolutionary sensornets
Evolutionary sensornets

- Single confined physical space (office, home, …)
- Heterogeneous sensors
- No direct access to sensor capabilities

Image: http://aycan.ca/house/plans/house-plan.jpg

Home security system
Medical alert system

- Motion sensor
- Floor & window sensor
- Temperature sensor
Evolutionary sensornets

- Augment & evolve existing sensing infrastructure using soft- and hardware
- New sensors may be added after deployment

Energy management
- Home security system
- Medical alert system

Image: http://aycan.ca/house/plans/house-plan.jpg
Key challenges

- Limited energy
- Limited hardware capabilities
- Sensors should have common API
- Additional data size & processing cost for structured access
Research goal

- Quantification of resource cost for providing structured and programmatic access to sensor nodes
- Minimize resource cost
- Trade-off between interface generality and resource efficiency
- Find optimal solution
Web services
Advantages of web services

- Interoperability
- Improved programmability
- Ease of integration through Internet
- Reduces need for protocol translation
Web service overheads

**Webservice Application Layer**
- Larger message size
- Higher processing complexity

**TCP/IP**
- Larger message size
- Higher latency

<table>
<thead>
<tr>
<th>Layer</th>
<th>Data Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Application</td>
<td>(Data)</td>
</tr>
<tr>
<td>Presentation</td>
<td>(Data)</td>
</tr>
<tr>
<td>Session</td>
<td>(Data)</td>
</tr>
<tr>
<td>Transport</td>
<td>(Segments)</td>
</tr>
<tr>
<td>Network</td>
<td>(Packets)</td>
</tr>
<tr>
<td>Data Link</td>
<td>(Frames)</td>
</tr>
<tr>
<td>Physical</td>
<td>(Data)</td>
</tr>
</tbody>
</table>
Web service application design

- Supporting duty cycled nodes

- What about the other direction?
Web service application design

- Web service method encapsulation
  - Specified by Web Service Description Language (WSDL)

- XML parsing on sensor nodes
  - Only when URL encapsulation insufficient

- XML Compression and optimization
  - LZW, XML-specific compression, method name encoding (single byte)
Web service application design

- Brief summary
  - Overheads due increased message size and processing complexity
  - Duty cycled nodes to save resources
  - WSDL
  - If XML is needed, use compression/optimization
Network and transport layer design

- Use persistent TCP connections
  - Only overhead is heartbeat message
  - Works only for HTTP 1.1

- Disable delayed TCP acknowledgments
  - Delayed TCP ACKs reduce number of messages but introduce latency overhead

- Use link layer retransmissions
  - Don’t wait for TCP timeouts
Network and transport layer design

- Use low-power mode between TCP messages
  - Fixed minimum delay due to link capacities, hop count and packet size
  - Calculate or measure

- Use 6lowpan to connect sensor nodes to IPv6 network
  - Provides way to transmit IPv6 packet over 802.15.4

- Use link layer fragmentation
  - Split data in several TCP segments, acquire channel and send packet burst to reduce overhead
Network & transport layer design

- Brief summary
  - Use persistent TCP connections (if possible)
  - Disable delayed TCP ACKs
  - Don’t wait for TCP timeouts – use link layer retransmissions
  - Try to save energy between TCP messages
  - Use link layer fragmentation
Experiment
Experiment

<table>
<thead>
<tr>
<th>Time (ms)</th>
<th>Event</th>
<th>TCP Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.00</td>
<td>Server Tx start</td>
<td>TCP data (74 byte request)</td>
</tr>
<tr>
<td></td>
<td>Server Tx done</td>
<td></td>
</tr>
<tr>
<td>6.19</td>
<td>Sensor Rx done</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Packet processed</td>
<td></td>
</tr>
<tr>
<td>9.68</td>
<td>Sensor Tx start</td>
<td>TCP ACK</td>
</tr>
<tr>
<td>10.67</td>
<td>Sensor Tx done</td>
<td></td>
</tr>
<tr>
<td>10.68</td>
<td>Sensor Tx start</td>
<td>TCP data (27 byte request)</td>
</tr>
<tr>
<td></td>
<td>Sensor Tx done</td>
<td></td>
</tr>
<tr>
<td>29.29</td>
<td>Server Tx start</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Server Tx done</td>
<td></td>
</tr>
<tr>
<td>33.35</td>
<td>Sensor Rx done</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Packet processed</td>
<td></td>
</tr>
<tr>
<td>35.53</td>
<td>Sensor Tx start</td>
<td>TCP data (37 byte reply)</td>
</tr>
<tr>
<td>36.35</td>
<td>Sensor Tx done</td>
<td></td>
</tr>
<tr>
<td>36.36</td>
<td>Sensor Tx start</td>
<td></td>
</tr>
<tr>
<td>37.78</td>
<td>Sensor Tx done</td>
<td></td>
</tr>
</tbody>
</table>
Experiment

### Experiment Diagram

- **IEEE 802.15.4 Interface**
  - PPP over RS232
- **Measurement Server**
- **Timing Node**
  - Timing 1
  - Timing 2
  - Timing 3

### Time (ms) | Event                        | TCP Action                  |
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>0.00</td>
<td>Server Tx start</td>
<td>TCP data (74 byte request)</td>
</tr>
<tr>
<td>6.19</td>
<td>Server Tx done</td>
<td>TCP ACK</td>
</tr>
<tr>
<td>9.68</td>
<td>Sensor Rx done</td>
<td>TCP data (27 byte request)</td>
</tr>
<tr>
<td>10.67</td>
<td>Packet processed</td>
<td>TCP ACK</td>
</tr>
<tr>
<td>10.68</td>
<td>Sensor Tx start</td>
<td>TCP ACK</td>
</tr>
<tr>
<td>11.71</td>
<td>Sensor Tx done</td>
<td>TCP ACK</td>
</tr>
<tr>
<td>29.29</td>
<td>Server Tx start</td>
<td>TCP data (27 byte request)</td>
</tr>
<tr>
<td>33.35</td>
<td>Server Tx done</td>
<td>TCP ACK</td>
</tr>
<tr>
<td>35.53</td>
<td>Sensor Rx done</td>
<td>TCP ACK</td>
</tr>
<tr>
<td>36.35</td>
<td>Packet processed</td>
<td>TCP ACK</td>
</tr>
<tr>
<td>36.36</td>
<td>Sensor Tx start</td>
<td>TCP data (37 byte reply)</td>
</tr>
<tr>
<td>37.78</td>
<td>Sensor Tx done</td>
<td>TCP data (37 byte reply)</td>
</tr>
</tbody>
</table>
Experiment

<table>
<thead>
<tr>
<th>Time (ms)</th>
<th>Event</th>
<th>TCP Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.00</td>
<td>Server Tx start</td>
<td>TCP data</td>
</tr>
<tr>
<td>6.19</td>
<td>Server Tx done</td>
<td>(74 byte request)</td>
</tr>
<tr>
<td>9.68</td>
<td>Sensor Rx done</td>
<td></td>
</tr>
<tr>
<td>10.67</td>
<td>Packet processed</td>
<td></td>
</tr>
<tr>
<td>10.68</td>
<td>Sensor Tx start</td>
<td>TCP ACK</td>
</tr>
<tr>
<td>11.71</td>
<td>Sensor Tx done</td>
<td></td>
</tr>
<tr>
<td>29.29</td>
<td>Server Tx start</td>
<td>TCP data</td>
</tr>
<tr>
<td>33.35</td>
<td>Server Tx done</td>
<td>(27 byte request)</td>
</tr>
<tr>
<td>35.53</td>
<td>Sensor Rx done</td>
<td></td>
</tr>
<tr>
<td>36.35</td>
<td>Packet processed</td>
<td></td>
</tr>
<tr>
<td>36.36</td>
<td>Sensor Tx start</td>
<td>TCP data</td>
</tr>
<tr>
<td>37.78</td>
<td>Sensor Tx done</td>
<td>(37 byte reply)</td>
</tr>
</tbody>
</table>
Response time

- Increased response time (~20 ms), still acceptable
- Significant increase when payload is split in multiple packets
Energy consumption

- Additional cost relatively small when message fits in a single packet
- Frequent message exchanges significantly reduce lifetime
- Lifetime computation based on timing and hardware data
Prototype
Prototype system

'Resource-constrained platform' with 802.15.4 radio

Implemented on PC

Specifies supported method calls

HTTP Server

Sensors (Web Service hosts)

HTTP Client

Sensor Registrar

Controller

HTTP Server/Proxy

Device Info.

Eventing Info.

Specifies how methods are encapsulated & transported

Home Energy Management

Client Applications
Home energy management application

- 12 day period
- Volunteer family
- Motion sensors in living area, study room and each bedroom
- Use data from home’s security system
- Smart-sockets on most-used entertainment electronics and lamps

Home energy management application

- Energy Saver: control heating by motion data
Conclusion

- Web service based evolutionary sensornets are flexible and extensible
- Ease of access leads to many new possibilities
- Proof of concept successful
- More detailed experiments need to be performed to prove efficiency and scalability
Personal opinion & discussion

- Web service application design evaluation
- Low power mode between TCP transmissions
- Battery lifetime
- Multi-hop networks
- Security
Questions?