WISEBED: an Open Large-Scale Wireless Sensor Network Testbed

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Overview

• Motivation for Federated Sensor Network Testbeds and WISEBED Goals
• Previous Related Work
• Our contribution
• Overall Architecture and Considerations
• Software Aspects of WISEBED
• Infrastructure of interconnected testbeds
• Wiselib
• Use-case Scenarios
• Conclusions
Goals of Wisebed

• The Goal of WISEBED is to establish a large scale pan-European network of WSNs
• Develop services for accessing managing and federating large-scale structures, rather than just some large network
• The resources deployed will be available over the Internet
• This will enable researchers to run large scale experiments and industries for showcases and testing of their applications
• Collect and provide traces for common sensor network scenarios
• Provide a library of algorithms (wiselib) that it can be used in every hardware platform
Previous Related Work

- The Trio testbed
  - One of the largest wireless sensor testbeds, indoor and outdoor, built yet (557 nodes)
  - It was not open to the public research community, since it was targeted to a specific application
- MoteLab testbed
  - An indoor sensor network testbed on the campus of Harvard University and is open to the public
  - It currently features 190 Tmote Sky sensor nodes.
- TWIST testbed
  - Resides indoor in a building in the campus of the Technical University of Berlin, spanning across several floors
  - ~200, with heterogeneity supported to some extent
- TutorNet testbed
  - 3-tier network topology with testbed servers, gateway stations, and sensor nodes (~100)
  - Authorized-only users connect to the testbed servers and use command-line tools to control the testbed nodes
Our Contribution

- We plan to develop and deploy several connected testbeds, each with several hundred nodes.
- We plan to connect these testbeds into a much larger heterogeneous network (with a few thousand nodes), creating the potentially largest sensor network testbed in the world.
- This federation of testbeds is based on the concept of testbed virtualization and virtual links between them.
- The system will provide a variety of interfaces for end-users and applications.
- We aim at providing a unified algorithmic and software environment, thus overcoming the impediments of customization and allowing for convenient usage of the testbed.
The WISEBED Experimental Facility (WEF) currently consists of a number of independent sensor networks located at 9 locations throughout Europe.

- University of Lübeck
- FU Berlin
- TU Braunschweig
- CTI
- University of Berne
- University of Geneva
- UPC Barcelona
- TU Delft
- University of Lancaster
### Hardware Aspects of WISEBED - Current Deployment

<table>
<thead>
<tr>
<th>Partner</th>
<th>Nodes</th>
<th>Sensors</th>
<th>Wireless Interface</th>
<th>Backbone Type</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>UZL</td>
<td>iSense</td>
<td>Temperature, Light, PIR, Accelerometer</td>
<td>IEEE 802.15.4 (2.4GHz)</td>
<td>Wireless (WiFi)</td>
<td>50</td>
</tr>
<tr>
<td></td>
<td>Pacemate</td>
<td>None</td>
<td>Xemics RF (868 MHz)</td>
<td></td>
<td>50</td>
</tr>
<tr>
<td></td>
<td>TelosB</td>
<td>Temperature, Humidity, Light</td>
<td>IEEE 802.15.4 CC2420 (2.4GHz)</td>
<td>Wired (Ethernet)</td>
<td>50</td>
</tr>
<tr>
<td>FUB</td>
<td>MSB-A2</td>
<td>Temperature, Humidity</td>
<td>CC1100 (864-970MHz)</td>
<td>Wired (Ethernet)</td>
<td>45 + 20</td>
</tr>
<tr>
<td>TUBS</td>
<td>iSense</td>
<td>Pressure</td>
<td>None</td>
<td>Wired (Ethernet)</td>
<td>34</td>
</tr>
<tr>
<td>RACTI</td>
<td>TelosB</td>
<td>Temperature, Humidity, Light</td>
<td>IEEE 802.15.4 CC2420 (2.4GHz)</td>
<td>Wired (Ethernet)</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>Mica2</td>
<td>Temperature, Light, Accelerometer, Acoustic and Magnetic fields</td>
<td>IEEE 802.15.4 (2.4GHz)</td>
<td></td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>iSense</td>
<td>Temperature, Humidity, PIR</td>
<td>IEEE 802.15.4 (2.4GHz)</td>
<td></td>
<td>60</td>
</tr>
<tr>
<td></td>
<td>SunSPOT</td>
<td>Light</td>
<td>IEEE 802.15.4 (2.4GHz)</td>
<td>Wired (Ethernet)</td>
<td>60</td>
</tr>
<tr>
<td>UPC</td>
<td>SunSPOT</td>
<td>Temperature, Light, Accelerometer</td>
<td>IEEE 802.15.4 (2.4GHz)</td>
<td>Wired (Ethernet)</td>
<td>12</td>
</tr>
<tr>
<td>UBERN</td>
<td>TelosB</td>
<td>Temperature, Humidity, Light</td>
<td>IEEE 802.15.4 CC2420 (2.4GHz)</td>
<td>Wired (Ethernet)</td>
<td>20</td>
</tr>
<tr>
<td>UNIGE</td>
<td>iSense</td>
<td>Temperature, Light, PIR, AMR, Accelerometer</td>
<td>IEEE 802.15.4 CM1200 (480MHz)</td>
<td>Not Available</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>MicaZ</td>
<td>Temperature, Light, Accelerometer, Acoustic and Magnetic fields</td>
<td>IEEE 802.15.4 (2.4GHz)</td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>TUD</td>
<td>TNode</td>
<td>Temperature, Humidity</td>
<td>CC1000 (868 MHz)</td>
<td>Wired (Ethernet)</td>
<td>24</td>
</tr>
<tr>
<td>ULANC</td>
<td>Tmote Sky</td>
<td>Temperature, Humidity, Light</td>
<td>IEEE 802.15.4 CC2420 (2.4GHz)</td>
<td>Wireless (WiFi)</td>
<td>30</td>
</tr>
</tbody>
</table>

- More than 500 nodes deployed, variety of HW platforms & sensors
- Other testbeds have wired or wireless backbone
- Outdoor deployments
<table>
<thead>
<tr>
<th>Partner</th>
<th>Nodes</th>
<th>Sensors</th>
<th>Wireless Interface</th>
<th>Backbone Type</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>UZL</td>
<td>iSense + Roomba Robot 530</td>
<td>Touch, Cliff, Dirt</td>
<td>IEEE 802.15.4 (2.4GHz)</td>
<td>Wireless (IEEE 802.15.4 at 2.4GHz)</td>
<td>10</td>
</tr>
<tr>
<td>TUBS</td>
<td>iSense + Roomba Robot</td>
<td>Touch, Cliff, Dirt</td>
<td>IEEE 802.15.4 (2.4GHz)</td>
<td>Wireless (IEEE 802.15.4 at 2.4GHz)</td>
<td>10</td>
</tr>
<tr>
<td>RACTI</td>
<td>Humans wearing iSense</td>
<td>Temperature, Light</td>
<td>IEEE 802.15.4 (2.4GHz)</td>
<td>Wireless (IEEE 802.15.4 at 2.4GHz)</td>
<td>10</td>
</tr>
<tr>
<td>UPC</td>
<td>SunSPOT + Moway</td>
<td>Temperature, Light, Accelerometer, Infrared</td>
<td>IEEE 802.15.4 (2.4GHz)</td>
<td>Wireless (IEEE 802.15.4 at 2.4GHz)</td>
<td>6</td>
</tr>
</tbody>
</table>
Technische Universität zu Braunschweig (TUBS)

- Stationary sensor node deployment
  - 34 iSense
  - Connected to the Portal via Ethernet
  - Pressure sensor

- Mobile sensor node deployment
  - 10 iSense and Roomba robots
  - IEEE 802.15.4 as backbone
  - Touch, cliff, and dirt
Stationary sensor node deployment
- 20 TelosB and Mica2 each
- 60 iSense and SunSPOT each
- Connected to the Portal via Ethernet
- Temperature, humidity, light, accelerometer, magnetic field, PIR, acoustic

Mobile sensor node deployment
- 10 iSense nodes wore as arm-band by employees
- IEEE 802.15.4 as backbone
- Temperature, light
The architecture of the WISEBED system is based on a hierarchy of layers where each layer is comprised of one or more peers.

- Peers are services which are activated by the system as a response to various events, actions and communicate with other peers.
- The bottom layer contains the wireless sensor nodes that are running iSense, Contiki, TInyoS devices.
- The individual testbeds are controlled by the Portal Servers that provide access and expose interfaces to manage and operate them.
- The Portal Servers of each testbed partner site are interconnected via an overlay network. Peers connecting to the overlay network may access one or multiple testbeds in a distributed manner.
WISEBED: Overall Architecture

Overlay Software running on the Portal Server

Testbed Portal Servers at each WISEBED Partner Site

Each WISEBED Partner maintains its own testbed with different hardware equipment and setup

Overlay Network

Users connect to a single testbed directly using Web Services defined by the OFA standard

Users connect to the federated testbed using the Web Services defined by the OFA standard via the Overlay Network

WISEBED: Overall Architecture

- The overlay nodes and portal servers expose the same interfaces.
- The users connected to the overlay network can access unifying distributed testbeds the same way individual testbeds accessed via the portal servers.
- The peers of our system follow a modular architecture of essentially two layers, the inner layer that includes a minimum set core functionalities and an outer layer that hosts a variety of services.
WISEBED: Overall Architecture

- Portal Servers inner layer includes:
  - Services responsible for accessing the sensor devices via gateways.
  - Connections to local data stores (XML files, RDBMS systems) for storing debug traces, access lists, network topologies etc.

- Portal Servers outer layer includes:
  - A set of services used by users to control the testbed e.g. (run experiments, collect data, generate events etc.), and are accessed via the public IP interfaces of the Portal Server.
• Overlay Node inner layer includes
  - Client software of services of the Portal Servers. User commands are directed to the corresponding service of the Portal Servers

• Overlay Node outer layer includes
  - Interfaces that translate the incoming requests to one or more Portal server
• High level description of web services
  – Authentication, Authorization, Accounting (AAA)
    • Decentralized PKI-based AAA infrastructure (shibboleth)
    • Protect and simplify the access to the WSN testbeds
  – Network Control, Debugging and Configuration (WSN API)
    • Programming the nodes (binary images)
    • Configuring the nodes (channel, transmission power)
  – Data Acquisition, Query Processing, Network Operation (OPT API)
    • Provide a list of the testbeds nodes with their capabilities (in SensorML)
    • Provides services for accessing the data retrieved from the sensors and issuing queries for data
WISEBED: Overall Architecture

- The web services of the portal servers use a flexible API and open standards such as graphML and sensorML
- Every entity in the network is uniquely identified using URN
- Each testbed topology is described using graphML
- The sensors capabilities are described using sensorML
- OPT API example:
  - string getRecords():
  - string getCapabilities(string urn)
  - string describeCapability(string urn)
Software Aspects of Wisebed

- Shawn is a simulation framework for WSNs
- It focuses on an abstract, repeatable approach to a WSN simulation
- Shawn can be used as a virtual testbed
- Developers can test their code before deploying real hardware
- Create testbeds with a mix of real & virtual nodes

Infrastructure of Interconnected Testbeds

- Virtual links between sensors of discrete testbeds
- Discrete geographic areas can communicate
- Testbeds may have different infrastructure
- Use resources from different testbeds transparently
The message is routed to the local Portal Server of the testbed.

The Portal Server checks with the virtual testbed description where are the neighbor nodes.

Receiving Portal Servers checks the LQI and calculate the probability to drop or alter part of the message.

Messages are converted to the format of the target platform and delivered.
Heterogeneity causes significant difficulties when developing/testing algorithms
Wiselib: a generic algorithmic library for heterogeneous sensor networks
Provides a generic API to implement algorithms, and then compile them for several HW and SW platforms
Run the same algorithm in a heterogeneous sensor network
Written in C++, intensive use of templates
Currently supports a wide range of platforms and OSes:
  * iSense, SCW, Tmote Sky, TelosB, MicaZ, Tnode, Imote2, GumStix
• External Interface
  – Connection layer between the Wiselib and the underlaying Os
  – Functionality such as adding a timer or sending messages over the radio

• Internal Interface
  – Connection between Wiselib components, i.e., algorithms, data structures and utility classes

• Algorithm Concept
  – Abstract interfaces for classes of algorithms and data structures
  – Decouples the algorithm logic from the data storage
• An application using wiselib algorithms can be compiled:
  – to run natively on the target platform
  – as an opencom component
  – to run inside the shawn simulator
Use-case Scenarios

- Suppose that Mr. Smith, working on an office and building automation application
- Wishes to test whether his software is functioning properly in practice
- He would like input on events like motion sensors detecting movement in specific offices, etc
- Connects to the WISEBED infrastructure using the authorization/authentication services of the project
- In the Portal Server web interface, the user can upload and administer the sensor code images they intend to load to the sensor nodes
Use-case Scenarios

- The map on the left depicts the selected sensor nodes, along with the links between sensor node pairs.
- This information is dynamically created using data obtained over the serial interface of the sensor nodes.
- Clicking on a sensor node in the picture or a link, the system displays additional information about the sensor node, such as name, type, radio, and the last sensed sensor values.
- Then he can reserve some testbed resources (e.g., 6 office rooms and the sensors associated with these offices).
Use-case Scenarios

• Then uses the provided services in order to retrieve data about the occurrence of events in the network and its operation

• The user can observe the current state of every sensor node and links in real time

• Also The user can send any kind of commands over the web-interface to each sensor node, as e.g. the sense command which prints the current sensor values, or the neighbors command, which displays the current neighbors of a node, etc.

• After an experiment ends all the output that was emitted by the sensor nodes are available along with the timestamps in an XML file
Conclusions - Future Work

- Mainly isolated sensor network testbeds exist across Europe and the rest of the world.
- Their homogeneity, small scale and narrow application scope limit their use.
- WISEBED tries to answer these challenges by the establishment of a large-scale sensor network by a number of federated testbeds.
- Future work on the project involves:
  - the extension of the existing testbed sites
  - implementation of the software ecosystem surrounding the project
- http://www.wisebed.eu