Green Sensor Networks for Structural Monitoring (GENESI)

Wireless Sensor Networking Solutions for Structural Health Monitoring?

The GENESI Node v1.0

Dr David Boyle

First GENESI Workshop, March 11th, 2011
Amsterdam, Netherlands

www.tyndall.ie
Presentation Outline

Introduction:
• Tyndall National Institute, University College Cork, Ireland
  - Wireless Sensor Networks - devices and applications
  - Research and Vision
• High level GENESI platform requirements

Technical Details and Solutions Proposed:
• Sensor selection and Requirements
• Node/Device Requirements
• Component Selection
• Integration challenges
  - Sensor Interface
  - Power Interface
• Other considerations (Research platform?, Form factor?, Compatibility?, etc.)

Conclusion:
• GENESI - summary of vision and design challenges
Established in 2004 evolving from the National Microelectronics Research Centre (NMRC - since 1980s)

Brings together researchers in:

- Photonics
- Microelectronics
- Nanotechnology
- Microsystems

420 research engineers, scientists, students, interns & support staff

Creates a critical mass of researchers in the field of ICT in a multidisciplinary environment

Tyndall postgraduates and researchers come from multi-disciplinary backgrounds including microelectronics, physics, chemistry and life sciences.

Currently, we host students of more than 20 nationalities. Target to double number of 4th level students in Ireland over 7 years

Target to reach 500 in 5 years, from:

- Irish Universities and Institutes of Technology
- Industry suites
- Overseas visitors

www.tyndall.ie
What is GENESI?
- Long lasting, pervasive, portable, autonomous, wireless sensor networking technology applicable to structural health monitoring (SHM)

What does this mean?
- “Off-the-shelf” sensors currently known, trusted and USED in SHM
- Wirelessly connected
- Easily re-deployable (portable)
- Extended functional lifetime
- Operates largely with autonomy
- Fitness for purpose
- Compatibility

What are the goals?
- Provide the highest possible levels of Quality of Service ***
- Functional lifetime that extends to decades
- Develop a flexible system that extends far beyond the pilot deployment scenarios
High level GENESI platform requirements

- **Green**
  - Energy scavenging
  - Energy Harvesting
  - Renewable Sources

- **Sustainable**
  - Longevity
  - Low-power components, algorithms, communications ...

- **Robust**
  - Rugged deployment environment
  - Fault tolerance
  - Recoverable

- **Portable**
  - From one application scenario to the next
  - Re-deployment in the field
  - Pre, mid, post construction

- **User-Centric**
  - High level of system responsiveness
  - Maximized end-user perceived quality of service

- **Interoperable**
  - Existing end-user front and back ends

www.tyndall.ie
High level GENESI platform requirements

How can this be achieved?
• End-user involvement in the design from the beginning

What is the expected outcome?
• Leadership in the field of wirelessly enabled and reliable SHM
• A system that meets the needs of the SHM community that is portable from one deployment scenario to the next - and compatible with existing back/front ends
• A stable legacy research platform
• Advancement of the state-of-the-art in:
  - Wireless Sensor Network devices/motes
  - Network programming/reprogramming
  - Quality of Service in pervasive sensor networks
  - Integrated power systems (fuel cell, energy scavengers/harvesters and battery with intelligent control) for the next generation of WSN technology

Where to start?

www.tyndall.ie
Traditional Wireless Sensor Networks and Devices:

- Sensors
- Microprocessor
- RF Transceiver (ISM bands)
- Memory
- Power supply

MOTE!

Sensor(s)

MCU

RF TRX

Battery

, RS232, etc.
Towards a GENESI Node:

- Sensors
- Microcontroller
- Radio Transceiver
- Smart Power System

- Interfaces to:
  - Sensor Layer
  - Power Layer

SENSORS

MCU + RF

Smart Power System

- Displacement
- Pressure
- Tilt
- Inertia
- Temperature
- Fuel Cell
- Energy Scavenger
- Energy Harvester
- Battery
- Microcontroller
### Sensors Specified and Associated Requirements

#### Sensors proposed for GENESI - Pont de la Poya

<table>
<thead>
<tr>
<th>Sensor Type</th>
<th>Manufacturer</th>
<th>Sensor</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Displacement Meter</td>
<td>Gefran</td>
<td>100mm</td>
<td>Rectilinear Displacement Transducer</td>
</tr>
<tr>
<td>Tilt Meter</td>
<td>Wyler</td>
<td>Zerotronic Type 3</td>
<td>Digital Inclination Sensor</td>
</tr>
<tr>
<td>Gas/Liquid Pressure</td>
<td>Keller</td>
<td>23 Series</td>
<td>Piezoresistive Pressure Transmitter</td>
</tr>
<tr>
<td>Temperature</td>
<td>PTS</td>
<td>PT1000</td>
<td>Platinum Resistive Temperature Sensor</td>
</tr>
<tr>
<td>Inertia (Accelerometers)</td>
<td>TBC</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wind</td>
<td>TBC</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Measured variable</td>
<td>Sensor</td>
<td>Interface / Connection</td>
<td>Supply</td>
</tr>
<tr>
<td>-------------------</td>
<td>-----------------</td>
<td>-------------------------</td>
<td>-------------------------</td>
</tr>
<tr>
<td>Displacement</td>
<td>Gefran 100mm</td>
<td>analogue, 3 wires</td>
<td>0 bis 60V, &lt;&lt; 10 mA</td>
</tr>
<tr>
<td>Gas / liquid</td>
<td>Keller 23 Series</td>
<td>analogue, 2 wires</td>
<td>8V - 28V, 25 mA max.</td>
</tr>
<tr>
<td>Inclination</td>
<td>Wyler Zerotronic</td>
<td>Digital, RS 485</td>
<td>5V ca. 14 mA</td>
</tr>
<tr>
<td>Temperature</td>
<td>ITS PT1000</td>
<td>analogue, 2/4 wires</td>
<td></td>
</tr>
<tr>
<td>Wind and</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Accelerometer TBC</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Sensors Specified and Associated Requirements

- **Sensors proposed for GENESI - Metropolitana Linea B1 Roma**

<table>
<thead>
<tr>
<th>Sensor Type</th>
<th>Manufacturer</th>
<th>Sensor</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strain Gauge</td>
<td>Sisgeo</td>
<td>OVK4200VC00</td>
<td>Vibrating Wire</td>
</tr>
<tr>
<td>Temperature</td>
<td>PTS</td>
<td>PT1000</td>
<td>Platinum Resistive Temperature Sensor</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Measured variable</th>
<th>Sensor</th>
<th>Interface / Connection</th>
<th>Supply</th>
<th>Output</th>
<th>Resolution</th>
<th>Time for measurement (warm up)</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strain</td>
<td>Sisgeo OVK4200VC00</td>
<td>Analogue, 2 wire</td>
<td>2.5 - 12 V ca. 20mA</td>
<td>Resonance Frequency (Voltage)</td>
<td>0.1%FS</td>
<td>Approx. 1 s</td>
<td>500 - 1200 Hz within ~100/200ms</td>
</tr>
<tr>
<td>Temperature</td>
<td>ITS PT1000</td>
<td>analogue, 2/4 wires</td>
<td></td>
<td>ca. 0.2°C</td>
<td>&lt; 0.5 s</td>
<td></td>
<td>Normal range -30 to + 50 °C</td>
</tr>
</tbody>
</table>
Vision of the GENESI Node

- **SENSORS**
  - Interface Board (2,3,4 Wire, RS232/485, SPI, etc.)
  - Flash Memory
  - 16-Bit ADC

- **CABLES**
  - Connector

- **GENESI NODE**
  - MSP430 Microcontroller
  - CC2420 RF Transceiver

- **G E N E S I N O D E**
  - Fuel Cell
  - Battery
  - Energy Harvesters
  - Interface Board
  - Power Unit Monitor
Preliminary Integration Work

Proof of Concept:

- Wyler Inclinometer & GENESI v1.0 Node
- Data visualisation in Labview

The Tyndall GENESI Node v1.0
(MSP430F5437/CC2420)

www.tyndall.ie
# Component Selection: GENESI Node v1.0

**Microcontroller:**
- Texas Instruments MSP430F5437
- Atmega1281

## Features

<table>
<thead>
<tr>
<th>Feature</th>
<th>MSP430F5437</th>
<th>Atmega1281</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Power</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Power supply</td>
<td>2.2V … 3.6V</td>
<td>2.7V … 5.5V</td>
</tr>
<tr>
<td>Sleep modes</td>
<td>6 modes (incl. AM)</td>
<td>6 modes (incl. AM)</td>
</tr>
<tr>
<td>Min. Current (sleep mode)</td>
<td>1.69 µA at 3.0V</td>
<td>0.1 µA at 1.8V</td>
</tr>
<tr>
<td>Active mode</td>
<td>312 µA /MHz at 8 MHz, 3.0 V</td>
<td>500 µA /1MHz, 1.8V:</td>
</tr>
<tr>
<td>Wake up time</td>
<td>&lt;5µs</td>
<td>6µs</td>
</tr>
<tr>
<td><strong>Memory/clock</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FLASH</td>
<td>256 KB</td>
<td>128 KB</td>
</tr>
<tr>
<td>SRAM</td>
<td>16 KB</td>
<td>8 KB</td>
</tr>
<tr>
<td>EEPROM</td>
<td>-</td>
<td>4 KB</td>
</tr>
<tr>
<td>Instructions</td>
<td>51 instruction</td>
<td>135 instruction</td>
</tr>
<tr>
<td>General purpose Working Register</td>
<td>16 x 16 bits</td>
<td>32 x 8 bits</td>
</tr>
<tr>
<td>CPU</td>
<td>16-bit RISC CPU</td>
<td>8-bit RISC CPU</td>
</tr>
<tr>
<td>MIPS</td>
<td>Up to 25 MIPS</td>
<td>16 MIPS throughput 16 MHz</td>
</tr>
<tr>
<td>Clock Frequency</td>
<td>18MHz</td>
<td>0 ... 16MHz</td>
</tr>
<tr>
<td>Crystal</td>
<td>Up to 32 MHz</td>
<td>0 - 4 MHz @ 1.8 - 5.5V, 0 - 8 MHz @ 2.7 - 5.5V, 0 - 16 MHz @ 4.5 - 5.5V</td>
</tr>
<tr>
<td>External data memory interface (64kB)</td>
<td>-</td>
<td>Yes</td>
</tr>
</tbody>
</table>

---

[www.tyndall.ie](http://www.tyndall.ie)
# Component Selection: GENESI Node v1.0

## Features

<table>
<thead>
<tr>
<th>TI CC2420 (Texas Instruments)</th>
<th>TI CC2520 (Texas Instruments)</th>
<th>AT86RF231 (Atmel)</th>
<th>ADF7242 (Analog Devices)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SLEEP (No State Retention) device off</td>
<td>SLEEP Basic State Retention</td>
<td>Transmit current at 0dBm</td>
<td>Transmit current at max Pout</td>
</tr>
<tr>
<td>Bandwidth</td>
<td>N/A</td>
<td>Transmit current at 0dBm</td>
<td>N/A</td>
</tr>
<tr>
<td>SLEEP Basic State Retention</td>
<td>0.02uA</td>
<td>Transmit current at max Pout</td>
<td>N/A</td>
</tr>
<tr>
<td>Transmit current at 0dBm</td>
<td>0.03uA</td>
<td>Receive Current</td>
<td>18.8mA</td>
</tr>
<tr>
<td>Transmit current at max Pout</td>
<td>N/A</td>
<td>Supply voltage</td>
<td>2.1 – 3.6</td>
</tr>
<tr>
<td>Select Current Consumption and Vcc</td>
<td>AT86RF231 (Atmel) 0.02uA (max)</td>
<td>AT86RF231 (Atmel) 0.02uA (max)</td>
<td>ADF7242 (Analog Devices) 0.03uA (max)</td>
</tr>
<tr>
<td>Bandwidth</td>
<td>0.02uA (max)</td>
<td>ADF7242 (Analog Devices) 0.3uA</td>
<td>ADF7242 (Analog Devices) 1.7uA</td>
</tr>
<tr>
<td>Transmit current at 0dBm</td>
<td>0.03uA</td>
<td>ADF7242 (Analog Devices) 1.7uA</td>
<td>N/A</td>
</tr>
<tr>
<td>Transmit current at max Pout</td>
<td>N/A</td>
<td>ADF7242 (Analog Devices) 1.7uA</td>
<td>N/A</td>
</tr>
<tr>
<td>Receive Current</td>
<td>0.03uA</td>
<td>ADF7242 (Analog Devices) 1.7uA</td>
<td>N/A</td>
</tr>
<tr>
<td>Supply voltage</td>
<td>1.8 – 3.8</td>
<td>ADF7242 (Analog Devices) 1.7uA</td>
<td>N/A</td>
</tr>
<tr>
<td>Power Consumption</td>
<td>18.8mA</td>
<td>ADF7242 (Analog Devices) 1.7uA</td>
<td>N/A</td>
</tr>
<tr>
<td>Vcc</td>
<td>18.5 mA (f)/22.3mA (wait)</td>
<td>ADF7242 (Analog Devices) 1.7uA</td>
<td>N/A</td>
</tr>
<tr>
<td>Bandwidth</td>
<td>12.3mA high sensitivity</td>
<td>ADF7242 (Analog Devices) 1.7uA</td>
<td>N/A</td>
</tr>
<tr>
<td>Transmit current at max Pout</td>
<td>19mA</td>
<td>ADF7242 (Analog Devices) 1.7uA</td>
<td>N/A</td>
</tr>
<tr>
<td>Receive Current</td>
<td>18mA</td>
<td>ADF7242 (Analog Devices) 1.7uA</td>
<td>N/A</td>
</tr>
<tr>
<td>Supply voltage</td>
<td>18 – 3.6</td>
<td>ADF7242 (Analog Devices) 1.7uA</td>
<td>N/A</td>
</tr>
</tbody>
</table>

## Frequencies

<table>
<thead>
<tr>
<th>TI CC2420 (Texas Instruments)</th>
<th>TI CC2520 (Texas Instruments)</th>
<th>AT86RF231 (Atmel)</th>
<th>ADF7242 (Analog Devices)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bandwidth</td>
<td>0.42GHz</td>
<td>2.4GHz</td>
<td>2.4GHz</td>
</tr>
<tr>
<td>Transmit current at 0dBm</td>
<td>17.4mA</td>
<td>25.8mA</td>
<td>11.6mA</td>
</tr>
<tr>
<td>Receive Current</td>
<td>18.8mA</td>
<td>18.5 mA (f)/22.3mA (wait)</td>
<td>12.3mA high sensitivity</td>
</tr>
<tr>
<td>Supply voltage</td>
<td>2.1 – 3.6</td>
<td>1.8 – 3.8</td>
<td>1.8 – 3.6</td>
</tr>
</tbody>
</table>
Component Selection: GENESI Node v1.0

Radio Transceiver:
- TI CC2420 - a good match

Component Considerations:
- Plentiful support and proven compatibility with TI MSP430 family
- Well known in the field - implemented and tested
- IEEE 802.15.4 - 2003 Compliant
  => Compatible with
  - ZigBee
  - 6LoWPAN (IPv6 over Low Rate Wireless Personal Area Networks)
  - WirelessHART
  - etc.

Other Considerations:
- 2.4GHz ISM band - channels, range (hundreds of meters), data rates (~250kbps)
- Numerous other features (including hardware enabled security)
# Integration Challenges: Sensor Layer

<table>
<thead>
<tr>
<th>Measured variable</th>
<th>Sensor</th>
<th>Interface / Connection</th>
<th>Supply</th>
<th>Output</th>
<th>Resolution</th>
<th>Time for measurement (warm up)</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Displacement</td>
<td>Gefran 100mm</td>
<td>analogue, 3 wires</td>
<td>0 bis 60V, &lt;&lt; 10 mA</td>
<td>Ratiometric voltage V</td>
<td>0.01% FS</td>
<td>&lt; 0.5 s</td>
<td>16 bit resolution is required</td>
</tr>
<tr>
<td>Gas / liquid pressure</td>
<td>Keller 23 Series</td>
<td>analogue, 2 wires</td>
<td>8V - 28V, 25 mA max.</td>
<td>4 - 20 mA</td>
<td>0.1% FS</td>
<td>&lt; 0.5 s</td>
<td>16 bit resolution demanded</td>
</tr>
<tr>
<td>Inclination</td>
<td>Wyler ZeroTronic Digital, RS 485</td>
<td>5V ca. 14 mA</td>
<td>RS485 or PVM signal</td>
<td>0.01%FS</td>
<td>Measurement 1 s, warm up approx. 5 to 10 s</td>
<td>Warm up time of several seconds</td>
<td></td>
</tr>
<tr>
<td>Temperature</td>
<td>ITS PT1000</td>
<td>analogue, 2/4 wires</td>
<td></td>
<td>ca. 0.2°C</td>
<td>&lt; 0.5 s</td>
<td>Normal range -30 to + 50 °C</td>
<td></td>
</tr>
<tr>
<td>Wind and Accelerometer TBC</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Summary:

The following must be supported:
- variety of interfaces/(electrical) communications protocols
  - RS232/485, Analogue wire, serial, etc.
- variety output types (for sampling)
- variety of supply voltages

Additionally:
- 16-bit resolution/granularity => ADC required
- More memory is required (Flash)
- Minimization of leakage
Summary:

The power layer will provide ~3V DC to the upper layers, and will exist as a standalone “Smart Power Unit”:
- Fuel Cell
- Energy Scavengers
- Energy Harvesters
- Battery
- Microcontroller Unit

Additionally:
- Communication with the “Main Layer” MCU is required
- Information will be provided regarding the state of the power unit, etc.
Other Design Considerations

- Form factor?

HARSH conditions

Rugged and Robust
Other Design Considerations

Additional requirements:

- Additional memory
- Network architecture (i.e. gateway and functionality)
- Device roles and functionality
- Compatibility with existing end-user platforms
- QoS model and infrastructure
- Number of sensors per node/ports?
  - Beginning with only one sensor port
  - Expand from there
Vision for GENESI v2.0

- Retain modularity and MSP430F5437
- Upgrade CC2420 to CC2520 RF transceiver

- Why?
  - Compliant with IEEE 802.15.4 - 2006
  - Fastest wake-up transceiver available
  - Smaller and cheaper

- Compatibility with existing WSN operating systems (Contiki, TinyOS)
- Full-functioned remote network (re)programmability
- Fully supported QoS model
- Multi-port to GENESI nodes

www.tyndall.ie
Thanks for your attention

david.boyle@tyndall.ie