CORA Cork Open Research Archive
Cartlann Taighde Oscailte Chorcaí

Title	GENESI: Wireless sensor networks for structural monitoring
Authors	O'Flynn, Brendan;Boyle, David;Popovici, Emanuel M.;Magno, Michele;Petrioli, C.
Publication date	2011-09
Original Citation	O Flynn, Brendan; Boyle, David; Popovici, Emanuel M.; Magno, Michele; Petrioli, C. (2011) GENESI: Wireless sensor networks for structural monitoring 35th International Conference of IMAPS - CPMT IEEE Poland, Gdansk-Sobieszewo, Poland, 21-24 Sep, 2011.
Type of publication	Conference item
Link to publisher's version	http://imaps2011.eti.pg.gda.pl/, http://genesi.di.uniroma1.it/
Rights	https://creativecommons.org/licenses/by/4.0/
Download date	2026-09-10 03:32:11
Item downloaded from	https://hdl.handle.net/10468/572

UCC
University College Cork, Ireland
Coláiste na hOllscoile Corcaigh

35th International Conference of IMAPS - CPMT IEEE Poland
Gdansk-Sobieszewo, September 21-24, 2011

GENESI:
Wireless Sensor Networks for Structural Monitoring

Brendan O'Flynn[1,2,3)], David Boyle[2,3)], E. Popovici[1,2,3)], Michele Magno[3,4)]and C. Petrioli[5)]
[1)] Clarity CENTRE, [2)] Tyndall National Institute, [3)] University College Cork, Ireland.
[4)] University of Bologna Italy, [5)] University of Rome, Italy
brendan.oflynn@tyndall.ie

Abstract: *The GENESI project has the ambitious goal of bringing WSN technology to the level where it can provide the core of the next generation of systems for structural health monitoring that are long lasting, pervasive and totally distributed and autonomous. This goal requires embracing engineering and scientific challenges never successfully tackled before. Sensor nodes will be redesigned to overcome their current limitations, especially concerning energy storage and provisioning (we need devices with virtually infinite lifetime) and resilience to faults and interferences (for reliability and robustness). New software and protocols will be defined to fully take advantage of the new hardware, providing new paradigms for cross-layer interaction at all layers of the protocol stack and satisfying the requirements of a new concept of Quality of Service (QoS) that is application-driven, truly reflecting the end user perspective and expectations.*

The GENESI project will develop long lasting sensor nodes by combining cutting edge technologies for energy generation from the environment (energy harvesting) and green energy supply (small form factor fuel cells); GENESI will define models for energy harvesting, energy conservation in super-capacitors and supplemental energy availability through fuel cells, in addition to the design of new algorithms and protocols for dynamic allocation of sensing and communication tasks to the sensors. The project team will design communication protocols for large scale heterogeneous wireless sensor/actuator networks with energy-harvesting capabilities and define distributed mechanisms for context assessment and situation awareness.

This paper presents an analysis of the GENESI system requirements in order to achieve the ambitious goals of the project. Extending from the requirements presented, the emergent system specification is discussed with respect to the selection and integration of relevant system components.The resulting integrated system will be evaluated and characterised to ensure that it is capable of satisfying the functional requirements of the project.

Keywords: Structural Health Monitoring, Green Wireless Sensor Networks, Green Energy Sources

1. INTRODUCTION

The GENESI project has the ambitious goal of bringing WSN technology to the level where it can provide the core of the next generation of systems for structural health monitoring that are long lasting, pervasive and totally distributed and autonomous. Sensor nodes are being redesigned to overcome their current limitations, especially concerning energy storage and provisioning (we need devices with virtually infinite lifetime) and resilience to faults and interferences (for reliability and robustness). New software and protocols will be defined to fully take advantage of the new hardware, providing new paradigms for cross-layer interaction at all layers of the protocol stack and satisfying the requirements of a new concept of Quality of Service (QoS) that is application-driven, truly reflecting the end user perspective and expectations. The GENESI system will be deployed in two pilot deployments; namely the monitoring of a bridge (Pont de la Poya, Switzerland)

and a metro tunnel (Metropolitana Linea B, Rome), both during and after construction.

2. SYSTEM REQUIREMENT ANALYSIS

GENESI (Green sEnsor NEtworks for Structural monItoring) [1] exhibits a range of system requirements from a variety of established and emerging technical scientific disciplines.

The systems are required to be "Green" and Sustainable – The use of energy scavanging techniques (i.e. harnessing available environmental energy) to extend the lifetime of GENESI nodes will be employed. Realistic potential sources include solar and wind energy. A fuel cell or series of fuel cells, capable of providing significant amounts of energy, will also be integrated in the design of a novel power unit. This unit may also make use of integrated suitable battery cell(s) and/or other storage techniques (such as capacitors). It should provide sufficient energy to power the GENESI wireless sensor nodes for extended periods of time.

In addition to developing novel hardware to address the challenge of providing a solution for structural health monitoring with virtually infinite lifetime, appropriate algorithms and networking protocols must be developed to facilitate these goals. The lowest possible amounts of energy should be consumed during periods of communication, algorithms and protocols should account for fluctuating available energy whilst exhibiting fault tolerance in the presence of malfunctioning devices and lossy channels. Finally, the overall system should ensure maintenance of suitable levels of quality of service.

The GENESI nodes, with minimal maintenance from initial deployment, are required to have an operational lifespan extending to decades and the following characteristics:

Portability – The intended use of the system requires that, during the construction phase, one of the desirable properties of the proposed GENESI system is that it should facilitate easy redeployment, or repositioning, of the nodes/sensors as construction work progresses. For example, when one section of monitored construction is complete, it should be easy for the sensor nodes to be moved to the next section, Alternatively, they should be reconfigured in their current position to allow for a different type of monitoring, for instance moving from a monitoring modality intended for the construction phase, to long term monitoring of the system in operation. This functionality should be considered thoroughly as the design of the system progresses. It will relate to both the physical aspects of the GENESI devices (form factor – size, mass, connectors, packaging, etc.) and also the networking and dynamic reprogramming of the devices.

Robustness – GENESI is intended for use in the monitoring of structures. As such, its field of deployment is naturally rugged. The devices must be packaged in accordance with the requirements of the deployment field. Therefore, the end system must be robust in terms of physical protection from the environment (against elements such as moisture, lightning, temperature extremes, etc.), and also exhibit robust physical features such as protection from impacts/shocks, large simple connectors, etc. In addition to protection and increased robustness of the GENESI node, the system architecture should ensure reliability against node failures. The system should be capable of detecting failures and malfunctioning system components, should support adequate actions to cope with problems, e.g. restarting devices and reconfiguring them. Itshould be self-healing and robust in case of permanent failure, e.g. by dynamically changing routes, reallocating application tasks.

Flexibility – GENESI should be flexible enough in design to ensure that it is applicable to a wide range of structural monitoring scenarios beyond the pilot deployments. This will ensure maximum impact to the overall market.

Maximization of end-user utility – The development of protocols and algorithms to ensure the highest levels of system responsiveness and end-user perceived service quality by fully exploiting the variable energy availability of harvesting devices.

Interoperability with existing front-ends– the system should be compatible with the existing front-end provided by the end-user partners

In summary, GENESI must provide a robust wireless sensor network for structural health monitoring that exhibits high levels of quality of service, dramatically enhanced network lifetime, minimal maintenance requirements, flexibility to a wide range of monitoring scenarios and dynamic

configurability in the field. It must also be compatible with existing front-end structural monitoring solutions and significantly reduce overall costs for structural health monitoring in the field.

3. GENESI DEVICE LEVEL SPECIFICATION

In order to facilitate rapid prototyping and experimentation with various interfaces, both to sensors and power solutions, a modular approach to the design of the final hardware platform has been adopted. To this end, a prototype of the GENESI node has been developed by Tyndall, and the core components of which are described in the following sections:

3.1 Sensors

The sensors to be used for the two initial deployment scenarios are of the "off-the-shelf" variety. The requirement exists for the development of sensor interface layers to correspond to the type of communication supported by the sensors themselves. 2, 3 and 4-wire analogue, RS 485, RS 232 and SPI (digital) interfaces are required. Additionally, given the variety of supplies required for individual sensors – a number of power rails will be required. Similar interfacing must be achieved between the sensors, the motherboard and the smart power unit. In order to achieve the required 16-bit granularity for some of the sensors, an additional analog-to-digital converter (ADC) chip is required.

3.2 RF and Microcontroller Requirements

The primary enabling technologies of wireless sensor networks are low-power RF communication and microcontroller components. In keeping with design goals for the GENESI, state-of-the-art and standard compliant (IEEE 802.15.4) radio transceivers are implemented in combination with an appropriate microcontroller (e.g. Texas Instruments MSP430). In order to comply with GENESI objectives of ultra-low power operation for extended node lifetime, the lowest power components are chosen in the design of the electronic hardware.

3.2.1 RF Transceiver

The IEEE 802.15.4 standard for low-rate wireless personal area networks (LR-WPAN) is the most prominent and applicable for use with wireless sensor networks [2], underpinning a range of higher level standards and specifications (including ZigBee [3], 6LoWPAN [4] and WirelessHART [5]). It provides optimal trade-offs with respect to range, data rates and power consumption, in comparison with other wireless communications technologies that could be applicable to the GENESI platform (such as Bluetooth, WiFi, etc.; which usually offer superior data rates for higher power cost over a shorter range). The standard originally (2003) prescribed two physical layers based upon direct sequence spread spectrum (DSSS) techniques – one working in the 868 (Europe)/915 (North America) MHz bands, the other in the 2.4GHz band. In Europe, the 868MHz band allowed for only one communications channel (with a transfer rate of 20kbps (prior to the 2006 revision of the standard)), whereas the worldwide 2.4GHz band allows up to 16 channels with a transfer rate of 250kbps.

The decision for GENESI to function in the 2.4GHz band was agreed based upon the need for a number of channels and reasonable data rates – thus ensuring the possibility to enhance quality of service and meet design requirements for the project. We are also investigating the possibility to add a second radio on GENESI platform operating in the 868MHz band for specific application scenarios where 2.4GHz band may suffer from severe interference (such as structural health monitoring in buildings).

In choosing an appropriate RFIC, one is limited to those available commercially. The most well known transceiver in the WSN domain is the Texas Instruments CC2420 [6]. This transceiver supports the IEEE 802.15.4-2003 standard, operating in the 2.4 GHz channel. Along with its successor, the CC2520, the Atmel AT86RF231 and the Analog Devices ADF7242, are all state-of-the-art transceivers under consideration for the final GENESI system specification.

3.3 Smart Power System

From the perspective of power requirements for the GENESI system it is noticeable that industrial batteries on the market have a number of limitations from both the user and equipment perspective.

Firstly, they represent an unpredictable source of power. A user can have a little advantage if he knows that the battery is about to run out of energy or how much operating time is left. Secondly, the device cannot determine if the battery, in its current state, is

capable of supplying adequate power for an additional load (e.g. spinning up a hard disk in a laptop, turn on a flash-light in a camera, or start a burst radio transmission in a WSN). Finally,, battery chargers must be individually tailored for use with specific battery chemistry and may cause damage if used on different storage device.

For these reasons, the specification of an enhanced battery (called the Smart Power System, see Fig. 1) which can overcome the limitation of traditional batteries and jointly exploit the features of an energy harvester appears to be a winning approach. In this way, it is also possible to significantly improve the availability of power for the node; one of the most important factors towards the successful realisation of the GENESI sytem.

3.2 Smart Energy Supply

The GENESI Smart Power System has the following features: multi-harvester (wind, solar, thermal, etc.), multi-energy storage (e.g. super capacitor, batteries), intelligent interface to receive and provide information regarding energy availability, the fuel cell interface, and allow flexibility in operation.

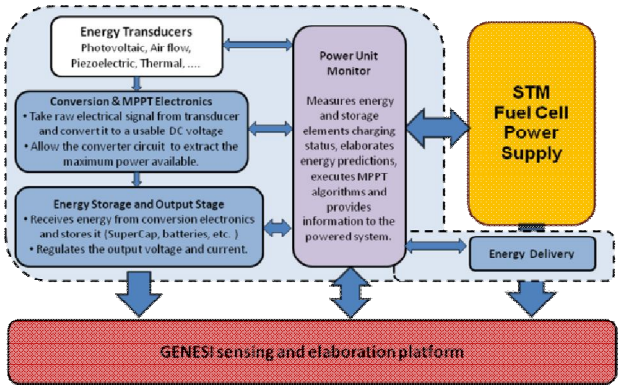

Figure 1: Block Diagram of the GENESI Smart Power System

Energy harvesting devices convert ambient energy into electrical energy and it is possible to tailor the power source to satisfy the different power consumption requests various sensors and scenarios in which the nodes will be deployed.

Depending on the scenario, a multi-harvesting unit able to convert energy from different kind of ambient source (solar, wind, thermal, etc.) is a good approach.

The energy harvesting requirements are directly related to the average power consumption of the application and depend on the expected quality of service and use-case requirements (sensing rate, distance between nodes and transmission power, etc.). Moreover, the different modules or typology of harvesting depends on the environment where the node is deployed. (For example, the use of photovoltaic cells, in an underground scenario, may provide less power than other sources, such as thermal. The opposite is true when the WSN is deployed outdoors).

Considering that one of the locations where the GENESI platform will be placed is a bridge, it has been decided that a wind-photovoltaic energy harvester is an optimal choice for implementation. The choice of a modular and flexible architecture of the harvester facilitates the interface operation with the fuel cell section, but also with other energy transducers not originally planned in this project (i.e. piezoelectric, thermal ones).

It is also expected that a significant amount of wind energy should be available in the tunnel deployment (due to air-conditioning and passing metro carriages), whereas, the photovoltaic energy may be in significantly lesser supply.

The Smart Power System will dynamically select the harvesting source (if the node is provided with more harvesters) and will adjust the power conversion parameters to extend the node lifetime.

In general, the harvested energy is stored in a super capacitor and/or battery. Capacitors are used when the application needs to provide huge energy spikes. Batteries leak less energy and are therefore used when the device needs to provide a steady flow of energy. However the GENESI smart battery system will use **both** of these solutions.

RESULTS AND CONCLUSIONS

Based on the requirements elaborated, the specified system components have been integrated to form a functional prototype of the GENESI node. Early experimentation has proven feasible the integration of off-the-shelf sensors traditionally used in structural health monitoring with low-power RF and microcontroller components (i.e. a WSN “mote”). Furthermore, an embodiment of the smart power system (inclusive of energy harvesting capabilities and fuel cell technology) has been shown to power the

unit. The prototype is currently under technical evaluation with respect to electrical characterisation (in various modes) and functionality. Detailed results will be presented in due course.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the support of Science Foundation Ireland (SFI) for funding the CLARITY CSET, the European Commission for funding the GENESI project, as well as Enterprise Ireland, Irelands Higher Education Authority (HEA) and the funding provided to the National Access Program (NAP) at the Tyndall National Institute by SFI, all of which have contributed to this work.

REFERENCES

[1] GENESI: Green sEnsor NEworks for Structural monItoring, available: http://genesi.di.uniroma1.it/ [accessed: 28/06/11]

[2] IEEE 802.15 WPAN Task Group (TG4). Available: http://www.ieee802.org/15/pub/TG4.html [accessed: 28/06/11]

[3] Zigbee alliance. Available: http://www.zigbee.org/ [accessed: 28/06/11]

[4] Ipv6 over Low power WPAN (6lowpan). Available: http://datatracker.ietf.org/wg/6lowpan/charter/ [accessed: 28/06/11]

[5] Wireless HART Technology. Available: http://www.hartcomm.org/protocol/wihart/wireless_technology.html [accessed: 28/06/11]

[6] CC2420 Datasheet. Available: http://focus.ti.com/lit/ds/symlink/cc2420.pdf [accessed: 28/06/11]