Title	Enabling Intelligence on a Wireless Sensor Network Platform
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Publication date	2012-03-08
Publication information	O'Grady, Michael J., Philip Angove, W Magnin, G. M. P. (Greg M. P.) O'Hare, Brendan O'Flynn, John Barton, and Cian O'Mathuna. "Enabling Intelligence on a Wireless Sensor Network Platform." Springer, 2012.
Conference details	Paper presented at Practical Applications of Agents and Multi-Agent Systems 10th International Conference on Practical Applications of Agents and Multi-Agent Systems 28th of March, Salamanca, Spain
Publisher	Springer
Item record/more information	http://hdl.handle.net/10197/3756
Publisher's statement	The final publication is available at www.springerlink.com
Publisher's version (DOI)	10.1007/978-3-642-28762-6_36

Chapter 1
Enabling Intelligence on a Wireless Sensor Network Platform

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Abstract Conventional Wireless Sensor Networks (WSNs) usually adopt a centralised approach to data processing and interpretation primarily due to the limited computation and energy resources available on sensor nodes. These constraints limits the potential of intelligent techniques to data analysis and such activities on the centralised host. In contrast, Intelligent WSNs (iWSNs) will be significantly more powerful thus enabling the harnessing of intelligent techniques for diverse purposes. One such purpose is the practical realisation of smart environments, and facilitating mobility and interaction with the inhabitants of such environments. As a step in this direction, this paper presents the design of an iWSN sensor node platform that enables the hosting of lightweight Artificial Intelligence (AI) frameworks whilst enabling the ubiquitous energy constraints be quantified, mitigated and managed.

1.1 Introduction

From a network topology perspective, networked sensors may be regarded as leaf nodes at the fringes of the network. Historically, many service providers would have regarded the mobile phone as the archetypical leaf node; however, current genres of smart phones are sophisticated computational platforms within their own right. This evolution from relatively dumb mobile terminals to highly sophisticated and robust platforms may be replicated in the coming years in the sensor world. Such an evolution is fundamental if

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the objectives of Ambient Intelligence(AmI) [8], namely achieving intuitive interaction between smart environments and their inhabitants, are to be realised in practice. Thus the question arises - to what degree can intelligent techniques be harnessed by sensor platforms and what particular category of problems may be solved (or mitigated) by adopting such techniques? A prerequisite for exploring these fundamental questions is the availability of robust intelligent Wireless Sensor Network (iWSN) platform that supports a variety of sensing modalities while supporting the practical operation of a lightweight intelligent frameworks.

1.2 Background

Sensors act in a reactive stimulus/report manner for the most part. On detecting some measurable phenomena, they report this to a central server or, more likely, a nearby base station in the WSN configuration. There, the data is processed and interpreted, according to the criteria specified by the network designers. The net result of this is significant data traffic on the network, which has considerable implications for power consumption, perceived network performance and ultimately, the operational lifespan of the WSN.

From this description, it is useful to classify networks using two schemes. In the first instance, the network connection adopted may serve as a classifier:

1. A wired sensor network uses a fixed network infrastructure, for example, Ethernet, to communicate either between nodes on the network, or with a centralised gateway node and server.
2. A Wireless Sensor Network (WSN) uses some wireless technology, for example, Zigbee, to communicate with other nodes.

Secondly the issue of power may be considered:

1. Many sensor networks can be connected to the electricity grid; others may be powered by significant power packs that can support the operation of the network for many months. Indeed, such networks can be reinforced with mechanisms for recharging, for example small solar panels.
2. Most sensors are powered by conventional batteries, meaning that their practical operation may be limited to days rather than months.

Traditionally, legacy sensor networks have fixed connectionss to the grid, support significant storage facilities. If real-time data feeds are required, the data may be routed via an fixed internet connection to a base station or web server. In industrial environments, a SCADA system would be a typical example.

Recent research in sensors is motivated in many instances by the potential of sensor platforms as enabling technologies for pervasive computing and

AmI. Thus WSNs, due to their flexibility and lightweight nature are of particular interest. Such networks are inherently resource constrained from a computational and power supply perspective, in the later case due to the finite power supply of their batteries. The potential of such networks and the practical constraints under which their operate make them a particularly interesting study and a promising platform for harnessing intelligent solutions to manage these constraints.

It should be noted that classifications of sensor and sensor network exist, for example static and dynamic, mobile and fixed, and so on. These have their own particular characteristics and pose many interesting research challenges. For the purposes of this discussion, focus remains on the typical wireless sensor node and its key operational constraint, namely energy supply.

A number of sensor mote platforms are available commercially. Typical examples include the TelosB [4] and the WASP mote [3]. TelosB motes are based on TinyOS and are programmed in NesC. The WASP mote is programmed in C. It can already be seen that the issues of heterogeneity and lack of interoperability will be become significant problems, should WSNs gain traction in the manner envisaged. From a software engineering perspective, the middleware construct has been proposed by many researchers as a solution to this problem [2] [11]. Though relatively simple computational artefacts, developing software for motes can be time consuming in all but the most trivial cases.

Within the WSN mote category, a more powerful platform is that of the Oracle SunSPOT [10]. This prototype mote platform supports a number of standard sensors. More importantly, it supports a J2ME compatible JVM - SQUAWK [9]. This makes application development easier, given the popularity of Java. It also suggests the possibility of interoperability with other embedded devices that support a compatible software framework, including mobile phones.

In summary: many developments have taken place in WSN-enabling technologies, and a number of prototype deployments have been described in the literature. Yet it must be stated unequivocally that WSNs remain theoretical entities for the most part, and a number of fundamental problems must still be overcome before their potential in smart environments can be fully exploited.

1.3 iWSN Requirements

Designing a node platform for iWSNs demands the consideration of three key issues

1. Power Monitoring - As discussed, power a key determinant of the network operational longevity. Thus its use must be understood and quantified in all scenarios. This exercise is more akin in many regards to embedded

systems design rather than conventional software engineering. However, conventional approaches using battery voltage are inherently inaccurate; thus a highly accurate method of measuring power consumption in real-time is required.

2. Intelligent Reasoning It is necessary that the platform supports embedded reasoning. A facility for meta-reasoning is also required, again due the available power being at a premium and its usage in all circumstances must be measured and justified. The applicability of embedded in-situ reasoning are many but one generic issue is that of minimising the need for data traffic. Thus rather than a simple *stimulus/response* behaviour pattern, a *stimulus/deliberation/response* pattern may be realised. In essence, this is a continuation of a trend that increasingly enables the deployment of intelligence in a distributed fashion and on the peripheral nodes of communications networks [7].
3. Scalability - Though scalability can be designed for, and simulation tools can be used to validate these designs, it is only in deploying a sensor test bed in the physical environment that scalability can ultimately be validated. Thus practical economic constraints limit the efficacy of scalability testing. This demands that unit price per node be kept to a minimum.

1.4 Design of Intelligent Sensor Node

A sensor mote platform has been commissioned by Tyndall National Institute in line with the requirements listed above. Conceptually, it may be regarded as constituting four layers - each of which is now described. Figure 1.2 illustrates the iWSN java board; a schematic may be viewed in Figure 1.1.

1.4.1 Power Monitoring Layer

This layer enables real-time system power usage measurement. This incorporates a battery gauge monitor utilizing a Coulomb counter which has a unique feature in that it continues to accumulate (integrate) current flow in either direction even as the rest of the internal microcontroller is placed in a very low power state, further lowering power consumption without compromising system accuracy. This achieves independence of current waveform shape, thus simplifying the required DSP calculations that are required due to the duty cycling & pulse current profiles of typical sensor mote platforms. This approach differs from conventional approaches that rely on a snapshot of the battery voltage - something that is highly susceptible to environmental operating conditions.

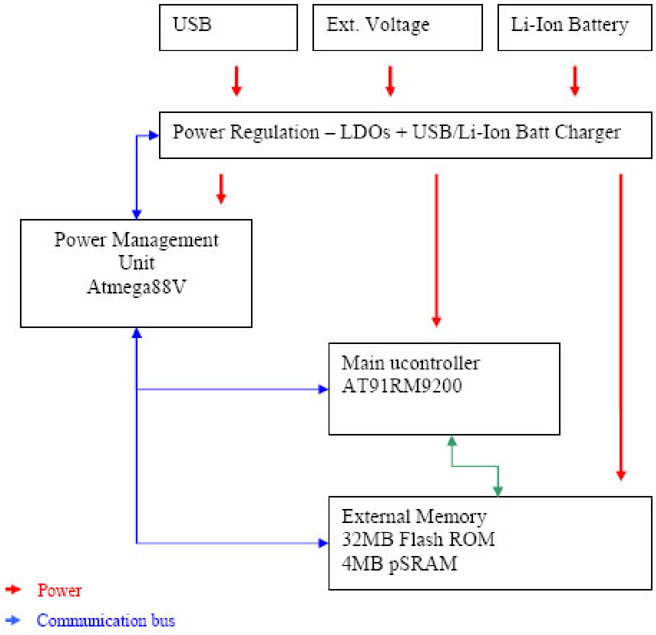

Fig. 1.1 Architecture of the iWSN Java board.

1.4.2 Java Board Layer

The Java board is based on the eSPOT board, an open source design of the SUNSPOT project. Compatible with J2ME, this allows the deployment of intelligent techniques such as intelligent agents, for example Agent Factory Micro Edition [5] or even expert system technology [1]. A software stack that can accommodate intelligent reasoning within a WSN has been successfully deployed on the Intelligent Sensor Node. The ability to host agents, specifically Belief Desire Intention (BDI) agents, on sensor nodes facilitates the opportunistic collaboration of sensing nodes in the collection, routing, filtering and analysis of data. It also enables the sensor network to operate in concert in the collection of data this is particularly important where the sensing devices are computationally challenged and where power depletion is critical to the continued operation of the network as a whole while preserving Quality of Service (QoS) constraints. It is often claimed that such sensor nodes ought to be denuded of in-network processing. Furthermore intelligent reasoning in situ has, historically, been viewed as computationally inappropriate. The iWSN power monitoring layer provides a mechanism by which we can directly compute the cost of intelligent computation and develop utility-based intelligent reasoning where the net benefit of a deduction in terms of potential power savings resulting from reduced data sensing, filtering or simply discarding of certain data.

1.4.3 Communications Layer

This consists of a 25x25mm Zigbee Layer, and enables interaction with legacy sensor boards. This design could easily be adapted to other wireless protocols technologies developed as a 25*25mm layer [6], for example, a Bluetooth layer has already been demonstrated.

1.4.4 Sensor Layer

This layer comprises a generic suite of sensors which can be configured as per domain requirements. A wide range of additional sensors can be incorporated if required.

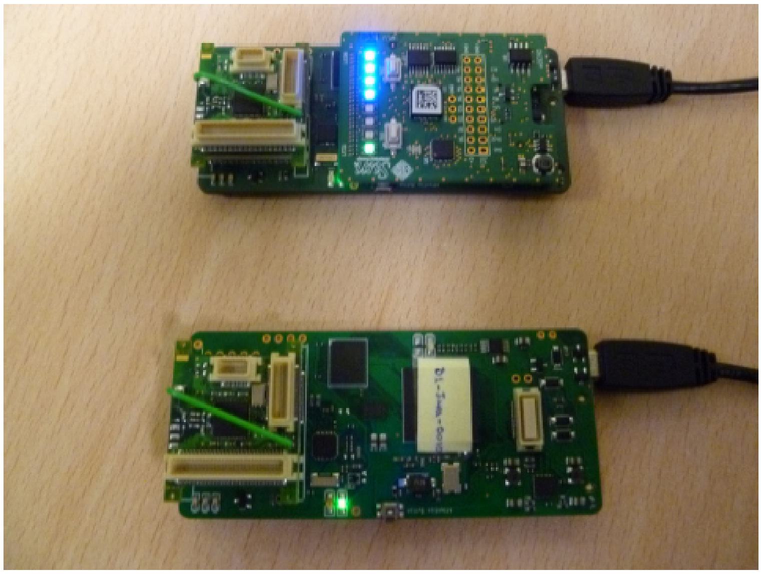

Fig. 1.2 The prototype iWSN Java Board.

1.5 Future Work

As an initial step towards validating the platform, the AFME framework has been successfully deployed on a node. Both agents and sensor networks are inherently distributed constructs, thus to fully validate the node, it is necessary to deploy iWSN testbed, and explore its operation under a variety of conditions. Plans for such a testbed are well advanced. It is hoped that this testbed will lead to new insights regarding the practical deployment of agents on WSN nodes, how best to harness their reasoning and social capabilities, as well as identifying scenarios where iWSNs may offer a more apt approach. It may be envisaged that in practice, WSNs will incorporate a heterogeneous suite of nodes. How this will manifest itself in practices remains to be seen; however as an initial step, the potential of supporting the SunSPOT eDemo board is being investigated. Finally, a range of additional power management approaches are also being considered.

1.6 Conclusions

iWSNs will constitute one of the cornerstones of the next generation of computing paradigms, including AmI solutions as well as services based on the sensor web. A deeper understanding of iWSNs and role they may fulfil is required, particularly in achieving intuitive interaction with a heterogeneous, static or mobile end-user population. Fundamental to this is the availability of a robust node hardware platform that support intelligent decision making in-situ. In this paper, the design of such a node has been presented.

Acknowledgements The support of the National Access Program (NAP) provided by the Tyndall National Institute, and that of Science Foundation Ireland under grant 07/CE/I1147 is acknowledged.

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