Cost-effective realisation of the Internet of Things

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***Abstract*—A hardware and software platform, created to facilitate power usage and power quality measurements along with direct power line actuation is under development. Additional general purpose control and sensing interfaces have been integrated. Measurements are persistently stored on each node to allow asynchronous retrieval of data without the need for a central server. The device communicates using an IEEE 802.15.4 radio transceiver to create a self-configuring mesh network. Users can interface with the mesh network by connecting to any node via USB and utilising the developed high level API and interactive environment.**

***Index Terms*—Wireless sensor networks, ubiquitous computing**

I. Introduction

A plethora of devices that generate information and provide services are now ubiquitous in modern society, yet only a fraction of these devices make this information and control accessible. Everything from the motion sensors connected to house alarms to refrigerators, geysers, computers, televisions and sound systems gather information, but they do not make this information externally available. Many devices also perform actions — such as refrigerators turning on and off to maintain a temperature — that could benefit from accessible external information such as the state of occupancy. An essential part of the Internet of Things is the ability for appliances to export this information and the control of these services so that they may be interconnected.

Energy conservation is of increasing importance in South Africa due to the increasing cost of electricity and the increase in the number of buildings being connected to the grid daily. Globally, businesses are adopting green practices in order to save money and lower their carbon footprints. These trends are making energy usage information critical.

Information about the quality of the provided power is equally important, especially in South Africa where service interruption and equipment damage due to power fluctuations are commonplace.

This research explores the creation of a network of interconnected devices with sensory and actuation capabilities, allowing energy usage to be monitored and automatically controlled. This will allow mitigating actions to be taken in response to "dirty" power events and will allow greater control over energy waste.

II. Related Work

Similar mesh networked power sensors have been constructed [1], [2], but the primary focus has been on power sensing and limited actuation functionality. In contrast, this research focuses on cheap mesh-networked sensors that are aware of power quality in addition to power usage and expose a high level control interface to the end user allowing dynamic functionality.

III. Hardware

At present, a custom hardware platform has been designed and constructed to provide an extensible mesh network of nodes, providing a variety of sensor data and control. The firmware and software layers are currently under development.

A. Power Sensing

The energy usage sensor built into each node utilises an in-line Hall Effect current sensing element combined with a voltage sensor to obtain the real and reactive power information from an instrumented device. This device can be a single three phase load or three independent single phase loads. This configuration allows the full complex power measurements to be used in later calculations of energy efficiency and power factor. Sufficient accuracy exists for appliance states to be inferred using Non Intrusive Load Monitoring disaggregation techniques, such as those presented in [3], allowing multiple devices to be connected to a single power monitoring node while still allowing the power usage of each individual device to be calculated.

B. Actuation

Actuation capabilities are important for the deployment of systems that can react to sensed information without requiring a human to manually turn instrumented devices on or off. Each node is equipped with three high current TRIACs that allow actuation capabilities. This can be used for automated response to power quality events or power consumption limits. A building, for examle, could be instrumented such that high power loads (such as air conditioning and water heating) turn off when the total current draw is approaching a pre-determined limit. This is also applicable in the residential sector where it allows houses that would otherwise require a more expensive 60 Ampere main electricity supply to function off a cheaper 40 Ampere supply. In addition, this allows appliances that are sensitive to intermittent power failures - such as refrigeration units or inductive loads - to be switched off while the power supply is sporadic or otherwise unclean.

By combining actuation capabilities with information present from sensor information gathered from multiple devices, advanced automated behaviour can be programmed. This allows systems that would typically require expensive Programmable Logic Controllers to be created with minimal cost and complexity, such as a smart building that turns on the air conditioning in a room when the door is opened, or a house that lowers the temperature of the bar fridge when the owner comes home from work.

C. Communication and Deployment

The platform has been designed for fast, zero configuration deployment. Each node connects to a mesh network using an IEEE 802.15.4 radio transceiver that automatically determines the best position for the node in the mesh topography. Currently the platform uses Microchip MiWi [4] to provide the network and transport layers, but the feasibility of ZigBee [5] is being investigated. The mesh topography is a cluster tree that differentiates between Full Function Devices (FFDs) which can be running permanently and Reduced Function Devices (RFDs) which are only powered on intermittently (either to save power or because they are part of a device that is not always on). Two different radio transceivers are supported allowing a low power node (with a range of 100m) or a high power node (with a range of 1km). Low power nodes utilise a battery as an alternative power source and continue to monitor and report on line voltage information even during brownout or blackout events, in contrast to high power nodes which require a connection to the power grid.

Every node is equipped with a USB port, allowing it to connect to a computer and function as a point of presence on the mesh. A user would typically plug their computer into a node and then access devices on the network.

D. Persistent Storage

Each node is equipped with an SD card so that the information gathered can be stored and returned to a client asynchronously. This differs from the approach of several sensor mesh networks [1], [2], [6] that only relay information to more powerful nodes with no persistent storage. Although this addition incurs a small increase in price, data is not lost when network failures occur. It also enables an end user to connect to the mesh at any point and query the nodes for data, rather than requiring the user to connect to a gateway that has been storing the data the sensor has generated. This is in line with the Internet of Things philosophy of smart appliances — rather than dumb appliances which rely on a single smart server. The smart server approach also creates a single point of failure.

IV. Software

A software suite named pyscade — PYthon Supervisory Control and Data Environment — has been written to allow interactive control of a mesh network of smart appliances using an embedded Python interpreter. The details of reliable communication, control and data acquisition have been abstracted to reduce the learning curve of interfacing with complex systems. A script that obtains a week of measurements from multiple sensors, averages them and plots the result requires approximately ten lines of code. The feasibility of deploying small Python snippets directly onto the nodes themselves is currently being investigated. This would allow custom automated responses to events even in the absence of a controlling client.

V. Instrumentation of Non-Smart devices

As the system utilises in-line power sensors and actuators to determine the energy usage of the instrumented devices, no modification needs to be made to the devices themselves. This allows devices without IP connectivity to become "smart devices" that can be controlled remotely. More invasive methods of instrumentation are being investigated that would provide a wider array of information about the internal states of appliances (such as how much time is left on the microwave timer). This is critical for the realisation of the Internet of Things where all information is available to users and users have the ability to control every device in their environment without being physically present.

VI. Conclusion

This platform offers vertical integration of hardware, firmware and software to create a powerful system that gathers power usage, power quality and appliance state information over a mesh network from a variety of devices. It then makes it accessible via a high level API. Work is currently in progress on the firmware and software layers, with the intention of deploying the system in a variety of scenarios for evaluation.

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References

[1] X. Jiang, S. Dawson-Haggerty, P. Dutta, and D. Culler, "Design and implementation of a high-fidelity ac metering network," in *Proceedings of the 2009 International Conference on Information Processing in Sensor Networks*, 2009, pp. 253–264.

[2] T. Weng, B. Balaji, S. Dutta, R. Gupta, and Y. Agarwal, "Managing plug-loads for demand response within buildings," 2011.

[3] H. Gonalves, A. Ocneanu, and M. Berges, "Unsupervised disaggregation of appliances using aggregated consumption data," 2011.

[4] Microchip MiWi - AN 1284. [Online]. Available: http://ww1.microchip.com/downloads/en/AppNotes/01284A.pdf

[5] Z. Alliance. (2012, 5) Zigbee standards overview. [Online]. Available: http://www.zigbee.org/standards/

[6] Y. Agarwal, B. Balaji, R. Gupta, J. Lyles, M. Wei, and T. Weng, "Occupancy-driven energy management for smart building automation," 2010.

Michael Andersen received his graduate degree from Rhodes University in 2012 and is presently studying towards his BSc Hons in Computer Science and Electronics. His research interests include pervasive computing, embedded hardware design and the Internet of Things.