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Towards a commodity solution for the internet of things

Haifeng Xu[a], William O. Collinge[a], Laura A. Schaefer[b], Amy E. Landis[c], Melissa M. Bilec[a], Alex K. Jones[a,*]

[a] Swanson School of Engineering, University of Pittsburgh, Pittsburgh, PA 15261, USA
[b] Brown School of Engineering, Rice University, Houston, TX 77005, USA
[c] College of Engineering and Science, Clemson University, Clemson, SC 29634, USA

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ABSTRACT

Embedded-class processors found in commodity palmtop computers continue to become increasingly capable. Moreover, wireless connectivity in these systems provides new opportunities in designing flexible and smarter wireless sensor networks (WSNs). In this paper, we present Lynx, a self-organizing wireless sensor network framework. Leveraging palmtop systems as sensor hubs, Lynx provides fundamental functionality to make a distributively managed, customizable WSN system implementation. Second, we describe Ocelot, a mobile distributed grid-like computing engine for commodity palmtop platforms. The combination of Lynx and Ocelot provides sensor nodes that are capable of collecting, recording, processing, and communicating data without any central server support. Significant energy savings can be achieved for light to medium weight tasks through the Lynx and Ocelot combined system compared to traditional server-class grid-solutions such as BOINC. We demonstrate Lynx and Ocelot in the context of life-cycle building energy usage.

1. Introduction

Wireless sensor networks (WSNs) can be broadly defined as any system containing wireless communication and sensing capability. Their applications range from the military domain, including tasks such as battlefield surveillance, to consumer products for in-home energy monitoring and control. As such, WSNs have become an area of significant interest and research activity for a wide variety of academic and commercial research groups. These research topics range from device-level energy harvesting to system-level communication protocol design.

Most of the existing standards for WSNs address specific points in the design space for such systems. The most common standard is the IEEE 802.15.4, more commonly referred to as the ZigBee communication standard. ZigBee is designed to provide inexpensive, low-power, reliable communication over relatively long distances, accomplished in part by utilizing a relatively low data rate in the kbps range. Thus, several WSN products exist that employ the ZigBee communication standard. However, while ZigBee is an attempt to optimize the communication protocol for implementing a WSN, WSNs can be constructed using any protocol and hardware platform including common communication standards such as Bluetooth and WiFi (IEEE 802.11).

There is considerable WSN research effort targeting improving system capabilities, including developing algorithms for improving node battery lifetime, system connectivity, and performance [1–3]. Further, some efforts explore methods for distributing data across the network to maximize data availability when link connectivity is lost, while minimizing system

* Corresponding author. Tel.: +412 624 9666; Fax.: +4126248000.

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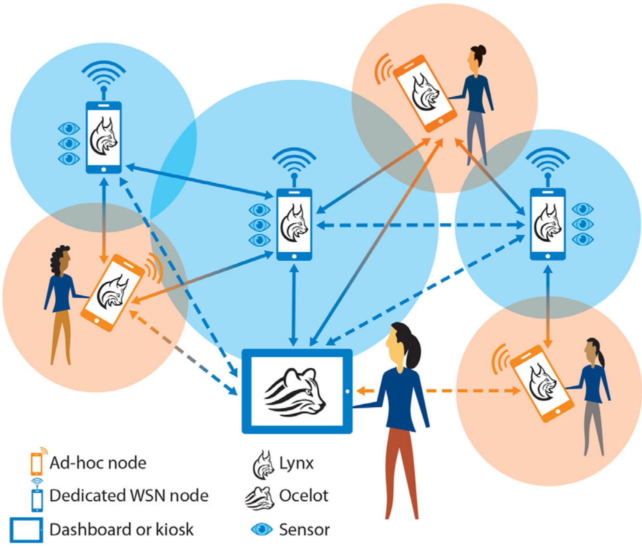

Fig. 1. Overview of the Lynx network with the Ocelot distributed computing system.

storage and energy overheads [4,5]. Goals of this class of research typically involve maximizing WSN lifetime and robustness under a fixed aggregate system energy storage capacity constraint.

Most of these efforts work at the algorithmic level and rely on simulation environments to determine their effectiveness. Popular simulators include NetSim [6] and OPNET [7]. Unfortunately, testing new algorithms and ideas in simulation does not always capture the full nature of the system. While certain faults and inefficiencies can be anticipated, use of a real system, even when employing hardware emulation and different physical layer communication protocols, can provide a much more realistic testing environment for WSN proposals.

This paper describes a complete WSN and distributed computing platform that is a first step towards a general commodity solution for nodes in the Internet of Things. *Lynx*[1] is a wireless sensor network research environment based on commodity hardware/software systems. Given the proliferation of tablets, smart-phones, and music players, there is a continually expanding platform of devices that can be used to form a WSN. The typical smart-phone or tablet supports multiple communication protocols such as WiFi, Bluetooth, near-field communication (NFC), and GSM. Further, these devices often offer several on-board sensors, including accelerometers, GPS sensors, light sensors, and temperature sensors. These devices are battery operated with relatively long lifetimes, making them highly portable and mobile.

Lynx has two fundamental goals and purposes:

- **Allow the creation of a WSN out-of-the-box, leveraging existing sensing and networking capabilities:** Using Lynx, it is possible to quickly construct a sensor network from existing devices, many of which are already deployed by users for their more traditional purpose (e.g., smart-phone, tablet function). Lynx can provide access to sensor data from on-board sensors and external sensors.
- **Study WSN system advancements using hardware emulation:** The relatively low cost, flexibility, and capability of smart-phones and tablets provides a natural platform for the study of WSN communication and resource management algorithms, including distributed storage and battery maximization techniques. Lynx provides a extensible framework to study these effects in real time and with real environmental conditions.

For integration with Lynx, we present Ocelot[2], our previous work in the distributed mobile computing area [8]. Ocelot can be used in scenarios where highly parallel, lightweight computational tasks can be partitioned and distributed in an effort to save energy over what would otherwise be required to complete the work with workstation or server machines. An overview of our Lynx and Ocelot system is shown in Fig. 1, and discussed in more detail in Section 3. Additionally, Ocelot can be used in an application-specific WSN scenario in which it is difficult/impossible or undesirable to deploy dedicated computational infrastructure. Conceptually, Ocelot is modeled after the Berkeley Open Infrastructure for Network Computing (BOINC) [9], an open source middleware system for volunteer and grid computing on PCs and servers. However, BOINC is complex, requiring considerable computational effort just to initiate and manage connections with the BOINC servers. On a

[1] The University of Pittsburgh mascot is the panther, which in different contexts refers to cougars, jaguars, or leopards. A lynx is a small wild cat related to leopards, and thus, also to panthers. The name was selected for this system because the relationship between a lynx and a leopard is similar to that of a low-power wireless protocol used in WSNs to high-power wireless protocols used in other contexts. Additionally, lynx is a homophone for network "links."

[2] Similar to Lynx, Ocelot is also a smaller leopard relative and represents the embedded processor in a tablet in comparison to workstation-class processors.