Dynamic Energy Management for the Constrained IoT

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***Abstract*—A generic energy management on IoT nodes that maximizes performance while being accurate and reliable can be challenging. Solutions to this problem are often tied to platform specific properties and not reusable. This research statement outlines the problem space of dynamic energy management for constrained IoT devices. It gives a short introduction on related work that already addresses some of these problems. The first contributions in form of a vertical implementation of a widely applicable self-measurement for class-1 IoT nodes are discussed. Additionally, a fully modular experimentation-platform for tests and evaluation of energy management components in real deployment scenarios is highlighted. Towards a generic solution for dynamic energy management, an outlook on future research directions targeted by the author is presented.**

***Index Terms*—Internet of things, energy management, self-measurement**

I. INTRODUCTION

The IoT will connect everything, everywhere at any time. To move towards that vision cheap embedded systems are used. All of these ubiquitous devices require energy to operate. Thus, energy management should be available as a generic system component. In contrast to scarce resources like memory and computational power, energy is of a much more dynamic nature in this case.

Many solutions exist to work around the various limitations of IoT devices. Low computation and memory capabilities are tackled by light-weight versions of protocols and software implementations. Optimized operating systems provide hardware abstractions for platform independent programming and shorten time for development by providing helpful standard functionality and extension libraries. Even more than other resources on typical IoT devices, energy is scarce and needs to be managed effectively. Energy-Harvesting for example poses a real alternative to conventional battery-powered systems. With varying inflow the dynamic energy availability heavily depends on environmental conditions. On top of the changing energy availability, adaptive and runtime updated code requires flexible control over energy resources that is application-agnostic. Though, energy management is still subject to proprietary and custom solutions without generic interfaces and most of the time requires deep knowledge of the underlying hardware platform to be implemented correctly.

II. PROBLEM DESCRIPTION

Energy management in general puts up multiple problem spaces that need to be addressed separately. For IoT devices the individual problems have further constraints because of the inherent properties like low cost and scarcity of almost any available resources. From an abstract perspective the following directions can be identified as separate problem spaces, each providing another focus-point for further research.

A. Quantification

Before energy can be managed as a resource, its availability and demand needs to be quantified. Most applied methods resort to either estimations or measurements. Additional challenges are implied by the required accuracy, overhead and general applicability. For estimations, a lot of work revolves around the creation, parametrization and evaluation of different model. On the measurement side, typical problems of metrology pair with the inherently low resource availability and low cost target of IoT devices. Custom solutions already provide good performance but on the downside void general applicability.

B. Attribution

Fine grained management of energy is only possible if there is a good understanding on how the energy is spent. Attribution mechanisms differ e.g. in the physical or logical entities to which the energy usage is attributed. For very simple sensors it might be enough to know the overall power consumption for the system. More sophisticated instances with higher dynamics from meshed networking, adaptive applications or even runtime deployed code require finer granularity for attributing used energy to software components.

C. Allocation

Another essential requirement is a mechanism to provision available energy to entities in need including a descriptive configuration pattern that can be controlled by the developer. A respective system component would be responsible for monitoring and enforcing developer defined policies and strategies. Defining how this allocation should be performed also requires an expressive format for description, encoding and exchange of those definitions.

D. Abstraction & Integration

For small IoT devices abstraction is a major concern. The IoT application developer should not be bothered with low level details of various platforms an application will be running on. Providing a single compatible interface to control the low-level features of embedded MCUs is difficult though. As an example, configuring low power settings of modern MCUs differs significantly in terms of granularity and inter-peripheral dependencies, especially when crossing vendor borders. Implementing dynamic energy management as a generic system component thus requires substantial efforts towards creating light-weight, yet powerful abstraction layers.

III. Related Work

Several approaches can be found in the literature which address the problems described in section II. Different research directions exist for measurement [5], estimation [2], simulation [8] and attribution [4]. Until now, lots of the research is focusing either on single aspects or specialized solutions for isolated domains. While lots of work can be found on very accurate external measurement of node power consumption [6], [9], self-measurement that can be employed on IoT devices directly was only implemented as very specialized solution tightly coupled with the used platform [3] or with estimations that require preliminary measurements for providing model parameters [2].

With this, energy management on constrained devices is still not available as a generic system service and often needs to be implemented from scratch for every application. As of now, there is no generic solution that combines measurement, attribution and allocation in a generic system service and is applied online.

IV. Contribution

The research contribution I am working on targets making energy management available as a generic base-component within the IoT operating system RIOT [1]. The following describes ongoing research contributions and how they will improve the state-of-the-art.

With a first step, research on self-measuring power consumption on IoT nodes is targeted. For that, applicability of commodity measurement instrumentation on nodes themselves is investigated. Extensive evaluation measurements were performed to gain insights on how much overhead is associated with fine-granular self-measurement and what degree of accuracy is achievable while keeping platform independence.

For early prove-of-concept trials of new approaches and for thorough in-field testing a fully modular, self-sustaining Energy-Harvesting system was developed based on our previous work [7]. The System builds upon off-the-shelve components and enables long-term field trials – even at remote locations completely off-grid. It allows flexible hardware configurations including different power sources, energy storage components, peripheral sensors and actuators and network interfaces.

A full vertical implementation of first OS-level energy management primitives were implemented and tested under real deployment conditions with the developed system. First results indicate that combining commodity power measurement instrumentation with OS-level hardware abstraction and consumption attribution is promising for generic, light-weight energy management that is agnostic to used hardware platforms and application software.

Providing generic energy management as part of the OS enables developers to build platform independent energy aware applications that can prolong lifetime and adapt to runtime conditions without knowledge of low level system properties.

V. Outlook

Planned topics for future work raise from the domains introduced in section II. Correlating used energy with executed software and individual hardware peripherals requires some preliminaries to be in place. First, a light-weight tracking of system and peripheral states (similar to the mechanisms presented by Dunkels *et al.* [2] and Fonseca *et al.* [4]) must be provided at operating system level and thoroughly evaluated for several platforms. Additional work is also needed for evaluating the question: *Which are appropriate and required entities to meaningfully represent energy conditions in a system?*

A mapping at suitably low-footprint is required to use the state tracking with the self-measurement of power consumption previously described in section IV to attribute energy to the respective entities at runtime.

Extensive long-term deployments in a mobile environmental sensing context will be conducted to gather credible data and perform real-world testing of developed methods and tools.

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