Bringing IoT closer to carbon neutrality

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Abstract—Internet of things (IoT) is present in our daily lives in a variety of forms, including wearable devices, smart home appliances, smart sensors and actuators, healthcare, and smart mobility. The IoT market is anticipated to reach \$3,352.97 billion by 2030. IoT devices are primarily battery-powered, so power management is the primary concern. In 2012, author had his first experience with power consumption and energy measurement through a collaborative project with the Institute of Horticulture. Since then, author has been striving to make the Internet of Things more energy-efficient. This abstract summarizes the results of the ongoing work this area.

Keywords-IoT, WSN, TestBed, GHG, Carbon footprint

I. INTRODUCTION

Carbon footprint, sometimes referred to as climate footprint, is an estimation of ecological impact, often in relation to global warming, often estimated as the sum of all greenhouse gas (GHG) emissions of a specific process [1]. In the world of Internet of Things (IoT), calculating GHG is difficult because no one knows the total quantity of GHG emitted by an IoT device due to the complex calculations required [2]. The total quantity can only be speculated and estimated by factoring in the footprint of each chip, the manufacturing of the device itself, the energy costs of software development, the energy efficiency of the device while running, its overall life expectancy before replacement, impact of deployment, etc.

Author is concentrating on the energy efficiency portion of the IoT carbon footprint because it is a variable that can be measured and influenced by certain actions, such as selection of specific hardware components, software component optimization, duty cycle adjustments, etc. The author has been acutely aware of the carbon footprint issues of IoT devices ever since the the development of their first Wireless Sensor Network (WSN) node - SADmote [3], described in Section II. After developing this node, the author commenced work on a real-time energy consumption measurement system for WSN [4] described in Section III, which was subsequently incorporated into WSN TestBed [5] described in Section IV. Finally the current results and future work are shortly discussed in Section V.

II. SADMOTE

SAD was the first project in which the author was challenged to create a node that could withstand harsh environments and capture data for an extended periods of time [3]. Author created a sensor node dubbed SADmote, whose primary purpose was to collect data on environmental factors such as temperature, humidity, and available light. This node needed to be effective enough to collect data and transmit it throughout the network. The sensor network of these nodes was deployed in an orchard owned by the Institute of Horticulture. The primary goal of this network was to collect environmental data that would aid researchers in boosting crop yield and combating horticultural issues such as insufficient water or sunlight. The author was tasked with developing this device's circuitry from the ground up, during which the author identified the need for current measurements to enhance the field dependability of WSN nodes.

III. REAL TIME ENERGY CONSUMPTION MEASUREMENT DEVICE

As part of a term paper [4], the author began working on a superior method for measuring the energy consumption of WSN nodes following the development of SADmote. The device was required to be both dependable and simple to use with terminal or USB connections. The idea arose after using instrument-based energy consumption measurements [6], which included a multimeter and occasionally an oscilloscope to gather the measurements. The devised device was able to automatically collect energy consumption data with an error rate of up to 13.44%.

IV. WIRELESS SENSOR NETWORK TESTBED

The subsequent step was to increase the scale and introduce the capability of real-time energy consumption measurements to multiple WSN nodes at once. The energy consumption measurement device was created in EDI TestBed [5], a facility that enables users to develop, test, and debug the WSN as a whole, not just its individual components. The error rate of this measuring instrument was reduced to 0.5% through its enhancement. Afterwards, energy measurement capabilities were added to mobile EDI TestBed workstations [7] so that this functionality could be used outside of laboratory constraints and directly in the target environment. The next stage is to enhance EDI TestBed's overall functionality [8]. The measurement of energy consumption is one of the most crucial aspects of a refined and debugged IoT system. The TestBed v2 has ambitious requirements, but they are not unreachable.

A. TestBed v2 current measurement requirements

The requirements are set as follows:

- Current measurement range 2nA 3A
- Current measurement frequency 1MHz

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Fig. 1. EDI TestBed v2 enclosure 3D render.

• Current measurement accuracy 100pA

Multiple variables influence the formulation of requirements: (i) There are ultra low power microcontrollers (MCU) available [9], that in an ultra-low power-saving mode can consume as little as $0.03\mu A$ of current. (ii) Current consumption by modern IoT devices is significantly higher than it was a few years ago. A basic smart watch, for instance, can consume 3A of current while charging. (iii) To see the overall power consumption in real time during the duty cycle, it is necessary to see the current consumption changes as quickly as possible, displaying the current consumption during a packet transmission, register configuration, or memory access.

B. Progress Report

We designed the hardware portion of the testbed (See Fig. 2) and were able to acquire the majority of the necessary components for its assembly, but were unable to complete it due to the global semiconductor shortage and the complications it caused. Additionally, we designed the initial enclosure prototype for the EDI TestBed v2. As a proof-of-concept, it helps us understand the logistics of electronic components and wiring (see Fig. 1), despite the fact that it lacks the required IP67 rating at the present. At the moment, we were able to simulate our concept and construct a functional version of the MCU side of the TestBed, but additional components are required to construct the remainder of the system.



Fig. 2. EDI TestBed v2 3D render.

V. RESULTS AND FUTURE WORK

To demonstrate the significance of current consumption measurements, it is necessary to complete the development of EDI TestBed v2. After the prototype is complete, it will be used to evaluate how the actual real-time current consumption data can be used in order to enhance the device and reduce its carbon footprint. As previously mentioned, it is challenging to calculate the true carbon footprint of the WSN as a whole; however, knowing the WSN's current consumption will allow tests in multiple configurations, during which the power consumption will be logged in detail in order to get real time detailed power consumption data and based on that to optimize the WSN to have the least carbon footprint.

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