

Design and Prototype Implementation of the WattsApp Telemetry Platform

Abstract—Telemetry is an important function of the Internet of Things as it is being developed and deployed today. Of particular interest within this area are energy monitoring services. In this paper we describe WattsApp, a social telemetry gathering and comparison platform, which was built as a demonstrator that integrates technologies from embedded systems to mobile applications. We used the SNMP protocol stack developed for the Contiki embedded operating system to retrieve telemetry information from a hardware interface that reads data from S0 meters (e.g., power meters, fluid meters). A web interface and an Android mobile application lets users view this data. To ensure privacy of users' data, it is only stored at users' own premises and all communication takes place over encrypted connections. This paper provides an overview of the implementation of WattsApp.

I. INTRODUCTION

The emergence of embedded computing devices capable of wireless communications is leading to the emergence of an Internet of Things (IoT). The availability of network computing devices capable of performing limited tasks themselves opens up opportunities to develop multiple new applications in various fields. From home automation to an energy balanced smart grid for electricity generation and distribution, the IoT is expected to introduce a plethora of new computing services that rely on integrating existing software services on the Internet with the control and data-gathering capabilities of embedded devices.

However, since most embedded devices to be used in the IoT do not use an IEEE 802.11 WiFi interface [1], interconnecting them with the existing Internet infrastructure requires the development of protocols and systems that take into account the low-power and lossy radio standards currently used in embedded wireless sensor networks. To avoid the emergence of devices that are neither interoperable nor documented, the IETF developed the 6LoWPAN standard [2], [3] to enable IPv6 networking over the IEEE 802.15.4 radio standard, which is commonly used in embedded networks [4].

Using IoT technologies, like 6LoWPAN, and integrating them with well established Internet and mobile application services, WattsApp was built as a technology demonstrator to showcase a typical application of the IoT. Development was completed within a short time-frame of approximately one month within the framework of a graduate networking lab

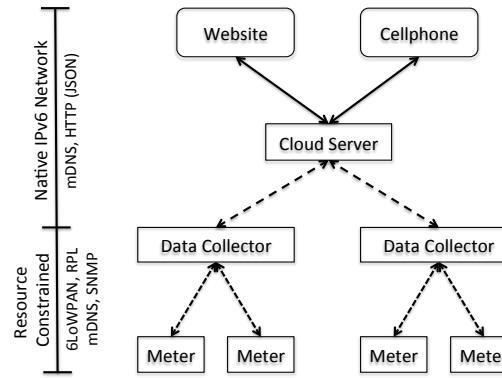


Figure 1. An overview of the WattsApp architecture. The meters and data collectors typically function within a resource constrained network, whereas all other components are based in traditional IP networks.

course. The WattsApp telemetry platform integrates embedded hardware with standard network management protocols, like SNMP, and allows users to view telemetry (e.g. energy, water or gas consumption) and share it using the Facebook social network. Multicast-DNS (mDNS) provides for automatic discovery of services (meters and data-collectors) offered within a network.

The following sections of this paper present an overview on the design of WattsApp along with a short discussion on related work. Starting from the architecture described in Section 2, we discuss the hardware interface (Section 3), the polling and storage components (Section 4), the gatekeeper located on the cloud server (Section 5) and the user interfaces (Section 6). Related work is discussed in Section 7, before we conclude the paper.

II. ARCHITECTURE AND APPLICATION OVERVIEW

The WattsApp telemetry platform is designed to collect and report time-series data from different sources. Data such as power consumption can be collected using embedded sensors or external meters attached to IPv6 enabled sensor boards.

An overview of the WattsApp architecture can be seen in Figure 1. Our implementation integrates a native IPv6 network with an 802.15.4 resource constrained network. Within the resource constrained network, meters measure power consump-

tion. Each meter uses the Contiki operating system [5] running on an Atmel AVR Raven platform and has the ENTITY-MIB [6] and ENTITY-SENSOR-MIB [7] implemented within the Contiki SNMP agent [8]. These meters are able to interface with different data reporting devices using appropriate hardware interfaces. We designed an electricity consumption meter based on the S0-Interface [9], however, the versatility of the S0-interface makes it easy to make hardware interfaces for water or gas consumption as well. In our setup, the data collectors deployed at users' premises to retrieve the data collected from the S0-interface circuit using SNMP.

The data collector communicates with the WattsApp server, i.e. the gatekeeper located at the cloud server (in Figure 1) using encrypted RESTful HTTP requests using the JSON data format. The cloud server is used for authentication and access control. It also acts as an intermediary between front-end clients and the data collectors/meters. A website and an Android OS mobile application are the front-ends which retrieve and display metered data using requests to the cloud server.

The aim of developing WattsApp was to demonstrate the integration of multiple Internet technologies, from native IPv6 and resource constrained networks to mobile and web-based applications, into a single system by using pre-existing tools. Specifically, the demonstrator was designed as a student project for the Advanced Distributed Systems Lab¹ graduate course within a period of about one-and-a-half months. Given more time, the system could likely have been designed to provide better performance, however, by using mostly pre-existing tools it became clear that it is possible to rapidly develop a stable IPv6 capable system.

Furthermore, since each meter device is capable of being assigned a globally routable IPv6 address, it can be reasoned that any device, mobile or otherwise, could directly communicate with them. Reusing protocols such as SNMP for management and monitoring of these devices then presents a great advantage because a number of existing tools (e.g. graphing tools like Cacti) can be used without adaptation.

III. HARDWARE INTERFACE

Since WattsApp is a telemetry platform, gathering data is one of the most important tasks. Since the IoT is expected to be an enabling technology for smart-grids, designing meters capable of measuring energy, water and gas consumption was deemed important for the demonstrator. Not only was it necessary to build the hardware to gather this information, but ensuring that this information could be accessed in an Internet standards compliant way was also important.

The following sub-sections present the design of the metering hardware, along with information on the interface that allows retrieval of this data over SNMP.

A. S0 Pulse Counter Circuit

High power AC-current circuits and digital circuits normally do not mix very well due to the high differences in the

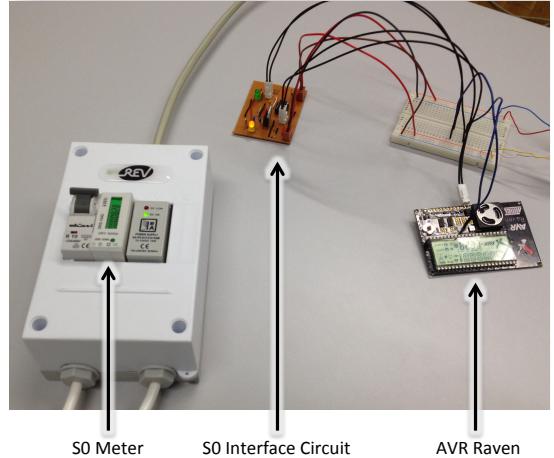


Figure 3. The S0 interface for the electricity meter along with the AVR Raven based data exporting device. The S0 interface converts the S0 current pulses into digital voltage pulses, which are logged via interrupts in the AVR Raven in order to count energy consumption and export this data to a collector via a poller script.

voltage and currents involved in such systems. As such, in order to measure electricity consumption, with the ability to transfer this information into digital systems poses some challenges. Furthermore, since the aim of WattsApp was not only to monitor electricity consumption, but also other utilities like water and gas, it was important to choose a metering method that enables recording consumption values for all these utilities.

The S0-interface was chosen for this purpose since there are many meters capable of measuring electricity, gas and water consumption based on this system. The S0-interface is a pulse-modulation system that, unlike digital systems, is based on current rather than voltage modulation. An S0 meter takes in a DC voltage between 12-27V as power supply and causes the current across the output lines to rise up between 10-27mA, once a cumulative load of a certain value is achieved. For example, the S0 electricity meter we use causes a current pulse between 10-27mA once 1 kWh of energy has been consumed.

While counting these current pulses gives us a method of calculating the amount of energy consumed over a certain time period, digital systems are not capable of directly measuring current, and as a consequence current pulses. Digital systems normally work by equating 5V to a digital 1 (on) and 0V to a digital 0 (off). As such, pulse-modulation in digital systems normally works by measuring a voltage of 5V as on and 0V as off. This necessitates a method of converting the S0 current pulses to digital voltage pulses. We achieved this conversion by building an interface circuit, the schematic for which can be seen in Figure 2.

Since the S0 meters operate at voltages between 12-27V it is important to ensure that this voltage does not leak into the digital part of the circuit, which operates at 5V. As such, we use a digital optocoupler device which takes the output from the S0 meter. Each time the S0 meter outputs an ON pulse of 10-27mA current, an LED within the optocoupler turns on

¹<http://cnds.eecs.jacobs-university.de/courses/adsl-2011/>

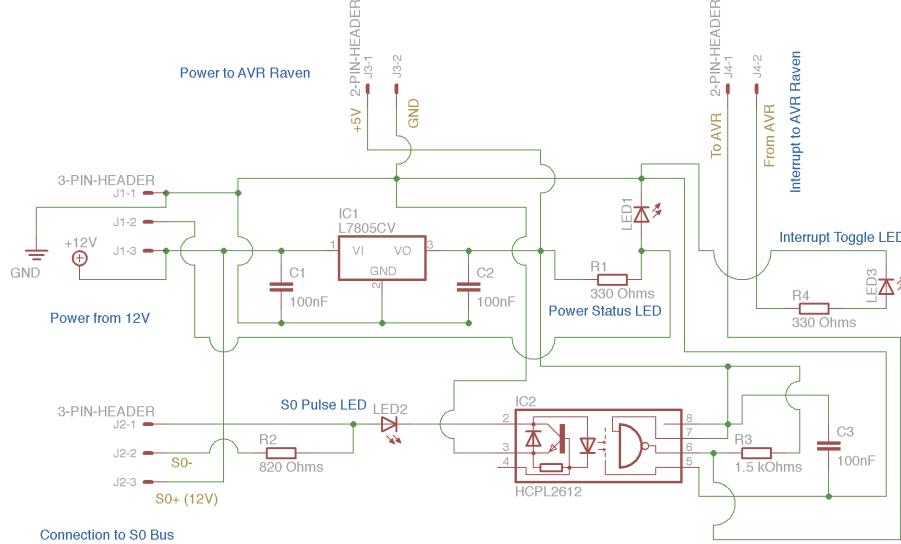


Figure 2. A circuit diagram showing the S0-interface circuit that converts S0 current pulses to digital voltage pulses. The HCPL2612 digital optocoupler is used to isolate the high voltage and current circuit from the digital part. When the S0 circuit causes a high current pulse, the HCPL2612 allows a 5V circuit to be completed, thereby causing a voltage pulse that can be counted. The L7805CV voltage regulator is used to ensure a clean and stable 5V digital signal.

and allows for the digital circuit to turn on as well. Not only does this ensure that higher voltages are never leaked into the 5V digital circuit, but it also converts a current pulse into a digital voltage pulse. These digital voltage pulses may now be counted and aggregated to obtain consumption values over time.

B. AVR Raven Contiki SNMP Interface

Once the output from the S0 meters is available in digital form, this must be aggregated and a method provided for it to be retrieved via a network. Since the aim was to integrate everything using IPv6, this retrieval must happen using Internet standard technologies and the meters must be reachable via IPv6. To accomplish this, the AVR Raven hardware platform was chosen since it is capable of running the Contiki OS, which brings IPv6 networking to embedded devices. Furthermore, since a SNMP agent is available for Contiki, the telemetry can be retrieved using an implementation of the ENTITY-MIB and ENTITY-SENSOR-MIB.

To retrieve consumption values from the S0-interface circuit, described in the previous sub-section, the output of the interface circuit was connected to a digital-input line on the AVR Raven. A driver for the AVR platform, which caught an interrupt each time a voltage of 5V was observed on the connected digital-input line, was written. This made it easy to count energy consumption since each time the interrupt occurred, in case of our meter it meant that 1 kWh of energy had been consumed. This data is aggregated by the AVR Raven and can be retrieved using SNMP. A poller script, described in greater detail in following sections, running on data-collectors retrieves this data and stores it in a SQLite database.

It is important to note that the stability of this system has been excellent. Ever since the system went online in late October, the only downtime that was encountered was when

the coffee-machine being monitored was removed for cleaning, prompting the University cleaning-crew to also disconnect our meter. However, this was also quickly recovered from since reconnecting the system was not difficult. An overview of the complete metering solution can be seen in Figure 3.

IV. POLLING AND STORING

Since the meters integrated with WattsApp can provide telemetry in many different units and formats, the polling script is responsible for making any device specific adaptations before storing the data in the database. This data is then relayed to the clients by a collector service, via a gatekeeper running as web-service on the cloud server. This section provides an insight into the poller and collector services of WattsApp.

A. The Polling Script

The poller is responsible for collecting data from the IPv6-enabled meters in order to store it into a database. Since interfacing to devices often requires device specific adaptations, we decided to write the polling engine in the Python language. While Python in general is a perfect fit for these kind of tasks, we were surprised that we could not find a single packaged SNMP extension for Python that supported IPv6 well.

As such, we ended up using a wrapper around the NET-SNMP tools in order to fetch data. Furthermore, we learned quickly that the poller needs to be resilient to all sorts of failures. In particular, we occasionally experience 802.15.4 failures exceeding the retransmissions we do. Furthermore, data storage can fail, in particular during times of development or software updates. The originally rather short script did grow into a script defining a class `Snmp` wrapping the NET-SNMP `snmpget` command, a class `Meter` modeling a single meter (e.g., a temperature meter or an energy meter), and a class

Exporter modeling an exporter providing access to several meters.

A discovery method detects meters at startup and assigns UUIDs to them as needed. The script is capable of detecting discontinuities and taking appropriate actions. During the development phase, Python's flexible logging API helped a lot since it allowed us to get notified about failures via Email, something invaluable since many problems occur at unforeseen times of the day. There are still many improvements possible but perhaps it is also time to consider the adoption of polling engines of applications like Nagios² or Cacti³ that already incorporate many more advanced features.

B. The Collector

The WattsApp Collector was chosen to be written in Node.js [10], which is an event driven, asynchronous I/O JavaScript environment based on Google's libv8 JavaScript engine. This choice was made, since the event-driven nature of Node.js allowed concurrent processing of requests without the drawbacks of adding complexity that comes with a multithreaded approach.

The WattsApp Collector allows clients to query for meter data via HTTP. It advertises its service upon startup via an mDNS advertisement so that any clients in the local network can discover the collector and retrieve data from it, if they are authorized to do so. All data transfer between the collector and clients is encrypted using the built-in Node.js TLS library and authentication of clients is done using X.509 certificates. If an unauthorized client tries to connect to the WattsApp Collector or a connection without TLS is initiated, an error message is returned to the initiator.

After successful authentication, a client can send HTTP GET requests to the collector and receive data in JSON format. If a valid query is received by the collector, it responds with the appropriate JSON message by retrieving data from the SQLite database into which the poller writes data collected from the meters. Functionality exposed by the Collector to authorized clients includes listing of all meters, showing meter details, blacklisting and renaming meters and setting the physical location of meters. The GET query allows the client to specify the meter for which data should be returned along with the time interval that data is requested for.

Collectors are located within a users' premises since this is the data aggregation point. Not only does this encourage data privacy, since it is not located in a central location, but also limits the chances of unauthorized access since only clients for which the user installs a X.509 certificate are permitted to communicate with it.

V. THE GATEKEEPER - CLOUD SERVER

The gatekeeper web service, which resides on the cloud server (as in Figure 1) performs the function of authenticating users and performing access control to data from collectors. This service is written in PHP using the Vanilla

²<http://www.nagios.org>

³<http://www.cacti.net/>

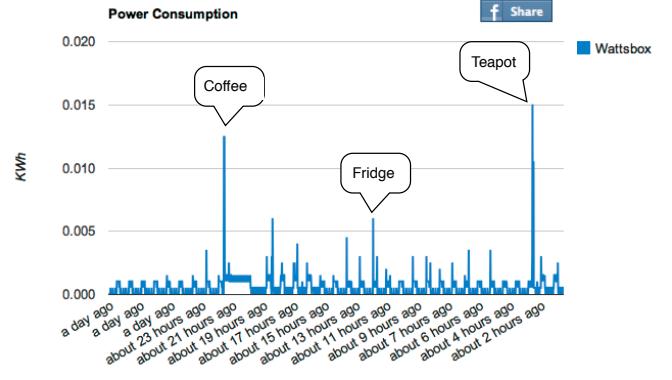


Figure 4. A typical graph output on the website client interface. This graph plots the power consumption obtained from a single meter connected to an exporter named Wattsbox. Annotations can be added to these graphs and it can also be shared on Facebook.

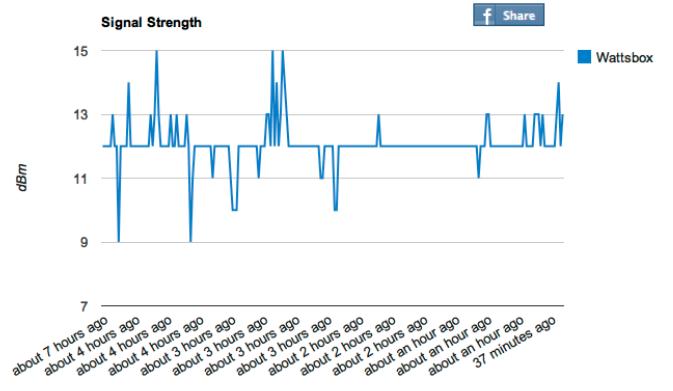


Figure 5. A typical graph output on the website client interface. Instead of energy consumption this graph plots the radio signal strength of the connection to an exporter named Wattsbox. Annotations can be added to these graphs and it can also be shared on Facebook.

MVC Framework. Once a user is successfully authenticated by using the Facebook single-sign-on, it provides both the user interfaces (web and android) application with meter data through a RESTful interface. To perform the authentication, the user interfaces provide the gatekeeper with the token and email address that Facebook returns to the application once an authentication, directly with Facebook, is completed. The gatekeeper then uses this token to check with Facebook whether the email address supplied with the token matches the user requesting access and what permission levels are associated with that user, i.e. which meters the user has access to and whether these can be edited as an administrator.

The meter data can be filtered and requested along a particular time frame. The queries to rename or change the location of a meter from either of the interfaces are also managed through the gatekeeper. The gatekeeper in itself, for privacy reasons, does not store any data which it passes to the user interfaces, but is meant to keep the user authentication and authorization centralized and simplistic. All data exchanges between the user interfaces and the gatekeeper web-service take place using the JSON data format.

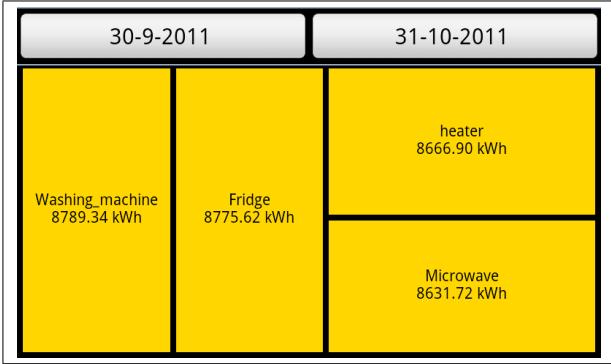


Figure 6. The treemap view, as shown by the Android application. Data returned from meters, which have directly comparable units, can be displayed in this view in order to get a quick overview of the energy consumption relationship between meters or devices.

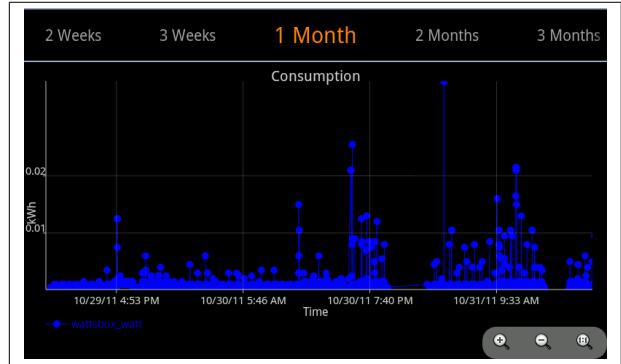


Figure 7. The detailed graph mode, as shown by the Android application. Data displayed in this view can provide deeper insights into the energy consumption patterns.

VI. USER INTERFACES

The visualization and interaction of the meter readings is possible either using our standalone website or through a freely available Android application. The web application serves two purposes; firstly, it is meant to provide a lowest common denominator for all users and to be the most powerful platform to deliver the richest experience in energy usage visualization. On the other hand, the mobile application is meant to provide data to users on the move.

A. Web Application

The web application⁴ provides a simple platform for a user to view the usage of the energy meters. The web application uses Facebook's Javascript SDK⁵ to provide single sign-on using OAuth 2.0 [11]. Once logged in, the user can view the list of the collectors he can administer or has been given permission to view the data from. A similar layout is available for the list of meters as well.

The collectors and their associated meters have their locations pinned on a google map using the Google Maps API. The energy usage can be visualized using either tree maps or line charts. Tree maps can be used to relatively compare and contrast the energy usage of the meters, which provide data in the directly comparable units. This display is similar to the one found in our Android application, as shown in Figure 6. A thorough analysis of the energy usage of a particular meter is also possible. For instance, the graph in Figure 4 shows the visualization of our energy meter that measures the power consumption of the fridge and the coffee machine connected in our office. Similarly, the signal strength of the AVR Raven that exports this energy usage is shown in Figure 5. The website is built using the jQuery framework [12].

B. Android Application

To give mobile users an opportunity to gather an insight into their telemetry data, a mobile application for Android⁶ was

developed as a client for WattsApp. This mobile application provides a simple and intuitive way of viewing data (power consumption, water consumption, etc.) that is passed to it, as well as of modifying information related to meters that collect data.

The WattsApp application uses Facebook credentials in order to authenticate itself with the server that provides the data. It also uses a single sign-on feature so that if the smartphone has a Facebook application installed and the user is logged into it, signing into the WattsApp happens automatically. Otherwise, when the application is launched the first time, a Facebook login screen is presented to the user. Once the user provides credentials and is successfully logged in, appropriate permissions needed by the application (access to the e-mail address of the user) must be accepted. After successful authentication the application stores the Facebook access token, the user ID and the time for which the token is valid since this data is used to support the Single Sign-On feature.

Authentication and permission levels are retrieved from the WattsApp server, i.e. the gatekeeper at the cloud server, by supplying to it the user ID for which the token was obtained. Since the WattsApp server has access to the token and user ID information as well, a successful match can be used to confirm the users' identity. Following this, the WattsApp server looks up the list of collectors a user has access to (including administrator privileges) and returns this data to the mobile application. The user can filter the meters by their units as well as the collectors which the meters are associated with. In case a user has full read-write permissions on a particular meter, an edit button is presented in front of the appropriate meter. Pressing the edit button displays a meter configuration page, where the user can rename a meter or manually set its new location.

⁴<http://www.wattsapp.net>

⁵<https://developers.facebook.com/docs/reference/javascript/>

⁶<https://market.android.com/details?id=de.jacobs.university.ads.wattsapp.activities>

A user may select multiple meters to display the data from by selecting the check boxes next to each meter. Data from meters can be displayed in two modes - Treemap or Graphical plot. In the Treemap mode only the information obtained from the devices that measure comparable data (i.e. has the same measurement units) can be viewed. The Treemap display, shown in Figure 6, is useful to observe the relative relationship at a glance. For further insight, the user can tap on meters in the Treemap display and choose to graph these, as shown in Figure 7. The graphing capability was added using the Achartengine API⁷, which is distributed under the Apache 2.0 license. The user can select the time period for which the data is plotted by either using a calendar to pick the exact time frame, or using a rotating picker that allow picking between pre-set options (e.g. one-month, one-week, etc.).

One more feature WattsApp provides is the ability to search for the collectors in the local network by the means of mDNS. Our original intention was to use the jMDNS library⁸ for this purpose, the most popular open-source mDNS Java solution. However, when IPv6 was used, we faced difficulties with running it on the Android devices. Therefore, we decided to make use of the standard java.net package in order to join the IPv6 multicast group and listen to the advertisements sent out by the collectors on the local network.

VII. RELATED WORK

The IETF EMAN working group is currently defining a set of MIB modules for power and energy management of devices and for monitoring batteries. While these MIB modules will provide a much more detailed approach to monitor and manage so called energy objects, it was for us sufficient to utilize the existing ENTITY-SENSOR-MIB [7].

The S0 interface [9] used by our meters is a very simplistic interface since it only defines pulses and it does not entail any data communication. As such, S0 is a very cheap solution for small installations but lacks in providing further details about what S0 pulses represent, nor is there information about quality aspects of the power consumed. More advanced meters make use of the MODBUS protocol [13], which can run over serial lines but also over TCP connections. MODBUS provides much more functionality but also requires more logic inside of the meters, hence impacting the price of the meters. Given our system design, we would interface MODBUS devices, in particular MODBUS over TCP capable devices, directly with the collector instead of using a wireless sensor mode between the meter and the collector.

VIII. CONCLUSION

Given the short time frame of just over one month to take WattsApp from inception to completion, a fully working system capable of delivering energy usage data to the user is a positive outcome. Adoption of the S0 interface ensures that WattsApp can be used to track utilities, beyond electricity, like gas and water as well. However, the ability to compare

data between different types, e.g. temperature and electricity consumption, makes WattsApp an interesting tool suitable for demonstration of the capabilities of the IoT. The successful integration of multiple technologies within WattsApp, at a rapid pace, is proof that enough tools exist to develop distributed applications using IPv6 for all communication between the components.

Given the seeming popularity of S0 meters, we were surprised that digital interface circuitry for these was not easily available. The only products were USB interfaces, which worked with proprietary data formats and applications. A lack of open and non-proprietary interface devices prompted us to design our own S0 interface circuit.

Due to the short development time, certain design decisions made can be changed to improve user experience. For example, currently the gatekeeper acts as a broker for all data exchange between the user interfaces and collectors. However, removing the gatekeeper from the data-path could considerably improve latency issues.

It is also interesting to note that this student project has had over 1000 downloads of its mobile app, and we have recorded over 700 registered users on our web application. This can possibly indicate a high interest in such energy monitoring applications.

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⁷<http://www.achartengine.org/>

⁸<http://jmdns.sourceforge.net/>