Design of IPv6 Network enabled Smart Water Flow Meter System for India

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Abstract—Water is one of the major requirements for human survival. During the past decade, water needs have risen exponentially to an unprecedented scale in India. The rapid urban development, increasing human population, climate change and wasteful usage have led to severe water shortages. The solution lies largely in areas of effective mechanisms for conservation, distribution, efficient use and management of this resource. Ensuring access to safe and clean water is another issue that requires attention. In this paper, we present an IPv6 network connected design for real-time water flow metering and quality monitoring system. Our prototype implementation uses the emerging HTTP-compatible CoAP based monitoring and control approach for seamless web integration, thus supporting internet based data collection. The system addresses new challenges in the water sector - ease of billing, fair billing and the need for a study of supply versus consumption of water in order to create awareness to curb water wastage and encourage its conservation. The traditional water metering systems require periodic manual intervention for both metering and maintenance making it inconvenient and often least effective. Shortcomings of the existing models call for a ubiquitous usage of wireless systems for smart water flow metering and quality monitoring. We propose to do this with the aid of CC2538 motes that monitor the water consumption and communicate the data to a gateway wirelessly so that the data can be made available online through the internet to both the consumers and the authorities of the water supply board.

Index Terms—Contiki, CC2538, IoT, Water, Wireless, 6LoWPAN

I. INTRODUCTION

According to the World Bank report released in 2014, urban water supply in India is faced with severe challenges such as distribution inefficiency leading to higher operational costs while only 20% connections are metered and in most cities about 40% water supply does not result in any revenue. Hence, the traditional water metering system employed in India needs both infrastructural improvement and smart flow metering approach. The manual examination of water meters for billing purposes is prone to human error and inefficiency. Further, the physical presence of the residents is also required in order to provide access to the meters. Some of the residential complexes use common water meter where the bill amount is shared equally irrespective of an individual usage, providing little incentive for residents to conserve water. The data collected from water meters is manually fed to a computer for billing purposes, a method that is again vulnerable to human error. The monthly water bill often shows the total consumption of water for the entire month with very little insight into the usage pattern and progressive amount to be paid on daily basis for the benefit of consumers.

Smart water metering systems can serve as alternatives to overcome the shortcomings of manual metering systems. They are wireless sensor networks with smart water meters installed in thousands of households collect periodic measurements that are reported in real-time over a wireless network to a central database [1]. For individual households, smart metering can provide early warnings of unusual events such as continuous flow of water which may be “leaks”. For the water utilities, smart metering aids decision making on pricing strategies, intervention policies and setting water use reduction targets.

To achieve remote real time monitoring for water consumption of residences, systems that combine communication technology with sensor technology and embedded technology are required. A few attempts have been made in this direction to develop wireless systems for water metering. The Smart Aqua meter [2] uses digital flow sensors to measure the quantity of water. It has been demonstrated that this method provides more accuracy than the traditional analog water meters used in India currently. The system uses ZigBee technology for communication. The integration of the system to the open standards based internet and also seamless access
to the water meter over the internet is a challenge. Wireless Digital Water Meter with Low Power Consumption for Automatic Meter Reading [3] also proposes a solution to transmit water consumption data to a gateway using the ZigBee wireless protocol.

The Wireless Smart Water Meter Reading System [4] is another approach and consists of two parts, the upper network and the lower one. ZigBee wireless technology is used to solve the problems of communication among water meters, acquisition spots and data concentrators in the lower network [5]. The communication between data concentrators and data processing center in the upper network is via GPRS transmission.

The paper starts with the proposed solution giving a detailed explanation of our approach. It is followed by the system architecture and the software implementation. The paper then highlights its results and is concluded.

II. PROPOSED SOLUTION

In this paper, we use the emerging 6LoWPAN [6] protocol based approach for wireless communication and it has many advantages over ZigBee, although both are based on the IEEE 802.15.4 standard. ZigBee based devices are typically suitable for communication with one another and they cannot directly communicate with Internet-based devices and web servers/browsers. 6LoWPAN or IPv6 over Low powered Wireless Personal Area Network offers an alternative because it employs the IPv6 protocol and hence can provide interoperability with IEEE 802.15.4 physical link devices as well as with devices on another IP network [7]. This means that we can obtain global connectivity to sensor networks directly through the internet without having to go through the ZigBee to IP conversion process, thus making 6LoWPAN more suitable for Internet of Things based applications.

The existing systems and designs proposed so far focus only on measuring the quantity of water flow through the main supply outlet. In this paper, we propose a novel system that provides users with a web enabled interface to monitor the distribution of water consumption in their houses. The quantity of water flow through individual outlets in residences is measured and statistical analysis on this data is presented to the users. This will serve as an indication to residents regarding where and when excess water is being used in their respective houses and motivate them to conserve water in order to cut down on their water bills, especially since water scarcity is likely to lead to increased prices. Tracking the real-time consumption on a day to day basis can prove to be an effective way to identify water wastage and additional analysis on the data collected can help residents control the use of water. This is especially important in India with increasing population, urban population density, climate change and wasteful usage, all create an exigent need for the economic use of water.

The proposed system also aims to tackle the issue of water quality that requires attention in India. Though treated water is supplied by the water boards, long distance travel and waste seepage can lead to contamination of water. Water quality being a major concern, this paper presents a system to measure the pH and ORP of water supplied to each house and also allows the users to monitor these parameters in real time through a web enabled interface.

The system is developed using ContikiOS, an open source operating system for networked, memory-constrained systems with a particular focus on low-power wireless Internet of Things devices [8]. The IPv6 stack in Contiki utilizes the routing protocol for low-power and lossy networks (RPL) along with the 6LoWPAN header compression and adaptation layer for IEEE 802.15.4 links. 6LoWPAN allows the transmission of IPv6 packets over IEEE 802.15.4 links [9]. It keeps the IPv6 protocol, but compresses it to leave more space for the payload [9]. This way, transmitting a given amount of data takes less frames and consequently less power. The 6LoWPAN is often used with the connectionless, unreliable UDP protocol at the transport instead of the TCP implementation [9]. This allows the application layer to take better control in handling potential errors through retransmissions and when required, delay the transmission.

Above the IP network layer, a suitable application layer protocol is required. In the Internet, HTTP is one of the prevailing application layer protocols. But it is not suitable for use in constrained networks due to its high computational complexity and high power consumption. This paper presents a system that uses the Constrained Application Protocol (CoAP), a lightweight HTTP alternative for constrained networks, developed by the IETF Constrained RESTful Environments (core) Working Group [10]. The implementation of the IETF Constrained Application Protocol for the Contiki operating system leverages the ContikiMAC low-power duty cycling mechanism to provide power efficiency [11].

III. SYSTEM ARCHITECTURE

In this section, we look at the hardware prototype of the Smart Water Flow Metering System (SWFMS) and the building blocks used to realize the same. The system is realized using Texas Instruments CC2538 wireless microcontroller SoC. The device combines a powerful ARM Cortex-M3-based MCU system with up to 32KB on-chip RAM and up to 512KB on-chip flash with a robust IEEE 802.15.4 radio. It is ideal for a wireless sensor network due to its multiple low power modes with retention that enable quick startup from sleep with minimum energy spent on performing periodic tasks for wireless solutions.

A. Hardware prototype of Smart Water Flow Meter

Fig.1 shows the hardware prototype of flow metering system. A CC2538 mote is used for the underground tank and is interfaced with pH and ORP sensors to monitor water quality and a flow sensor to estimate the total volume of water flowing through the main supply outlet into the tank. A float switch that controls the water pump is also interfaced to this mote. Water from the overhead tank is distributed to various outlets in the house such as those in the kitchen and bathroom. Flow sensors connected to these outlets are interfaced with other CC2538 motes.
B. Transmission Unit

Fig. 2 shows the CC2538 motes interfaced with the pH, ORP, temperature and flow sensors. Phidgets’ pH and ORP sensors are used to check the quality of the water in order to ensure that parameters such as the pH and ORP of water lie within permissible limits. The temperature sensor is used for accurate calculation of pH. The water flow sensor consists of a plastic valve body, a water rotor, and a Hall-effect sensor. When water flows through the rotor, the rotor rolls. Its speed changes with different rates of flow. The Hall-effect sensor outputs the corresponding pulse signal. External interrupts are enabled on the CC2538 motes to detect these pulse signals in order to calculate the rate of flow and thus estimate the volume of water consumed at each outlet. The float sensor is an electrical ON/OFF Switch, which operates automatically when liquid level goes up or down with respect to a specified level.

Float sensors contain a hermetrical sealed reed switch in the stem and a permanent magnet in the float. As the float rises or falls with the level of liquid, the reed switch is activated by the magnet in the float. The signal available from the float sensor is used to automatically turn on a motor to pump water from the underground to overhead tank. The motor can also be controlled remotely through the CoAP interface.

C. Receiving and Data processing Unit

The processed sensor values transmitted by the CC2538 motes are received by another CC2538 mote acting as the border router. The border router is interfaced to a BeagleBK through the USB 2.0 port. The BeagleBK acts as a gateway connecting the wireless sensor network running 6LoWPAN to an Ethernet network. The 1GHz AM3359 Sitara ARM Cortex-A8 processor is ideal to run Ubuntu 14.04 LTS on the BEAGLEBK thereby eliminating the need of a personal computer or a desktop computer to be always powered on and connected to the border router. The BeagleBK passes IP traffic to and from the border router over a serial line by creating a virtual network interface using the Serial Line Internet Protocol (SLIP). It acts as an intermediary device providing conversions between 6LoWPAN and standard IP headers. This allows users connected to the internet to access and control the motes remotely. The individual motes can be accessed, monitored and controlled (actuated) in real time from remote locations using CoAP, an application layer protocol, as shown in Fig. 3. The motes are accessible individually using their IPv6 addresses. MySQL database and a web application is developed using Visual Studio Express 2013 for Web. This web application provides a GUI for users to interpret the raw data in a graphical form and also provides the water bill.

Long range communication can be achieved through multihop. The motes in each house forward the data from other motes that lie further away from the border router as shown in Fig. 4. The border router receives data from the mote connected to House N which is nearest to it and lies within its communication range.
IV. SOFTWARE IMPLEMENTATION

This section describes how the various functionalities of the smart meter are programmed. The system uses two main software codes, one for the border router connected to the BeagleBK (acting as the gateway) and the other for the end nodes running CoAP. Fig.5 below shows the IoT protocol stack used to implement the Smart Flow Metering.

<table>
<thead>
<tr>
<th>LAYER</th>
<th>PROTOCOL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Application</td>
<td>CoAP</td>
</tr>
<tr>
<td>Transport</td>
<td>UDP</td>
</tr>
<tr>
<td>Network</td>
<td>IPv6/RPL</td>
</tr>
<tr>
<td>Adaptation</td>
<td>6LowPAN</td>
</tr>
<tr>
<td>MAC</td>
<td>CSMA</td>
</tr>
<tr>
<td>Radio duty</td>
<td>ContikiMac</td>
</tr>
<tr>
<td>Physical</td>
<td>IEEE 802.15.4</td>
</tr>
</tbody>
</table>

Border routers are found at the edge of a network and are used to route data between the WSN (RPL network) and external IP network. The border router forms a DAG (directed acyclic graph) with the other CC2538 motes and acts as the root node. With this RPL network the border router communicates with the end nodes. It receives a prefix from the BeagleBK and this is used for assigning its own IPv6 address as well as those of the end nodes. The border router hosts a webpage to display the addresses of the neighboring nodes and the routes through which they can be reached by it.

For the end nodes, we have used the Erbium-CoAP implementation that is bundled with Contiki 2.7. The REST engine defined in Contiki 2.7 includes a framework for developing both CoAP server and CoAP client applications. The end nodes in our system run the CoAP server and this makes these IPv6 enabled nodes reachable from any internet enabled device. CoAP allows us to define resources for the pH, ORP and flow sensors that are used. As shown in Fig.6, for a flow sensor based on interrupts, a counter value is used to keep track of the number of falling edges detected. It is used to calculate the flow rate and volume after regular intervals of one second each. For obtaining the pH and ORP values, as shown in Fig.7, the ADC channels connecting to the sensors are initialized. Taking the reference voltage of the ADC into consideration, necessary calculations are performed to obtain the pH and ORP values from the digital values obtained. The resources for the required sensors are activated. Results are retrieved either periodically or when required using CoAP options (OBSERVE or GET respectively). A resource is also defined for the actuation of the motor which can be controlled manually using CoAP (using POST option).

![Figure 4. System architecture for a large number of houses](image)

![Figure 5. Protocol Stack](image)

![Figure 6. Flow chart for processing flow sensor output](image)

![Figure 7. Flow chart for processing pH/ORP sensor output](image)
V. RESULT

As shown in Table 1 the quantitative analysis of a water metering system based on the flow sensor was performed to estimate the accuracy of the method. The diameter of the pipe used for the flow sensor is 7mm. For higher volumes of water flow, larger flow sensors can be used.

TABLE 1. QUANTITATIVE ANALYSIS OF A WATER METER BASED ON FLOW SENSOR

<table>
<thead>
<tr>
<th>Expected Value milliliter (ml)</th>
<th>Measured Value milliliter (ml)</th>
<th>Average milliliter (ml)</th>
<th>Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>I</td>
<td>II</td>
<td>III</td>
</tr>
<tr>
<td>100</td>
<td>88</td>
<td>93</td>
<td>102</td>
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<td>200</td>
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<tr>
<td>700</td>
<td>702</td>
<td>710</td>
<td>712</td>
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</tbody>
</table>

Overall efficiency – 97.90 %

It is evident from Fig. 8 that the deviation between the measured and expected values are quite less, thus making the system highly efficient.

The sensor parameters can be monitored using any CoAP client. Fig. 9 shows CoAP client making use of the Copper plugin for Firefox web browser. The browser displays individual icons for each request method like GET, POST, PUT and DELETE. The panel on the left shows the list of resources that can be use with these methods.

Fig. 10 shows the GUI developed using Microsoft Visual Studio Express 2013 for the Web. The user is provided with a web application to access water bills over the internet. The data about water consumption through the various outlets is used to plot graphs which are also made available to the user through the web application.

![Figure 10. Secure login to view bill and graphs](image)

Fig. 11 shows a sample of the water bill that can be made available to the user online. By this approach, notifying the user of any tariff hikes at peak hours becomes easier, thus allowing the user to prioritize his usage patterns and cut down on the cost.

![Figure 9. Monitoring SWFMS sensors in CoAP](image)

![Figure 11. Sample bill](image)
Fig. 12 shows the water consumption pattern on an hourly basis. This lets the user determine at what hours of the day large quantities of water have been used. Fig. 13 and Fig. 14 shows the water consumption at 2 outlets in our prototype. Analyzing these graphs make the user aware of where and when most water has been consumed.

VI. CONCLUSION

In this paper, we presented an internet-based approach to the design of smart water flow metering and water quality monitoring system. The prototype implementation was carried out connecting to IPv6 networking using 6LoWPAN wireless sensor network with CoAP at the application layer. A flow sensor based water metering system is used for automated billing, eliminating the drawbacks of traditional water metering systems. Further, multiple houses in a building can use separate end nodes in mesh topology with a common gateway connecting to the internet for accurate billing based on individual consumption of houses. An analysis of water usage through various outlets in a house is provided in order to persuade residents to cut down on wasteful usage. Residents can also monitor the quality of water stored in their underground tanks. Future enhancements could include leakage detection along the pipes, prepaid billing and notifications indicating possible contamination of water.

REFERENCES


