Design of 6LoWPAN enabled Real Time Water Quality Monitoring System using CoAP

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Abstract: The discharge of wastewater effluents untreated or equally treatment without periodic quality monitoring, can lead to catastrophic water pollution in the long term affecting the aquatic life, agriculture farming and soil conditions of the entire downstream ecosystem. In this paper, we present a 6LoWPAN-enabled approach to designing a real-time water treatment monitoring and control system connecting to the internet. Our prototype implementation also uses emerging HTTP-compatible CoAP based monitoring and control approach for seamless web integration supporting internet based data collection suitable for various stakeholders such as government pollution control authorities, industries and domain scientists. The feedback control system responsible for neutralization when the desired water quality is beyond a permissible range, for example, adjusting the pH levels by adding acid or base solution, has also been implemented using the CoAP protocol. The system was designed using Contiki OS cooja simulation environment followed by the hardware implementation using TelosB motes running 6LoWPAN/CoAP stack interfaced to temperature, pH, ORP and conductivity sensors.

Keywords: Water quality; Water treatment; WSN; 6LoWPAN; CoAP.

1. Introduction

According to the UN-Water, every day, 2 million tons of human wastes are disposed of in watercourses, and in developing countries 70% of industrial wastes are dumped untreated
into waters where they pollute the usable water supply [1]. In many developing countries like India, rapid growth in terms of industrialization, urbanization, population increases the consumption and pollution of water. Nearly 50% of the wastewater comes from small and medium size industries [2]. But rarely the wastewater is treated and large volumes of untreated wastewater are being used in agriculture. There are 234 Sewage Water Treatment Plants (STPs), most of those were developed under various river action plans (from 1978-79 onwards) and are located in (just 5% of) cities/towns along the banks of major rivers [3]. With rising consumption, deteriorating water quality and inadequate governance, India is likely to face severe water shortage problem. The textile industries have great economic significance by virtue of its contribution to overall industrial output and employment generation. This sector has wide spectrum of industries ranging from small scale units that use traditional manufacturing process to large integrated mills using modern machineries and equipment. The textile units use a number of dyes, chemicals and other materials to impart desired quality to the fabrics. These units generates a substantial quantity of effluents, the quality of which in most of the cases is unsuitable for further use and can cause environmental problems, if disposed off without proper treatment. To meet the requirement of the fresh water demand, we need to use available water efficiently and reuse waste water after necessary treatment.

This paper provides an approach and prototype implementation of real-time water quality monitoring and effluent treatment in the context of requirements in industries like textile using CoAP [4] in WSN. The water quality monitoring sensors and feedback system resources are managed using RESTful approach using HTTP methods like GET, PUT, POST and DELETE in web browser and command line.

The next section of this paper provides overview of background and related work. Section 3 provides prototype design of water quality monitoring system and section 4 gives the details of implementation. Finally, section 5 provides conclusion and future work.

2. Background and related work

The potential of Wireless Sensor Networks monitoring can enable important new class of applications such as structural monitoring, office/home automation, automatic weather observation systems, patient health monitoring, agricultural field measurements and automated early warnings to an impending disaster. The open standards and protocols used in this paper include IEEE 802.15.4 LoWPAN, IPv6 over 802.15.4 (6LoWPAN), Constrained Application Protocol (CoAP) and an overview of these protocols are provided below.

2.1. IPv6 over Low power WPAN (6LoWPAN)

The IETF 6LoWPAN working group has defined specifications to efficiently transport IPv6 datagrams over IEEE 802.15.4 links. The Internet Protocol (IP) is predominantly used over Ethernet links that offer increasingly high throughput. The transmission of IPv6 packet
over LoWPAN links are faced with several challenges due to the resource constraints. IETF RFC 6282 defines an adaptation layer considering that the minimum IPv6 MTU (1280 bytes) is much larger than the largest 802.15.4 frame size (127 bytes). The major functions of the 6LoWPAN adaptation layer that works between IPv6 and 802.15.4 MAC layer are listed as, Fragmentation, Header compression and Layer 2 forwarding.

2.2. Constrained Application Protocol (CoAP)

CoAP is a Web-oriented protocol adopting major features of HTTP. The central ones are the resource abstraction, RESTful interaction, and extensible header options. These features allowed the Web to evolve from a simple document retrieval mechanism (‘World- Wide Web’) to a rich application platform (‘Web 2.0’). Being a successful, widely used IETF standard, HTTP allows us to combine different resources or services with very little scripting effort in so called ‘mashups.’ This interoperability is the key enabler in what is known as ‘Web of Things’ initiative to push HTTP down to the device level. HTTP over TCP, however, has a one-to-one communication model without any push notifications and is rather heavy-weight for constrained devices.

To overcome the above constraint, CoAP enables size-optimization and reliable datagram communication. On the one hand, it offers URIs (e.g., coap://vs0.inf.ethz.ch/), the RESTful methods GET, POST, PUT, and DELETE, and extensions through header options that can be defined independently. On the other hand, CoAP uses UDP, which is lighter than TCP, but moreover allows for efficient IP multicast. Group communication is a significant requirement for the Internet of Things. To make up for the unreliability of UDP, CoAP defines transactions with retransmissions. Native push notifications for eventing are supported with the publish/subscribe pattern to observe resource changes. Finally, a resource discovery mechanism is provided, which also provides for resource descriptions.

“SmartCoast” Multi Sensor System for water quality monitoring [5] that allows for the integration of the different sensors like water-temperature, phosphate, dissolved oxygen, conductivity, pH, turbidity and water level. The system uses Zigbee communication to meet the low power requirements of the deployment scenario. The Smart Coast project also developed a portable, field deployable sensor for long-term monitoring of phosphate levels in natural water which was set with a limit of detection of 0.3 mg/L. For resolving the problem of the manual analytical method adopted in water quality detection with lack of real-time data, a novel type of remote water quality measuring and monitoring System based on WSN [6] is implemented, where the sensor nodes in the system enter the sleep mode when it does not collect the data so as to reduce the power consumption.

Another approach [7] explains the development and testing of a multi-sensor heterogeneous real-time water monitoring system which was deployed in the River Lee Co. Cork, Ireland to monitor water quality parameters such as pH, temperature, conductivity, turbidity and dissolved oxygen. Sensor interface infrastructure (incorporating Programmable
System on Chip - PSOC technology) and data telemetry systems compatible with the Zigbee data transmission system were developed which is capable of transmitting the data to the Smart Coast server, which processed the data for transmission to the web. The PSOC system accommodates the output magnitude from the sensors and processes the data in order to make it generic for the communication and processing unit of the system.

A water quality measurement system based on thick-film technology [8] is used for sensing pH, temperature, oxidation reduction potential (ORP), conductivity and turbidity. Other sensors are being developed for, organic contamination, dissolved oxygen and diversions. Here, the entire system is coated with a transparent resin, with the exception of the sensor area which must be in direct contact with the water, for serving the purpose of sensing.

As compared to some of the earlier works, we use emerging open internet protocols such as 6LoWPAN and CoAP, with open source tools and low-cost sensors for real-time monitoring of water quality and effluents. The real-time monitoring using internet based approach enables better integration of the WSN into existing internet and giving dynamic control based on the monitored data as compared to traditional methods.

3. WQMS – Prototype Design

In this section, we will look into the Water Quality Monitoring System (WQMS) design requirements and the building blocks to realizing the same.

3.1. Transmitter

Transmitter part of the WQMS consists of four sensors that can be deployed in water treatment plant interfacing to the wireless sensor node. Our prototype deployment includes pH, electrical conductivity, temperature and oxidation reduction potential (ORP) sensors for monitoring water quality. The output of all these sensors are analog with voltage ranging from 0 to 2V. The raw output from sensors are connected to the ADC pins of the mote for appropriate conversion and further transmission as shown in the Figure 1. Subsequently the data will be transmitted to the receiver block.
3.2. Receiver

Receiver part of the system consisting of border router acting as a gateway connecting to the transmitter part of the WSN system running 6LoWPAN on one side and to the internet on the other as shown in Figure 2. By connecting the 6LoWPAN enabled WSN node to the low power single board computer such as panda board, 6LoWPAN border router (6LBR) can be realized connecting to the internet over 3G, Wi-Fi or wired Ethernet. The CoAP clients can use public internet to connect to the sensors for monitoring real time data and controlling actuations. The mote connected to the 6LBR can communicate over wireless radio transceiver like CC2420, which covers the range of 50m in indoor and 120m in outdoor. Further communication range to the WSN field network can be realized using multi-hop routing using RPL. The collected real-time data from the sensor nodes can also be stored in a data base for further analysis. Since all sensor nodes are enabled with IPv6, it is possible to reach any of the sensor nodes from any internet enabled devices.

3.3. Actuator System

Actuator system is designed to maintain acceptable range of pH level in water as shown in the Figure 1. Two scenarios are possible while performing actuation: (1) Internal automatic control based on monitored data crossing a predefined threshold (2) CoAP external control initiated remotely by the end user. Acceptable range for pH of water is set and if the value from sensor is not in the acceptable range, the GIO pins of the controller are enabled. GIO pins of the controller, in turn enables the relay circuit and water pump is turned on to neutralize the pH level. Basic or acidic solution is added to the water depending on the variation in pH, till the value of pH is neutralized and lies in the specified range.
actuation control to turn on the water pump can be automatic or user controlled using CoAP POST method from the browser.

The actuation mechanism is provided in the flow chart shown in the Figure 3. The process starts with the initialization of the motes and sensors. Once the motes and sensors are initialized, CoAP GET method is used to retrieve the real-time sensor data. This real-time data can also be further accessed through the CoAP browser [9] or by jCoAP [10] command line by directly using the IPv6 address of the mote. The feedback system has been designed based on the monitored pH value. As shown in the flow chart, permissible range of pH for drinking water is checked for the range of 6.5 to 8.5. If the measured pH value is below 6.5, then the motor which pumps the basic solution will be turned on. If the pH value is above 8.5, then the motor which pumps the acidic solution will be turned on. If both the conditions are false, then no motor will be turned on.

![Flow chart of the actuation system.](image)

**Figure 3.** Flow chart of the actuation system.

The proposed system for effluent monitoring and treatment is shown in Figure 4. The field WSN network uses 6LoWPAN, RPL enabling connectivity from internet enabled devices and
users connected to the internet. The application protocol for monitoring and control from heterogeneous devices is possible using CoAP protocol.

4. Implementation

Our prototype setup for water quality monitoring system consists of motes, sensors, gateway devices and actuators.

![Proposed Real Time System Architecture for Effluent Treatment using 6LoWPAN/CoAP.](image)

**Figure 4.** Proposed Real Time System Architecture for Effluent Treatment using 6LoWPAN/CoAP.

![Electrical Conductivity Sensor, Oxidation Reduction Potential Sensor, pH Sensor, Temperature Sensor](image)

**Figure 5.** (a) EC Sensor (b) ORP Sensor (c) pH Sensor (d) Temperature sensor

4.1. Hardware
The sensors in our implementation include Sansel EC (measures of the water’s ability to conduct electric current), Phidget ORP (measures the ability of a solution to act as an oxidizing or reducing agent), Phidget/Sansel pH (measure of the acidity in water) and Phidget/Sansel temperature (Figure 5). All sensors are calibrated for accuracy and suitable conversion formulas are applied depending on the specific DC output voltage range. Other hardware used in our implementation of the system are as shown in the Figure 6. The TelosB mote, was used as wireless sensor node. TelosB is an ultra-low power wireless module based on TI MSP430 microcontroller and 802.15.4 complaint CC2420 RF transceiver module in 2.4GHz. The Panda board is used as 3G/6LoWPAN gateway for remote location and Wi-Fi/6LoWPAN gateway for lab experiments. The submersible water pump is used for adding acid/base solution works at an operating voltage of 5V DC. Since the mote will not be able to directly drive the pump, it is connected to the pump via a relay circuit that will drive the motor.

**Figure 6.** (a) Panda Board. (b) Relay Circuit. (c) Water Pump. (d) TelosB Mote.

### 4.2 Software

Prior to implementation, we have tested the WSN setup in Software simulation environment in Contiki 2.7, an open source OS developed for constrained networks. In our work, we have used Erbium-CoAP implementation that is bundled with Contiki 2.7 for our development. The REST engine defined in Contiki 2.7 includes framework for developing both CoAP server and CoAP client applications. Firefox browser plugin, Copper (Cu), a CoAP user agent implementation for monitoring resources using Web browser, is also included in this framework. CoAP resources are defined using the RESOURCE macro. For example, the following macro defines a temperature sensor resource,

```c
RESOURCE (temperature, METHOD_GET, "temperature");
void temperature_handler (REQUEST* request, RESPONSE* response)
```

The parameters defined in the above example are, name of the resource, request methods supported, URI path string, title and the resource type. Similarly, the conductivity, ORP and pH resource of water sensors are also defined using the following macros:

```c
RESOURCE (conductivity, METHOD_GET, "conductivity");
void conductivity_handler (REQUEST* request, RESPONSE* response)
```
All the resources are statically defined and the associated functions are registered when the REST engine in CoAP server is started. Each resource has to implement a handler function with the name [resource_name]_handler. For example, when the CoAP client sends a GET request to the Erbium CoAP server for the CoAP URI /conductivity, conductivity_handler function will be called by the Erbium REST engine. The handler implements actions for sending an excitation signal to water sensor that results in reading of the conductivity value. The CoAP response message is formatted according to the client requested format, which can be plain text, xml or JavaScript Object Notation (JSON). The implementation of the rectification system for pH level through an external control is achieved using CoAP POST methods. The macro definition to perform this action are given below,

```c
RESOURCE (acid, METHOD_POST, "acid");
void acid_handler(REQUEST* request, RESPONSE* response)
```

```c
RESOURCE (basic, METHOD_POST, "basic");
void basic_handler(REQUEST* request, RESPONSE* response)
```

4.3. Design of feedback system

![Figure 7. Feedback System.](image)

The feedback system to perform the rectification process is based on the functionality depicted in flow chart in Figure 3 and our implemented solution of the same is as shown in
Figure 7. The water pump is connected to the relay circuit as shown in the Figure 7 and output of the relay circuit was given to the GIO pin of the mote. If the pH of water is above the specified range, acidic solution is added or basic solution is added if it is below, by turning on the corresponding motor.

**Figure 8.** (a) Prototype Test at IIHR Lab. (b) BWSSB Remote Deployment [Inset Picture: WQM Sensors].

The prototype of water quality/effluent monitoring system was deployed at IIHR (Indian Institute of Horticultural Research), Bangalore (Figure 8.a) using 6LoWPAN/Ethernet where ERNET IPv6 connectivity is available. Our other remote deployment location is one of the BWSSB (Bangalore Water Supply and Sewerage Board) water treatment plant using 6LoWPAN/3G gateway (Figure 8.b).

The sensor parameters can be monitored using any CoAP client. Figure 9 shows CoAP client copper plugin in Mozilla web browser displaying the 200 OK, which is a successful response received for a GET request for pH sensor. An alert message is also displayed on CoAP browser, when the value of any of the parameters does not lie in the permissible range. The browser displays individual icons for each request methods like GET, POST, PUT and DELETE. The panel on the left showing the expanded list of resources for the DISCOVER request.

**Figure 9.** (a) Monitoring WQM sensors as (b) Actuating Control for pH level using
CoAP resources using Web Browser. CoAP resources.

The feedback control is also made available through CoAP browser for user controlled actuation over the web. Due to the memory constraint, the monitoring CoAP server (Figure 9.a) is run in one TelosB mote and the actuation CoAP server (Figure 9.b) is run on another mote.

Further the WQM sensor data can be monitored using CoAP command line clients, such as jCoAP. jCoAP is a Java implementation of CoAP for unconstrained devices and embedded systems such as Java-based smart phones and mobile devices (e.g., Android). It provides a CoAP-to-HTTP and HTTP-to-CoAP proxy which performs protocol translations between the two protocols. We have utilized jCoAP for periodic monitoring of sensor data and storing into database for offline access and further analysis. The jCoAP output received for a GET pH resource is shown in Figure 10.a.

```
root# java -jar WQMClient.jar GET
   \   \   \     coap://[2001:e30:187c:2:212:7400:1465:d9dc]:61616
     /pH
receiving response...
==[ COAP MESSAGE]=========================================
URI : coap://[aaaa:0:0:0:212:7400:1465:d9dc]:61616
ID : 7424
Type : ACK code : 200 OK Options : 2
   * Content-Type: text/plain; charset=utf-8
   (1 Bytes)
   * Etag- 41 42 43 44 (4 Bytes)
Payload:78 Bytes
ph is 7
===========================================
Round Trip Time (ms): 334
```

Figure 10. (a) jCoAP command line output. (b) Temperature Sensor Plot.

Figure 10.b shows the plot created using the JpGraph [11] tool based on the historical temperature data stored in the database. The temperature data is varying due to the measurement range test performed over a period of time. If all the collected sensor data are available in a database, it will give researchers/domain experts and end users the ability to analyse historical data for water treatment and forecasting.

5. Conclusion and future work

In this paper, we presented an internet-based approach to monitoring and control of the water treatment system. The prototype implementation was carried out using IPv6 enabled Wireless Sensor Network (6LoWPAN) and emerging HTTP-compatible CoAP application protocol for both monitoring and control. Since the system is supporting seamless internet connectivity, offline access to the historical water quality data and graphical analysis are also possible. As the monitoring system gives real time data, it can act as an early warning system.
providing important timely alerts before the water pollution level reach to a catastrophic level. Hence, the described prototype system overcomes the disadvantage of manual chemical analysis providing periodic real-time data ensuring desired water quality before the industry effluents are discharged into the downstream. We are currently in discussion with the relevant local state departments in India for a real field deployment to demonstrate the usefulness of the approach. Further, our prototype can also be augmented with suitable sensors depending on specific application requirements, industry type and the chemical composition of the effluents that will be dealt.

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References

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