Real-time water grids: Safe drinking water using wireless sensors & low-powered data routing technologies

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Abstract

Clean drinking water is the very essence of life. It has been affirmed by the world health organization that 'the human right to water entitles everyone to sufficient, safe, acceptable, physically accessible and affordable water for personal and domestic uses'[1]. In 2002, over 1.1 billion people lacked access to safe drinking water, of which nearly two-thirds live in Asia. It has also been found that of the 1.8 million people who die of diarrheal diseases every year, over 90% are children under five, mostly in developing countries. A large majority of these people typically do not have the **necessary timely information or the technical know-how to detect the impurities in the water they are drinking**. Basic chemical sensors are available that can detect, in real-time, the presence of ionic contaminants like pH, Chloride, Fluoride, Arsenic, Lead, Iron, etc. This article explores the application of low-powered wireless sensors and pervasive technologies for the detection and dissemination of information and for alerting the end-user of water purity levels in real-time.

Introduction

Impurities in drinking water can cause significant harm to the environment and to those who consume it. Water contamination occurs due to both point (single-point of entry) and non-point (pollution due to contamination of the surrounding land) sources of pollution. Some of the key water pollutants found in India are Fluoride, Arsenic, Iron, Nitrate, Salinity, Heavy Metals and Pesticides. Skeletal fluorosis is said to affect over 25 million Indians due to fluoride-laden drinking water from bore wells dug in the earth.

Wireless sensor networks based real-time solutions can assist in solving this critical problem using technology which is simple to use and which can still be effective on a large scale. This paper discusses some of the key challenges that need to be addressed in any given practical solution, the existing wireless sensing technology available to implement such a solution at a prototype level and finally the current state of research in the related issues. In the following section, a real-world

[1] http://www.who.int/water_sanitation_health/publications/facts2004/en/index.html

scenario of a dense urban environment is discussed where conventional detection and dissemination techniques have failed and where this particular wireless sensing solution can make a significant impact.

Detecting impurities in the water distribution system of a dense urban environment

Cities with large slum settlements have a unique set of challenges in providing clean drinking water to the urban poor and slum dwellers. Dharavi in Mumbai, India, spread over 217 hectares, is one of Asia's largest slum and is home to between 600,000 to one million people. The city's water distribution system runs through this urban slum settlement where leaks occur regularly in the water pipelines that carry drinking water to several other parts of the city. The image below shows a drinking water pipeline surrounded by slum dwellings, garbage, human waste and the people living in those settlements.

Image Courtesy: Time Magazines 'Blue Planet Run'.

The conventional techniques for detecting water qualities in dense and large urban areas involves taking periodic water samples at the source and sending the sample to chemical labs for analysis. One of the vulnerabilities and limitations of this process is that there can be tampering/modification/manipulation of the data collection process as well as the lab analysis that is done on the samples collected. The tampering is at times done by the small-scale industries in these urban slum settlements where low-cost and low-quality operations forces them to blatantly ignore the various waste disposal standards and regulations.

A project at the Department of Chemistry of the Indian Institute of Technology, Bombay has created a low-cost rugged and tropicalized sensors which can simultaneously detect ionic contaminants like pH, Chloride, Mercury, Fluoride, Arsenic, Lead, Iron, etc. In the field of nano-technology, a large number of research universities have been building microfluidic devices called "lab-on-a-chip" where many of these chemical sensors have been specifically designed for detecting water pollutants.

Typical parameters which are tested for in water distribution systems are pH, conductivity, temperature, turbidity, free chlorine. Empirical testing has shown that chlorine and, at times, turbidity are the best indicators of potential contamination. Usually arsenic, lead and other chemical pollutants (other than iron) don't need to be monitored in the distribution system, since there aren't a momentary intrusion of these, instead these parameters need to only be tested at the source.

Besides chemical sensors, **water pressure is one of the most important parameter to maintain and monitor** in order to ensure bacteria and other contaminants do not enter the pipe when supply is turned on. To ensure continuous safe drinking water, there is a critical **need for a low-cost sensor that measures pressure in the distribution system at very periodic intervals and transmits that data in real-time** (say every 30 minutes) and with an accuracy of +1 or -1 psi. The hardest part of deploying such a solution is to make the flow-meter devices easy to maintain regularly (most of the currently installed flow-meters fall into disrepair very quickly). A company based out of Portland, USA has built a device which provides water flow measurements, non-intrusively through differential pressure across an orifice without reducing pressure head.

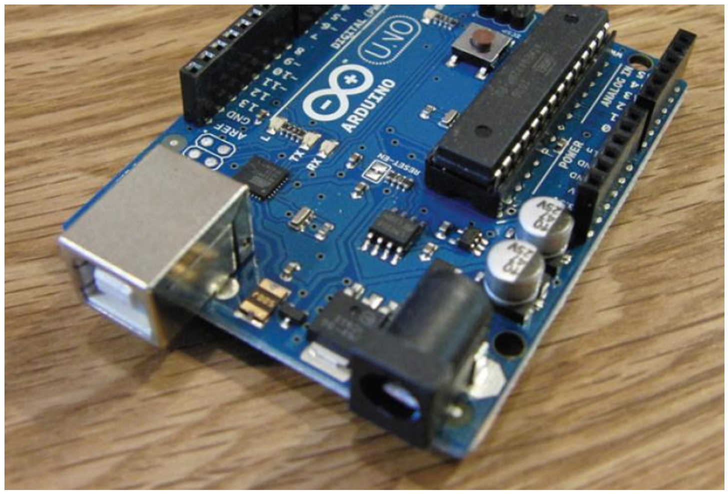
The problem of localized pollution detection can be overcome by deploying hundreds, if not thousands of low-cost wireless sensors along the entire water distribution system. A unique contribution of a wireless sensor based solution would be the real-time sampling and detection of the water quality. The distributed nature of the wireless sensors would also make it easier to detect both point and non-point based pollutants.

A low-powered wireless networking solution using water-based sensors

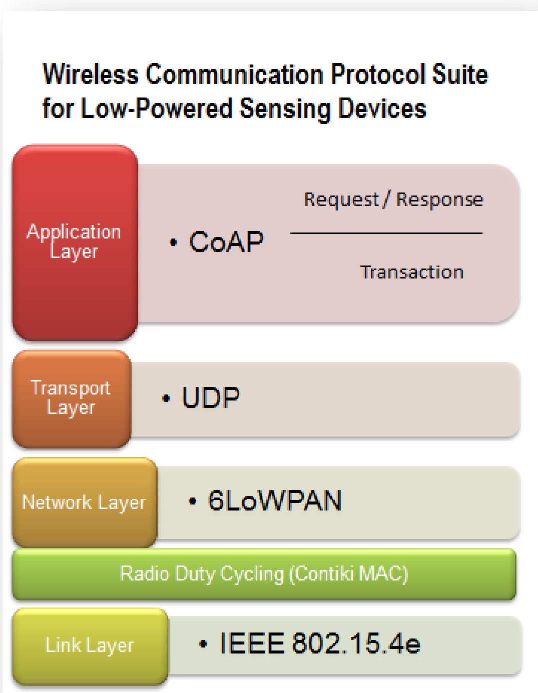
While the stationary chemical sensors can provide information to the person operating the sensor devices, a wireless IP (Internet Protocol) based, multi-hop networking solution can provide significant flexibility and a tighter integration between the physical world and the internet-connected world. A wireless IP and Web services based solution using these water quality sensors could help create a sensor networking platform or substrate, which can then allow other end-users/developers to query these large-scale sensors and build meaningful applications using this substrate.

Data from the water-based electrical transducers/sensors can be transmitted to the internet-world using microcontroller modules equipped with built-in analog-to-digital converters (ADC) and wireless connectivity. A popular ADC micro-controller being used at present is the Arduino boards.

Arduino boards are particularly popular among researchers and developers, in part, due to the wide variety of Arduino shields available to extend the base functionality of the micro-controller. A few examples include the 3G/GSM/GPRS shield (which provides Voice/SMS as well as HTTP/HTTPS and FTP/FTPS data transmission capability); Wireless shields (which provide XBee, ZigBee, 802.11 Bluetooth, etc) and Motor shields (these are used for driving inductive loads such as relays, solenoids, DC and stepping motors).



Embedded devices such as Arduino or other similar low-powered devices used in outdoor applications, tend to be severely constrained in terms of the (battery-powered) energy that is available to them. These devices need to optimize all their operations (like sensing, actuating, computing, data storing and wireless transmission) such that the energy/battery-power consumed is kept at the bare minimum. The existing communication protocols available (like HTTP, SSH, TCP/IP) cannot be used as-is in the applications where such devices are used. A new set of communication protocols are being developed by global standardization bodies like IETF, IEEE, etc.



Energy-efficiency can be built into the Real-time smart water grid solution right at the data communication protocol layer by using the globally standardized protocols like CoAP, 6LoWPAN and the IEEE 802.15.4e. The protocols have been specifically designed for low-bit rate communication like the transmitting water-pressure and other similar parameters.

The data collected from all these Arduino-enabled sensors can also be made available to the end-user via IP enabled devices or via SMS to mobile-phones. In addition, small digital displays can be attached to the drinking water faucets or taps from where people consume water. These displays would be getting their data from all the distributed sensors and hence can co-relate the data to identify the water purity levels.

Related Research Work

A number of university and industry based research groups have begun working on and built initial prototypes to address some of the issues involved in building a practical solution. University of Minnesota researchers are building a network of wireless sensors that are non-mobile and positioned at key points near ponds and streams to measure besides other factors - turbidity, salinity, pH and nitrate levels. Another real world research funded project by the European Commission, BMT Group and researchers at University of Essex are building mobile robotic fishes that are equipped with tiny chemical sensors to find the source of potentially hazardous pollutants in the water, such as leaks from vessels in the port or underwater pipelines. A prototype has also been built by researchers at the Carnegie Mellon University's Living Environments Lab where they have developed a low cost, non-invasive method for detecting water flow in a pipe. They have also suggested a solution to detect water quality using easily measurable properties of water such as temperature, pH and light attenuation.

About the Author

Ronak Sutaria is a lead researcher in Mindtree Research Labs. He has over a decade of professional technical experience in building large-scale internet applications and online payment security solutions. His current area of research focus is in low-powered wireless sensing technologies, solutions and deployments, also covering applications in smart water grids. He has a Bachelor of Engineering in Computer Engineering and a Master of Science in Computer Science. He is currently based in Mumbai, India.

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