Towards a Real-Time Campus-Scale Water Balance Monitoring System

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***Abstract*—In this paper, we describe the design of a real time water balance monitoring system, suitable for large campuses. The battery operated sensor nodes consist of an ultra-sound level sensor, a 16-bit microcontroller and a sub-gigahertz radio to setup a hub and spoke system. Real time data from the sensors is pushed to a server on the cloud to log as well as perform analytics. Industrial design of the device allows flexible mounting on a variety of tanks. Experimental results from a trial deployment in a medium sized campus are shown to illustrate the usefulness of such a system towards better management of campus water resources.**

Keywords-Water Distribution Systems, Ultrasonic Level Sensors, Real time monitoring

I. INTRODUCTION

Water is a very valuable and limited resource. A survey conducted by UNICEF in the year 2013 has identified that India has 16 per cent of the world's population compared to only 4 per cent of water resources. Table 1 showcases the current and estimated population versus per capita water availability per year in India[1].

TABLE 1: POPULATION VERSUS WATER AVAILABILITY

YEAR	POPULATION (Millions)	Per capita Average Annual Availability (m3/year)
2001	1029 (2001 census)	1816
2011	1210 (2011 census)	1545
2025	1394 (Projected)	1340
2050	1640 (Projected)	1140

Per capita availability of less than 1700 cubic metres is termed as a water-stressed condition while per capita availability below 1000 cubic metres is termed as a water scarcity condition[1].Evidently, India is currently facing water stressed condition and the survey hints that if water resources are exploited injudiciously, water scarce condition is not a distant future. Thus, meticulous management of water resources is indispensable. Management of a Water Distribution System (WDS) involves supervising the following –

I) Water balance
II) Water distribution planning and distribution patterns
III) Water wastage due to losses
IV) WDS health
V) Contamination of water due to the WDS

The paper focuses on technologies to manage and monitor a campus scale WDS. We have used a medium sized campus of about 440 acres as the test bed and discuss our initial results and experiences.

We look at related work in Section II. Section III outlines the challenges and constraints for such a system. Our proposed system architecture is presented in Section IV, followed by experimental results and discussions in Section V.

II. RELATED WORK

The Wireless Water Sentinel project in Singapore (WaterWiSe@SG) (2009) [2] was aimed to demonstrate the concept of pervasive sensing to enable data driven simulation of network performance, operations and control. It involved development of sensor nodes for pressure and flow measurements, deployment of sensors at strategic locations in the distribution network and online hydraulic modeling of the system to predict the consumer demands using the sensor data. It also involved analyzing the long term reliability of sensors for measuring pH, residual chlorine, Dissolved Oxygen etc. Initially, 8 sensor nodes were deployed across a 60 km^2 of area of Singapore water distribution system. The node collected the data at a high rate (2 kHz-1 kHz) and was capable of analyzing the data locally. The sensor node consisted of custom made sensing board and off the shelf hardware. The main processing board was a GumstrixVerdex Pro running in Linux operating system. It was powered by a 12V 33Ah battery recharged by 50W solar panel attached to poles near the nodes.

Rapid Adaptive Needs Assessment kit or RANA kit is a water quality monitoring module developed for military purposes to assist in water quality monitoring of water resources in disaster hit locations [3]. Their design has been optimized for short duration deployments (about 3 days), for places which don't have adequate cellular coverage.

III. CHALLENGES

The primary function of a campus WDS is collection, storage and distribution of water from source to various buildings on the campus. Ideally, it is expected that there is

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no loss of water in a WDS. But in the process of water transmission and storage, losses can occur due to leakages or theft. It is very important that these losses are identified swiftly to reduce wastage. Thus the water monitoring system needs to function on a real-time basis to identify any anomalies in the water balance instantaneously.

The schematic of a typical campus water network is shown in Fig. 2. It has many ground level reservoirs (GLR) and overhead tanks (OHT) for distributing drinking water to various parts of a campus. The campus receives 2.76 MLD of water from Bangalore Water Supply and Sewerage Department (BWSSB) which is stored and distributed from 11 GLR's and 8 OHTS's with total capacity of 5718 cubic meters with the help of 7 pumping stations. The campus pipe network is about 25 km long, serving residential quarters, hostels, mess, departments, labs etc. The water consumption varies from 130 to 330 lpcd (litres per capita per day).

Water inflow-outflow (water balance) assessment can be easily done by installing flow sensors in pipes at the inlets and outlets of the WDS. However most flow sensors are invasive and quite expensive. Hence the installation at every inlet and outlet and their maintenance can be quite expensive.

An alternative approach is to monitor the flows at only the inlet pipes into the campus, which are small in number. The water volumes in all the campus reservoirs and building tanks can also be monitored. The volume of water in the reservoirs and tanks then should reflect the cumulative difference in ingress and egress flows.

To predict hydraulic and water quality behaviour of the IISc water distribution system, a mathematical model of the real system is developed using EPANET, an open source modelling tool by US EPA. This model needs to be calibrated by adjusting the model parameters to match the field observations [4]. The integration of the real time data with mathematical models can be used for various applications like real time detection and quantification of leak, pump optimization, implementation of water security systems and system behaviour during emergency events [5].

Practical challenges for such a system of flow and level sensors include: battery operated sensors for installation intanks without power outlets, long range communication network to cover the entire campus which could be about 5 km across and real time monitoring of the information to enable rapid response to events.

IV. SYSTEM DESIGN

A. Water level sensor nodes

Water level in tanks can be measured by using the following two techniques –

a) Water pressure measurement – This can be accomplished by submersing a pressure sensor at the bottom of the tank.
b) Distance measurement – This can be achieved by installing ultrasonic transmitter-receiver setup at the top of the tank.

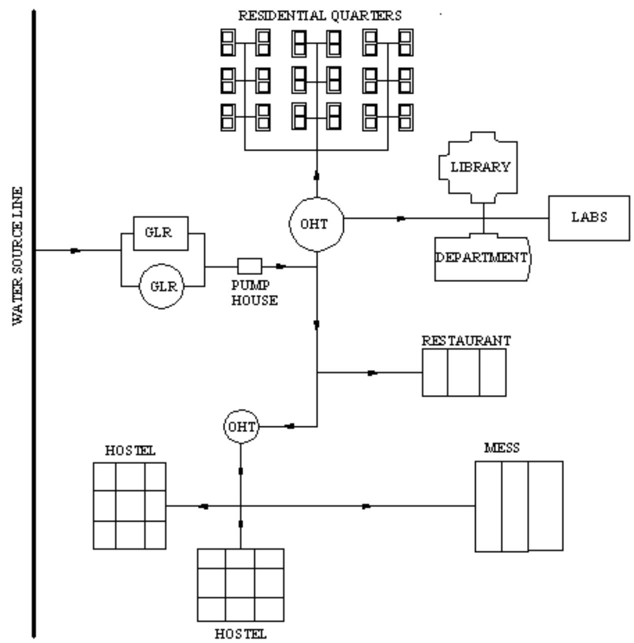

Figure 1: Schematic of a typical campus water network indicating intermediate storage reservoirs (GLR), overhead tanks (OHT) and the final consumers (buildings).

The latter approach is preferable since it is non-invasive and eases concerns about water contamination as well as maintenance of the sensors. We use an ultrasonic transceiver HCSR04 measure the distance of the water surface from the top of the tank. This allows us to estimate the tank volume in conjunction with the tank geometry.The block diagram of the sensor node is shown in Fig. 2.

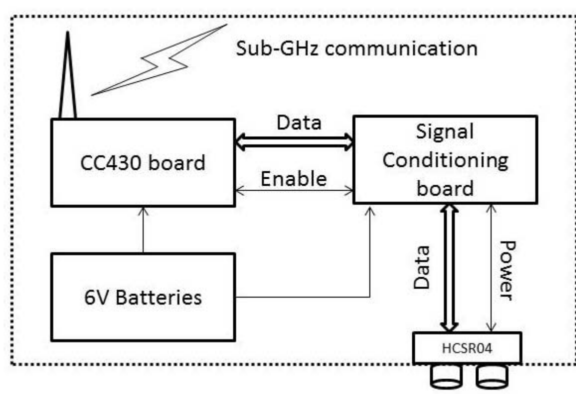

Figure 2: Sensor device architecture consisting of a microcontroller board based on TI's CC430 and a separate, power controlled, sensor signal conditioning board.

The CC430 microcontroller from Texas Instruments is the main controller unit that monitors and manages the sensor subsystem. The CC430 chip is an SOC (System-on-Chip) consisting of an MSP430 low power microcontroller and a CC1101 RF module integrated on the same die. The frequencies of operation of the RF module are 868 MHz and 915 MHz. The CC430 IC provides a communication range of up to 1km (line of sight) at a transmission power of +13 dBm. The chip also has on-board ADCs and GPIOs to sense and control the sensors deployed in the tank.

When the system is idle, the CC430 operates in a very low power mode. In this mode, the transceiver section is turned off, all the input-output ports are disabled and most of the timers are shut down.

The CC430 also controls the level sensor unit, which consists of HCSR04 ultrasonic transceiver and the associated signal conditioning circuits. The power supply to the signal conditioning board and subsequently the HCSR04 sensor is controlled by an enable signal from the CC430. Hence the sensor unit is powered up by the CC430 only during data acquisition. This allows us to duty-cycle the operation of the sensor board, thus saving power. Current consumption of the boards during their ON and OFF states are shown in Table. 2.

TABLE 2:CURRENT CONSUMPTION OF DEVICE'S SUBSYSTEMS

Module	ON current	Sleep Current	ON time per reading
CC430	21 mA	7 µA	120 ms
Sensor Unit	15 mA	3 µA	80 ms

Due to a large duty-cycling ratio in the system, the average current consumption of the sensor node is in the range of 100s of µA. Using batteries of 2500 mAh, and considering 80% duty-cycle ration, the battery is expected to last more than two years.

Industrial design of the sensor node is a very important aspect for long term field deployments. The ultrasonic water level sensor functions as intended only if it is parallel to the water surface. This poses a serious constraint since OHTs and GLRs are of various shapes with their lids aligned at different angles. The current industrial design ensures that the sensor is always aligned to the water surface irrespective of the lid alignment. Fig.3 shows the overall setup of the sensor module at a tank. Ultrasonic water level sensor is placed insidethe tank along with its signal processing board. Apart from this, everything else is mounted outside the tank.The view of ultrasonic sensor module (Shown in green), quality sensor module (shown in red) and the tank lid with a tilt of a random angle is shown in Fig. 4. Initial prototypes have been fabricated using a 3D printer.

B. *Campus-scale communication network*

The parameters of the WDS, like flow and pressure can be measured at a relatively low rate of few samples per minute. With about 100 sampling parameters for a campus scale WDS the data rate requirement is in the low kilobits per second. Thus the data rate doesn't impose too much of a constraint on communications requirements. The more serious constraints are related to range and power.

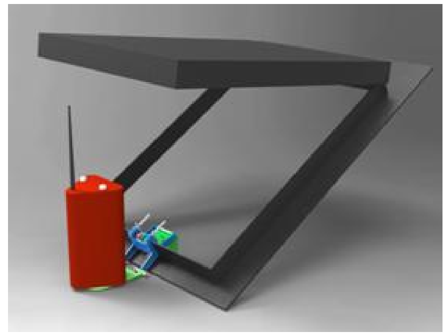

Figure 3: Sensor module

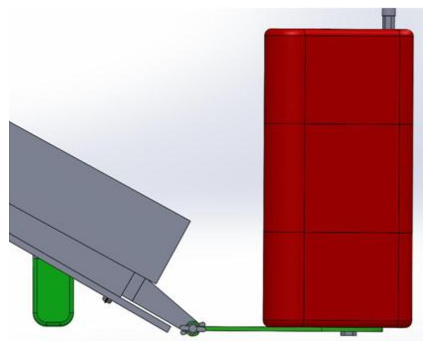

Figure 4: Ultrasonic sensor module (green) and Quality sensor module (red)

Medium sized campuses are typically a few kilometres in diameter. While a cellular network provides the required coverage in most urban areas, it is not suitable for remote battery operated, long term monitoring systems.Radios based on IEEE 802.15.4 at 2.4 GHz have been used by many researchers to deploy wireless sensors networks[6,7].However they mainly suffer from the range problemwith each link restricted to about 100 m. This requires a mesh type network topology, which in turn leads to complexity in deploying and managing the network. An alternative is to use long range Wi-Fi[8]. However that is also heavy in terms of power consumption, though recent chips demonstrate low power operation. Recently, sub-GHz has emerged as an attractive alternative to build large scale machine-to-machine networks[9]. Consequently, we have used TI's sub-GHz solution[10] to form the communication network in our deployment. The network architecture we have chosen is the hub and spoke model (or the star topology).

C. System Architecture and Data aggregation

The overall system architecture is illustrated in Fig. 5.

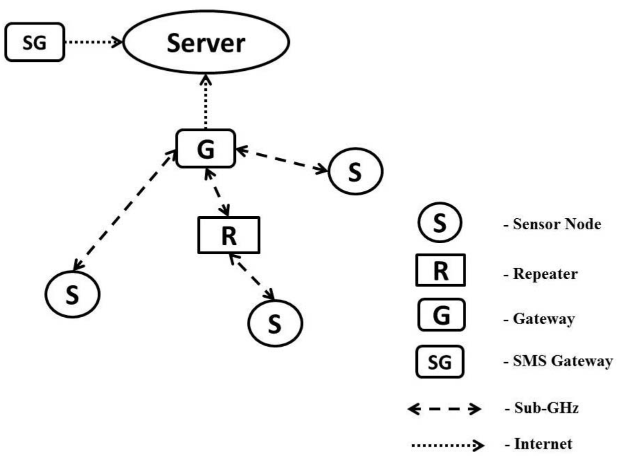

Figure 5: System Architecture consisting of the sensor nodes and gateway. These are connected in the start topology by wireless links.

The data from the sensors nodes is communicated wirelessly to the internet gateway. The wireless network architecture is the star network, though repeaters are used in select links to enhance range. The various components of the system are:

Repeaters: The line of sight communication range of the chosen sub-GHz radio has been experimentally verified to be 1 km. However installation at the ground level severely reduces to the communication range to hundreds of meter, both due to larger signal attenuation due to larger path loss exponent, as well as obstructions like trees etc. Thus it varies drastically with the surroundings. Because of this limitation, the data communication between the sensor nodes and the gateway may not be established in a single hop for some links. To alleviate this shortcoming, repeaters are installed in optimal locations of the radio network. The function of repeaters is to collect the data transmitted by sensor modules and retransmit it. The challenge of maintaining and managing the repeaters is same as the case of mesh network.

Gateway: The gateway consists of a CC430 transceiver module along with a Wi-Fi modem. Data from all the sensor nodes are received by the CC430 module and transmitted to the workstation. The workstation is equipped with internet connectivity, which enables it to upload the aggregated data onto a remote server. Multiple gateways can also be placed in a single WDS in order to reduce the number repeaters. The placement of repeaters and gateways poses unique challenges depending on the location and environmental factors of WDS. If gateways are dysfunctional due to malfunction or power loss, the data transmitted from the sensors will be lost. However, the loss of internetconnection will not possess such a severe repercussion since the data at received end can be backed up in a local database and uploaded onto the server whenever the connection is re-established.

The server chosen for data storage and visualization in the current solution is the Google App Engine Server[11]. Real-time data obtained from the water level sensors deployed in the campus can be visualized online.

We also have an additional SMS gateway that is made by attaching a GSM module to the workstation. The workstation continuously parses the water level information downloaded from the Google App engine server. The Google App Engine Server also consists of contact numbers of concerned personnel. The system can then send alert messages to assigned personnel in case of tank overflows and other maintenance issues. The SMS gateway is also capable of sending out water levels in any particular tank upon request by a user using an SMS query.

Figure 6:Integrated water level and water quality module deployed in a ground level reservoir. The level sensor unit is looking into the tank and is separate from the main controller module (white triangular box).

V. Experimental Results And Discussions

Comparison of the RANA kit with our proposed sensor device is tabulated in Table 3. The difference between the RANA kit and the real-term smart water monitoring kit is that the latter is meant for long term deployment lasting years and hence has been optimized on power consumption. The RANA kit is meant for short deployments in disaster hit areas.

In the initial deployment, we have installed the sensors in two tanks on the campus: One is a ground level reservoir and the other is an overhead tank in the building. The data from these two devices is shown in Fig.7 and Fig.8 respectively.

Looking at the data from the reservoir in Fig. 7, we observe that the inflow-outflow pattern is consistent throughout the week. The timings of inflow and supply are deterministic and any deviation from the existing pattern can indicate abnormality.

The water level is fairly constant during the early morning hours indicating that there is no usage and then it drains the rest of the day till the next inflow. We also notice that the peak level of water is not uniform indicating that there is no feedback control based on level. The amount of water supplied to and water consumed from the WDS on a particular day can be easily calculated using the water level rise/fall in the tanks. The erroneous readings obtained from the sensors are indicated in red. These were periods when the sensor node was undergoing some maintenance or there is some short term disturbance from outside. It must be noted that the sensor modules begin to operate properly again after some time. Any online analytics system should be able to determine and filter out such disturbances automatically.

TABLE 3: COMPARISON WITH RANA KIT

Comparison	Real-Time Smart Water Monitoring System	RANA kit
Application	Water balance monitoring of a WDS	Water quality monitoring for reservoirs of disaster hit areas
Communication	915/868 MHz to enable deployment in remote areas	900 MHz – Disaster hit areas lack communication facility
Deployment	Non-invasive	Submersible
Duration of deployment	Long-term deployment	Deployment for a few minutes to maximum of three days
Parameters to be monitored	Water Level	pH, Turbidity, Dissolved Oxygen, Temperature, Total dissolved salts
Battery life	More than two years	Less than 72 hours
Decision algorithm	Detects overflow and sends out alert messages	Detects reservoirs with best water quality

A similar analysis can be made about the water level in the building tank where it is pumped every weekday morning and consumed throughout the rest of the day. Water is pumped into the tanks on a regular basis every morning. But water is not pumped into the tanks on Sundays (indicated by green) in the graph. The water consumption is continuous over the entire day. There are no intervals of zero water consumption. This might suggest that there is a possible leakage/loss. Any leakage or loss if existing is of a very minor order since tank is not emptied even though water depletes from the tank continuously. The consumption is observed to be high during the morning hours, and the rate of water consumption is gradually decreasing with water level. We again note that the peak water levels are not constant, indicating a manual approach to fill the tank. We also note that there is excess water in the tank, beyond what is required for daily usage – thus indicating an opportunity to optimize the water redistribution into the final tanks from the reservoirs.

Figure 7: Water level data for a week from a storage reservoir

Figure 8: Water level data fora week from an overhead tank on a building.

VI. CONCLUSIONS

Our preliminary experimental setup to monitor the water balance in a campus-scale water distribution system has thrown up some interesting points. Technologically, it is now quite feasible to monitor campus-scale water distribution systems using off-the-shelf, low cost sensors, electronics, communication links and cloud software stack. With careful attention to industrial design aspects, a robust system can be developed and deployed for long term monitoring. Even with preliminary data based on a small term deployment, we could identify several issues with monitored campus WDS: one was the presence of a low level leak – which was never observed before. Other is that the water levels in the reservoirs are not "managed" in a scientific way. We are currently working on more extensive monitoring in more tanks and reservoirs for extended periods of time. We expect that real-time data, coupled with appropriate water balance models will lead to better management of water on the campus.

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REFERENCES

[1] Water in India: Situation and prospects, UNICEF, 2013.

[2] A.J. Whittle, L. Girod, A. Preis, M. Allen, H.B. Lim, M. Iqbal, S. Srirangarajan, C. Fu, K.J.Wong, and D. Goldsmith,

"WATERWISE@ SG: A testbed for continuous monitoring of the water distribution system in Singapore", Water Distribution System Analysis, 2010.

[3] J.E. Angello, A.M. Corrigan, R.K. Garg, S.S. Hewitt, K.L. Hudgins, E.C. Lester, C.A.E. Sorensen, M.R. Wilson, B.M. Brinkman, and G.E. Louis, "A Rapid Adaptive Needs Assessment kit for water quality monitoring in humanitarian assistance & disaster response applications," Systems and Information Engineering Design Symposium, 2012.

[4] C.A. Bush, and J.G. Uber, "Sampling design methods for water distribution model calibration," Journal of Water Resources Planning and Management, vol. 124(6), pp. 334-344, 1998.

[5] A. Preis, A.J. Whittle, and A. Ostfeld, "Online hydraulic state prediction for water distribution systems," World Environmental and Water Resources Congress, ASCE, 2009.

[6] http://en.wikipedia.org/wiki/ZigBee

[7] http://en.wikipedia.org/wiki/Bluetooth

[8] http://en.wikipedia.org/wiki/Long-range_Wi-Fi

[9] http://www.sigfox.com/en/

[10] http://www.ti.com/product/cc1100

[11] http://www.micropik.com/PDF/HCSR04.pdf

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