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DATA DRIVEN MONITORING OF IOT ENABLED WATER DISTRIBUTION NETWORKS

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Abstract

Real time monitoring capabilities of many domestic water networks are still very limited. This could lead to several direct and indirect issues such as inability to detect leaks leading to wastage of water, failure to identify over usage and exploitation of water by certain end nodes in the system, non-equitable supply of water and abnormalities like pipe volume reduction due to scaling and deposition of silt in pipelines. Since water networks are expected to operate for several decades, these issues lead to large uncertainty in the quantity of the water being supplied and utilised by any community. The present work proposes a system for monitoring the water supply system with the help of Internet of Things (IoT) where sensors and free spectrum communication techniques measure, transmit, store and analyse parameters of interest like flow, level and vibration. Here we make use of easily available and economically feasible sensing techniques like ultrasonic level sensors, hall effect based flow sensors and 3 axis gyroscope based vibration sensors. Suitable communication modules based on free spectrum transmission techniques like HC-12 and LoRa are utilised for transmitting the data from the sensor nodes. This work emphasizes the use of non-intrusive sensing methods, thereby reducing the difficulties arising due to disruption in water supply during installation and maintenance of the system. Low-cost monitoring capabilities and scalability are inherent advantages of the proposed work.

Keywords
Water distribution networks (WDN), Internet of Things (IoT), Telemetry, Free spectrum communication.

1 INTRODUCTION

1.1 WDN monitoring using IoT based sensor systems

Access to clean water is critical for the existence of life in the planet. Thus monitoring of water distribution networks using basic parameters like flow and level to identify the quantitative variation of the water supplied at different nodes is of great importance. In majority of the water distribution systems we come across in and around us, there is near to none quantitative feedback taken from the network to measure the amount of water being utilised, wasted or circulated in the system. Being a system that is meant to run for an indefinite period of time, this leads to a large uncertainty in the quantity of the water being supplied and utilised by any community. Proper quantisation of the water supply system with the help of sensors which can measure and store the parameters of interest like flow and level in this case, can bring down this amount of uncertainty to a large extend.

1.2 Related work

Water networks and efficient usage of water resources are actively studied due to the decrease in quantity and quality of water available to consumers. Deployment of monitoring systems [1] in water distribution networks can enhance the quality of service by balanced supply and reduction of water wastage. It has been estimated that the per capita water usage of a developed nation like USA is around 330 lpcd [2] while that of a country like India is 135 lpcd [3].

Internet of things (IoT) represents a network of physical objects or things which are inter-connected and exchange data between them. It has been gaining popularity in a variety of fields in the recent years due to its extensive applications and possibilities in low power, inexpensive and reliable data collection and transmission capabilities. In any sensor based systems for remote used cases, there is always a concern regarding the range of the nodes to transmit the collected data [4]. Application of new technologies including free spectrum transmission networks can rectify such concerns and thus help devise a practical system for WDN monitoring. Adige, a LoRa based WDN monitoring system communicates to several hundreds of meters with much lower energy expenditure [5] when compared to traditional GSM/GPRS based systems, hence can be used in sensing data from remote location to a receiver gateway far from the sensor node. Making use of tools like Arduino IDE, SQL workbench, Grafana, Python IDE etc. for programming, data collection, storage and visualisation provides an efficient platform for developing a novel WDN monitoring system.

2 SYSTEM ARCHITECTURE

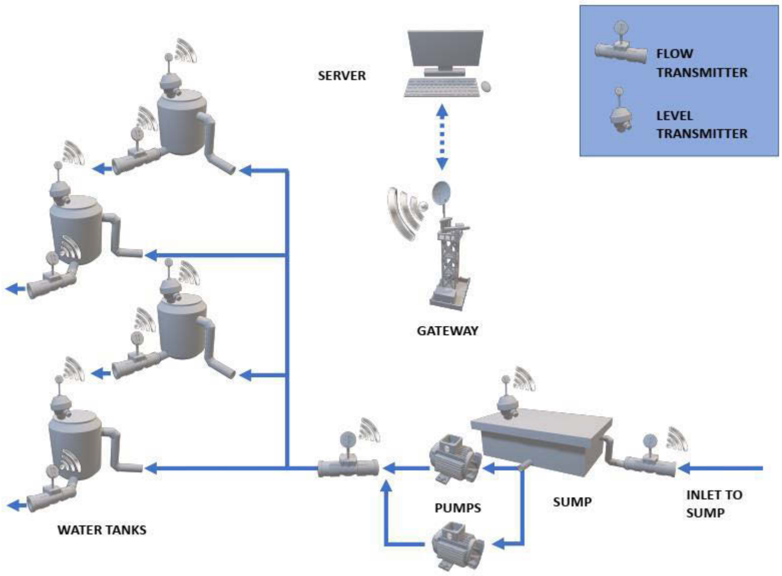

Figure 1. Domestic water distribution network

2.1 Components of parameter monitoring system in WDN

A typical domestic water distribution system consists of a sump, pumps, pipes and overhead tank as shown in Figure 1. Main components of a typical WDN monitoring system are the sensors (flow and level), the communication module, the sensor interface module and the gateway. The gateway pushes the data to the server which stores the data and visualises it on the dash board. The basic requirements for a sensor module for large scale deployments are the economic feasibility for acquisition and installation in large numbers, ruggedness and readiness for functioning environmental conditions with high heat and moisture, measurement accuracy and ease of electrical interfacing with the electronic system used for the module.

Most of the flow sensors available in market are very expensive since they make use of electromagnetic flow sensing methods or ultrasonic flow sensing methods. The high cost ranging from approximately 150$ (140 €) to a few thousand dollars per sensor render it practically difficult for implementation in large numbers. The more commonly used cheaper alternatives are the turbine based or vane based flow sensors. Here for our requirements, after testing multiple flow sensors available in the market, we decided to use turbine type flow sensors with Hall Effect magnetic pickup from Sea YF-S series sensors. These are readily available and considerably cheaper than the ultrasonic or electromagnetic alternatives.

Majority of the tanks in the water distribution networks have depths ranging from 5-10 feet. To monitor the level of water in these we need level sensors which were cheap and could continuously measure the level variation. The cheapest option was to use traditional conductivity probes which were immediately found unsuitable since they had discrete level measurements. Continuous measurement with a resolution of at least a few cm was necessary for data driven monitoring. In this perspective we had to look for alternatives which were at a reasonable price difference and support our requirements. After checking the available level measurement sensors like ultrasonic and LIDAR type sensors, we decided to finalise on ultrasonic level sensors which were comparatively cheaper and reliable. The added advantage of water proof design was ideal for outdoor applications.

For communication we tested multiple communication protocols like LoRa, HC-12, HC-05, BLE, etc. Depending on the topology the a typical domestic water distribution system we have chosen HC-12 modules. While LoRa is good for long range outdoor transmission with reasonable line of sight, HC-12 is ideal for places where obstructions like buildings are present. These are quite easily available, cheaper than other alternatives, reasonably low powered and ideal for indoor as well as outdoor application.

For interfacing the sensors, collecting and transmitting the data through the communication module, we need a sensor module. This includes a microcontroller which collects the data from the sensors and transmits them to desired destination nodes. Here we use an Atmel ATmega 328 embedded into an Arduino Nano module mounted on a custom PCB with necessary interfacing options with both sensor and communication modules. These PCBs were designed in house and fabricated from third party PCB fabrication companies. These also include solar panel integration for powering the whole system, Li Ion cell for backup during night time, charging and over discharge protection circuits for the batteries and standard interface pin outs for I2C and SPI interfaces.

Figure 2. Sensor interface module

For each cluster we needed a gateway node which collects data from the sensor nodes in the cluster and pushes it to the database. The obvious and tested option for this was to use a Raspberry Pi single board computer which met all the requirements including the ability to interface with a HC-12 based Arduino receiver node, LAN and Wi-Fi capabilities to use intranet/internet for transferring the data into the database and remote access feature for troubleshooting using tools like VNC server.

2.2 Hardware design of WDN monitoring system

WDN systems usually have large number of end nodes which collect level and flow data from tanks and pipelines associated with these. Using HC-12 modules for data telemetry data transmission have been found to be very efficient, low cost and reliable [6]. Here we make use of waterproof level sensors like Maxbotix MB series and low cost JSN-SR04 level sensors for level sensing in tanks. The Maxbotix sensor has a range of 10m at a resolution of 1 cm while the JSN-SR04 sensor provides a range of 4.5m at a resolution of 1 cm. The JSN-SR04 has a dead zone of 20 cm which can be tolerated. An ATmega 328 microcontroller based Arduino Nano provides the backbone for the interface unit. ATmega 328 has been found to be an ideal microcontroller for applications similar to ours by many researchers and hardware developers [8]. The Arduino uses two digital pins for interfacing with the JSN-SR04, one for the trigger pin and the other for the echo pin. No special libraries are required for interfacing the sensor since it makes use of the time of travel of the ultrasonic wave to determine the depth/ height of water in the tank.

Figure 3. (a)Maxbotix MB series sensor (b) JSN-SR04 level sensor

We used flow sensors ranging from 3/4 inch size to 2 inch size for majority of the installations. These sensors are using a Hall Effect type pulse counter mechanism which utilises the number of pulses to quantify the flow through the pipeline. They have a three wire connection two of which are for the Vcc and Ground and the third wire is the signal wire. These were available in both brass metal build as well as ABS plastic build depending on the size of the pipeline. The smaller sizes from 1/4 inch to 1 inch were brass made and 1.5 inch and above were brass. The installation was fairly straight forward since the sensors came with threaded ends which were using standard thread types and sizes which were compatible with PVC, uPVC and cPVC fitting.

Figure 4. Hall Effect type flow sensors

2.3 Data management and IoT

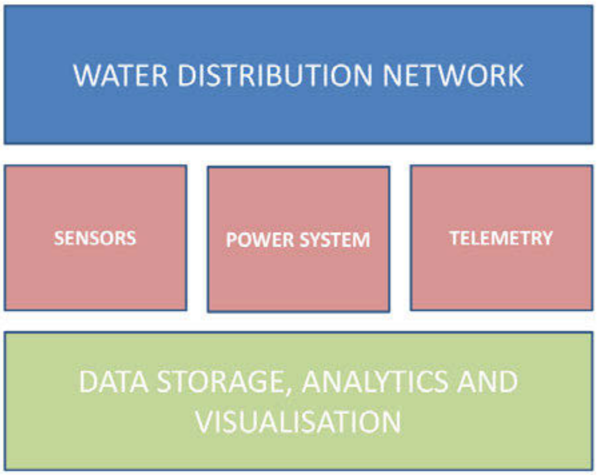

Figure 5. Components of an IoT system

Internet of things links objects around us with a central management system for seamless data exchange [8]. In the case of a WDN, the objects are the tanks and pipeline systems and associated sensors monitoring parameters like level and flow. The wireless telemetry provides the link between the objects and the central system comprising of the storage, analytics and visualisation. These will be done using free spectrum technologies like HC-12 or LoRa.

The data acquired from the sensor is then transmitted by the node using an HC-12 wireless transmission module which is interfaced to the Arduino using a software serial based UART interface. HC-12 supports 100 channels from C001 to C100 which can be set using AT commands. It can transmit at 8 different power levels from -1 dBm to 20 dBm [7]. This can also be set using AT commands. These features are quite useful when we are dealing with multiple clusters in nearby areas and chances of interference are quite high. An external antenna connected using a UFL to SMA Cable is also used for better transmission. Because of these customisation options in transmission, HC-12 is very versatile and useful. Isolation of clusters is also possible by assigning different channels for different clusters.

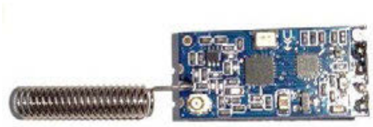

Figure 6. HC-12 module

The gateway node also includes an HC-12 module which is programmed to receive data from different sensor node using time based reception. The data is then transmitted to the server where it is stored and visualised.

A server is deployed to host the data collected from the water distribution systems. This is stored in the database for further analytics. The data is also displayed on a web based dashboard for real time monitoring.

Powering the individual components is also crucial when it comes to IoT systems as these are meant to be low power systems which should run on batteries. The end nodes might be located in remote locations where mains power may not be available and thus need to be powered using rechargeable batteries with solar recharging mechanisms. Gateway systems can be powered using mains power since these cater to a large number of end nodes and can be installed in locations with power availability. Gateway systems also require networking capabilities thus wired or wireless network access also needs to be provided. Data management in the central system is carried out in a well-equipped system, typically a server, PC or industrial computer.

3 RESULTS

We consider a system consisting of intermittent water supply. Since water is supplied intermittently, a ground level storage reservoir is used to store the water supplied and pumped to overhead tanks (as shown in Figure1). Current operation procedure for pumping of water from sumps into overhead tanks is purely time based and there is no feedback from the tank given to the pump operator regarding the level of water in the tank. Thus there is complete uncertainty regarding the amount of water being pumped into the tank and how long the pump has to run for maintaining optimum water in it. All the tanks have a ball float arrangement to prevent overflow while the pump continues to run at low flow rates.

3.1 Operation schedule

Figure 7 shows the variation of flow rate of water pumped into a tank vs. the level of water (depth from surface) in one of the installations.

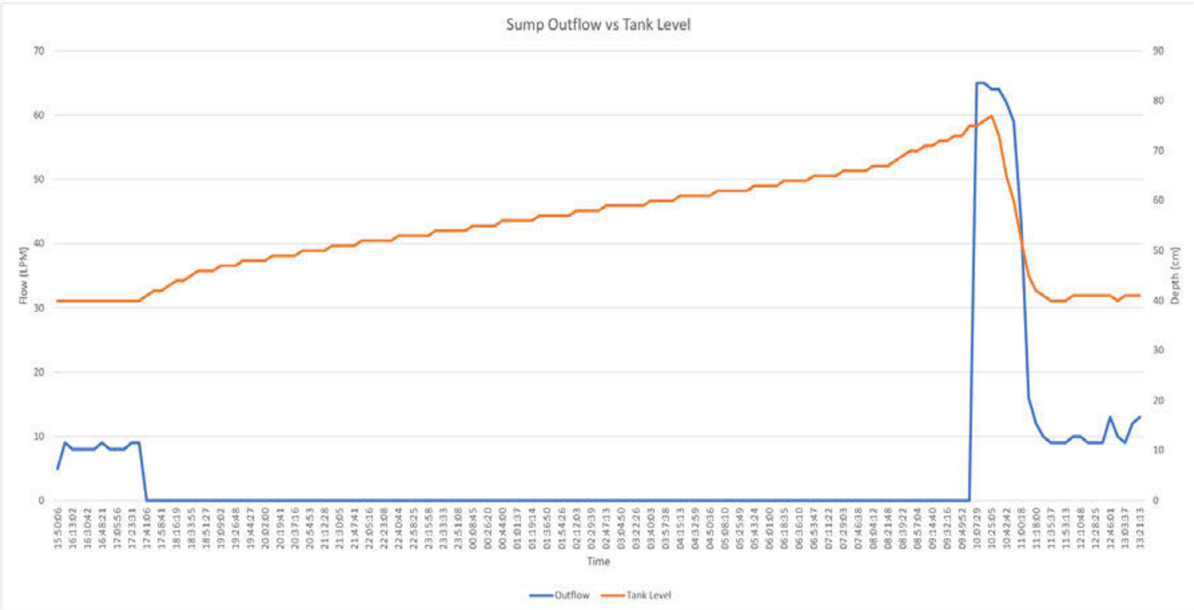

Figure 7. Flow rate of water pumped (LPM) vs. depth of water from top of tank (cm)

We can see that same pump operation schedule followed on a daily basis. Here it is evident that the pumping starts at around 10:00 am and goes on till 5:30 pm. The pump is pumping process fills the tank at around 65 litres per minute (LPM) and the tanks get filled by around 11: 30 am. The ball floats valve closes the input to the main tank and the flow rate into the tank reduces to around 10 LPM. But unaware of this the pump is still running for a much longer time till 05:30 pm. This is caused because of the absence of a feedback system to alert the pump house when the tank is full. This leads to wastage of power by running the pump beyond the required time to fill the tank. The 3 hp pump at the pump house consumes around 2kW of power from our observation. Daily the pump is running for an extended period of 5 hours, which results in an energy loss of 10 kWh. Approximate estimate of water usage in the building monitored was found to be 10275 LPD (litres per day).

3.2 Estimation of flow from level and associated measurements

One of the main advantages of having a data driven monitoring system is the derivation of unknown parameters from known ones. Flow is one of the most important parameter we need for WDN monitoring system. But flow meters are mostly intrusive and require more maintenance when compared level sensors. Here we make use of the level data to derive the flow and then compare this derived value with actual measured value in the network.

We look into a number of parameters in this estimation technique as follows:

Table 1. Relevant parameters for flow estimation and verification

Parameter	Character	State / Unit
State of pump	A	ON/OFF
State of inflow	B	ON/OFF
Level in tank	C	cm
State of ball float valve	D	Open / closed
Flow into sump	F_1	LPM
Flow from sump	F_2	LPM
Volume of sump	V	L

Among these parameters, F_1 and F_2 are measured to verify the accuracy of the estimated flow rates to the actual values. Considering the other parameters, it is possible to estimate the water consumed from minimal measurements. Here we consider a network which consists of an underground sump which receives water from the main supply line from the main sump. The water is then pumped to the main water tank on top of the building from where it is distributed to the end nodes.

Here we can consider 4 cases as follows:

Case 1: A on; B on; C known,

In this case,

$$F_1 - F_2 = \frac{dV}{dt} \quad (1)$$

In order to compute the volume of water supplied or consumed, when there is simultaneous filling and pumping of water, we need to determine F_1 or F_2 as shown above in equation (1). Under some conditions, it is possible to determine the water supplied or consumed if F_1 or F_2 follow certain trends and can be estimated independently.

Case 2: A off; B on; C known

In this case,

$$F_1 = \frac{dV}{dt} \quad (2)$$

This relation can be used to estimate the filling rate to the sump or equivalently the water supplied. If the filling rate does not vary over a time period the average flow rate can be calculated using a linear fit as described below.

In Figure 8 we considered roughly 400 data points collected from level sensor which has been time stamped using an RTC (real time clock) module. We use a linear trend line to determine the rate of change of volume in the sump. Fig. 1 shows the plot of Level vs. time in sump corresponding to case-2. The slope of the trend line determines an approximate value of rate of change of volume. This gives the inlet flow rate at normal conditions. It was found to be approximately 7.99 LPM. This is very close to the actual reading of the flow meter which was approximately 8 LPM. If the filling rate varies, the volume supplied can be obtained by numerical integration.

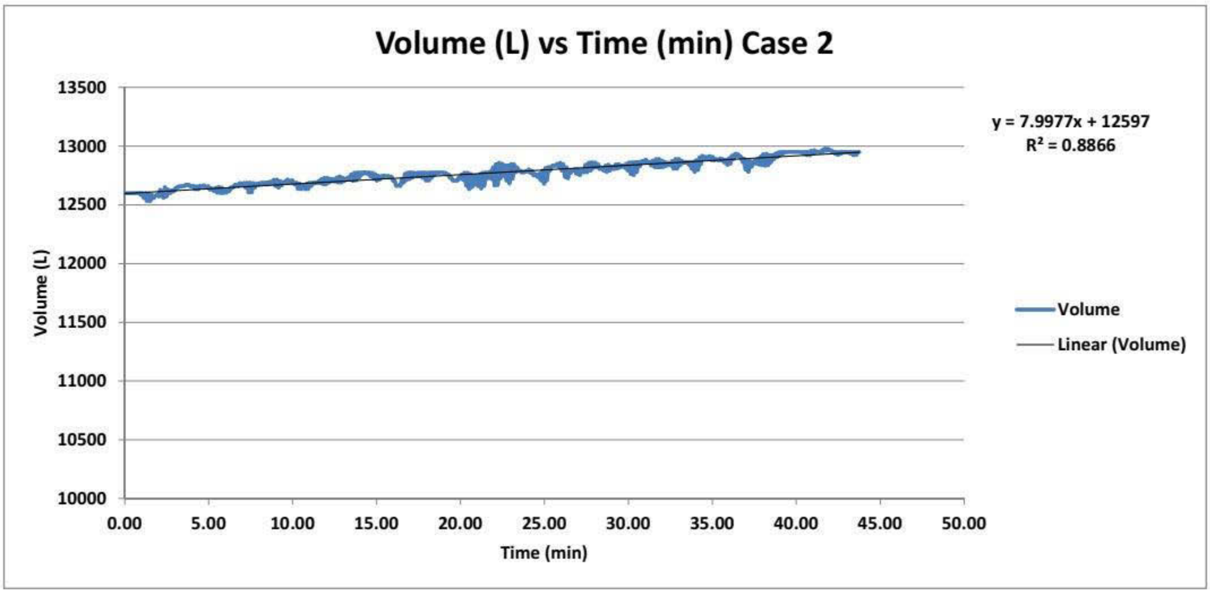

Figure 8.Volume vs. Time (Case 2)

Case 3: A on; B off; C known

In this case,

$$F_2 = -\frac{dV}{dt} \tag{3}$$

Equation (3) gives the pumping rate of the sump. This value is constant since the pump runs at identical conditions all the time. Here also we considered roughly 400 data points collected from the level sensor in the sump. In Figure 9, the slope of the linear trend line gave a value of around -67.45 LPM. This is approximately equal to the 65 LPM shown by the flow sensor installed in the line. The negative shows that the flow is from the tank and thus the volume varies with a negative slope.

Case 4: A on; B off; C known; D closed

This condition occurs when the float valves in the tanks gets closed when the water level reaches the max value. This causes a high resistance in the system and thus the flow rate decreases from the pump although the pump is running. This drastically reduces the flow rate which can be monitored from the level feedback from the supplied tank. In Figure 10, the slope of the trend line was found to be -9.39 which is very close to the 10 LPM value observed in the flow sensors.

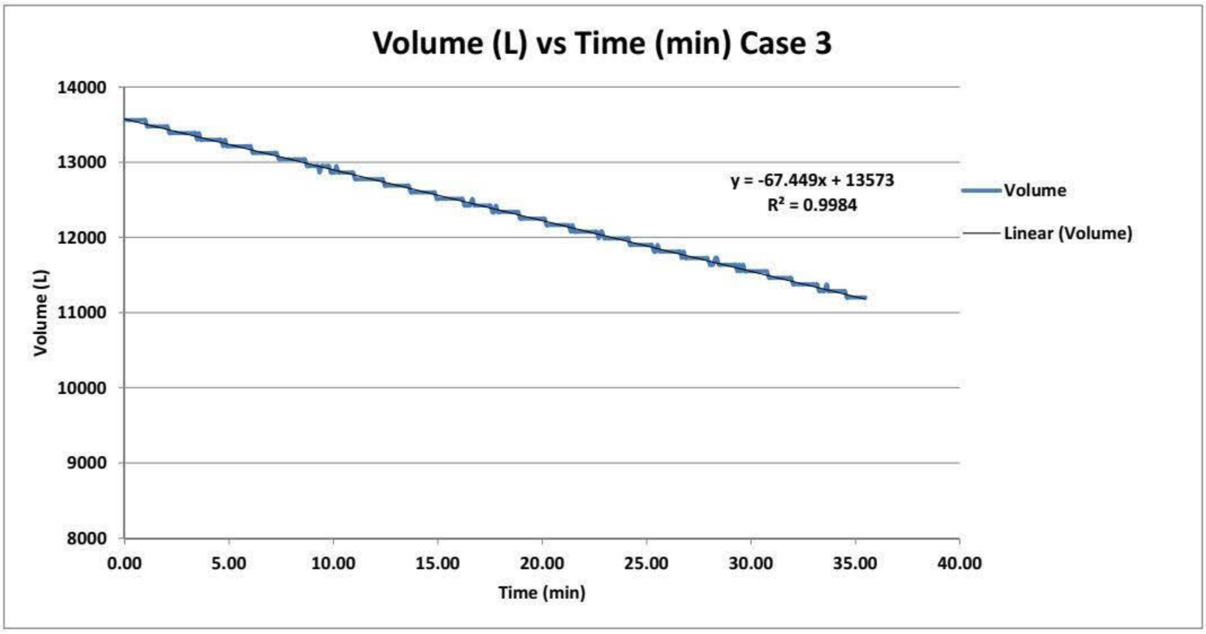

Figure 9.Volume vs. Time (Case 3)

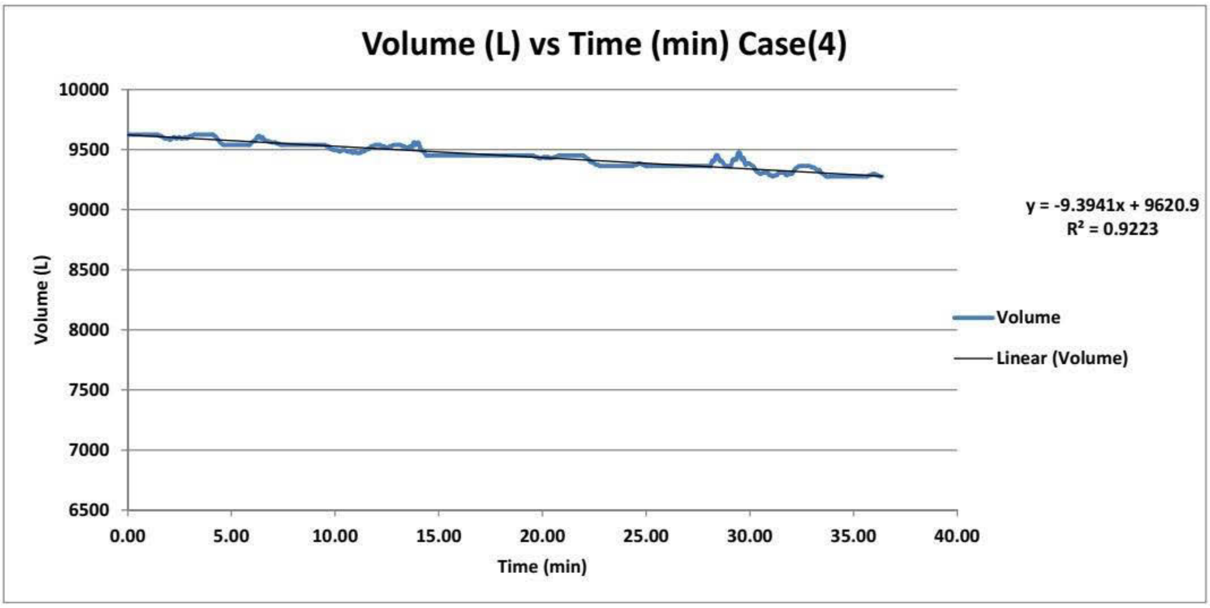

Figure 10.Volume vs. Time (Case 4)

4 CONCLUSIONS AND FUTURE SCOPE

In this paper we present an efficient, easy to implement IoT based wireless system using free spectrum technologies for monitoring water distribution networks. Uncertainties arising both from operation of the network from the operator side and utilisation of resource from the end user side is minimised. The disruption of water supply arising due to installation and maintenance of flow sensors is avoided processing the data appropriately to determine the flow from level and associated parameters.

Data collected from the IoT base WDN monitoring system is stored for further analysis. Real time data from the monitoring system can be visualised for checking the performance and operation schedule of the WDN. Further developments in both software and hardware side to implement a dashboard for mobile application is underway. The proposed system can be scaled for larger networks in various communities and organizations.

5 ACKNOWLEDGEMENT

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