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TOWARDS A SUSTAINABLE AND SAFE WATER SECTOR: EXPLOITING INTERNET OF THINGS FOR BUILDING A SMART WATER MANAGEMENT SYSTEM

by

Nael A. M. Zidan

Supervisor

Dr. Mohammed A. M. Maree

Co-Supervisor

Dr. Subhi Samhan

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Nael A. M. Zidan

This thesis was defended successfully on March 3, 2021, and approved by

Committee members	Signature
1. Dr. Mohammed A. M. Maree	....
2. Dr. Subhi A. R. Samhan	....
3. Dr. Mujahed O. Q. Eleyat	....
4. Dr. Marwan G. A. Ghanem	....

Declaration

This is to declare that the thesis entitled "Towards A Sustainable and Safe Water Sector: Exploiting Internet of Things for Building a Smart Water Management System" under the supervision of Dr. Mohammed A. M. Maree and Dr. Subhi Samhan is my work and does not contain any unacknowledged work or material previously published or written by another person, except where due reference is made in the text of the document.

Date: 22/03/2021

Name: Nael A. M. Zidan

Signature

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Abstract

The MENA region in general and Palestine, in particular, suffer from water problems of various forms at different levels. Among these are the depleting of water resources, water losses, water pollution, irregular water distribution, and limitations associated with collecting water revenues. These problems have a direct impact on the infrastructure of the water management and threaten water sustainability. These problems have become a pressing issue for decision-makers and water supply stakeholders to keep looking for innovative solutions that enable them to manage better and face existing challenges. The need for controlling, monitoring, and alerting water supply automation, especially water chlorination, has continued to form a danger that affects human life. The proposed solutions aim to keep water quantity and quality, control and automate and alert water chlorination, regulate the water distribution, improve service delivery, legitimate water consumption, decrease water loss, and detect untraceable non-revenue water. To realize the goals of the proposed water management solutions, researchers in the field and water supply stakeholders continue looking to incorporate and exploit new sources of information, tools, and equipment .

The exploitation of such resources assists in optimizing water management systems, improving their functionality and control. For instance, they can be used to describe and analyze a situation, make decisions based on the available data in a predictive or adaptive manner, and take smart actions accordingly. To effectively and efficiently realize that, smart water management systems need data to be readily available to make adaptive decisions that best suit the underlying conditions. Such data must be collected from many water clients (a.k.a. devices) such as pumping stations, pipes, tanks, and water meters. The size of the down-streamed and up-streamed data from such water clients can be enormous (Big Data). Additionally, water clients' propagation in a communicating-actuating network creates an Internet of Things (IoT) in the water sector. Accordingly, by using enabling device technologies such as Radio-frequency Identification (RFID) tags and readers, Near Field Communication (NFC), embedded and wireless sensors and actuators, we can collect the needed data, control, and monitor water clients, to be better employed and utilized in a smart water management system .

This research aims to exploit the Internet of Things (IoT) in the water sector and realize the newly introduced Big Water Data concept throughout the water supply infrastructure in Palestine region. We propose a smart water management system prototype that attempts to collect water data from water clients, process and analyze the data, highlight the issues in the water management infrastructure (such as areas that suffer from water losses and the reasons for the loss), and adaptively recommend action items to be carried out by the water supply stakeholders. Besides, the system will help monitor, control, and alert the water supply chlorination process on a real-time basis. We simulate and test the effectiveness of the proposed system. Furthermore, we experimentally validate the proposed system's quality using real-world data, scenarios, and settings.

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List of Abbreviations

SWMS – Smart Water Management System

IoT – Internet of Things

MENA – Middle East and North Africa

RFID – Radio-frequency Identification

NFC – Near Field Communication

WPS – Water Pumping Station

PCBS – Palestinian Central Bureau of Statistics

GIS – Geographical Information System

SCADA – Supervisory Control and Data Acquisition

WDS – Water Distribution System

AIS – Artificial Immune System

AIN – Water Distribution Network

CNN – Convolutional Neural Network

pH – Potential of Hydrogen

DO – Dissolved Oxygen

GSM – Global System for Mobile

WiMAX – Worldwide Interoperability for Microwave Access

LTE – Long Term Evolution

LoRaWAN – Long Range Wide Area Network

API – Application Programming Interface

JSON – JavaScript Object Notation

GUI – Graphical User Interface

IPv4 – Internet Protocol version 4

IPv6 – Internet Protocol version 6

SDK – Software Development Kit

SaaS – Software as A Service

PaaS – Platform as A Service

IaaS – Infrastructure as A Service

HTTP – Hypertext Transfer Protocol

HTTPS – Hypertext Transfer Protocol Secure

1. Introduction

With the recent development of the internet, the availability of various low-cost sensors, and the evolution of the Internet of Things (IoT), remote real-time monitoring and control systems – without the need for direct human intervention – have expanded significantly various application domains. The Water sector is one of the most important industrial application domains that demand to develop an efficient and effective water quality monitoring and control, considering the scarcity of natural water resources worldwide, particularly in the Palestine region.

Starting from this position, we propose a smart water management system that collects water data from multiple water clients, processes and analyzes the data, highlights the issues in the water management infrastructure (such as areas that suffer from water losses and the reasons for the loss) and adaptively recommends action items to be carried out by the water supply stakeholders. Besides, the system will help monitor and control the water supply chlorination process in a fully automated manner that helps make decisions and actions accurately and rapidly. We simulate parts of the system and test the effectiveness of the proposed parts of the system. We build and test a prototype for water chlorination automation. Furthermore, we experimentally validate parts of the proposed system's quality using real-world data, scenarios, and settings.

The remainder of this chapter is organized as follows. Section 1.1 presents the background and motivations behind our work. The problems face the water sector in Palestine, and its impact on water management are presented in Section 1.2. Section 1.3 provides the research methodology. Section 1.4 defines our research scope and the contributions we attempt to introduce through the proposed system. Section 1.5 presents our recently accepted publications in employing IoT for Building a Smart Water Management System. The structure of our thesis is presented in section 1.6.

1.1 Background and Motivations

Having a well-established water management infrastructure and a sustainable and safe water sector is one of the ultimate goals of water supply stakeholders in Palestine; achieving this goal, current water problems such as depleting of water resources, water losses, water pollution and contamination, irregular water distribution, and limitations associated with the collection of water revenues, water supply chlorination automated process need to be addressed. Among the recently proposed solutions for tackling such problems is the development of smart water management systems. However, such systems have not been exploited at their full capacity in Palestine. Also, the management of the enormous amounts of data and the various water clients in the water sector has not been put into the context of the newly emerging IoT technology.

1.2 Problem Statement and Research Questions

Chlorination is controlled and monitored manually in Palestine by service providers. Most of them realized water pollution due to chlorination deficiency after 500-900 cases went to the hospital; this happens at least once per year.

Besides, the water sector in Palestine faces many forms of problems at different levels. Examples of such problems are water resource scarcity, weak water infrastructure, and untraceable non-revenue water, leak on water supply chlorination, and fully automated process (Controlling, monitoring, Alerting). These problems negatively impact the water management infrastructure and threaten the water sector's sustainability and safety in

Palestine (Marie et al., 2012). Also, decision-makers and water supply stakeholders face difficulties in making the right decisions and taking the most proper actions towards addressing these problems (Gubbi et al., 2013). Accordingly, they are always looking for smart solutions that help them take appropriate and accurate actions. Recently, smart water management systems have been proposed to tackle the problems in the water sector (Robles et al., 2015) (Shah, 2017) (TongKe, 2013) (Di Nardo et al., 2013) (Stewart et al., 2010) (Jaiad and Ghayyi, 2017). However, such systems have not been exploited at their full capacity in Palestine. Also, the management of the enormous amounts of data and the various water clients in the water sector has not been put into the context of the newly emerging IoT technology.

1.3 Research Methodology

In this research, we propose an approach that employs the Internet of Things (IoT) to design, implement, and deploy a Smart Water Management System. Smart water devices will be identified and used. We will explain how the Smart System will collect data needed from the smart devices, controlling devices, monitoring devices, and monitoring all water processes such as water distribution, consumption, collecting revenues, and alerting to different users. Web applications, smartphone applications will be designed to be used by different users with different roles. The full system architecture will be designed and documented.

Experimental instantiation of the proposed system will be carried out to validate our proposal. This validation will be accomplished by developing a Smart Water Management System prototype that will be deployed and connected to smart water devices. Experimentally, we will validate the functions of the system and its produced results. We plan to evaluate the proposed approach's effectiveness by comparing the results produced by our systems' prototype using real-world data, scenarios, and settings. The following steps present the main phases and tasks that we carry out during our research work:

1.4 Contributions

The following points summarize the main objectives and contributions of our research work:

1- Exploiting the Internet of Things (IoT) in the water sector and realizing the newly introduced Big Water Data concept throughout the water supply infrastructure in the Palestine region.

2- Examining available water clients such as meters, tanks, and pumps and incorporating them in the proposed framework.

3- Designing and implementing Palestine's Internet of Things (IoT) water network.

4- Developing a data communication and exchange procedure between the system's clients.

5- Proposing web interfaces, authentication, and authorization scheme to determine the access roles of users.

6- Designing and implementing an alert, control, and monitoring component in the proposed system.

1.5 Publications

In this section, we list our recently accepted publications in the field of Monitoring and Controlling Water Chlorination Treatment. Our article addresses the problems facing the monitoring and controlling water chlorination that entirely depend on human intervention. Besides, we propose developing an IoT-based system prototype that remotely monitors and controls water treatment (Chlorination Treatment as a pilot phase) directly in Water Pumping Stations (WPS). The proposed system monitors chlorine concentration and controls the dosing pump to keep chlorine concentration as desired with little human intervention. Besides, it monitors the chlorine level in tanks and alerts the human operator for immediate actions in abnormal cases. A prototype of the proposed system has been set up for the experimental test to validate our proposal.

- Nael Zidan, Mohammed Maree, Subhi Samhan. 2018. An IoT Based Monitoring and Controlling System for Water Chlorination Treatment. In Proceedings of International Conference on Future Networks and Distributed Systems (ICFNDS'18) held on June 2018. ACM, New York, NY, USA. (Zidan et al., 2018)

1.6 Structure of the Thesis

The rest of this thesis is organized into the following chapters. Chapter 2 introduces a background about the Internet of Things (IoT) evolution and its roles in the water management sector. Also, in this chapter, we present a comprehensive comparative analysis of existing smart water management systems. Chapter 3 presents a general overview of the architecture of our proposed smart water management system. In chapter 4, we present a detailed description of the methods and techniques that we employ in the proposed system, in addition to the implementation of our proposed system. Chapter 5 presents the evaluation of the proposed system's results to validate the system's efficiency and effectiveness. Additionally, in this chapter, we compare our system's produced result to the current methods to tackle the problems. In chapter 6, we write the conclusions and highlight the future extensions of our research work.

2. Literature Review

This chapter aims to offer a state-of-the-art survey covering several topics, including IoT, IoT evolution, and its "roles, approaches, applications" in various sectors, and more specifically, the water sector. Also, it provides approaches, techniques, and systems proposed or implemented to tackle water problems, particularly water chlorination monitoring and controlling problems, water losses, irregular water distribution, and limitations associated with the collection of water revenues. Also, it provides the strengths and weaknesses of current smart water management systems. Accordingly, we start this chapter with background about IoT, IoT applications, the water sector, and the water management process. We discuss the current water management problem, particularly in Palestine, and present the state-of-art of solutions. Then, we provide a comprehensive comparative analysis of existing techniques/approaches/systems employed for water management.

2.1 Background

The term "Internet of Things" (IoT) was firstly introduced by Ashton, K. in 1999 (Ashton, 2009). Later, in 2005 the IoT was formally defined by the International Telecommunication Union (ITU) (Union, 2005). Among the most widely recent quoted definitions of this term is the one introduced (Tan and Wang, 2010). The authors define the IoT as "Things have identities and virtual personalities operating in smart spaces using intelligent interfaces to connect and communicate within a social, environmental, and user contexts".

The IoT is an internet extension that consists of various networks, which connect ever-present devices and applications that interchange data and information at anytime and anywhere (Gubbi et al., 2013) (Perera et al., 2014) (Choudhari et al., 2017). The IoT is a multi-layer architecture, where its layers from bottom to top are perception, network, service, and application layer. There are different architectures for the IoT that depend upon the number of layers used. These are the Three-Layer Architecture and the Service-oriented based Architectures (SOA) (Lin et al., 2017). The Three-Layer architecture consists of the Perception Layer at the bottom, the Network Layer in the middle, and the Application Layer on top of the architecture. The SOA Based Architecture consists of four Layers, which are the Perception Layer at the bottom, Network and Service Layers in the middle, and the Application Layer on top of the architecture (Lin et al., 2017) (Da Xu et al., 2014). Implementing IoT applications in practical rea-world settings, various elements need to be identified and configured. These elements are Sensing, Communication, Cloud-based data Capturing, Information interchange, and Semantics-based information extraction (Choudhari et al., 2017). Many technologies can be used to realize such applications. The most commonly employed technologies are Internet Protocol and Wireless Fidelity (Wi-Fi) (Choudhari et al., 2017), Radio Frequency Identification (RFID) (Xiaolin Jia, 2012), RFID Reader (Xiaolin Jia, 2012), GPS (Lei Zhang, 2012), Machine to Machine Communication (M2M) (J. Höller, 2014), Vehicle-to-Vehicle Communication (V2V) (Yaqoob, 2016), and Near Field Communication (NFC) (Yaqoob, 2016). A broad range of IoT applications has been developed recently. Examples are the exploitation of IoT applications in environmental monitoring (Lazarescu, 2013), health care (Riazul Islam et al., 2015), transportation (Chunli, 2012), inventory control and production (Zhang et al., 2016), workplace, and home support (Andrushevich et al., 2017) (Coelho et al., 2015), surveillance and security (Patil et al., 2017), smart parking, logistics, augments maps, data collection, smart water supply, smart homes and offices, smart cars, smart grids, traveling, health (Yaqoob, 2016). Perumal and Manohar have categorized IoT applications into four different domains, Personal and Home, Enterprise, Utilities, and Mobile, as depicted in Figure 1 (Perumal and Manohar, 2017).

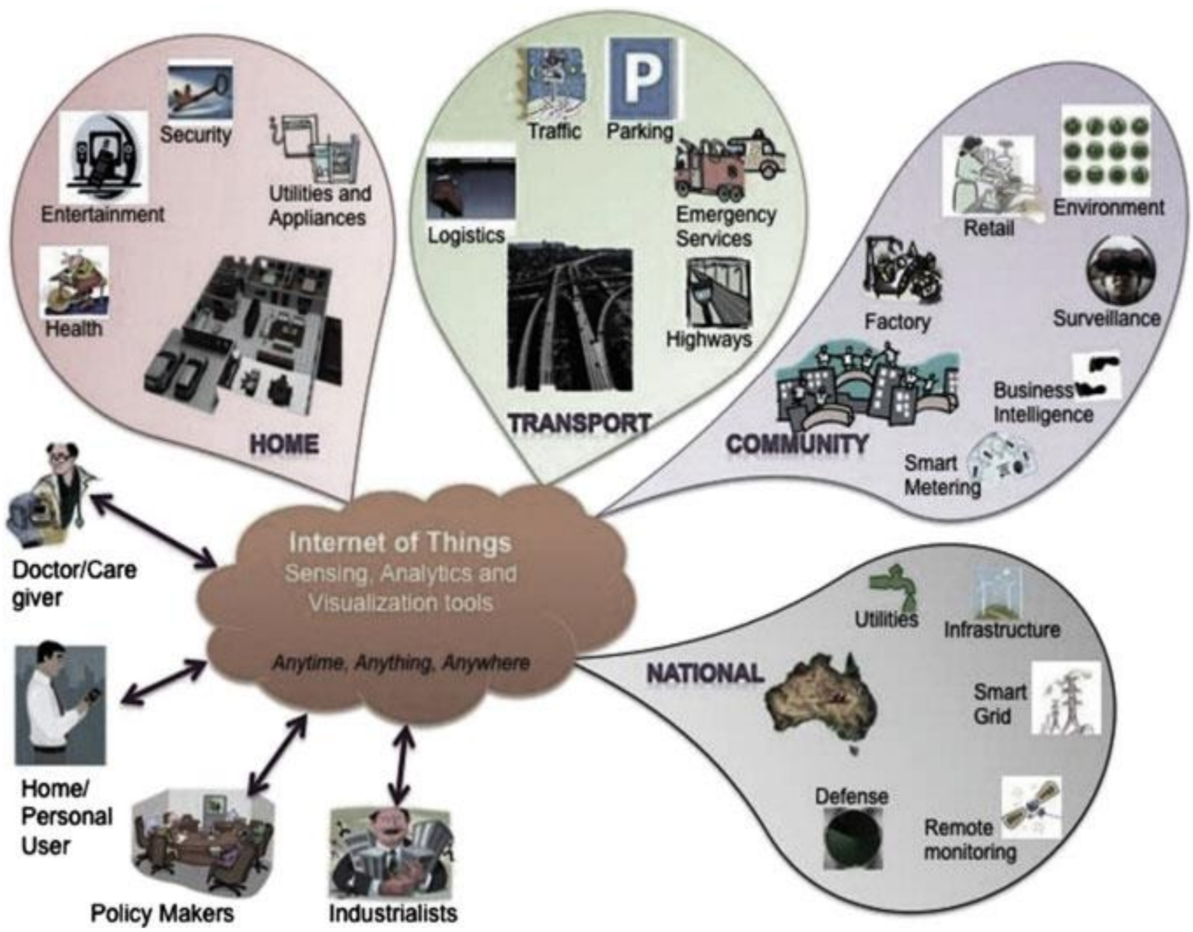


Figure 1. (Perumal and Manohar, 2017) Internet of things sensing analytics visualization tools

For the water sector, diverse applications have been developed, including applications for smart agriculture environment and irrigation (Keerthana et al., 2018) (Sarkar et al., 2018) (Praba et al., 2018) (TongKe, 2013), Smart Water Dispenser for Companion Animals (Lee et al., 2019), water level meter (Pachipala et al., 2018), smart water monitoring (Gowthamy

J, 2018) (Geetha and Gouthami, 2017) (R et al., 2017), water chlorination controlling and monitoring (Zidan et al., 2018).

The water sources in Palestine, as published in the Palestinian Central Bureau of Statistics (PCBS) website (Water Authority, 2017), are groundwater wells, water springs, desalinated drinking water, and an Israeli water company (Mekorot). Table 1 shows the percentage of these sources.

Table 1. (Water Authority, 2017) Water Sources in Palestine

Source	Percentage %
Groundwater Wells	70.50
Water Springs	6.26
Desalinated Drinking Water	1.07
Israeli Water Company (Mekorot)	22.17

The primary water source in Palestine is groundwater wells, wherefore, our research conducts the complete water management process starting from the groundwater well stations "Water Pumping Station (WPS)" to homes. As illustrated in Figure 2, the overall water management process consists of three modules, water source module, water distributors, and consumers or beneficiaries:

1- The Water Source Module

    This module consists of minimal options, water pumping station (WPS) is the first one; in this option, a station for pumping water from a groundwater well to storage tanks or water pipes network directly, this pipes network connected to water distributers "the second module." In this module, a water chlorination treatment process is handled. The chlorination is handled on behalf of pumping water from the well to the storage tank or pipes network. The second option is the Israeli Water

Company that pumps water directly to the distributor pipes network, as a water selling agreement. The last option is a distributor to a distributer connection.

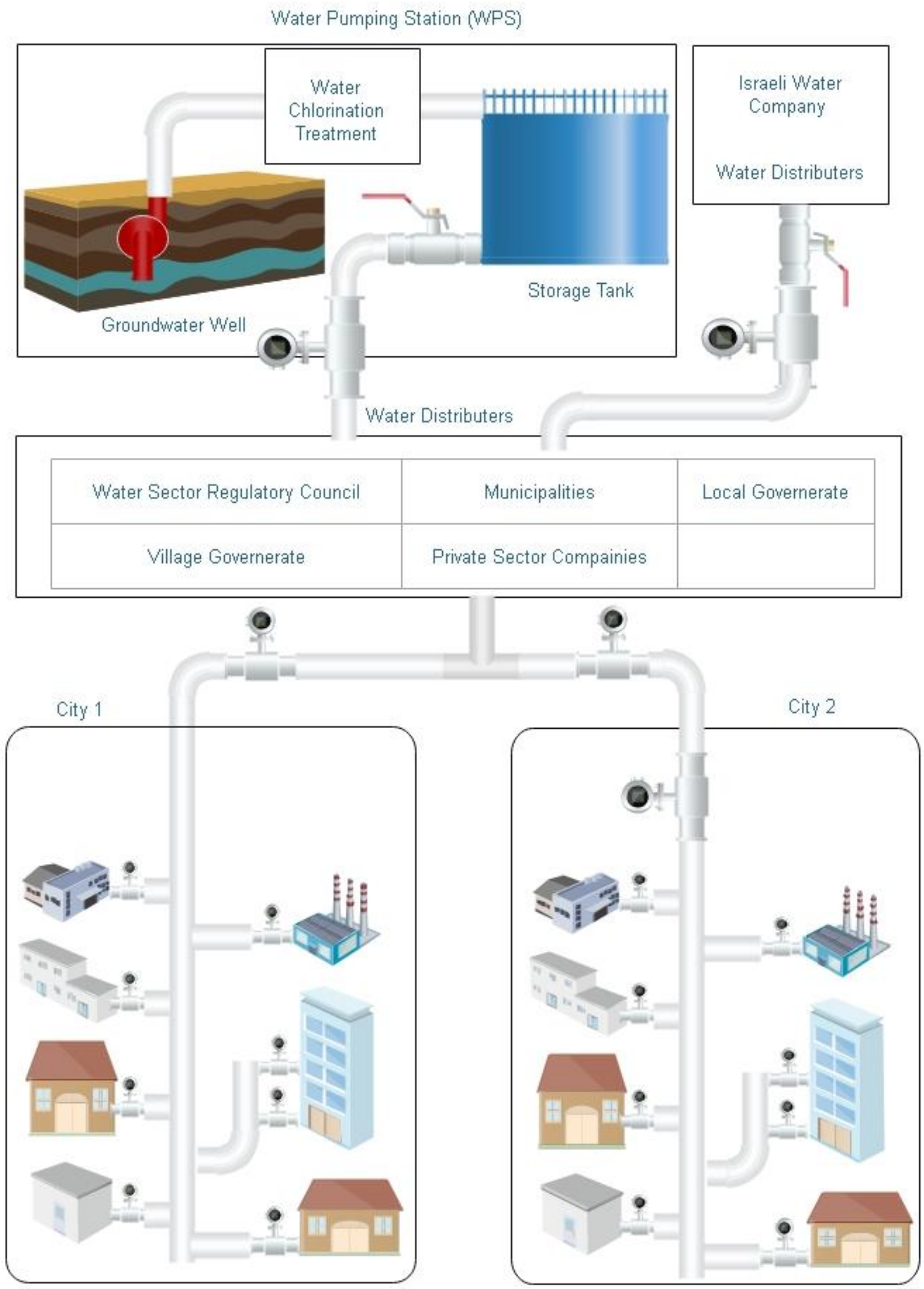


Figure 2. Overall Water Management Process

2- Water Distributors Module

This module consists of private sector companies like Jerusalem Water Undertaken[1], government organizations like Water Sector Regulatory Council[2], Local Government Units, municipalities, local governorates, or village governorates[3]. These distributors own pipes network that delivers water to cities and villages, also, pipes networks inside cities and villages. In many cases, the local governorate buys water from the distributor, its own pipes network inside a city or village, and sells water to consumers.

3- Consumers or beneficiaries

The people who consume water and consumers are the residence of a city or village, and they are connecting to the pipes network. Each of them has one or more subscriptions, and each subscription is associated with an analog water meter with a unique identifier; this meter calculates subscriber water monthly consumption. The owner of the local governorate pipes network issues monthly invoices and collects the revenue.

The MENA region in general and Palestine suffer from water problems of various forms at different levels. Examples of such issues are the scarcity of water resources, weak water infrastructure, untraceable non-revenue water, and lack of fully automated water treatment systems (e.g., water chlorination monitoring and control). These problems negatively affect the water management infrastructure and threaten the water sector's sustainability and safety in Palestine. Also, decision-makers and water supply stakeholders face difficulties

[1] https://www.jwu.org
[2] https://www.wsrc.ps
[3] http://www.molg.pna.ps

in making the right decisions and taking the most appropriate actions towards addressing these problems (Marie et al., 2012). Besides, in urban territories with enormous monetary development, the water request of individuals is additionally expanding. Water is a critical asset for every one of the livings on the earth. A few people are not getting adequate measures of water because of the unequal distribution of water. Water wastage is for numerous reasons; for example, we utilize drinking water for planting, and water leakages are not checked accurately. There is an additional issue of inconsistency of water supply. (Authority, 2017a, Authority, 2017b) PCBS annual statistics in 2017, the Palestinian Water Authority declared the water losses in Westbank and Ghaza Strip as shown in Table 2, the percentage is high and needs a real and effective solution, to find exact places that cause this loss and how to decrease as possible this annual total loss.

Table 2. (Authority, 2017a, Authority, 2017b) Domestic Sector Water Total Losses in Palestine in the Year 2017

State	Supplied Water for Domestic Sector (million m^3)	Total Losses (million m^3)	Total Losses Percentage %
Gaza Strip	96.4	35	36.31 %
West Bank	116.8	32.7	28.79 %

By looking closely at the overall water management process illustrated above in Figure 2, the determination of any problems that occurred at any stage is so complicated by humans. The more difficult is the determination of loss that happened in the city pipes network, the more difficult the loss occurred in the city distributor pipes network. The distributer depends on meters that are dedicated to every client, but what about the case of pipes between one client meter that belongs to the distributor and the primary meter that belongs to the client? We mean hear if any pipes ruin or water leaks, the distributor meter will count the water loss on a client; on the contrary, the client meter will not measure this water loss quantity. This water loss is calculated for the client, and here lies the problem. Figure 3 illustrates the case that we are discussing. The same issue also could happen in the client pipes network. So, the client cannot determine the place of water loss. Here, the water leak is in his pipes network, the main pipe of building, or apartment pipeline, so the problem is more complicated and more difficult to determine. In addition to the case of water theft, which leads to non-counting water at the client meter.

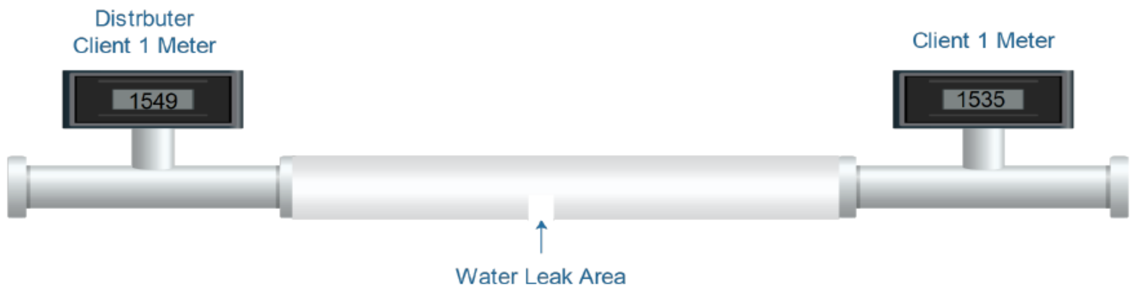


Figure 3. Water Loss Case Occurred on Pipe Between Distributer & Client

The case of water theft that occurs in the client pipe network is illustrated in Figure 4.

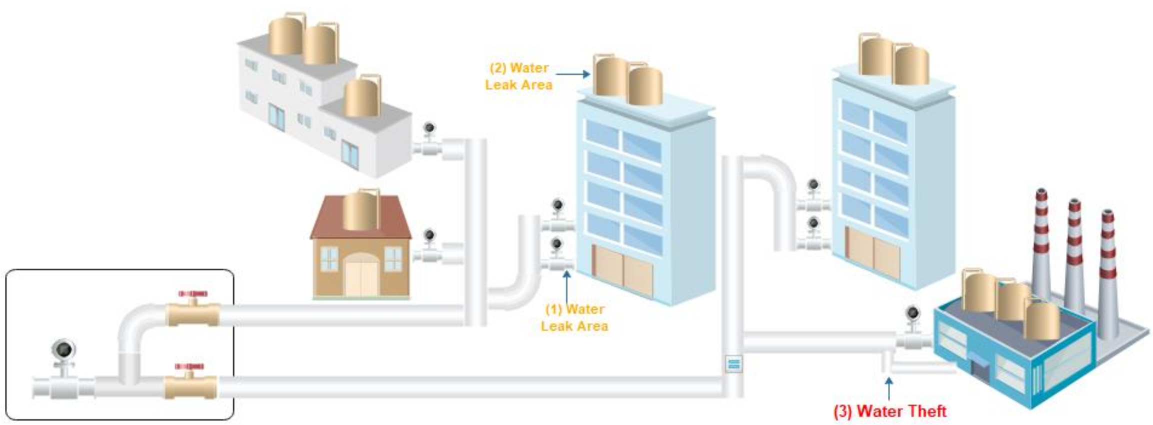


Figure 4. Water Loss Case Occurred on Client Pips Network

In the case here, the water loss issues that occur in the client pipes network are counted for the client, and it does not count as water loss our research is covering. Figure 4 illustrated that the water loss is counted to the client meter (1) Water Leak Area and (2) Water Leak Area. However, we should also focus on these cases, considering the water use guidance perspective. Also, the water loss happened in the pipes network from water tanks to building internal pipes network. Case (3) Water Theft is associate with our research since the water is counted on the distributer meter, on the other hand, non-counting on the client meter.

2.2 Existing Systems

Many approaches, techniques, and systems have been proposed for addressing water loss management, detection, and prediction. We will highlight the approaches, techniques, and systems that use artificial intelligence, genetic algorithms, machine learning, fuzzy, hydraulic parameters of the water flow, and smart systems & solutions. We grouped the approaches, techniques, and systems into three categories, artificial Intelligence & genetic algorithms techniques, machine Learning & fuzzy techniques, and smart systems & solutions.

A. Artificial Intelligence and Genetic Algorithms Techniques

Many artificial intelligence approaches and techniques have been employed to tackle the detection and determination of water loss and water leakage locations. (Rojek and Studzinski, 2019) developed and tested neural networks-based algorithm used for water leak detection and locating, depending on a proposed concept that consists of GIS, SCADA, and water supply network hydraulic model. The algorithm reads the inputs from archived data of all pressure and flow distributions of all nodes and pipes in the network that saved in a particular distribution database. The data to be collected nodes and pipes of the network should be connected and identified in SCADA. There test result comparing with approaches that depend on the only SCADA is better. This approach needs a SCADA system that monitors all stations pumps for determining pressures and water flow; the concept is to archive a normal water distribution water flow and pressures, then comparing the new period reads of water flow and pressures to the normal one, but what about the water consumption variation, between daytime and nighttime, and seasons, so the approach will not be the best one, and it will be very costly to implement.

An optimized calibrated model for quantifying and locating the water loss in the water distribution system (WDS) was developed (Eryiğit, 2017) (Eryiğit, 2019); they used an artificial immune system (AIS) and EPANET 2 in conjunction with their modified clonal selection algorithm. Their model is based on the difference between the total quantity of water inflow and the total quantity of water outflow, and they eliminate the pressure; their model is hydraulic computation based. They simulate their model using the MATLAB 2012a software with EPANET 2 system. Their model was tested on a two-loop virtual WDN, four-loop virtual WDN, six-loop virtual WDN. The model detects the location and amount of water loss on all nodes. They concluded a performance testing should be made and should be explored in different WDNs in the future.

An optimization-based approach via hydraulic model calibration for quantifying and locating water loss using genetic algorithms was presented (Wu and Sage, 2008). They used roughness of pipes, demand adjustment multiplier, and link operation status as water distribution system parameters. According to the demand, the presented model is needed for each customer, and different methods assign the recorded demand for water according to customer meter values. The problem here is that each customer's water demand is challenging to determine since it varies between families, government institutions, and factories. Unless it is determined by historical information, it still differs in seasons and the changes in families, institutions, and factories. They do not mention the methods for collecting customer meter information, which is a significant matter that affects the results' accuracy.

B. Machine Learning and Fuzzy Techniques

Machine learning and fuzzy techniques are used in almost all fields nowadays. We will highlight several approaches that have been specifically proposed for the detection of water loss.

In the chapter entitled "Leak Detection in Water Distribution Networks via Pressure Analysis Using a Machine Learning Ensemble" (Fuentes and Pedrasa, 2020), the authors considered the water demand and the physical characteristics of WDN. The authors developed a learning machine (LM) approach for water loss detection and locating. Their methodology composed of three stages, EPANET simulation, is the first stage, by using three distinct constructed EPANET networks; in the simulation, a demand profile is taken into concern previous consumption demand, demand variations in the morning, evening, and midnight, in this stage for leak detection they implemented sensor for every EPANET simulation on WDN. The second stage, "Feature Extraction and Wavelet Decomposition," by applying a wavelet transform on pressures datasets signals generated from sensors in stage one, after detecting the transients in the signal by different detail levels coefficient leads to the determination for the water leakage detection. The final stage is "Classification via Machine Learning Ensemble," the data generated from stage two is analyzed using ML convolutional neural network (CNN) ensemble. As a result of analyzing the occurrence of leakage scenarios identified. This approach takes in concerning new parameters, such as various water demand; since real-life datasets are incomplete and challenging to be ready, they used generated datasets from the EPANET simulator. As a result of this approach, pipeline leak occurrences were determined in different WDN, different sensor densities, and certain combinations. The approach is perfect, but it did not consider how to deal with water distribution in the real or closest time.

The Water Loss Risk Index (WLRI) framework was proposed (Zyoud and Fuchs-Hanusch, 2020) by indexing the occurrence of water losses in pipes and identify each of them with an interval between 0% to 100%. There proposed framework considered many factors that influencing water loss. These factors are physical, operational, environmental factors, the system's pressure, pipes' age, water meters, service connections, the water demand, type of materials, and traffic volumes. Each introductory factor rate in the WLRI framework fuzzified into factor membership function classified into three levels (Low, Medium, and High). Fuzzy Synthetic Evaluation Technique (FSET) applied to aggregate essential factors contributions to WLRI.

Furthermore, finally, defuzzification of the three-tuple fuzzy set out from the (FSET) into crisp values represents the WLRI/pipe in the zone. They make scenario analyses to provide knowledge about the relevance among inputs and outputs of their model and Monte Carlo simulation analysis to examine the changes of wights of main categories and essential factors that can have impacted the values of WLRI at the zone level. This approach is requiring the availability of information needed. Also, it did not consider how to deal with water distribution in the real or closest time.

C. Smart Systems and Solutions

Our research on building a smart management system for water by employing IoT, so here we will point out and discuss several systems and solutions related to smart water distribution and quality management, monitoring, and controlling.

In the conference paper entitled "IoT BASED SMART WATER SYSTEM" (Bennet Praba et al., 2018), the authors have focused on developing a water quality monitoring system in location monitoring of the remote water level through a wireless sensor zone. The project focused on wireless sensors deployed in overhead tanks. The concept is based on the ultrasonic sensor, slow sensor, and pH sensor, all sensors connected to the Arduino controller, a REST API called from Arduino controller to collect periodic values from the sensors and save them in a cloud database. An android application is connected to a cloud database for viewing sensor data and sends alerts when actions base on determined thresholds for tank water level, water flow, and pH. A real-time water level monitoring based on IoT is proposed. This approach focuses on the last part of the water distribution system, the water tank over the building. So, it helps with water use guidance, and there is no focusing on any control of water flow.

A real-time system for monitoring water quality by using wireless sensor networks (WSN) was proposed (R et al., 2017). Arduino board aggregates the sensors available at the water tank for real-time monitoring. The sensors are temperature, dissolved oxygen (DO), the potential of hydrogen (pH). The approach proposes the monitoring system, without any experiment, without details of how the sensors data will be transferred from Arduino to an internal or external database. There are no details of any application for displaying the sensors' data. They do not mention any alerts when the quality is not in the allowed range.

(Malche and Maheshwary, 2017) proposed a prototype design for a system based on IoT for monitoring water level; this system can be applied to smart villages and smart agriculture. They subdivided their prototype into a physical, service, and presentation layer. They illustrated the interaction between the three layers, as shown in Figure 5. They used the Arduino Uno board on the physical layer connected to the internet with an ethernet shield, in addition to an analog liquid level sensor for determining the level of water. They use the Carriots[4] opensource application hosting and development platform for data collecting and freeboard[5] for data visualization. Their proposed prototype focused on monitoring, and there are no controlling parts and their research on how to detect the water level in tanks and monitor that.

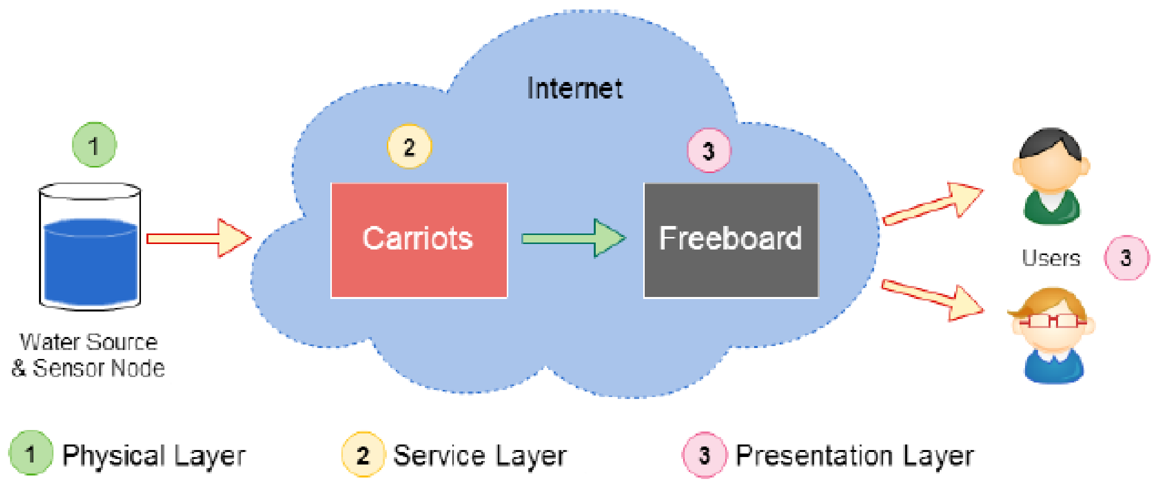


Figure 5. (Malche and Maheshwary, 2017) proposed system layers with interactions between layers.

A low-cost system that monitors water quality and quantity in real-time was presented (Gowthamy J, 2018). The sensors record the flow of water and values saved to the database on the cloud. The sensors used are pH, temperature, turbidity, pressure, and flow. An Arduino controller with a Wi-Fi module is used for transferring sensor data to the cloud. The paper contains figures for graphs of pH and ultrasonic sensors generated data. There are no details for APIs used to extract data from sensors or push data from sensors to the

[4] https://iot5.net/iot-platforms/carriots-iot-platform/
[5] https://freeboard.io/

cloud server, no threshold of quality and quantity, and the prototype does not contain an alert module.

A smart water quality monitoring system based on four parameters was presented (Mukta et al., 2019), pH, temperature, electric conductivity, and turbidity. The sensors for the four parameters are connected to the Arduino Uno controller. Sensors values extracted through a .Net desktop application are compared to standard values to show water quality results. After the sensors' data analyzed and classified, the determination occurred if the water is drinkable or not. Figure 6 illustrated the presented block diagram of the system.

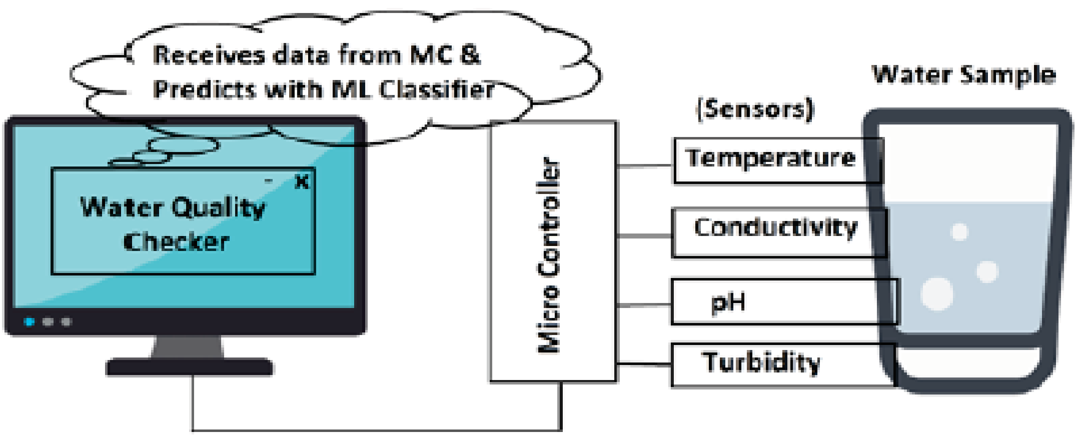


Figure 6. (Mukta et al., 2019) the presented block diagram of the proposed SWQM system.

A strategy to concentrate on continuous and constant water supply supervision in the IoT scheme was proposed (Jaiad and Ghayyi, 2017). Water distribution with constant supervising formulates a legitimate dispersion so the quantity of water in tanks, flow rate, variation from the norm in the supply line can be made. Internet of things is only the method of substantial items embedded with electronics, sensors, programming, and system network. Monitoring should be possible from any place as a central server. Utilizing Ada natural product as free disjoin information always pushed on the cloud so data can be seen continuously. They use typical sensors with controller and raspberry pi as minicomputer can supervise information and control tasks from the cloud with a skilled customer on server communication. This framework is centered on IoT, a new situation to make a smart city with various applications. The principal target to implement this scheme is to sketch out and make up a negligible effort dependable and productive system to make appropriate water conveyance by consistently checking and controlling it from a central server to achieve water-related problems taken care-of. Arduino collects the data from sensors and forwards it to a raspberry pi. The water distribution process's critical issues, including overflow, overutilization, and water quality, are solved.

2.3 Summary

This chapter aims to simplify a state-of-the-art survey of IoT, IoT roles, applications, and approaches in the water sector. We have particularized the techniques, practices, and systems proposed or implemented to tackle water problems, including artificial Intelligence & genetic algorithms techniques, machine Learning & fuzzy techniques, and smart systems & solutions. We have then accompanied a comprehensive comparative analysis of these techniques, approaches, procedures and highlighted their strengths and weaknesses.

3. System Overview

3.1 Introduction

This chapter introduces IoT application architecture theoretical basics and the multiple architectures of the proposed IoT-based Smart Water Management System (SWMS). First, in section 3.2, we present IoT theoretical basics that we count on to build our proposed system architecture. Then, we offer and clarify our proposed smart water management system architecture in section 3.3. Finally, in section 3.4, we summarize this chapter.

3.2 Theoretical Basics

Internet of Things (IoT) refers to the rigorous interconnection between the physical world and the digital one (Ray, 2018). In general, IoT connects things to anyone, any service, in any place, at any time through any network (Soumyalatha, 2016). IoT system consists of several functional blocks to facilitate the various operations to the system, such that sensor identification, communication, management, sensing, actuation, and data sending/receiving. These functional blocks are sensing/actuation devices that control and monitor the activities, exchange data between them, or other IoT things. The communication block, the interconnection environment, enables various devices and things to communicate with others. The services block, responsible for serving multiple functions. Such as device modeling, device controlling, device data extraction, data analysis, and device discovery. The management block, various parts contain the IoT system to pursue the core IoT system governance. The security blocks manage authentication, authorization, data security, and data integrity. The last application block represents the user interface, facilitates user function on the system, including results for monitoring and analysis, in addition to actions needed from different users (Ray, 2018).

IoT is a system that includes many different categories, for example, wire or wireless sensors/actuators networks, low-power embedded systems, smart devices, smart homes, smart agriculture, smart cities, cloud services, APIs. So, no one architecture will suit all these different categories. We will discuss some IoT architecture that suits our IoT-based system. We will then explain and determine the chosen architecture for our IoT system that can be applied in our country, the State of Palestine.

3.3 System Architecture

This section discusses IoT system architectures that can be adopted for building our system; then, we present a general overview of our proposed approach.

IoT system consists of four fundamental components, sensors/devices component, connectivity component, a data processing component, and user interface component. For implementing and interconnecting these components, multiple different IoT system architectures can be used. We will discuss our SWMS IoT components. Then, we discuss the architecture we choose to apply, which is the most applicable in our country, the State of Palestine.

3.3.1 SWMS IoT Components.

The IoT architecture includes four main components: sensors/devices component, connectivity component, data processing component, and user interface component. We will explain each of them and their role in our SWMS.

A. Sensors/Devices Component.

Sensors, devices help us on collecting information from the surrounding environment. These devices take the place of human actions. Different sensors with different sensing actions. In our SWMS actions, we need are:

1. Water flow Quantity (Water Meter Readings)
2. Tank water level
3. Chlorine concentration value

A smart water meter, a device that is used for counting water flow consumption, also has wired/wireless technology for connecting to LAN or WAN networks. (Marais et al., 2016) in his review article, he talked about smart water meters and how they can be developed with different technologies. In addition to the networking and communication used in smart meters, there is a wired communication using USB cabling, power-line communication, or telephone lines. The wireless communication with low power and low data rate sensor networks are based on IEEE 802.15.4 standard. The installation options for wireless, as he mentioned, are:

1) (RF) Short-range Radio Frequency
2) (GSM) communications Global System for Mobile
3) (WiMAX) Worldwide Interoperability for Microwave Access
4) (LTE) Long Term Evolution

B. Connectivity Component.

The connectivity component interconnects the sensors component with the data processing component. It is the communication environment for connecting sensors to on-premises or cloud storage in the data processing component. The connectivity could be one of the following:

1) Wired connectivity, through power-line cables, telephone lines cables, or fiber cables. A smart water meter, a device that is used for counting water flow

consumption, also has wired/wireless technology for connecting to LAN or WAN networks.

2) Wireless connectivity, by using a global system for mobile (GSM), Wi-Fi for short to medium range with low power consumption, Worldwide Interoperability for Microwave Access (WiMAX), and LoRa wireless (Long Range and Low Power Consumption).

C. Data Processing Component.

The component that contains data storage, different software agents with application programming interfaces (APIs), communicate with sensors component out of connectivity component. The software agent is calling APIs that send actions to sensors or receiving data from sensors. Agents are responsible for the real-time collecting data from the sensors, checking the real-time status of sensors. The data processing component also contains software agents for processing the data, then outputting the desired results. These results are used for monitoring the state of sensors, which reflects the state of the pipes network—also, areas that the water flow is available, the water distribution process. In addition to determining if water leakage exists, the location of water leakage, besides sending actions to shortage the water leakage by stopping water flow in the smallest area as possible depending on the leakage location.

The data processing component responsible for managing the data storage. The data storage used from SWMS should be high in writing data and reading data. It should be distributed, highly horizontally scalable, highly available, run anywhere, and highly secure. Data storage with the dynamic schema as possible, data storage handles unstructured data, one does not need a predefined data schema while building or maintaining the system. A document-oriented data storage is recommended because it supports JavaScript Object Notation (JSON), a lightweight format for storing and transporting data, especially web-based applications. The data storage we are using in our system is MongoDB (MongoDB, 2021), a document database that stores data in a JSON-like format that supports arrays and nested objects—used for a flexible and dynamic schema, a rich and expressive query language. A high-performance No-SQL document database on writing and reading, a highly secure database, supports horizontally scaling. The database supports the deployment on-premises or cloud, or hybrid. It supports single instance deployment or distributed one by using replica sets or sharding in addition to easy deployment for single or multi-replica sets.

D. User Interface Component.

It is the top component in architecture. It is the graphical user interface (GUI) component. It is a responsive web-based application that any browser rendered on any device (smartphones, tablets, laptops, desktop computers, or personal computers). Humans use the GUI. The GUI is a group of graphical tools by which humans can set up the system's initial configuration. This configuration includes distributors, local governorate areas, buildings, customers, and customer meter accounts. It is interconnecting each smart meter with the customer account, interconnecting meters with feeder meter, monitoring dashboards, historical view of data, roles management, user's management including authentication and authorization, notifications management.

3.3.2 SWMS Architecture.

As illustrated by (Yaqoob et al., 2017), the IoT architecture, including the four main components we explained in section 3.3.1, is visually depicted in Figure 7.

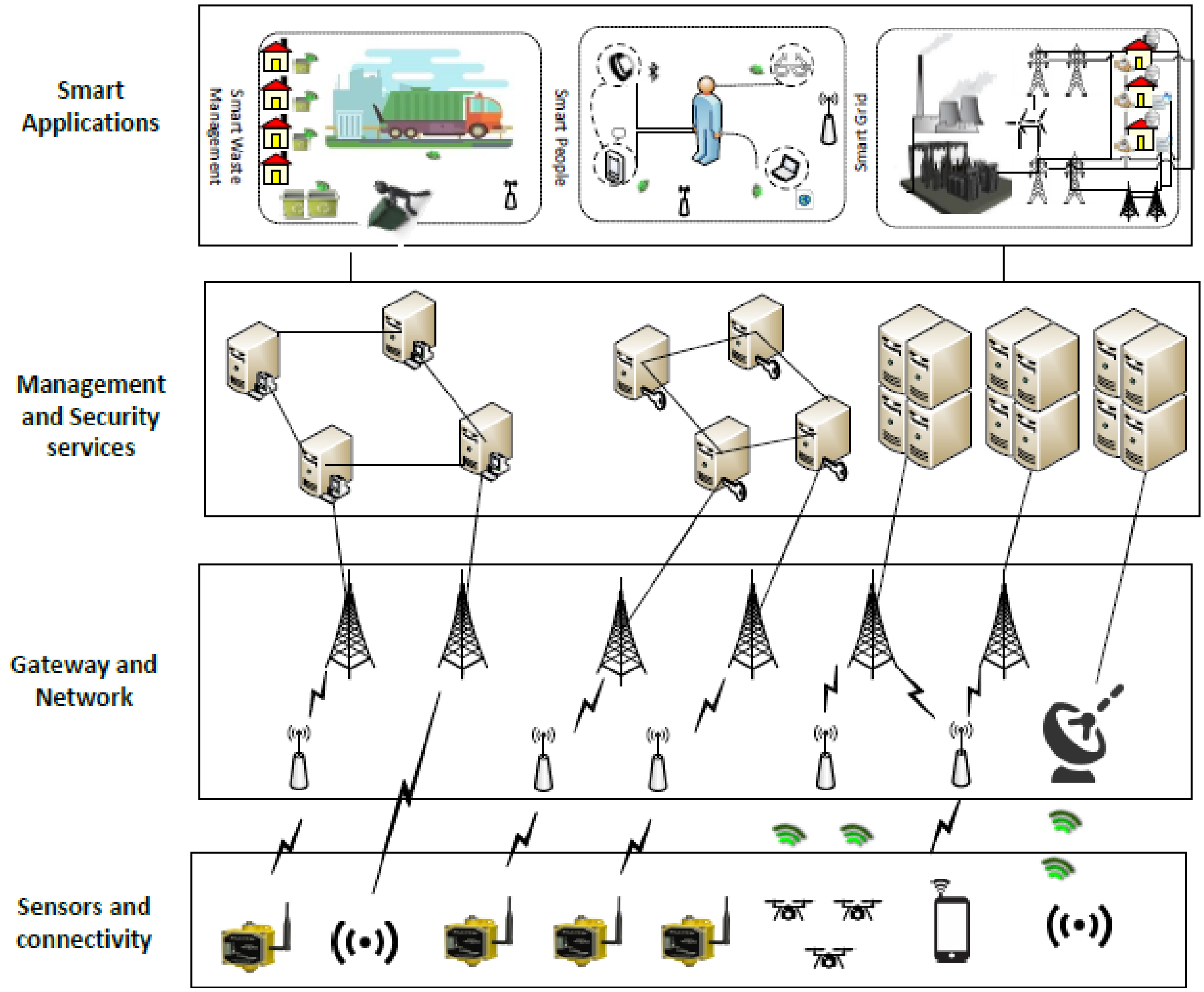


Figure 7. (Yaqoob et al., 2017) Internet of Things Architecture

Based on this architecture. Besides, communication services in the State of Palestine are not fully covered. We will use hybrid architecture with different communication, data storage, application servers. We should guarantee that our SWMS is deployed in all places without obstacles in application servers, communication, or storage obstacles. Based on PCBS information society indicators in 2019 (Statistics, 2019), table 3 clarifies the percentage of families that can access the internet, the rate of families with phone lines, and the percentage of families with smartphones, computers, or laptops.

Table 3. Information Society Indicators in 2019 based on PCBS Statistics

Indicator	Value %
Percentage of the households that have fixed telephone line	31.2 %
Percentage of households that have a smartphone	86.2 %
Percentage of the households that have a computer (desktop, laptop, tablet)	33.2 %
Percentage of the households that have internet access at home	79.6 %

Table 3 values indicate that the homes connected to telephone lines are 31.2%. This percentage is low, so our IoT architecture will not bank on phone-lines communication. Besides, households that have internet access is a significant percentage 79.6%. Still, we should consider that homes use Israel Global System Mobile, and we cannot use Israel GSM based on our country regulations. Based on that, we will classify the local governorate that distributes water into the following categories.

A. Big and medium towns and cities

   These areas have the best communication technologies, high-speed internet with high availability percentage. Phone lines cover all the areas that have buildings. Fiber networks cover most of the area, but the use of fiber networks for homes is shallow. Commercial and industrial organizations use this service. Microwave networks are also used, these networks cover most of the areas with buildings, and the possibility of increasing the covered area is easy and fast. Global System for Mobile Communication third-generation (3G) covers most of the regions with accepted high speeds. This service is provided by Palestinian cellular providers Jawwal and Ooredoo.

B. Villages and small towns

In some of these areas, phone lines are available with speeds, 4 Mbps and 8 Mbps, considering that phone lines are shared for at least 16 Users, so the internet speed is not as fast as required and depends on concurrent usage peak time. Fiber networks are not available. Microwave networks are available in some of them, also with the ability to expand the covered area. Palestinian cellular providers cover a high percentage of these areas. Besides, we should be considering that many of people who live in these areas use Israel cellular GSM (3G, 4G) since the near of cellular towers belongs to Israeli providers, the fourth generation of GSM that not available on Palestinian cellular providers in addition to the lower cost of using 4G than 3G.

C. Small Villages

These areas are a tiny percent, and the phone lines are not available, microwave networks do not exist, besides some of them, Palestinian Cellular GSM 3G does not cover.

Based on IoT architecture illustrated in Figure 7 and the information security indicators in Table 3, and the local governorate categories. For building our IoT SWMS, our system will be consisting of different architectures. It means that we will be considering all area categories and what is suitable architecture will be used for each of them.

Figure 8 demonstrates the overall SWMS IoT architecture that suites the big and medium cities category, also villages that have the availability of phone lines or GSM or microwave networks. The figure illustrates the four components and the role of each of them. This architecture concept depends on the smart water meter (sensors component) on the communications ports available. No matter of different meters with different communication ports attached, the goal is that the meter is connected to the internet and could have an IPv4 or IPv6 to communicate through.

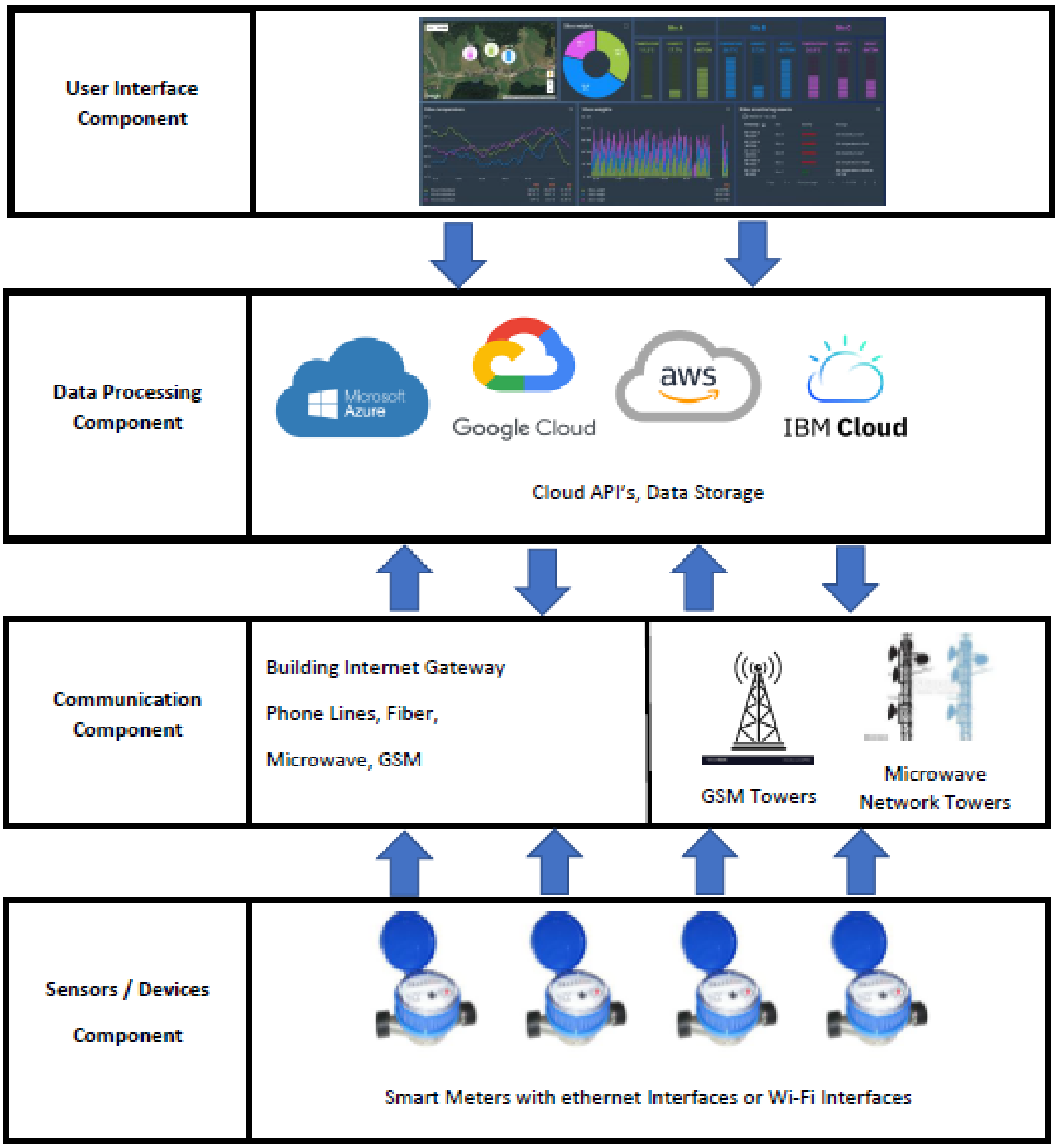


Figure 8. SWMS IOT Architecture I

The regions category includes the small villages, in which phone lines, fiber networks, and microwave networks do not exist. So, the use of phone lines, fiber, or GSM using the cloud for data processing components is not a choice. Figure 9 illustrates the replacement architecture for these areas and how our system deployed on these areas.

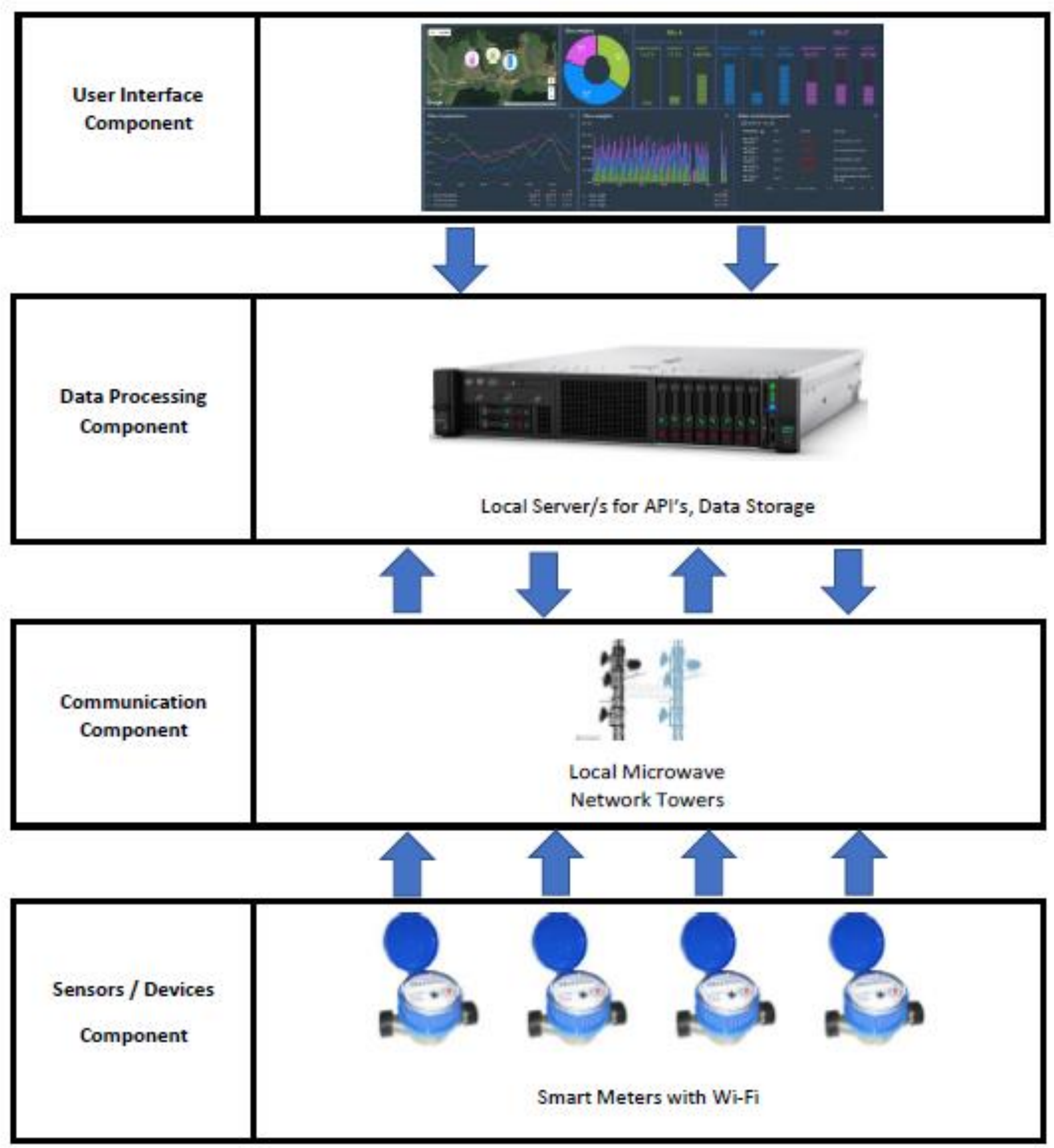


Figure 9. SWMS IOT Architecture II for Small Villages without phone lines, fiber, microwave.

Figure 10 illustrates the water chlorination treatment process on Water Station Pump (WSP). The architecture we proposed and implemented to control and monitor the water chlorination process by employing IoT is illustrated in Figure 11.

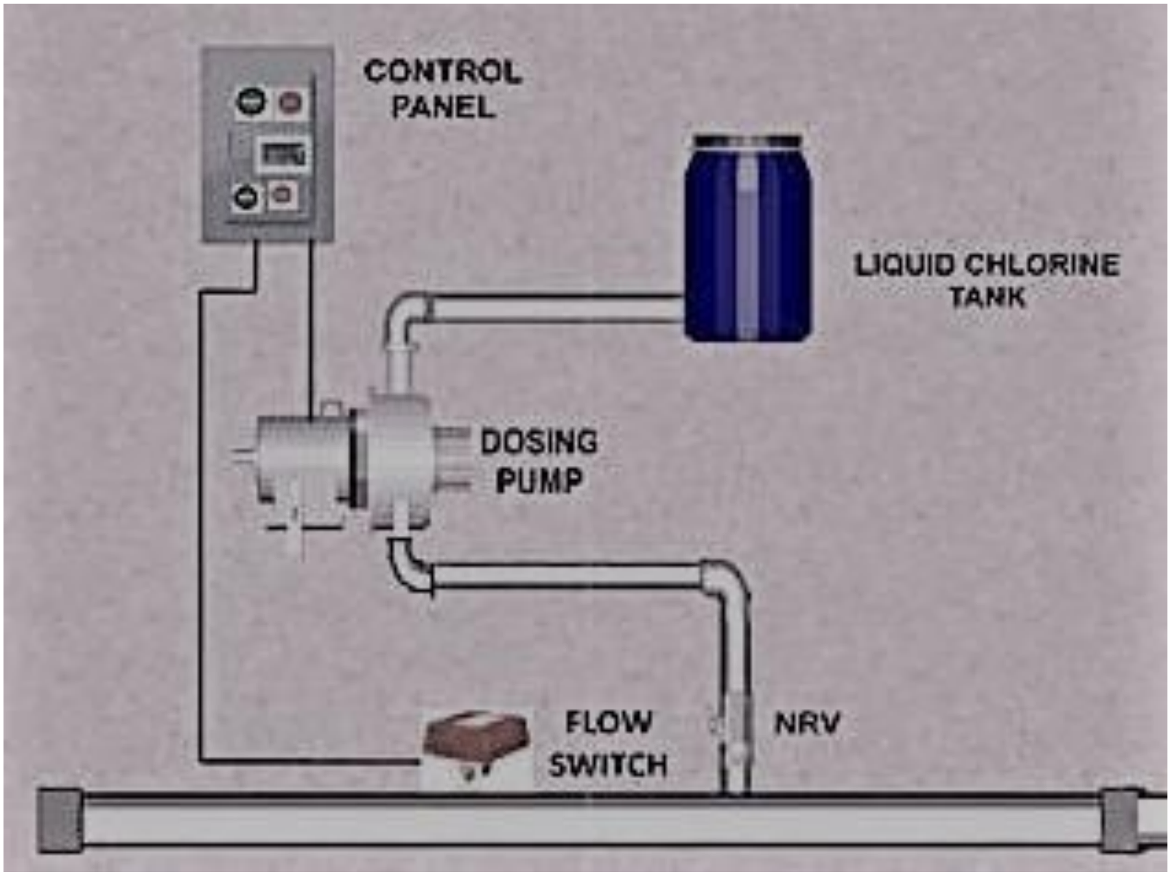


Figure 10. (Zidan et al., 2018) Architecture for Water Chlorination Treatment.

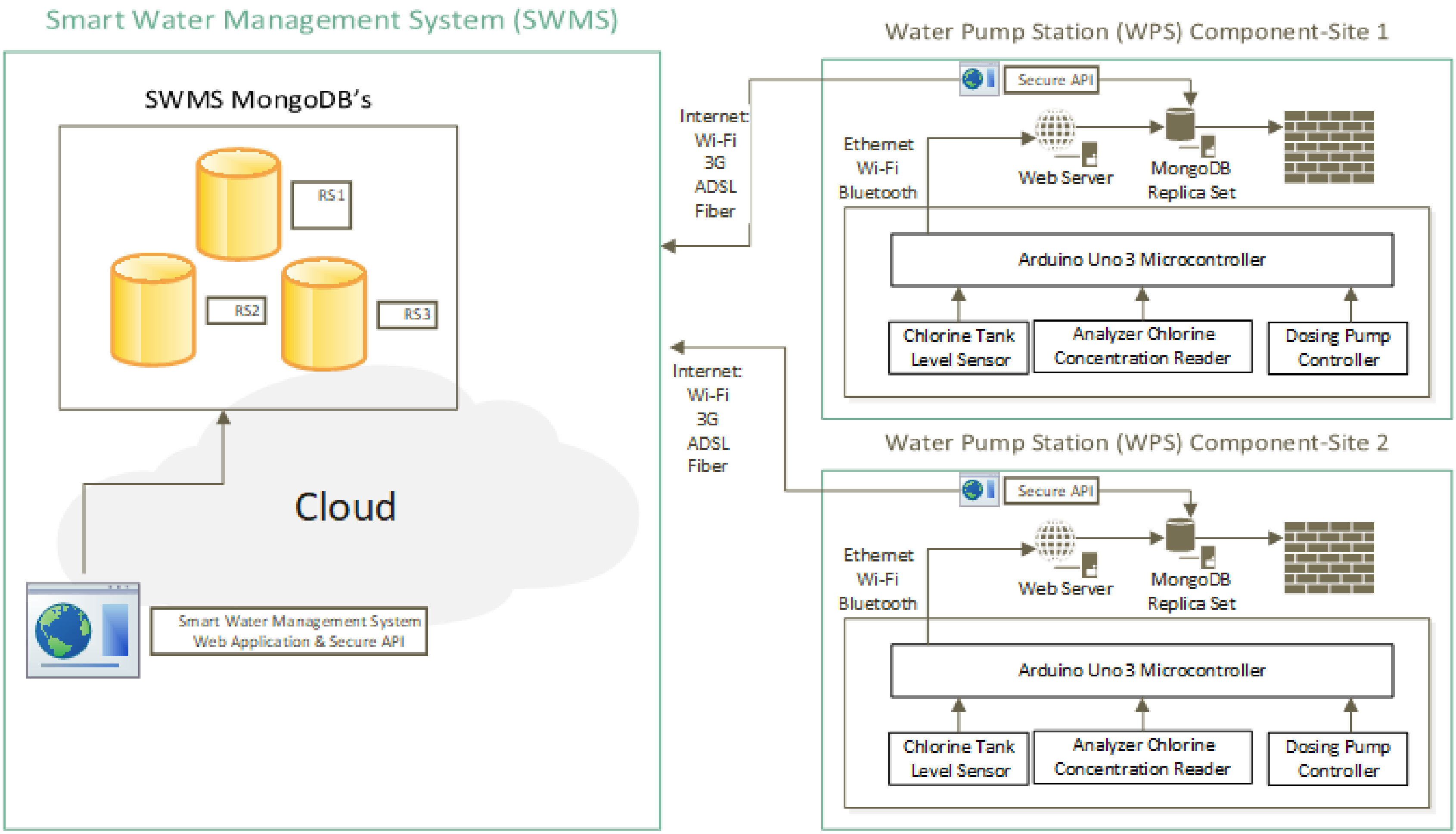


Figure 11. (Zidan et al., 2018) IoT Based Monitoring and Controlling System for Water Chlorination Treatment Architecture.

3.4 Summary

This chapter objects to present a general overview of our proposed smart water management system by employing the IoT and illuminating the proposed system's overall architecture. Also, we explained that our proposed system has four main components (Sensors/ Devices component, Communication Component, Data Processing Component, and User Interface Component). We clarified the role of each component. We explain the two IoT architectures for our proposed system and the criteria that each of them is applied. Also, we describe the IoT-based architecture for the water chlorination process in the water pump station.

4. System Implementation

This chapter describes the proposed smart water management system's implementation details, including the detailed implementation of IoT-based components. First, we present the details related to the sensors' data sending and receiving in section 4.1. Then, in section 4.2, we describe the IoT collectors and the mechanisms used to collect meter readings from the smart meters. After that, we describe the data storage architecture and schema, also the restful APIs used in section 4.3. Then, in section 4.4, we describe the IoT platform's main features for the user interface. In conclusion, we summarize this chapter in section 4.5.

4.1 Sensors Data Sending and Receiving

There are few sensors needed in our SWMS to accomplish the research goal. The most used one is the smart water meter. A smart water meter is a device that should replace the current magnetic meter, and the current meters did not have any connectivity technologies, so human interaction is needed for recording the readings of the available meters. The reading is recorded by an employee once monthly in the best times. The reading sometimes is estimated based on last reading consumption based on no reading recorded on an entire month. This case occurs in a repeated matter to tackle this problem, the smart water meter with an ethernet interface/and Wi-Fi connectivity is used. Table 4 compares the current meter in use and the new one we are proposed to use.

Table 4. A comparison between the current magnetic water meter and smart water meter

Feature	Magnetic Water Meter	Smart Water Meter
Meter Image		

Network/Internet Connectivity	No	Yes
Readings Recording	Human	Software Robotics
Readings Recording Periods	Monthly at least	Every 5, 10,..etc. Minutes, Hourly, daily, weekly
Readings Accuracy	The human recording errors occurred usually	Accurate, no errors occur on the recording process
Detection of the water leak or water theft	Hard, needs effort and time (days or weeks)	Easy, without human effort, little time (minutes or hours)
Controlling and Monitoring	Possible, but hard and needs human physical interaction on the meter	Controlling and monitoring without physical interaction to meters, using a web application

The second sensor is tank level. This sensor is needed to determine the water level in tanks that available on the building's roofs. It is also used to determine the chlorine level of the chlorine tank located on the water pumping station (WPS). We implement and test a prototype for a tank level sensor using Ultrasonic Sensor (HC-SR04) and Arduino Uno 3, implement a prototype to control the process of keeping chlorine concentration as required by automatic control of the chlorine dosing pump. Figure 12 illustrates the Arduino and Ultrasonic Circuit we implemented. Arduino controller connected to the analyzer transmitter illustrated in Figure 13. Figure 14 shows the Arduino controller connected to the dosing pump. In Figure 15, the chlorination concentration sensor we are using for determining the concentration of chlorine in the water. The concentration of chlorine should be between a minimum of 0.2 mg/L and a maximum of 0.8 mg/L. If the concentration becomes lower than 0.2 mg/L, the water will be risky for lives and cannot be used for drinking. In case it is more than 0.8 mg/L, it will cause severe danger to human lives.

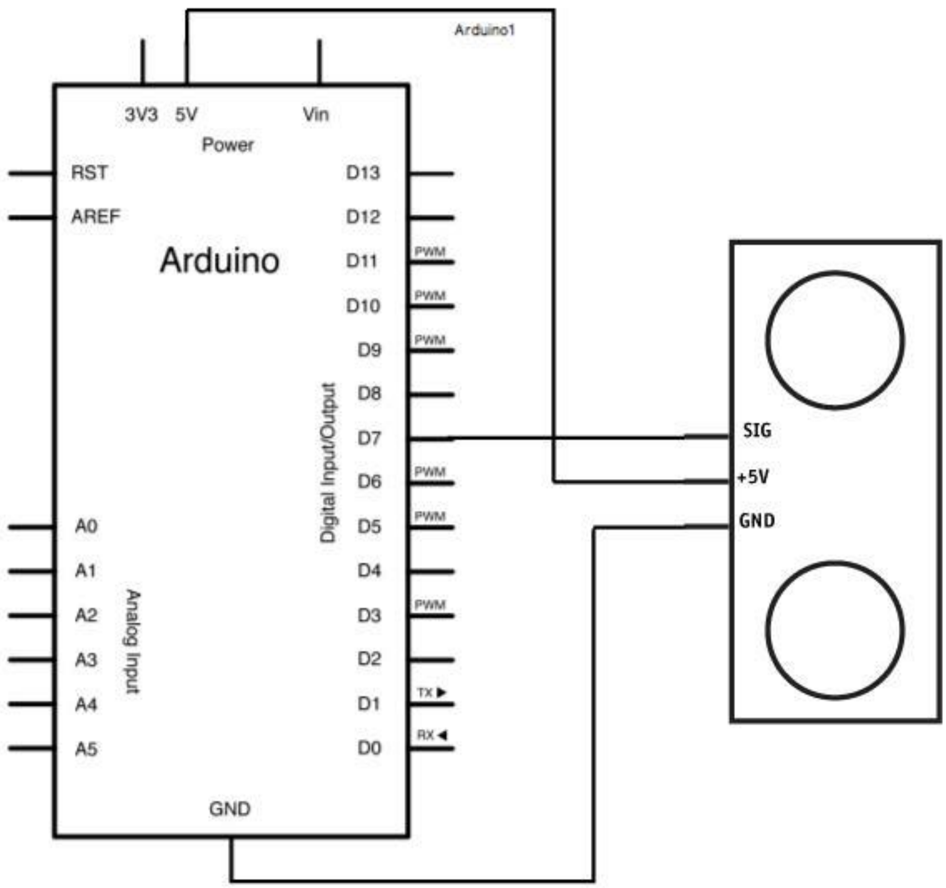


Figure 12. (Zidan et al., 2018) Arduino and Ultrasonic Circuit.

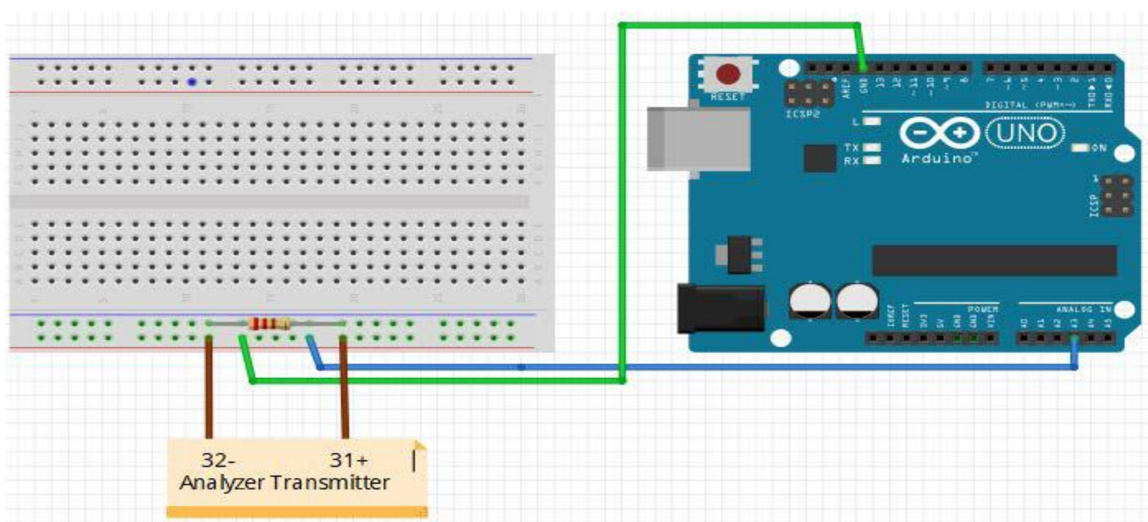


Figure 13. (Zidan et al., 2018) Arduino controller connected to the analyzer transmitter.

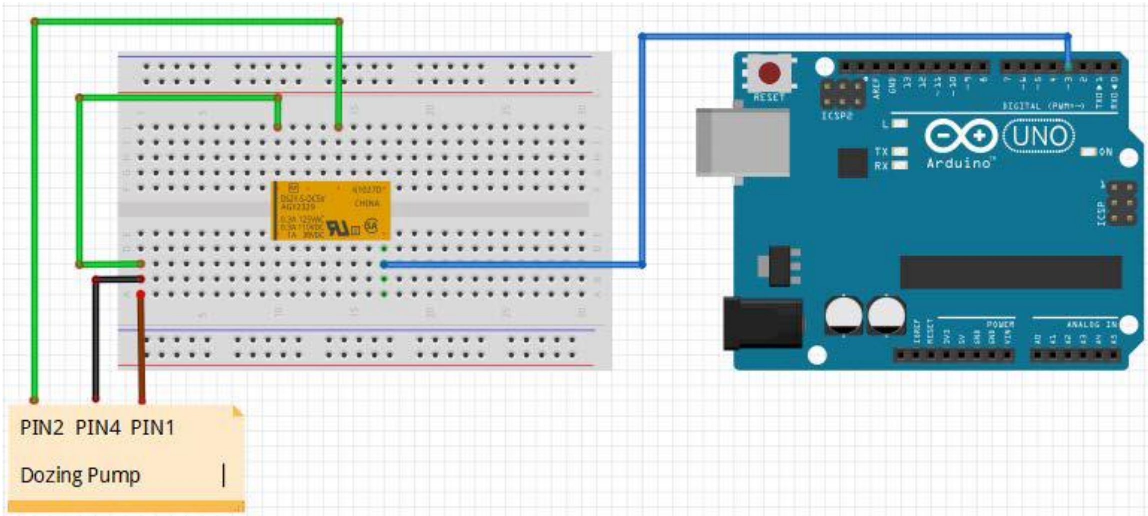


Figure 14. (Zidan et al., 2018) Arduino controller connected to the dosing pump.

Figure 15. Chlorine Concentration Sensor.

4.2 IoT Collectors

A smart water meter is made up of an industrial controller with Wi-Fi or/and ethernet interfaces, such as Controllino[6] and Raspberry Pi[7]. These controllers are programmable.

[6] https://www.controllino.com/
[7] https://www.raspberrypi.org/

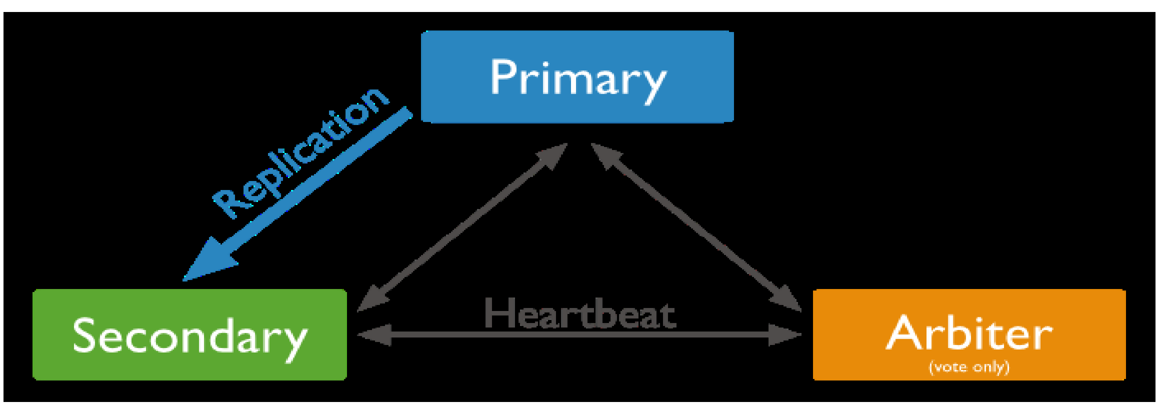
It means that we can embed C programming code for calling a restful API. Besides, it includes a light operating system that can host services. The minimal services we need are webserver services like Apache and NGINX, and these web servers can host Node.js web AP I application. In addition to a locally installed NO-SQL database like MongoDB and SQLITE3. (Hong and Cho, 2016) implemented a full-stack platform design in Raspberry Pi, they installed MongoDB database, and they used MEAN stack (MongoDB, Express.js, Angular, Node.js) for developing the full-stack application. So, the manufacturer of these smart meters provides customers with a software development kit (SDK) for configuration of readings schedule, and API for sending the readings from the smart meter to an API and receiving calls for checking the status of the smart meter, shutting off the water flow on a meter. These smart meters should be configured with an accurate date and time for time series readings with different meters with their feeder meter. Our research will not describe how these meters save the data and how they are calling restful APIs. These meters have at least the following characteristics:

1. Support of Public Static Internet Protocol version 6 (IPv6) for cloud-based SWMS architecture.
2. Support of private Static Internet Protocol version 6 (IPv6) or IPv4 for on-premises SWMS architecture.
3. Support of time-zone and date/time configuration.
4. Support locally, saving a time-series of water flow readings.
5. Support calling of restful API for sending the saved readings on a scheduler or by calling from an API consumer.

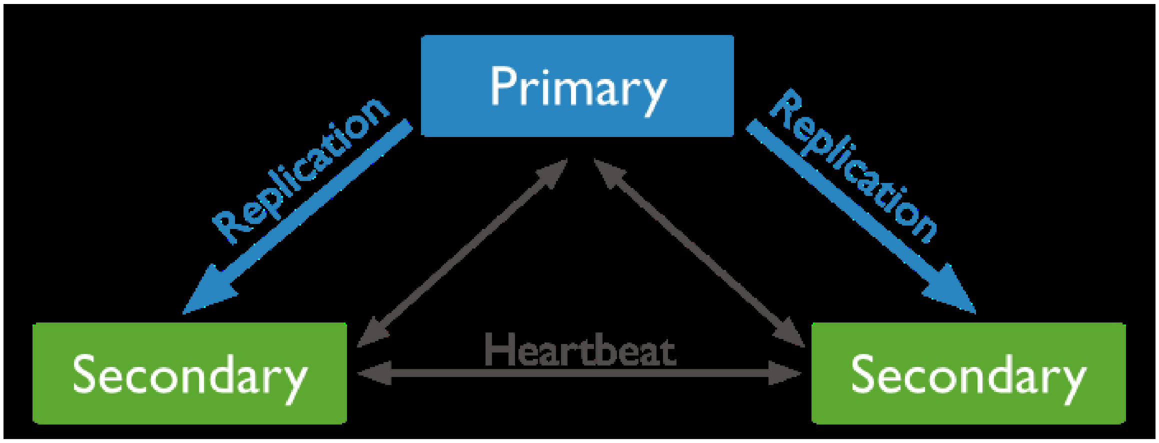
6. Support receiving API calls from a consumer for a status request, shutting off water flow.

4.3 Data Storage and Restful API's

Data storage is a critical and vital component; as we explained in chapter 3, our SWMS data storage is a NO-SQL document-oriented database that supports data storage on a format like JSON since our system has a module for communicating with restful APIs. The restful APIs requests and responses are a lightweight JSON format. So, using a document-oriented with dynamic schema database is a crucial choice. So, we choose the open-source NO-SQL MongoDB database. Figures 16 and 17 illustrate the architecture of the minimal requirement for deploying a high available MongoDB with horizontal replica sets scaling. The architecture could be deployed in any cloud platform like Microsoft Azure, Google Cloud, Amazon Web Services, the deployment could be (SaaS) application or software as a service, (IaaS) infrastructure as a service, or (PaaS) platform as a service. The chosen deployment type depends on the number of smart meters, data size, high availability requirements, security requirements, budget available for the system. Also, the architecture could be deployed in an on-premise server/s.



(Rattrout et al., 2017) Figure 16. Two MongoDB Replica Sets.



(Rattrout et al., 2017) Figure 17. Three MongoDB Replica Sets.

The proposed dynamic schema for data storage that our SMWS used to store and retrieve data is illustrated in Figure 18.

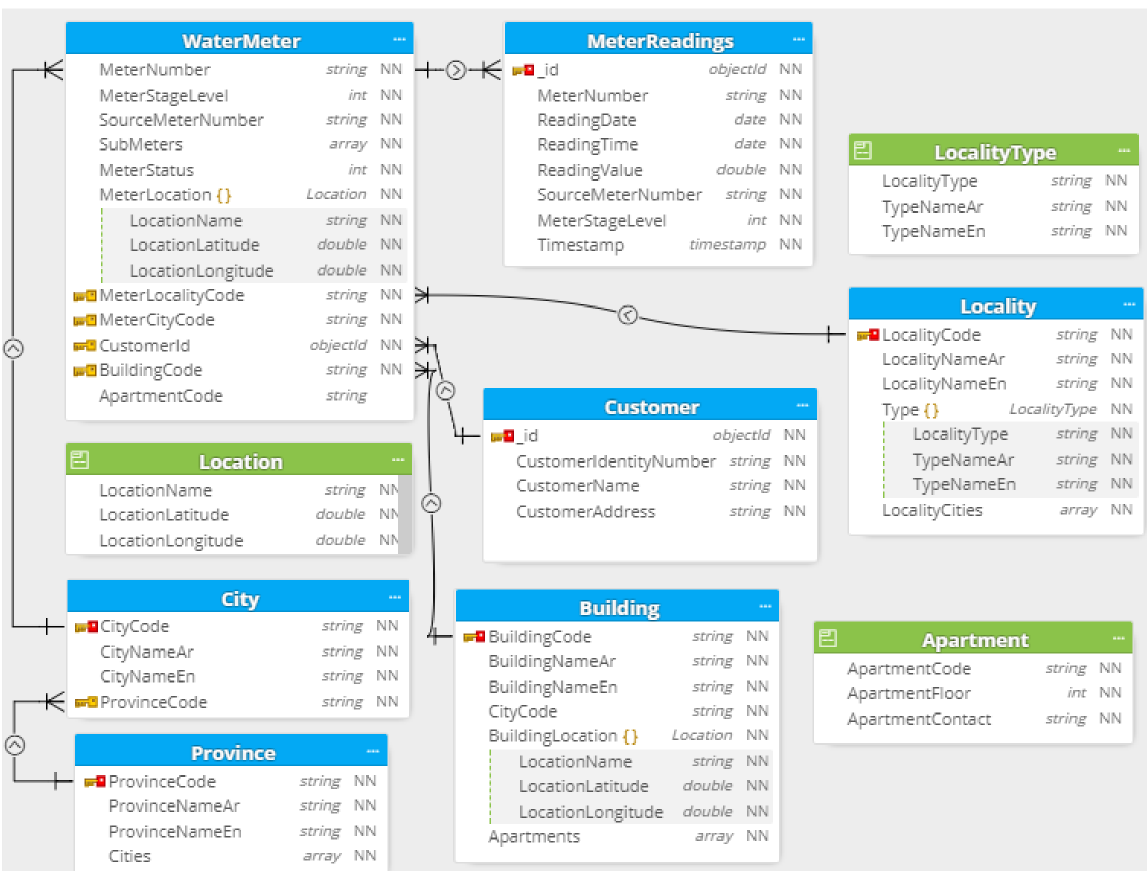


Figure 18. SWMS MongoDB Schema

The description of all items included in the SWMS MongoDB schema, as illustrated in Figure 18, is explained in Table 5.

Table 5. Smart Water Management Data Storage Schema Description

Object	Type	Description
Location	Document	Contains coordinates for meters and buildings
LocalityType	Document	Type of the localities (municipalities, local governorate, or village governorate)
Apartment	Document	Each building contains multiple apartments, and this is a document contains apartment information.
Province	Collection	Provinces information (Jerusalem, Hebron, Ramallah, Jenin, Bethlehem)
City	Collection	Each province manages multiple cities, and this collection contains all cities for each province
Locality	Collection	Inside the city, there are towns, villages, regions. This collection contains all information about these.
Building	Collection	Information about building on a city, region, village
Customer	Collection	Customers own the meters. This collection contains customers information
WaterMeter	Collection	The information about all the meters on SWMS
MeterReadings	Collection	The information collected from Smart Meters save to this collection, time-series readings

As we described in the system overview chapter, restful APIs are used to send and receive information between the sensors component and the data processing component. A restful API is an architecture style for API that uses hypertext transfer protocol (HTTP)[8] requests to retrieve and send it. The standard HTTP methods[9] are used, which are GET, POST, PUT, and DELETE, which are referred on order to as fetching (reading) data from the server,

[8] https://en.wikipedia.org/wiki/Hypertext_Transfer_Protocol
[9] https://en.wikipedia.org/wiki/Hypertext_Transfer_Protocol

sending data from client to the server, sending a resource from client to the server, and deleting a resource from the server. The restful API creation or consumption is supported for all programming, script languages. It uses the lightweight JSON data format for transmitting data between client and server. Since it works on HTTP protocol, security reasons using the secure hypertext transfer protocol (HTTPS)[10] are mandatory in our proposed SWMS. Table 6 summarizes a proposed APIs format that should be available on the smart meter as a server to accomplish our research goals or call these APIs located in the data processing component. Figure 19 illustrated a process flow diagram for a smart meter that acts as a server role.

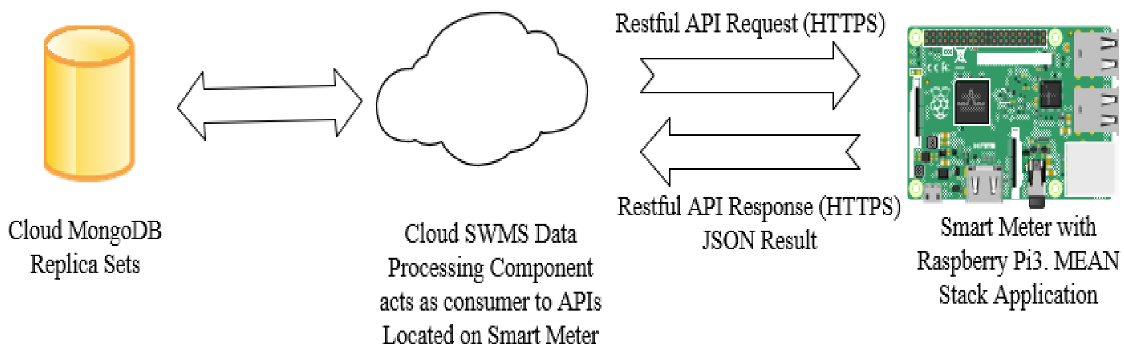


Figure 19. Process Flow Diagram between Smart Meter and data processing component

[10] https://en.wikipedia.org/wiki/HTTPS

Table 6. A proposed APIs format for Smart Water Meter

Function	API REQUEST	HTTP Method	RESULT/JSON OBJECT

Close Valve	HTTPS://METER_IP_ADDRESS/OPERATION=CLOSE_VALVE	POST	Success Response: {
			"MeterNumber":" 123456",
			"Timestamp":" 01-02-2021 23:00:00",
			"Operation": "CLOSE_VALVE",
			“StatusCode”: 1,
			"StatusText": "SUCCESS"
			}
			Failure Response: {
			"MeterNumber":" 123456",
			"Timestamp":" 01-02-2021 23:00:00",
			"Operation": "CLOSE_VALVE",
			“StatusCode”: 3,
			"StatusText": "FAILURE"
			}

Open Valve	HTTPS://METER_IP_ADDRESS/ OPERATION=OPEN_VALVE	POST	Success Response: {
			"MeterNumber":" 123456",
			"Timestamp":" 01-02-2021 23:00:00",
			"Operation": "OPEN_VALVE",
			“StatusCode”: 1,
			"StatusText": "SUCCESS"
			}
			Failure Response: {
			"MeterNumber":" 123456",
			"Timestamp":" 01-02-2021 23:00:00",
			"Operation": "OPEN_VALVE",
			“StatusCode”: 3,
			"StatusText": "FAILURE"
			}

Get Status	HTTPS://METER_IP_ADDRESS/ OPERATION=GET_STATUS	GET	Connected Response: { "MeterNumber":" 123456", "Timestamp":" 01-02-2021 23:00:00",

			"Operation": "GET_STATUS",
			“StatusCode”: 1,
			"StatusText": "CONNECTED"
			}
			DisConnected Response: {
			"MeterNumber":" 123456",
			"Timestamp":" 01-02-2021 23:00:00",
			"Operation": "GET_STATUS",
			“StatusCode”: 0,
			"StatusText": "DISCONNECTED"
			}

Get Readings	HTTPS://METER_IP_ADDRESS/ OPERATION=GET_READINGS	GET	Success Response: {
			"MeterNumber":" 123456",
			"Timestamp":" 01-02-2021 23:00:00",
			"Operation": "GET_READINGS",
			"Readings": [
			{"Serial": 1,
			"ReadingDate": "02-02-2021",
			"ReadingTime": "10:00:00",
			“ReadingValue”: 5005},
			{"Serial": 2,
			"ReadingDate": "02-02-2021",
			"ReadingTime": "10:10:00",
			“ReadingValue”: 5005.5},
			{"Serial": 3,
			"ReadingDate": "02-02-2021",
			"ReadingTime": "10:15:00",
			"ReadingValue": 5006}
			],
			“StatusCode”: 1,
			“StatusText”: “SUCCESS”
			}

4.4 IoT Platform

There are many existing open-source and commercial IoT platforms available. (Ray, 2016) summarizes these platforms. Table 7 includes some of the platforms his survey includes and their pros and cons.

Table 7. (Ray, 2016) IoT Platforms

Platform	Pros	Cons
KAA	Supporting No-SQL and Big Data Applications	Supporting Less Hardware Modules
Carriots	Supporting triggering based applications	Fewer user-friendly design
SeeControl IoT	Supporting for Push/Pull based devices	Visualization is not up to the mark
Xively	The easy integration of devices	Poor in notification Services
Oracle IoT cloud	Supporting of relational database	Lacks in open-source devices connectivity due to size restriction
Nimbits	Easy for adoption by developers	The real-time processing

Based on Table 7, the best platform suited for our SWMS and supporting NO-SQL and restful API is KAA. Figure 20 illustrated the KAA dashboard, shows the sensors and their locations, and some readings.

Besides, a platform could be created for more customization as required. Open-source technologies can be used, Dot Net Core[11] for backend API, IONIC[12] for frontend since it is a cross-platform mobile native and web application experience.

[11] https://dotnet.microsoft.com/learn/dotnet/what-is-dotnet
[12] https://ionicframework.com/

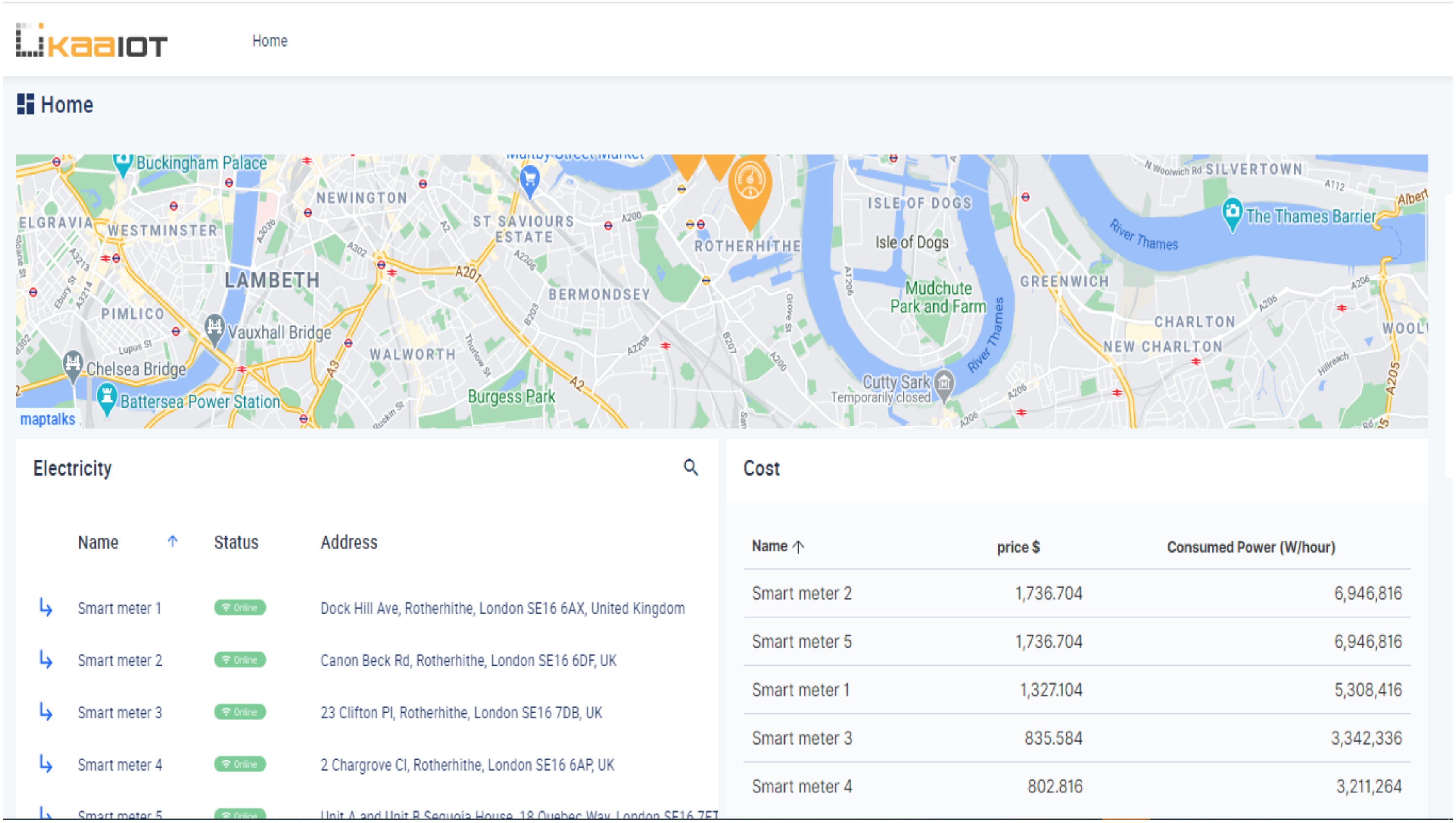


Figure 20. KAA IoT Dashboard

4.5 Summary

This chapter aims to clarify the detailed implementations of the SWMS sensors sending and receiving of data. Also, the detailed implementation related to IoT collectors. The detailed implementation of data storage, database deployment architecture, and the detailed schema was created for SWMS. Finally, the IoT platform for presenting the information, controlling, and monitoring all resources in SWMS.

5. Experimental Instantiation

This chapter describes and discusses the experiments that have been implemented to evaluate the proposed system's approaches and techniques. We will validate the results of IoT Based Monitoring and Controlling System for Water Chlorination Treatment results, and we will discuss the results with the current applied process for water chlorination treatment. We will also validate and discuss the water loss and theft detection algorithm and compare the results to the currently applied techniques for detecting the loss and theft of water. In section 5.1, we will describe the experimental validation of our SWMS techniques. Then, in section 5.2, we will analyze and discuss the results and compare them with the currently applied techniques. Finally, we summarize the experimental validation in section 5.3.

5.1 Experimental Validation

In this section, we present the experiments that we have carried out to evaluate the effectiveness of the IoT Based Monitoring and Controlling System for Water Chlorination Treatment and the experiments we have carried out to evaluate water loss detection theft's effectiveness in water distribution pipes network.

5.1.1 Evaluation of the effectiveness of the IoT Based Monitoring and Controlling System for Water Chlorination Treatment

In this experiment, we use an Arduino controller connected to the Dosing Pump and connected to Analyzer Transmitter that analyzes the chlorine concentration from the free chlorine sensor Anode. Our challenge is to connect all these and then map the analyzer's values to a percentage reflecting the water's chlorine concentration. We embedded a C code that reads the concentration values and sends them to an external API that gets the values and saves them to a database for historical review and monitoring purposes. The experiment is explained in detail by (Zidan et al., 2018). Table 8 shows the mapping results of the current input in the mA unit, the Arduino Analog Value (Analyzer Output Reading), and chlorine concentration after applying the required calibration for the analyzer and chlorine sensor Anode.

Table 8 shows that the mapping values enable us to read the chlorine concentration of water and transmit it to a percentage concentration. Actions should be taken according to chlorine concentration readings. The critical one is to control the Dosing Pump strokes. The number of strokes per minute controls the injected chlorine liquid inside the water; when it is rising, the concentration will be high; on the contrary, lowering the chlorine concentration will be lower—our challenge to control the strokes based on the reading of the chlorine concentration we described.

Table 8. Mapping the Analyzer Current Values, Arduino Analog Value, and Chlorine concentration

Current (mA)	Arduino Analog Value (0-1023)	Chlorine Concentration (mg\L)
0	0	0
4	80	0.2
8	160	0.4
16	320	0.8
20	400	1

Table 9 shows the values we are applied for controlling the strokes so that the chlorine concentration in the water not lower than 0.2 mg/L and not to be higher than 0.8 mg/L.

Table 9. Controlling Dosing Pump Strokes for keeping the required Chlorine Concentration

Chlorine Concentration (mg/L)	Stroke Speed	Delay in millisecond (ms)
0.55 - 0.6	Low	4000
0.45 - 0.54	Normal	2000
Less than 0.45	High	1000
Greater than 0.65	Off	500

The last challenge on this experimental validation is monitoring chlorine liquid tanks located on Water Pump Station. This case is critical since there are many Water Pump Stations located in distant areas in Palestine. An employer must visit each station to calibrate the chlorine concentration between the analyzer and the dosing pump, which is solved; the second task is to monitor the chlorine liquid tank. By asking him, what will occur if the chlorine liquid in the tank is empty? His answer, this case is occurring because sometimes the chlorine liquid is not available for all stations, and his visits are not enough for all stations, so sometimes he does not visit a station for weeks or more than a month. So, we implement a liquid level monitoring module. This module consists of an Ultrasonic sensor and Arduino controller. The liquid level in the chlorine tank is measured and sent by the Arduino controller to a database. A mobile application was created and deployed to employee smartphones. The application notifies the employee of the status of the chlorine tank. In case it is empty, an action is sent to the dosing pump to be shut off, which keeps the dosing pump working well and decreases electricity consumption without usefulness.

5.1.2 Evaluation of the effectiveness of Water loss and theft Detection

One of the critical objectives in our research is a technique for detecting water loss and theft. So, we are employing the Internet of Things (IoT) for building the system so that the goal could be accomplished. IoT helps us get the meter readings on predefined periods, for example, getting the meter readings every half hour. The data saved to data storage on the cloud enable us to present the data on the different dashboards for the authorized system users using an authentication mechanism. Also, the saved data gives us the ability to analyze the saved data. The meter readings are saved on MongoDB MeterReadings collection. The WaterMeter collection determines each feeder meter with meters that it is feed. Our challenge is to compare the feeder meter reading at a particular time with the summation of all the feeding meters reading belonging to the chosen feeder meter. Based on that, it is required for us to add a new collection to the schema; this new collection groups each feeder meter with the meters is feeding. Figure 21 illustrates the newly created collection schema.

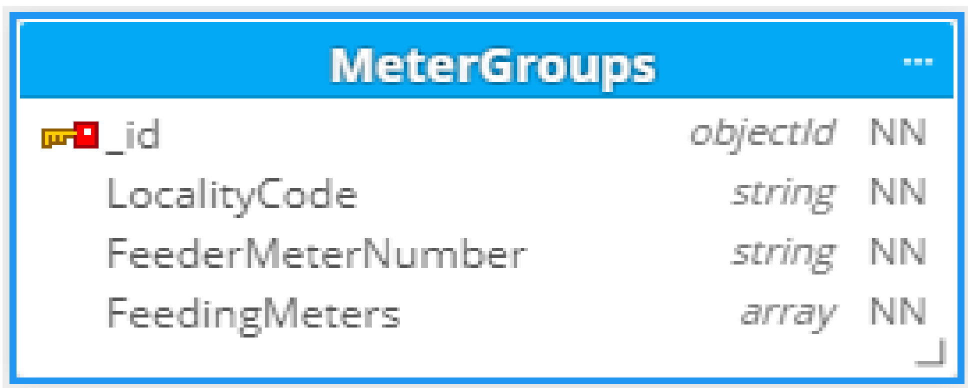


Figure 21. MeterGroups Collection Schema

This collection could be updated dynamically when any modifications occurred. Figure 22 is the pseudocode for the algorithm which updates this collection.

```
Algorithm : Update MeterGroups Collection
Result: Updating MeterGroups Collection is Success
Input: Locality Code;
METERSINFO: Fetch All Active Meters From WaterMeter Collection;
FFEDERMETERS: GET Meters from METERSINFO which IsFeederMeter TRUE;
MEETERGROUPS: LIST of MeterGroup;
while There is Item in FFEDERMETERS do
    CURRENTFEEDERMETER: Item;
    FEEDINGMETERS: GET Meters from METERSINFO which SourceMeterNumber
      equals CURRENTFEEDERMETER MeterNumber;
    METERGROUP.LocalityCode: CURRENTFEEDERMETER.MeterLocalityCode;
    METERGROUP.FeederMeterNumber: CURRENTFEEDERMETER: MeterNumber;
    METERGROUP.FeedingMeters: FEDINGMEETERS;
    METERGROUPS.ADD(METERGROUP)
end
RETURN TRUE;
```

Figure 22. Update MeterGroups Collection Algorithm

After updating the MeterGroups Collection, we can apply our water loss and detection algorithm for one or more meter groups. The grouping we are proposed gives performance and threaded or parallel execution of the proposed algorithm. Figure 23 illustrated the pseudocode of the proposed algorithm for checking water loss and theft.

```
Algorithm 1: Water Loss and Theft Detection for One Meters Group
Result: Water Loss and Theft Detected or Not Detected
Input: Locality Code;
Input: FeederMeterNumber;
Input: Readings Period From Datetime;
Input: Readings Period To Datetime;
METERGROUP: Get Meter Group From MeterGroups Collection where
FeederMeterNumber Equlas FeederMeterNumber Input ;
FEEDINGMETERSCOUNT: METERGROUP.FeedingMeters Items Count;
PERIODINTERVALSLIST: Get Distinct Period Intervals from MeterReadings Given
  SourceMeterNumber Equals FeederMeterNumber Input and (ReadingDate,
  ReadingTime) between Readings Period From Datetime and Readings Period To
  Datetime;
while There is Interval in PERIODINTERVALSLIST do
    FEEDERMETERREADING: Get Reading from MeterReadings Given MeterNumber
      Equals FeederMeterNumber Input and (ReadingDate=Interval.ReadingDate and
      ReadingTime = Interval.ReadingTime);
    FEEDINGMETERSREADINGLIST: Get Readings from MeterReadings Given
      MeterNumber In METERGROUP.FeedingMeters and
      (ReadingDate=Interval.ReadingDate and ReadingTime = Interval.ReadingTime);
    if FEEDINGMETERSCOUNT Equlas to FEEDINGMETERSREADINGLIST Items
      Count then
        FEEDINGMETERSREADINGSUM: Calculate the Sum of All Readings in
          FEEDINGMETERSREADINGLIST.ReadingValue ;
        if FEEDINGMETERSREADINGSUM Equlas to FEEDERMETERREADING then
            No Water Loss and Theft Detected;
            RETURN FALSE;
        else
            Water Loss and Theft Detected;
            RETURN TRUE;
        end
    else
        Cannot Proceed, Meter Readings Missed, ;
        RETURN FALSE;
    end
end
```

Figure 23. Water Loss and Theft Detection for One Meters Group Algorithm

The water loss and theft detection algorithm could be executed using parallel programming in C#, so the detection time is minimized to minutes. Our proposed algorithm for grouping the meters supports this technique. So, each group will be attached to a separate process independently for other groups.

5.2 Analysis

The evaluation results of the IoT-based monitoring and controlling system for water chlorination treatment effectiveness are promising. Comparing the results with the current human wholly dependent and unsatisfying. These results summarized to:

1- The water chlorination treatment is fully automated. So, the chlorination concentration in drinking water is between 0.2 mg\L and 0.8 mg\L all the time without any human action.

2- The water chlorination treatment and the chlorine liquid tanks are monitored without being on the water pump station by using a mobile application that is connected to the internet.

3- The dosing pump is controlled by the Arduino controller based on predefined roles.

4- Historical readings and alerts are kept; this gives researchers the ability to analyze the data and output results. These results help decision-makers for making decisions.

The water loss and theft detection evaluation results are awe-inspiring compared to the current human hardworking for detecting water loss and theft. By using the collected data kept on the data storage, the following are the benefits:

1- Decrease the effort and time for collecting the meter readings.

2- Accuracy of the readings. So, no need to estimate the readings.

3- Automatic creating of monthly invoices for consumed water for each customer.

4- Sending alerts of the invoice value to customer email or sending him SMS message.

5- Ability to create a dashboard specifically for the customer on the system, so he controls and monitors his meter. Review his meter invoices. Present a graphically historical consumption of water.

6- Ability to add electronic payments feature to the system with Palestine Payment Gateway companies.
7- Notify the customer when the distribution of the water starts in his region.
8- Notify the customer in case his water consumption is increasing than usual.
9- Smart meters are controlled remotely in a secure way. So, no need for a human to close or open valves in the meters place.
10- Analyzing the kept historical data helps decision-makers on making correct decisions.

5.3 Summary

In this chapter, we presented the evaluation effectiveness of the IoT-based water monitoring and controlling system, and we clarify the results and the effectiveness of the results. Also, we presented the evaluation of water loss and theft detection, and we proposed the algorithms used for this objective. Finally, we analyze and conclude our evaluation.

6. Conclusions and Future Work

This chapter summarizes our proposed approach to building a water management system by employing the Internet of Things for water safety and sustainability and outlines the future works and challenges related to manipulating IoT in building the proposed system. This chapter is organized as follows. Section 6.1 summarizes our research work and highlights the techniques and approaches we employ in the proposed system. Section 6.2 discusses the future work and other challenges related to employing IoT to build a smart water management system.

6.1 Conclusions

The MENA region in general and Palestine suffer from water problems of various forms at different levels. Examples of such issues are the insufficiency of water resources, puny water infrastructure, untraceable non-revenue water, and the absence of fully automated water treatment systems (e.g., water chlorination monitoring and control). These problems negatively affect the water management infrastructure and threaten the water sector's sustainability and safety in Palestine. Also, decision-makers and water supply stakeholders face difficulties in making the right decisions and taking the most appropriate actions towards addressing these problems (Marie et al., 2012).

Accordingly, with the recent development of the internet, the availability of a variety of low-cost sensors, and the development of the Internet of Things (IoT), the development of remote real-time monitoring and control systems – without the need for direct human involvement – has extended significantly in various application areas. The Water sector is one of the most extraordinary significant industrial application domains that demands developing efficient and effective water quality monitoring and control.

In this thesis, we have two primary goals. The first one is the automation of the current manual water chlorination treatment calibration, including controlling and monitoring. The second one is to evaluate the current water pipes network components and employ IoT techniques to tackle water loss and theft, no working meters, human errors in recording monthly meter readings, fastening monthly invoice creation, and collecting revenues.

To achieve the first goal, we contribute to proposing, implementing, and testing the IoT-based controlling and monitoring system for water chlorination treatment. We have accomplished both an experimental and theoretical study to monitor and control water chlorination treatment by employing Internet of Things technologies. We proposed a dosing pump controller, chlorine concentration sensor reader, and a chlorine tank level sensor. We have applied the architecture of all components of our prototype.

To achieve the second goal, we compare the current meters used with the proposed one to tackle the problems. We explain the IoT system component and how we implement our system based on these components and each component's role. We clarify the best architectures that suit our communication infrastructure and how they cover all the Palestine areas. We proposed and implement algorithms used for water loss and theft detection. We clarify the IoT platforms available and the most suitable for our system. Also, that a platform could also be created with our customization if needed.

6.2 Challenges and Future work

Though the conducted experiments showed promising results, other remaining challenges and research problems need to be addressed in future work. Below we discuss these problems and outline proposals on how to address them in our future work:

1- Our experiments are implemented using a non-industrial microcontroller board. An industrial microcontroller should be implemented and tested then installed in production.

2- Collect all sensors data and saving it to an existing real deployed high availability MongoDB replica set.

3- Reflects the collected data to be really shown in an IoT platform.

4- Implement a prototype for the proposed smart meter sensor by using an industrial microcontroller with existing smart meters, supporting all features we are proposed.

5- Build a prototype of a water pipe network that consists of multiple smart meters. These meters are fed from a source meter. Connect these meters to a water source. Connect the meters wirelessly with an IoT dashboard, and apply our proposed architecture.

6- Apply our proposed algorithms, prepare all tests configuration, and check the performance and the accuracy of the algorithms in a real-world environment.

7- Apply all the IoT components with the architectures we proposed and making tests in a real-world environment.

8- Integrate the system with the GIS System, so the smart devices' location data saved on database storage reflected on the GIS system help determine all smart devices' locations.

9- Add additional needs to the system, such as water distribution to clients automatically without human actions, new capabilities to the customer, and control and monitor water usage from the main building meter through storage tanks to home water network pipes.

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الملخص باللغة العربية

تعاني منطقة الشرق الأوسط وشمال أفريقيا بشكل عام، وفلسطين على وجه الخصوص، من مشاكل المياه بأشكال مختلفة وعلى مستويات مختلفة. من بين هذه المشاكل استنفاذ موارد المياه، وفقدان المياه، وتلوث المياه، وتوزيع المياه بشكل غير منتظم، إضافة إلى النقص في الإلتزام بدفع إيرادات المياه المستحقة على المستهلكين. لهذه المشاكل أثر مباشر على البنية الأساسيه لإدارة المياه وتهدد استدامة قطاع المياه في المنطقة. وقد أصبحت هذه المشاكل مسألة ملحة بالنسبة لصانعي القرار والجهات المعنية بالإمداد بالمياه لمواصلة البحث عن حلول مبتكرة تمكنهم من إدارة التحديات القائمة و مواجهتها بشكل أفضل. إلى جانب ذلك، فإنّ الحاجة الضرورية إلى المراقبة والرصد والتنبيه الآلي للعمليات الخاصة بإمدادات المياه، وعلى وجه الخصوص عملية كلورة المياه، التي لها خطر كبير يصل تأثيره لحياة الإنسان.

تهدف الحلول المقترحة إلى المحافظة على كمية المياه وتعقيمها والتأكد من صلاحيتها للاستخدام البشري، ومراقبة وأتمتة عملية كلورة المياه والتنبيه عند حدوث أية مشاكل قد تقلل من كفائتها أو تمنعها، وتنظيم توزيع المياه وعدم انقطاعها، وتحسين تقديم الخدمات واستهلاك المياه بشكل مشروع، والحد من فقدان المياه كانت بسبب التمديدات أو الاستخدام غير المشروع، وزيادة تحصيل إيرادات المياه.

يواصل الباحثون في الميدان، وكذلك أصحاب المصلحة في إمداد وتوزيع المياه، في البحث عن توظيف مصادر للمعلومات، وأدوات، ومعدات من أجل تحقيق أهداف تلك الحلول المقترحة في إدارة المياه، بالإضافة لتوظيف تكنولوجيا المعلومات، والاتصالات، وعلوم الحاسوب لتحقيق ذلك.

ويساعد استغلال هذه الموارد على الإستفادة المثلى من نظم إدارة المياه، وتحسين وظائفها، ومراقبتها. فعلى سبيل المثال يمكن استخدامها لوصف وتحليل الوضع، واتخاذ القرارات استنادا إلى البيانات المتاحة بطرق التنبؤ أو التكيف، واتخاذ الإجراءات بشكل آلي ذكي وفقا لذلك. من أجل تحقيق ذلك بفعالية وكفاءة، تحتاج نظم إدارة المياه الذكية إلى توافر البيانات بسهولة وبوقتها لاتخاذ قرارات التكيف التي تلائم الظروف الأساسية على أفضل وجه. لذلك يجب جمع البيانات من العديد من أماكن

الضخ ومعدات التزويد بالمياه، مثل محطات الضخ ، وأنابيب المياه، وخزانات المياه، وعدادات المياه.
إنّ حجم البيانات المرسلة والمستقبلة من أماكن الضخ ومعدات التزويد يعتبر هائلاً ويصنف كبيانات ضخمة. بالاضافه إلى ذلك، فإن توظيف أجهزة اتصال تعمل كمستشعرات في أماكن ضخ المياه وأجهزة تزويد المياه المنتشرة في أماكن الضخ وشبكة أنابيب المياه، سيمكننا من إنشاء شبكة إنترنت أشياء (IoT Network) تستخدم في قطاع المياه. وفقا لذلك، باستخدام تقنيات الأجهزة التمكينية مثل قارئات و رقاقات الراديو اللاسلكية (RFID) "تحديد الهوية بموجات الراديو"، ورقاقات التواصل قريب المدى (NFC)، وأجهزة الإستشعار اللاسلكية المدمجة، والمحركات الميكانيكية، يمكننا من جمع البيانات اللازمة ومراقبة أماكن الضخ وأجهزة شبكة تمديدات المياه، ومن ثم استخدامها بشكل أفضل واستخدامها في نظام آلي ذكي يقوم بإدارة ضخ وتوزيع المياه.
يهدف عملنا البحثي إلى توظيف تقنيات إنترنت الأشياء في قطاع المياه، وتحقيق مفهوم البيانات المائية الكبيرة الذي تم إدخاله حديثاً في جميع انحاء البنية التحتية للإمداد بالمياه في المناطق الفلسطينية. عملنا هو اقتراح لنظام حاسوبي ذكي لإداره المياه، وهذا النظام يجمع بيانات المياه من الأجهزة في أماكن الضخ وشبكة توزيع المياه، ويقوم بتخزين وتحليل هذه البيانات، ويسلط الضوء على قضايا البنية التحتية لإدارة ضخ وتوزيع المياه (مثل المناطق التي تعاني من فقدان المياه وأسباب الفقدان)، وكذلك العمل على إخراج تقارير ونتائج وتوصيات لأصحاب المصلحة في ضخ وتوزيع المياه، بالإضافة للتصرف المباشر والمتكيف عند حدوث أية إشكاليات في أماكن الضخ وشبكة توزيع المياه. بالإضافه إلى مراقبة عملية كلورة المياه في أماكن الضخ والتنبيه قبل حدوث أية إشكاليات تهدد حياة الإنسان. عملنا على عمل محاكاة لبعض أجزاء النظام وقمنا باختبار فعالية هذه الأجزاء في النظام المقترح.