A ZIGBEE MODEL FOR TELEMETRY BASED WATER FLOW BILLING.

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A Research Thesis Submitted to the Institute of Postgraduate Studies and Research in partial Fulfillment for the Requirements of the Master of Science in Information Technology of Kabarak University.

KABARAK UNIVERSITY

NOVEMBER 2016

DECLARATION

I hereby declare that this research thesis is my original work and has not been submitted to any other University or College for purposes of examination or academic award. Any information given is my entire work and all the relevant sources are quoted and acknowledged accordingly.

Sign ____________________________________ Date _______________________

Kirori Gathuo Mindo

GMI/NE/0149/01/15

RECOMMENDATION

To the Institute of Postgraduate Studies and Research:

The research thesis entitled "**A Zigbee Model for Telemetry Based Water Flow Billing**." written by Kirori Gathuo Mindo is presented to the Institute of Postgraduate Studies and Research of Kabarak University. We have reviewed the thesis and recommend it to be accepted in partial fulfillment of the requirement for the Degree of Master of Science in Information Technology.

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I thank Lord God for his grace, mercy and gift of life. For our light and momentary troubles are achieving for us eternal glory that far outweighs them all. 2 Corinthians 4:16-18

And so, Glory be to God for He fathers-forth whose beauty is without change. For rose-moles all in stipple upon trout that swim.Gerard Manley Hopkins (1844–1889)

My sincere gratitude to my supervisors Dr Moses M. Thiga and Dr Simon M. Karume for their wise, unyielding support and intellectual guidance during the study. I would not have triumphed without your lead.

My parents Duncan and Lucy Mindo. My siblings Gatimu, Wambui, Wangari, Wanjugu, Gathuo and Shiro Anna.

My classmate Justin Oguta,colleagueAntony Musabi,

Kabarak University electricians Francis Komen, Simon Chepkwony and plumber Andrew Kipkeror.

DEDICATION

To my father **Duncan Mindo**, for few things are harder to put up with than the annoyance of a good example.

ABSTRACT

Water and Sewerage service providers in Kenya have encountered challenges in proficient collection of water billing data from customer's meters. This necessitates the need to implement a proper data collection mechanism that can be implemented remotely, effortlessly, and accurately. Recent advances in telemetry now provide reliable water meter data. However no water utility has implemented a technology based, remote data collection strategy. A Zigbee WPAN-to-WAN solution for water meter data collection is thus a viable solution. This study addressed the ability to create a model, prototype and project for a water meter sensor network based on IEEE 802.15.4 ZigBee standard. The resulting mesh network allowed collection of data logged from the water meter sensors in real time remotely and accurately. The PPDIOO lifestyle approach was used to develop the model, prototype and set-up the project. Devices in the WPAN were identified using IPv6 to enable scalability. One FFD ZigBee device coordinated the WPAN and enabled multi-path forwarding of data collected to a Network Coordinator. The model, prototype and project developed in this study will serve to inform the development of Zigbee water meter networks with data collected consumed by third party software solution providers for purposes of analyzing, organizing and reporting.

Keywords: Watermeter, Zigbee, 802.15.4,Mesh, Multipath, WPAN, RFD, FFD

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ABBREVIATIONS

6LoWPAN	-	IPv6 over Low power Wireless Personal Area Networks
ACID	-	Atomic, Consistent, Isolated, Durable
AES	-	Advanced Encryption Standard
AMR	-	Automatic Meter Reading
ASD	-	Adaptive Software Development
BLE	-	Bluetooth Low Energy
CIA	-	Confidentiality, Integrity and Authentication
CO	-	Central Office
CSV	-	Comma Separated Values
DHCP	-	Dynamic Host Configuration Protocol
EEG	-	Electroencephalographic
FFD	-	Fully Functional Device
GPRS	-	General Packet Radio Service
GSM	-	Global System of Mobile Communication
ICMP	-	The Internet Control Message Protocol
ICT	-	Information Communication Technology
IEEE	-	Institute of Electrical and Electronics Engineers
IPv6	-	Internet Protocol Version 6
ISM	-	Industrial, Scientific And Medical
ISP	-	Internet Service Provider

LOS	-	Line Of Site
LTE	-	Long Term Evolution
MAC	-	Media Access Control
MGZ	-	MegaHertZ
MSK	-	Minimum Shift Keying
NAT	-	Network Address Translation
NAWASCO	-	Nakuru Water and Sewerage Company
NC	-	Network Coordinator
NC	-	Network Coordinator
NCCT	-	Noisy-Channel Coding Theorem
NS2	-	Network Simulator 2
NS2	-	Network Simulator 2
OSI	-	Open Systems Interconnection
OSPF	-	Open Shortest Path First
PHY	-	PHYSICAL Layer
PLC	-	Power Line Carrier
PPDIOO	-	Prepare, Plan, Design, Implement, Operate, and Optimize
PWM	-	Pulse Width Modulation
QPSK	-	Quadrature Phase Shift Keying
RAM	-	Random Access Memory
RF	-	Radio Frequency

RFC	-	Request For Comments
RFD	-	Reduced Functional Device
ROM	-	Read Only Memory
RTU	-	Remote Terminal Unit
SMD	-	Surface Mounted Diode
SQL	-	Structured Query Language
TLN	-	Telephone Line Network
TTL	-	Time-To-Live
UART	-	Universal Asynchronous Receiver/Transmitter
UDP	-	User Datagram Protocol
UNDP	-	United Nations Development Programme
UNICEF	-	United Nations Children's Fund
USD	-	United States Dollar
WAN	-	Wide Area Network
WHO	-	World Health Organization
WIFI	-	Wireless Fidelity
WiMAX	-	Worldwide Interoperability for Microwave Access
WPAN	-	Wireless Personal Area Network
WSN	-	Wireless Sensor Network
WSP	-	Water and Sanitation Program
ZTC	-	Zigbee Trust Center

CHAPTER ONE
INTRODUCTION

1.0 Introduction

This chapter gives a brief background of the main concepts and problems informing this study specifically on the lack of scalable, inexpensive, open, reliable mechanisms to collect water meter data. It further proceeds to state the research problem, outlines the research objectives and defines the scope, significance and the expected outcomes of the study.

1.1 Background Of The Study

Convectional water meter reading have been overtaken by newer cost effective, reliable and cost effective Automatic Meter Reading(AMR) solutions. These strategies involve technological use of wireless radio systems for the transmission of real time data smart devices within the area of jurisdiction (Kamal Shahid, 2015). Meter reading strategies can be divided either as conventional or manual, wireless and cabled meter reading. Normally the manual strategy and process of meter reading suffers from various weaknesses and common challenges globally. Reading is cumbersome and tedious is it dependant on the steadfastness, accuracy, speed and ability of the field agents or meter readers. Traditional meter reading for meter data consumption and billing done by human operator from establishment to establishment requires huge number of Field agents work for long hours so as to achieve conclusive data collection over a given domain or area. This kind of labor dependent data collection can also be restricted and even further slowed down by bad weather conditions (Sai Shuheel, 2013).

These strategies feature numerous cases of errors and inaccuracy, they have proven to be unreliable since reading is dependent on weather, access, transport. The water and sanitation companies also need to involve a large number of employees so as to perform these tasks (Kamal Shahid, 2015). Various strategies for transport of these data have been employed including use of Power Line Carrier (PLC) as well as Telephone Line Network (TLN) for propagation of data through the existing electric power and telephone lines for data transmission However, both electric and telephone lines have unique bottlenecks since they propagate low stability and reliability due the micro-wave noise interferences and electromagnetic interference. Transmission of this data through electric or telephone lines has proven to be expensive and cumbersome as the process of installation and maintenance as well as system security of the data being transmitted is not well articulated (Sai Shuheel, 2013).

Various Water and Sewerage service providers in Kenya such as NAWASCO, NCWSC etc continue to suffer colossal losses in both revenue water and non-revenue water. Poor billing and data collection not only hurts the customers, but also inhibits water service providers from amassing sufficient funds to efficiently operate and maintain water supply facilities and, consequently, provide adequate service to the end user. Majority of Water service providers are only recovering operation and maintenance costs and fall short of achieving full financial cost recovery (van den Berg, C. 2015) thus are unable to provide effective water services. Water utilities face a lot of challenges namely;

i) Meter Reading - The current strategy employed by most Kenyan water utilities where field officers physically read meters is at most inefficient and prone to manipulation (WSP Water Integrity Report, 2013).
ii) Meter reading can only be done during daytime and if weather permits. They rarely operate past the normal office hours, thus sufficient data on water meter/water use overnight cannot be sufficiently collected.
iii) Agents also face various logistical challenges including locked gates and hostile residents.
iv) Tenants are known at times to tamper with water meters, while agents are susceptible to corruption and human-errors (Water Services Trust Fund Report, 2013).
v) There is a significant existence of errors during manual data entry and consolidation for billing purposes.

To reduce these losses, it remains critically important to collect water meter data from water meter points. Monitoring these points can assist in proper billing, monitoring water leakages and identify cases of illegal siphoning. Recent advances in telemetry now provides reliable water consumption data at both the consumer and distribution level, thereby enabling improvement on water balance components and improving water loss control (Loureiro, Alegre, Coelho, Martins and Mamade, 2014). Proper water meter monitoring assists authorities, and consumers evaluate when, where and how often water is used and wasted, and in what quantities (Morrison and Friedler, 2015). Water meter data helps in the evaluation of factors influencing water consumption and as such, the data collected helps direct and promote water conservation and better water management (Xiao-jun et al 2015). The economic benefits of spending in better water management range between USD $3 to $34 for every USD $1 invested depending on expanse and technologies put in place (WHO, 2004).Technology based billing and data collection systems reduce information asymmetries and reduce incidences of corruption thus by making payment data more transparent (Krolikowski, 2014). A restructuring of billing and data collection activities through technology has seen successes in Burkina Faso which now boasts of collection rates of over 95 percent (Dominguez Torres, 2012). However, GSM technology initiated in Nairobi saw the project's budget swell to over Ksh 1 billion (Mugambi, Business Daily,2015 June 15).

Due to fragmented data sources and data collection strategies, authorities fail to make informed planning decisions that benefit consumers. There is a pressing need to cultivate a common information-sharing standard that will enable sharing of water meter data in real-time (Rezgui, Zarli, Ellis and McCann, 2015).

Access to clean, safe water and improved sanitation are critical investments in human capital, which translate to improved quality of life and consequently contribute to long term social-economic development and poverty eradication (Nyamboga, T. O., et al 2014) as well (Owuor, S. O., & Foeken, D. W. 2009). The developing world, due to lack of adequate water management, experiences deteriorating cases of water supply largely, water scarcity is increasing and poses a serious risk to sustainable development and quality of life (Fan, L., et al 2014).Concomitantly, demand for water among the general populace is rising while resources are quickly diminishing (De Graaf, I. E. M., et al 2014) while the proportion of urban populations in sub-Saharan Africa receiving piped water supplies has remained unchanged since 1990 (WHO/UNICEF, 2013).

Due to unrelenting population growth, Kenya's per capita water availability will be 235 cubic meters per year by 2025, which is a third of current availability of 650 cubic meters (Marshall, S. 2011). Concomitantly to lessening resources, Kenya is furthermore undergoing rapid urbanization. It is estimated that the entire demographic growth of the world over the next 30 years will be concentrated in urban areas, mostly in low-income countries (Cosgrove, W. J., & Loucks, D. P. 2015). This gigantic populace requires basic services and amenities to be accorded to them by Central and County governments. While the citizenry expects to have reliable access to clean and safe water for consumption and general household activity, only 59 percent of Kenyans have access to safe drinking water (Degol H., Sara R., Tsukada R. 2011).

The World Health Organization (WHO) recommends a daily per capita consumption of 20 liters per day for drinking, cooking and basic household sanitation chores as the minimum quantity required to sustain a decent living. In major Kenyan Cities, there is a significant prevalence of water deprivation among most households (Marshall, S. 2011).Further, the current dispensation has Kenyans' expenditure on water being above the affordability threshold with57 percent of households' consumption below the water poverty line (UNDP Report, 2011).However, due to unreliable water supply and other factors, end users seek water provision services from secondary enterprises and vendors who averagely charge 30.28 times the price charged by the water service providers through a piped connection, thus 63 percent of households in towns pay way above the affordability threshold on water (UNDP Report, 2011). Secondary water service providers by and large charge much higher, than the local authorities per unit of water provided. In addition, these water vendors illegally siphon water from the piped systems for resale thereby intentionally creates a water shortage thereby increasing demand for private water supply (Water & Sanitation for the Urban Poor. (2013, April 14). These cartels that collude to set high water prices are increasingly getting widespread among the urban poor communities (WSP, 2009).

Further, 53 percent of the water provided by the secondary water services providers comes from unfamiliar sources (Water & Sanitation for the Urban Poor. (2013, April 14). Consumers thus have no ability to verify the safety of the water purchased. Thus these illegally siphoned water sources can thus be contaminated by toxic chemicals, refuse, harmful residuals, and impure external water flows like rain water and flooded pools. Not only do majority of the citizens suffer, but they are also prone to poverty penalty, which refers to "the relatively higher cost shouldered by the poor, when compared to the non-poor, in their participation in certain markets" (Mendoza, 2008, p. 2).Poor sanitation as a direct consequence of lack of clean and safe water costs Kenya USD $ 324 Million or Ksh 27 Billion each year according to a study carried out by the Water and Sanitization Program. This is equivalent to USD $8 per person in Kenya which essentially is 0.9% of the national GDP (Water and Sanitation Program WSP, 2012).

In addition to these woes, water supply is generally unreliable. Water service providers have contributed to poor performance through non-payment of water bills, illegal connections, improper billing, data collection as well as diversion of revenue and waste of water through unattended leaks in the distribution network and at client's homes (Hirvi and Whitfield, 2015). The regular water rationing practices, lead to water shortages, and consequently, households respond by storing water. This creates a cosmetic demand for water beyond direct consumption levels, thereby aggravating water shortages. Water rationing breeds severe consequences, with ripple effects like interrupting production of goods and services, deterioration of hygiene standards, manifestation of diseases due to water storage and use of alternative unsafe and unregulated water sources as well (United Nations World Water Development Report 2015). The water crisis in Kenya has also had tremendous effects on maternal care. Due to the water shortage, hospitals like Kakamega Provincial District General Hospital have to collect buckets of water, which is then provided to its patients. The water is polluted with bacteria, viruses and parasites and many patients develop different diseases such as typhoid and cholera (Gitonga Njeru, 2010).

Preponderance of the current water crisis is as a result of poor management of water supply (Kenya National Water Development Report, 2006). Investing in water supply management is critical to the country and has direct social-economic impacts. Better water supply management relieves the burden on women, better hygienic conditions through improved water access and sanitation. The economic benefits range between USD $3 to $34 for every USD $1 invested depending on expanse and technologies put in place (WHO, 2004).

Piped water connections on premises remain the most affordable and safe system of water provision (Heymans C., Eales K., Franceys R., 2014), there is a need to strengthen capacity of water service providers so as to ensure affordability and quality of the water provided. In this regards, metered customers account for about 88 percent of Water Service Providers clients.

Effective billing and data collection systems are a critical component for ensuring the viability of a water service provider. This aspect ensures water supply management is optimal and effective revenue collection improves revenues and consequently the water service provider improves its service provision to general citizenry. (Water and Sanitation Program WSP, 2008). The figure 1below shows the Kenyan national water institution framework.

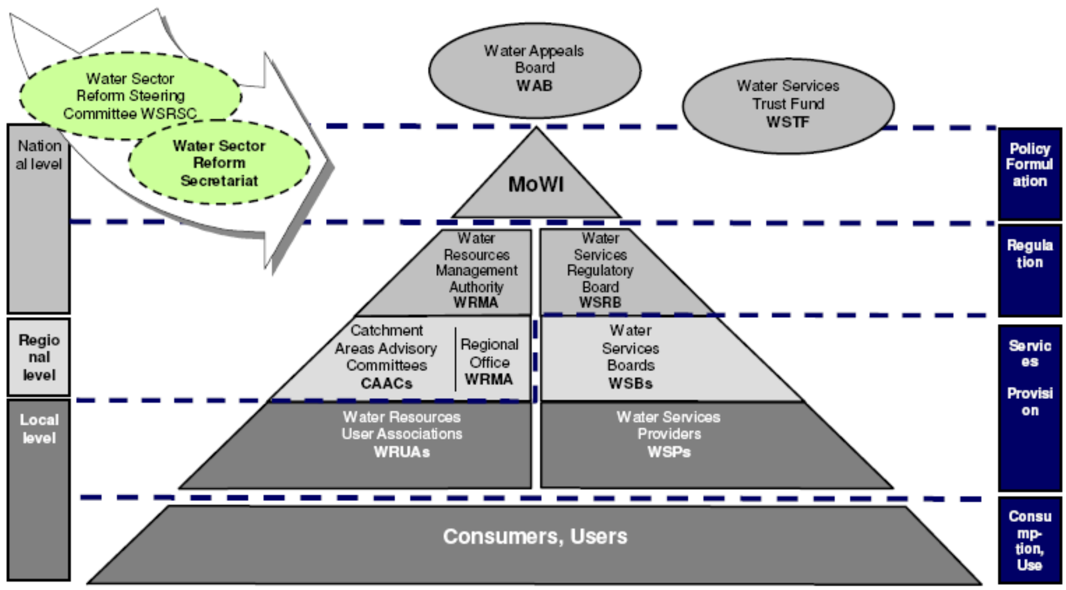

Figure 1: Kenya Nation Water Institutional Framework (source: WSP)

Improvement in billing and data collection systems, impacts positively on the revenue streams of a water service provider and enables citizenry to afford and get access to clean, safe water. This in turn, encourages efficiency in the commercial and operational tenets which in turn aids in expansion and delivery of improved, reliable, and sustainable services (Water and Sanitation Program Report, 2008). Access to clean, safe water is influenced by several factors including inefficient operations, poor levels or absence of metering, poor billing and data collection practices, poor structure and levels of water tariffs, increased and inefficient operational costs, and weak management(McKenzie D., Isha R. 2005). Poor billing and data collection not only hurts the customers, but also inhibits water service providers from amassing sufficient funds to efficiently operate and maintain water supply facilities and, consequently, provide adequate service to the end user. Majority of Water service providers are only recovering operation and maintenance costs and fall short of achieving full financial cost recovery (van den Berg, C. 2015) thus are unable to provide effective water services.

The primary contribution to urban water crisis is urban water governance failure (Rugemalila R, Gibbs L, 2015). For Kenya and developing countries to improve water supply, it is critical to understand the effects of water supply time restrictions on domestic water use activities and patterns, especially for hygienic purposes, is important for the elaboration of the water supply (Fan, L., et al 2014).

Reliable information is of utmost importance for planning and decision making (Moffat G. et al 2013).Technology based billing and data collection systems reduce information asymmetries and reduce incidences of corruption thus by making payment data more transparent (Krolikowski, A. 2014). A restructuring of billing and data collection activities through technology has seen successes in Burkina Faso which now boasts of collection rates of over 95 percent(Dominguez Torres, C. 2012).Recent advances in telemetry technology provide superlative consumption data at the consumer level, thereby enabling an outstanding knowledge improvement on water balance components and improving water loss control (Loureiro, Alegre, Coelho, Martins, Mamade, 2014).Thorough water use monitoring assists water planners, authorities, and household owners to evaluate when, where and how often water is used and wasted, and in what quantities (Morrison and Friedler, 2015).

Understanding the factors affecting urban water consumption is limited (Kontokosta, C. E., & Jain, R. K. 2015) especially when in retrospect, water use data is critical as it aids development of effective strategies for domestic water demand management. Harnessing actual data volume of daily water to be consumed is fundamental for any reasonable estimations and calculations (Parker, D. S., et al 2015). In additional, this provides superlative mechanisms through which policymakers can build on to intensify water efficiency in urban homes and to accelerate reductions in water use at the city, town or county scale and where water conservation resources and efforts should be focused. This data helps to evaluate factors which influence house water consumption and as such, the data collected helps direct and promote residential water conservation (Xiao-jun, W., et al 2015). Specific water use data also provides critical information about factors that influence demand-side water consumption, and the relationships that exist between different household appliances. While there has been exponential growth in knowledge needed in design of systems like water reuse systems, there isn't commensurate water use information to direct various aspects of planning. Data collected thus, lends knowledge needed in design of such water reuse systems therein quantifying of amounts and sources of water that can be reused and possible consumers of that recycled water. Water stress is a major supply challenge for many urban cities and tourist destinations. Strategies for mitigating water stress during peak times, holidays where high populace inhibits the households, hotels or cities as well as best practice, key performance indicators and performance benchmarks for water management in such times are critical (Styles, D., Schoenberger, H., & Galvez-Martos, J. L. (2015).

Thus, progressive nations have seen an increased interest in measures of demand-side management (Garcia-Valiñas, et al 2015).Due to fragmented data sources and collection strategies, water service providers and public officials fail to make informed planning decisions that benefit water wholesalers, retailers, and consumers or to efficiently operate water systems beyond their physical and organizational boundaries. There is a pressing need to cultivate a common information-sharing standard that will enable sharing of water use data in real-time (Rezgui, Zarli, Ellis and McCann, 2015).

While there is a wide range of technology that cab ne used to harness demand-side consumption data, there is evidence of significant disparity between these diverse telemetry technologies used in data collection (Dwyer, Campbell, Irwin and Franklin, 2015) thus the need to ensure a homogenous and error-proof system for harnessing the same. To routinely comb and collect data from devices appropriately, a modest mesh-local area network inter-connecting domotic water using appliances would be the ultimate solution.

In this regard, HydroSense which is a practical, low-cost, and unobtrusive approach to measuring human-water activity among households would be ideal for data collection (Froehlich, 2009). It offers a significant solution due to its ability to sense continuous water use within a home's water infrastructure from a single-point. HydroSense, successfully identifies individual water fixtures (e.g., a particular toilet, a kitchen sink, a particular shower) within a home according to the unique pressure waves that propagate to the sensor when valves are opened or closed. Technology helps evaluate and measure amounts of water used at a fixture in real time, based on the magnitude of the resulting pressure within the water infrastructure(Morrison and Friedler, 2015). The figure 2 below shows the installation of the hydrosense component within an illustrative schematic of a basic plumbing layout in a home

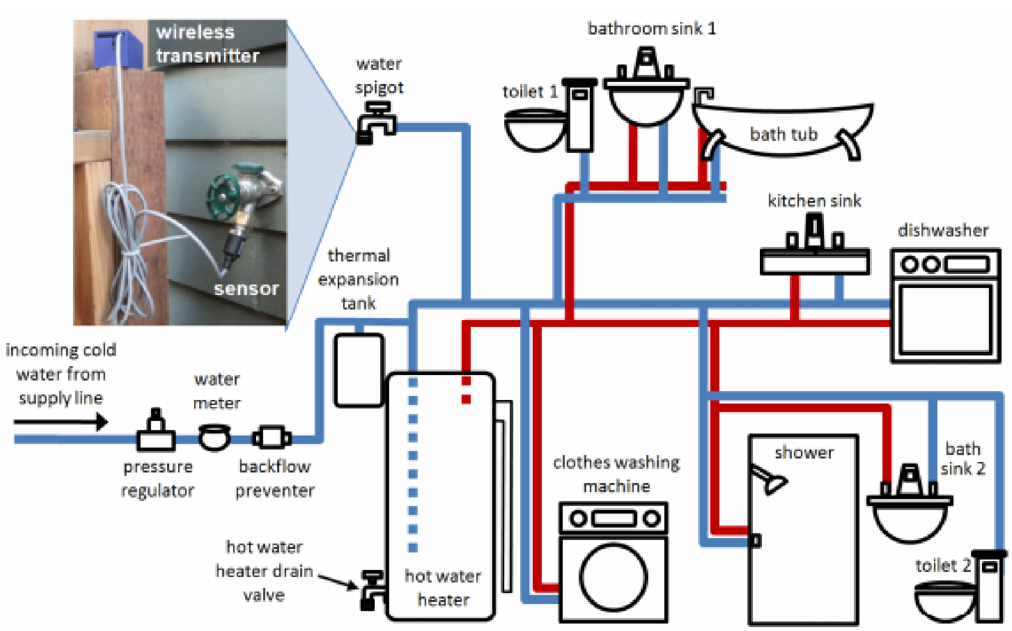

Figure 2: An Illustrative Schematic Of A Basic Plumbing Layout In A Home (Source: Morrison And Friedler) .

However, collecting records from the data loggers has so far been done using different methods. Hydrosense used Bluetooth technology to harness the logs. Flow trace analysis process involves the use of a small battery powered data logger to collect continuous flow data from the water meter (Larson et al. 2012), however, this information was collected on stand alone arrangements. Another data collection strategy used saw the use of direct metering on every water-using household appliance using Andrae Leonberg meters fixed in positions deemed the least obtrusive (Morrison and Friedler, 2015). Meters were scanned by telemetry with outstations used to hold the information, which was then downloaded to the main study system during the night using public switched telephone network lines. While there are competing technologies that could provide possible connectivity solutions, the open ZigBee standard plays out as the safest bet for purposefully generated content through sensor networks. ZigBee is powerful and easy to install because it was developed in order to be installed in a new or existing sensor network (Ibrahim, A. (2015). The figure 3 below shows the Transmission coverage and transmission rate of several common Wireless communication technology.

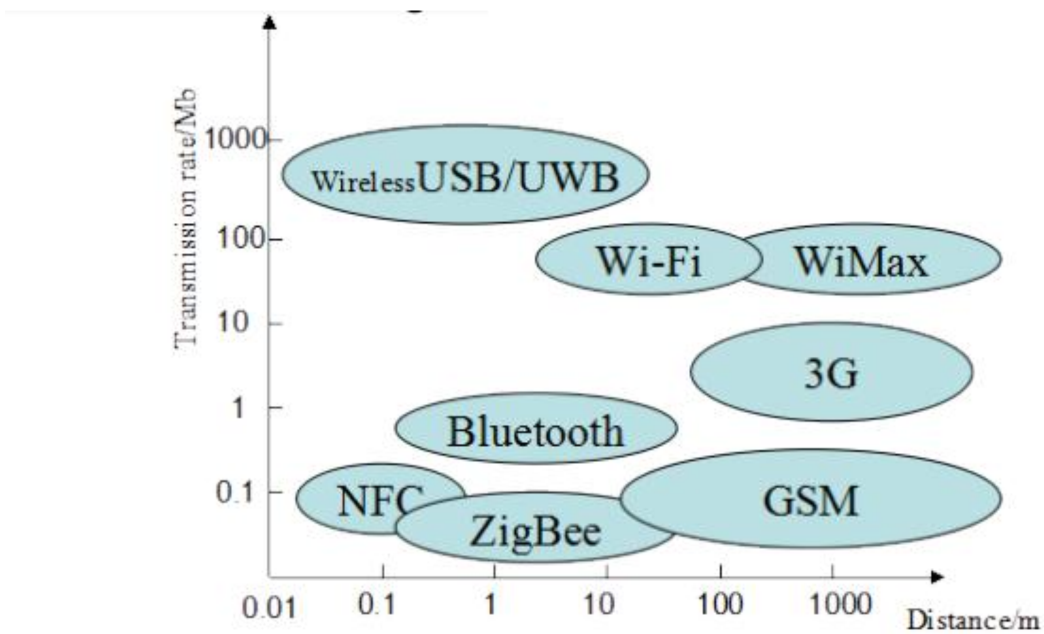

Figure 3: The Transmission Coverage And Transmission Rate Of Several Common Wireless Communication Technology (Source: Ibrahim).

The resulting water-meter network can be identified using either 16-bit or 64-bit addressing. Using the short addressing mechanism reduces the packet length and thereafter the space required to store the addresses (Rana, Y., et al 2014). Further, third-party applications can consume data collected to assist in making applications and information that makes sense of how Kenyans consume water. This information is critical. Companies and organizations are concentrating on more data to take informed and better decisions (Rajesh, 2013). The possibility to remotely connect and control the devices remotely thus offers huge benefits and opportunities

(Humpleman and Wolff, 2001). With the foundations if such networks the possibilities and prospects are endless.

1.2 The Problem

The current strategy employed by most Kenyan water utilities where field officers physically read meters is inefficient, inaccurate, unreliable and prone to manipulation. The process of physical data collection takes 2 to 3 days for Nakuru Water and Sanitation Company (NAWASCCO). 35 agents are responsible for 36,000 meters with each agent physically inspecting approximately 600 to 1,000 meters. Human errors during meter reading is generally experienced thereby necessitating zonal chiefs to manually inspect and adjust printed checklists consequently making the whole billing process a 14 day long affair. This scenario necessitates use of technology to tremendously reduce (i) time and effort taken during data collection and (ii) errors encountered in that process as well. While there is a wide range of technology that can be used to harness water meter data, there is evidence of significant disparity between these diverse telemetry technologies used in data collection thus the need to ensure a homogenous, open, reliable, cost-effective and achievable system for the same. GSM solutions are tremendously expensive on both consumers and the service provider. Bluetooth and WiFi have high energy consumption as devices can only be in operation for a maximum of 20 hours while Zigbee devices can operate on a drycell battery for between 10-20 years. There was need to then examine the use of the open ZigBee standard, which played out as the safest bet for purposefully generated content through sensor networks.

1.3 Objectives Of The Study

The main objective of this study is to develop a Zigbee mesh WPAN model for purposes of connecting and harnessing data from water meters and water distribution points, while relaying the same to stakeholders in real time.

The specific objectives of the study include:

1. To investigate the weaknesses of existing methods and technologies in collecting and harnessing data from water meters.
2. To design a scalable Zigbee Mesh WPAN model for remote water meter reading.
3. To implement a scalable Zigbee Mesh WPAN prototype for remote water meter reading.
4. To evaluate the performance of the Zigbee network.

1.4 Research Questions.

This proposal is guided by the following research questions;

1. What are the weaknesses of existing methods and technologies in collecting and harnessing data from water meters?
2. How can a scalable Zigbee Mesh WPAN model for remote water meter reading be designed?
3. Is a Zigbee Mesh WPAN prototype for remote water meter reading implementable?
4. What is the performance of a Zigbee mesh network?

1.5 Significance Of The Study

The use of an open, cost-effective, reliable standard in Zigbee will enable a trouble free mechanism for collecting water meter data in large scale in real time. A successful model will be significant in enabling interconnection of otherwise standalone devices. Such a model will also be instrumental in the development of affordable, adaptable and easy to use systems for billing and data collection. The proliferation of broadband internet within homes and business shoved up technology use. In addition, the reduction in internet connectivity costs as a result of the undersea fiber cable connection along Kenya's coast, are key success factors. Advancements in technology, penetration and usage of technology products like smart phones are contributive factors towards creating a perfect storm to incubate this proposed system. In addition, the proposed system will be of great benefit to the water service providers in the following ways; Enable them to accurately read meters in wide geographical areas while incurring minimal costs. Enhance efficiency and reduce time spent in collection of billing water-data. Reduce the overall cost of distribution by requiring less meter readers. Diminished instances of corruption and compromising of field agents. Lastly, it will help consumers detect instances of water losses by domotic appliances. It will also enable innovation and building of third party applications and solutions. The use of an open IEEE protocol Zigbee will enable trouble free mechanism for collecting data in large scale on both the consumer and distribution levels in real time. Since Zigbee is open, no license fees are required and as such modules are much cost effective.

The proposed Zigbee network for water meter telemetry will be significant in enabling interconnection of otherwise standalone devices. Such a prototype will also be instrumental in the development of affordable, adaptable and easy to use systems for both billing and water meter data collection.

It will enable an innovative billing system that supports both pre-paid and post-paid payments. The pre-paid system will further save more costs by negating the need for physical update of meters. It will also break away from the perennial use of pay-cards, as payment details can be propagated directly from the central office.

1.6 Scope Of The Study

This study focused on the developing of a model for a Zigbee mesh WPAN for purposes of connecting and harnessing data from the water meter points. A prototype to be developed will serve as a proof of concept. The evaluation of the system will be done from the same based on the initial objectives and system requirements.

1.7 Conclusion

This chapter gave a brief background of the main concepts and problems informing this study specifically on the lack of scalable, inexpensive, open, reliable mechanisms to collect water meter pattern data. It further proceeded to state research problem, research objectives, defined the scope, significance and the expected outcomes of the study.

CHAPTER TWO
LITERATURE REVIEW

2.0 Introduction

This chapter will present a discussion on the water management problem, activity sensors, WPAN, mesh networks, 802.15.4 and Zigbee models. The theoretical and conceptual frameworks for the study will also be presented and discussed.

2.1The Water Management Conundrum

The primary contribution to urban water crisis is urban water governance failure (Rugemalila, Gibbs, 2015). Improvement in billing and data collection systems, impacts positively on the revenue streams of a water service provider and enables citizenry to afford and get access to clean, safe water. This in turn, encourages efficiency in the commercial and operational tenets which in turn aids in expansion and delivery of improved, reliable, and sustainable services (Water and Sanitation Program Report, 2008). Access to clean, safe water is influenced by several factors including inefficient operations, poor levels or absence of metering, poor billing and data collection practices, poor structure and levels of water tariffs, increased and inefficient operational costs, and weak management (McKenzie, Isha, 2005). Poor billing and data collection not only hurts the customers, but also inhibits water service providers from amassing sufficient funds to efficiently operate and maintain water supply facilities and, consequently, provide adequate service to the end user. Majority of Water service providers are only recovering operation and maintenance costs and fall short of achieving full financial cost recovery (van den Berg, C. 2015) thus are unable to provide effective water services.

Kenya's per capita water availability will be 235 cubic meters per year by 2025, which is a third of current availability of 650 cubic meters (Marshall, 2011). The developing world, due to lack of adequate water management, experiences deteriorating cases of water supply largely, water scarcity is increasing and poses a serious risk to sustainable development and quality of life (Fan, et al 2014). Concomitantly, demand for water among the general populace is rising while resources are quickly diminishing (De Graaf, et al 2014) while the proportion of urban populations in sub-Saharan Africa receiving piped water supplies has remained unchanged since 1990 (WHO/UNICEF, 2013). Preponderance of the current water crisis is as a result of poor management of water supply (Kenya National Water Development Report, 2006). Investing in water supply management is critical to the country and has direct social-economic impacts. Effective billing and data collection systems are a critical component for ensuring the viability of a water service provider. This aspect ensures water supply management is optimal and effective revenue collection improves revenues and consequently the water service provider improves its service provision to general citizenry. (Water and Sanitation Program WSP, 2008).

2.2 Need for Technology Based Networks

Technology based billing and data collection systems reduce information asymmetries and reduce incidences of corruption thus by making payment data more transparent (Krolikowski, 2014). A restructuring of billing and data collection activities through technology has seen successes in Burkina Faso which now boasts of collection rates of over 95 percent (Dominguez Torres, 2012). Thorough water meter monitoring assists water planners, authorities, and household owners to evaluate when, where and how often water is used and wasted, and in what quantities (Morrison and Friedler, 2015).

2.3 IEEE 802.15.4 Sensor Networks

A wireless sensor network (WSN) is as a wireless network which consists of autonomous devices capable of monitoring the physical or environmental conditions such as temperature, sound, vibration, pressure, motion or pollutants, at various different locations especially for buildings (Joshi, S. S. P. A. et al 2012). Sensor nodes are the fundamental devices in a WSN (Yusuf 2014). The figure 4 below displays the architecture of a sensor node which includes a sensing device, processor subsystem, a communication and power systems.

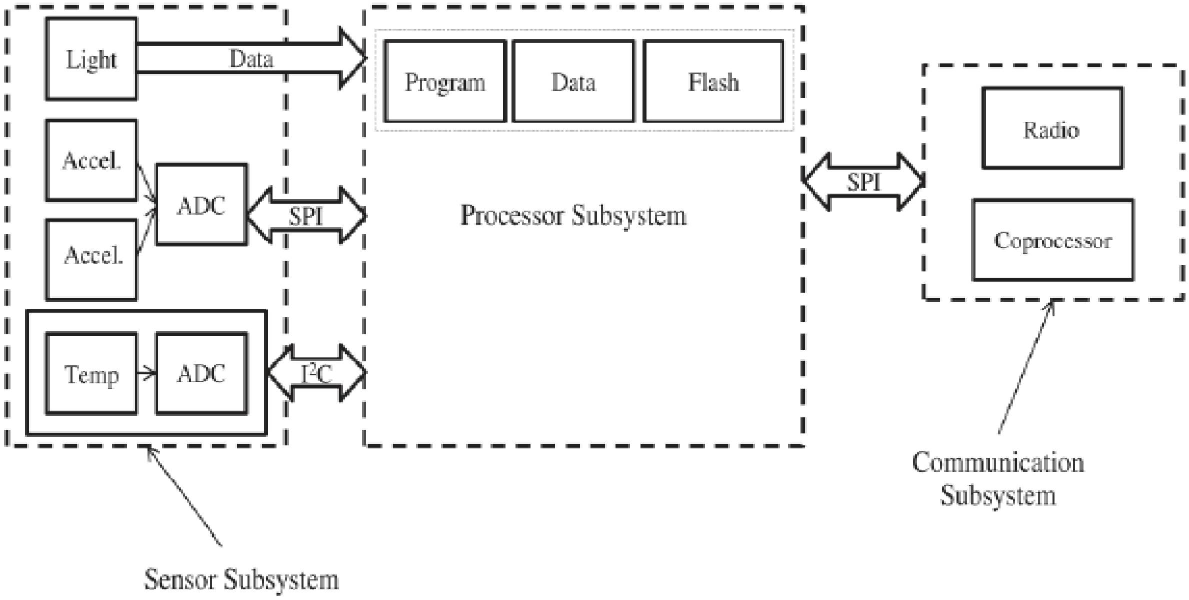

Figure 4: Architecture of a wireless sensor node (Yusuf, 2014).

2.4 Comparative study of Competing Technologies

There are various specifications that extend the standard by developing the upper layers which are not defined in IEEE 802.15.4. This standard only specifies and controls only the RF, PHYsical and Medium Access Control (MAC) layers (Zheng and Lee2004). This includes the EnOcean, a proprietary protocol with low speeds of 120 Kbits/s while the Z-Wave solution has even lower speeds of 40Kbits/s and it has no security feature. The RFID protocol has very low speeds with no dynamic addressing of devices (Lee et al 2007). Zigbee networks are very energy efficient as the devices are usually asleep thus operate on low power and bandwidth with batteries lasting between 10-20 years and consume a fraction of power in comparison with Wi-Fi 802.11 networks (Bras et al 2010). Zigbee devices operate as sleeper nodes thereby limiting their use of energy. Zigbee is an open global standard for wireless technology designed to use low-power digital radio signals for personal area networks. Zigbee operates on the IEEE 802.15.4 specification and is used to create networks that require a low data transfer rate, energy efficiency and secure networking (Ran et al 2006). The protocol needs less than 64 kb of ROM and 2-32 kb of RAM. Zigbee devices are readily available in frequencies other than 2.4/5Ghz, which may be beneficial in environments with saturated 2.4 and 5GHz bands (Lee, Su and Shen, 2007). ZigBee is designed specifically to co-exist with technologies in the ISM. Further, ZigBee networks choose the quietest channel in which to operate and can even change channels as conditions warrant. In addition, it is an acknowledgement based protocol and will re-send a message if no acknowledgement is received. Most critically, a ZigBee mesh provides an easy to install reliable, self-configuring, self-healing network which operates on multi-paths (Ali 2011). This means that devices do not have to connect directly to the central office; but rather, packets can hop and be relayed to the destination via next available zigbee device within a 1Km radius in the mesh. This greatly reduces complexity, and thus a huge mesh network is possible because Zigbee is designed to support upto 65,645 nodes (Bormann 2014). By addressing devices using IPv6 then a vast number of devices can be setup. WiFi devices however require very high amount of energy in comparison with zigbee. Further, as zigbee networks can accommodate more than 65,645 nodes within one WPAN as opposed to WiFi which has a limit of 2000. This aspect allows zigbee networks to scale in large proportions (Lee et al 2007). IPv6 communication energy overhead remains reasonable as well in scaled networks (Ran et al 2006).

2.5 Low power Wireless Personal Area Networks

Low power Wireless Personal Area Networks are a group of RFC IEEE 802.15.4 that propagate wireless personal area networks. 6lowpan working group provides a specification that allows use of the Internet Protocol for IEEE 802.15.4 networks. The Low power Wireless Personal Area Networks aims at defining various compression methods that allow IP packets to be sent to and received from over 802.15-based wireless networks. Applications for Low power Wireless Personal Area Networks are very similar Internet communication (Ana de Pablo Escolà, 2009). The figure 5 below shows the Open systems interconnectivity for a LPR network. The figure 5 below shows the OSI model for low power radio networks.

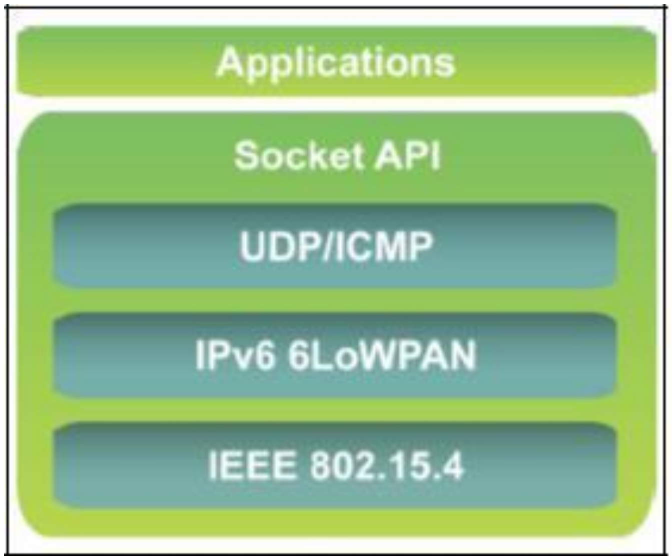

Figure. 5: Open Systems Interconnectivity Model For A LPR Network (Source: Ana De Pablo Escolà)

2.5.1 Characteristics Of Low Power Wireless Personal Area Networks

Those are the main characteristics of Low power Wireless Personal Area Networks specification include, a small packet data size that only propagates a PHY packet size of 127 Bytes and another 81 octets for data packets. It supports both 16-bit short as well as the IEEE 64-bit extended MAC address. it uptakes low bandwidth with transfer rates of 250 kbps, 40 kbps, and 20 kbps for the physical layers. This technology supports logical topologies like star and most commonly mesh. It also has ability to a large number of wireless devices within its network. Further, these devices may sleep for long periods of time in order to save energy. Devices in the network can be classified into two; full function device (FFD) and reduced function devices (RFD). The FFDs typically require and use more resources and may need to be directly powered. In addition, FFDs aid RFDs by managing network coordination, packet data unit forwarding, as well as interfacing with other types of networks (Ana de Pablo Escolà, 2009).

2.5.1.1 Comparison Between The LoWPAN and ZigBee standard

The major difference between these technologies is that ZigBee propagates a small-scale network while 6LoWPAN supports large and scalable networks due to use of IPv6 protocol. The ZigBee is limited to a single radio standard and only defines how devices communicate between these nodes. 6LoWPAN can be applied to any wireless radio technology. While Zigbee only defines upper layers, and thus utilizes the existing standards.

2.5.1.2 Use of Internet Protocol addressing in LoWPANs

The application of Internet Protocol for purposes of addressing is very advantageous, as it allows the use of existing infrastructure that is well-known, open and free, and work efficiently. As a result, IP addressed devices can be easily connected into other IP networks, without the need for interconnection devices. Further these devices user other kinds of networks interfaces such as Ethernet or IEEE 802.11, the goal is to easily integrate the existing networks over those technologies. However there is a need to consider the following; many devices in these LoWPAN expect auto configuration and address statelessness highly desirable. IPv6 has the ready solutions since it has high address density as well as a limited packet size. Further, headers for IPv6 and other OSI layers above must be compressed whilst forwarding data (Ana de Pablo Escolà, 2009).

2.5.1.3 Packet Routing

These LoWPAN propagate various logical topologies that include mesh, ring, fully connected and star topologies. Mesh topologies allow multi-hop of data packets. This scenario, intermediate devices act as packets forwarders to the next device neighbor at the link layer and consequently the packets is received at the destination.

2.5.1.4 Device Authentication and Network Security

Low power Wireless Personal Area Networks provide Confidentiality, Integrity and Authentication (CIA). However since the networks only carry small data sizes, this feature inhibit ability to propagate more security choices and multifaceted security mechanisms. Due to this, the network can suffer from attacks like denial of service attacks. For proper network layer security, end-to-end security can be implemented to the wireless portion of the network.

2.5.1.5 Internet Protocol version 6

The Internet Protocol version 6 (IPv6) is an Internet Layer protocol for packet-switched networks and the Internet. Globally networks use Internet Protocol version 4 (IPv4)which is the current dominant Internet Protocol version, and was the first to receive widespread use.IPv6 has a much larger address space than IPv4. This results from the use of a 128-bit address, whereas

IPv4 uses only 32 bits. IPv6 has the ability to provide much needed flexibility by allocating addresses, better security and ability to route traffic as well as eliminating the need for network address translation (NAT) since there are enough addresses for all devices.

IP normally runs on current underlying network technology. This includes cable ethernet networks, Wireless Fidelity (WiFi), as well as low powered radio internetworks. The major advantage of IP is the ability to propagate data is easily through encrypted channels over the global Internetwork.

IPv6 addresses are normally composed of two logical parts which are: the 64-bit host address part and the 64-bit sub-network prefix. These two can be automatically generated from the interface's MAC address or assigned sequentially through stateless auto-configuration.IPv6 addresses are normally grouped into eight segments or hextets/groups of four hexadecimal digits, each segment is divided by a colon (:). Since the addresses can be very large, they can be shortened by writing and presenting the addresses in the following ways;

a) All preceding zeros in a segment can be truncated.
b) All preceding zeros in a consecutive group of 0 value can be replaced with two colons (::), but only once in an address, with the second less group of zeros replaced by a single 0 (:0:)

2.5.1.6 Transition Mechanisms

To enable migration from IPv4 to IPv6 two major transition mechanisms are currently implemented. Mainly;

i) IP Tunneling
ii) Dual Stacking

For packets to access the IPv6 internetwork, isolated hosts and networks normally use the existing IPv4 infrastructure to carry IPv6 packets. This is done using a technique known as tunneling which consists of encapsulating IPv4data packets inside IPv4 packets and vice versa. Dual stacking is the process of assigning both IPv4 and IPv6 addresses to a network device thus allowing the device to join a network and propagate using either of the two addresses.2.5 The Zigbee specification

A typical zigbee network will require the following devices.

1. A **ZigBee coordinator** which contains all network information. It can initiate a network, seek the neighbor nodes, and form a new network under various zigbee topologies. The coordinator can also provide dynamic IPv6 addresses to the other devices in the WSN.
2. A **ZigBee Router** whose function is to coordinate or connecting other ZigBee Routers and/or ZigBee End Devices forming a network.
3. A **ZigBee End Device**, which communicates with ZigBee Router and complete sending and receiving information. The end device is also the sensor node that measures various entities in the environment.

Zigbee nodes spend much of their time sleeping, but the protocol is enhanced to allow rapid wake up and response. When a Zigbee node is powered down, it can wake up and get a packet in around 15 msec (Black, Mason, Schneider and Bricketto, 2015). These nodes communicate wirelessly with each other, and forward measurements to a central network administrator or wireless gateway (Petersen, Myhre and Røstum, 2014).

2.6Zigbee Network Topologies

A zigbee network can be set up to support peer-to-peer, star, cluster trees topology or mesh network topology. The IEEE RFC 802.15.4 standard, defines the Medium Access Control layer (MAC) and the physical layer as well. The ZigBee network is built upon these two layers. Thus, both standards complete the communication protocol stack which defines the Wireless Sensor Network (Yusuf, 2014). Figure 6 shows the various formations of zigbee logical topologies.

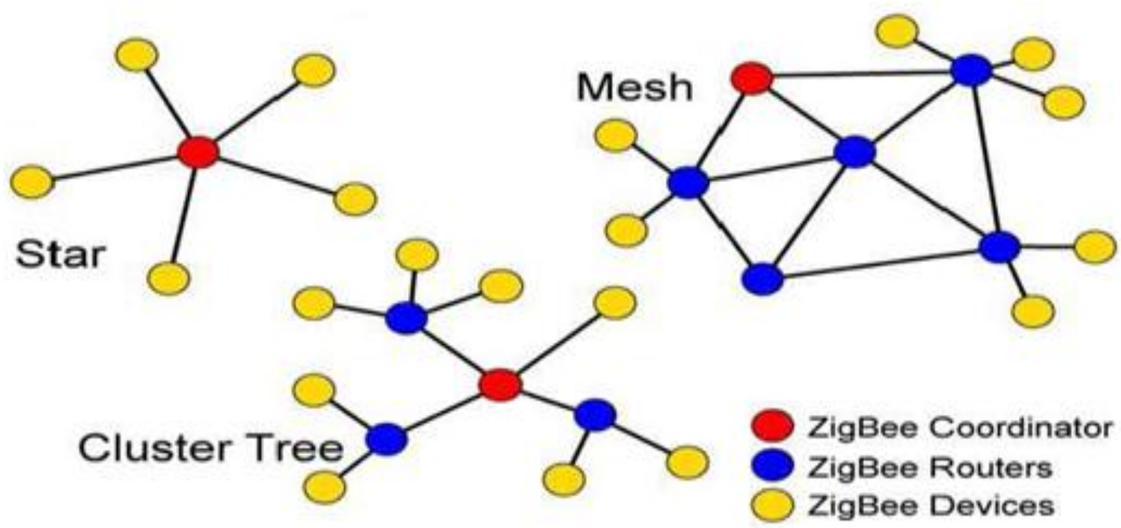

Figure 6: Various Zigbee Network Topologies (Yusuf, 2014).

A zigbee mesh topology has multi-hop capability as it allows data packets route through several devices called multi-hops to reach its intended destination. Multipath routing enables high reliability (Bidai and Maimour, 2014). This type of protocol is more robust and it uses a more complex routing protocols compared to star or tree topology. Mesh topology is a form of an ad-hoc network, is self-healing and self-organizing (Mahmoud, 2013).The figure7 below shows a multi-path connection between various devices.

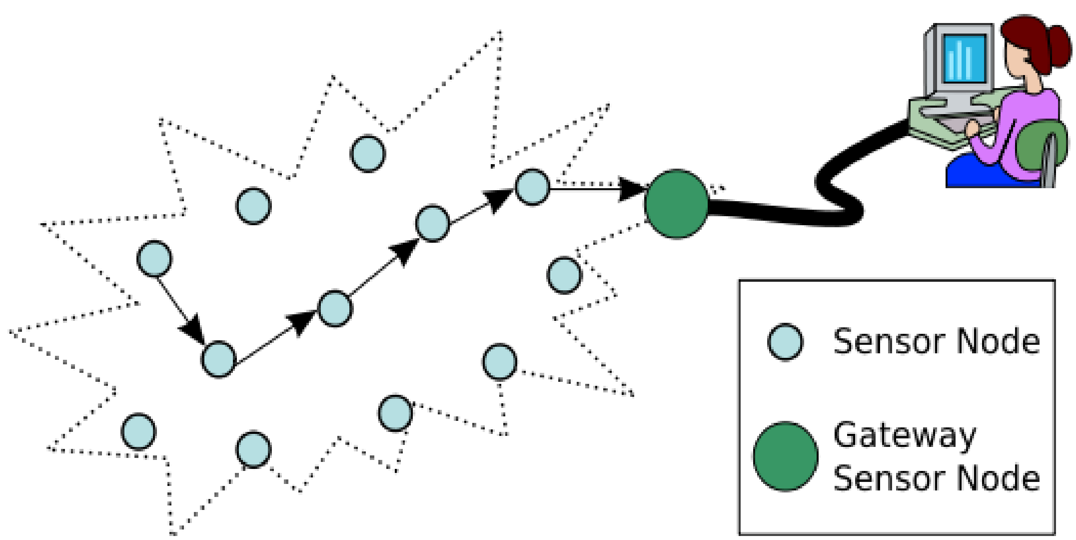

Figure 7: Typical Multihop Wireless Sensor Network Architecture (Source: Victor, Khader, Rao and Mehta, 2013)

2.6.1Zigbee Network Addressing

IPv6 is the ideal addressing protocol for the zigbee network as it has limitless addressing space to accommodate a scalable network (Qi, Gao& Zhang, 2015). All the ZigBee nodes are assigned with IPv6 addresses dynamically by the network. Packets are encapsulated with IPv6 addresses and forwarded into ZigBee network. The IPv6 model considers IP-based wireless sensor networks as an extension of the Internet. The gateway provides a seamless connection between WSNs and the Internet, thereby traditional communication networks interface with sensor networks to make network communication easier and manage the devices of sensor networks (Luo and Sun, 2015). The figure 8 below shows the protocol stacks mapping for the TCP/IPv6 network

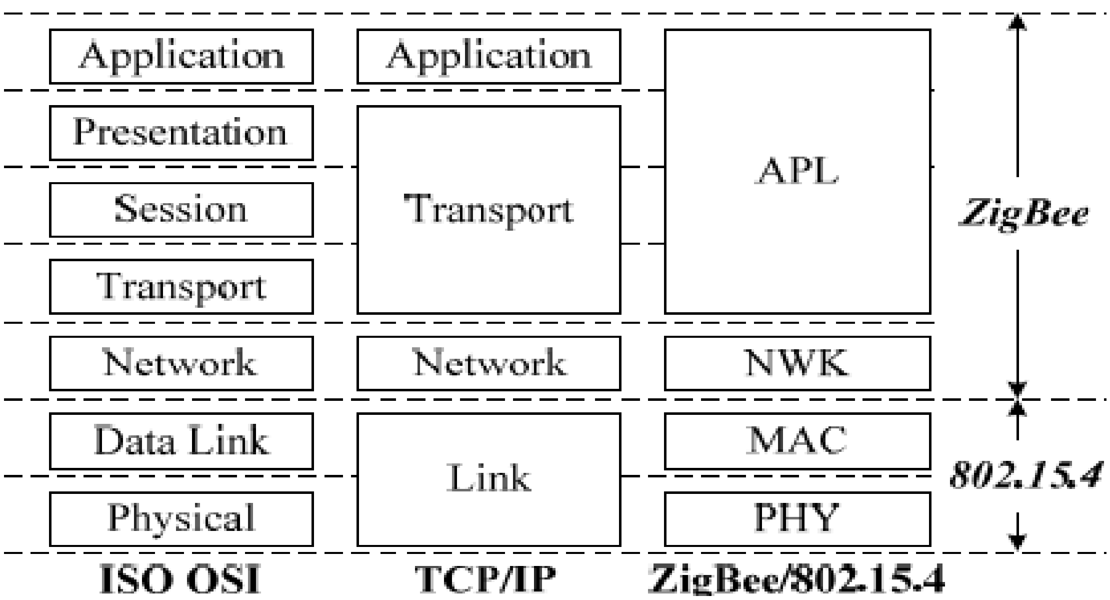

Figure 8: Protocol Stacks Mapping (Wang, Chang and Chao, 2007).

Nodes in the WSN network and expended 802.15.4 network connect to IPv6 hosts through the gateway sensor node, and the other sensor nodes in the heterogeneous sensor Zigbee networks are interconnected with the Internet via a transition device (Luo and Sun, 2015). The figure 9 below displays a proposed design and implementation of the 802.15.4sensor gateway and the communication system.

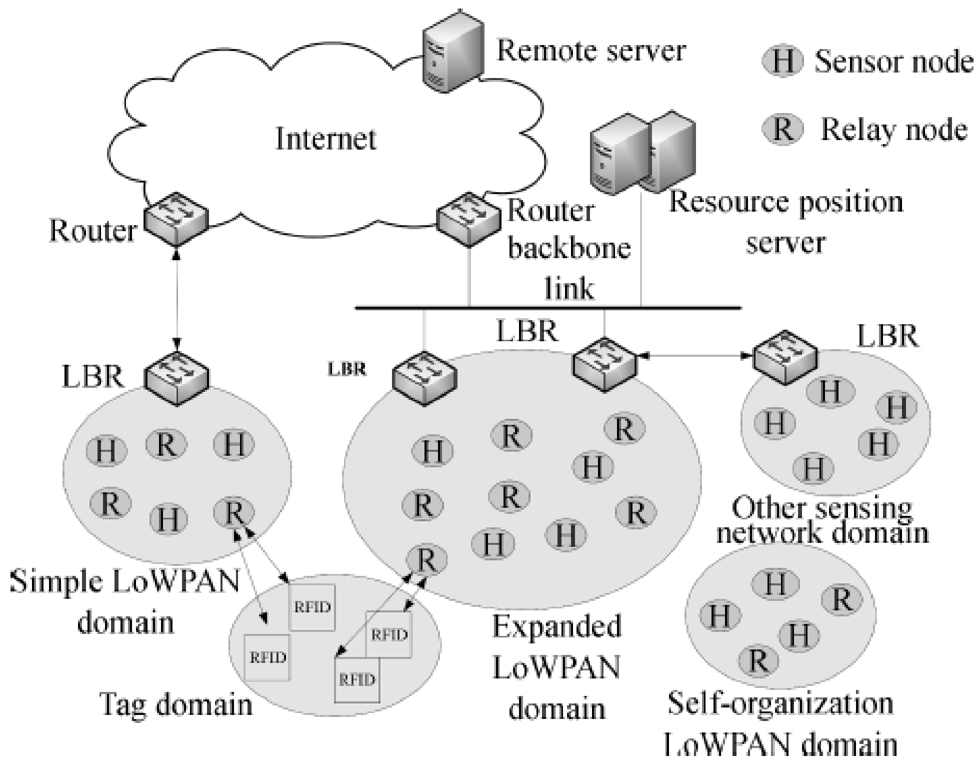

Figure 9: The architecture between IPv6 hosts and sensor nodes (Luo and Sun, 2015).

2.7 Theories informing this Study

In setting up a Wireless Sensor Network for Emergency Response Notification for Indoor Situations (Victor, Khader, Rao and Mehta,2014) with objectives of creating a system focusing on one aspect of the emergency fire detection. To complete the interface Zigbee devices were connected to a PC with a Zigbee Interface Module so as to provide a range of sensing applications which can be developed using 802.15.4 MAC and PHY along with ZigBee stack. Figure 10 below shows the ZUXP ProXR Zigbee Interface Module used in the prototype.

Figure 10: The ZUXPProXRZigbee Interface Module (Victor, Khader,Rao and Mehta, 2014).

In the design of a Zigbee transceiver for IEEE 802.15.4 using matlab/Simulink, Ravikanth Kanna built the simulation by using HDL languages Verilog HDL. By using Minimum Shift Keying (MSK) modulation technique is described, it was proven that the theoretical maximum bandwidth efficiency of MSK is 2 bits/s/Hz which is equal to Quadrature Phase Shift Keying (QPSK) and Offset Quadrature Phase ShiftKeying (Offset QPSK). The results confirmed the viability of theoretical approach by use of mathematical blocks. No physical devices were used in this research. The figure 11 below shows a superhetrodyne receiver modeled by quadrature phase shift keying.

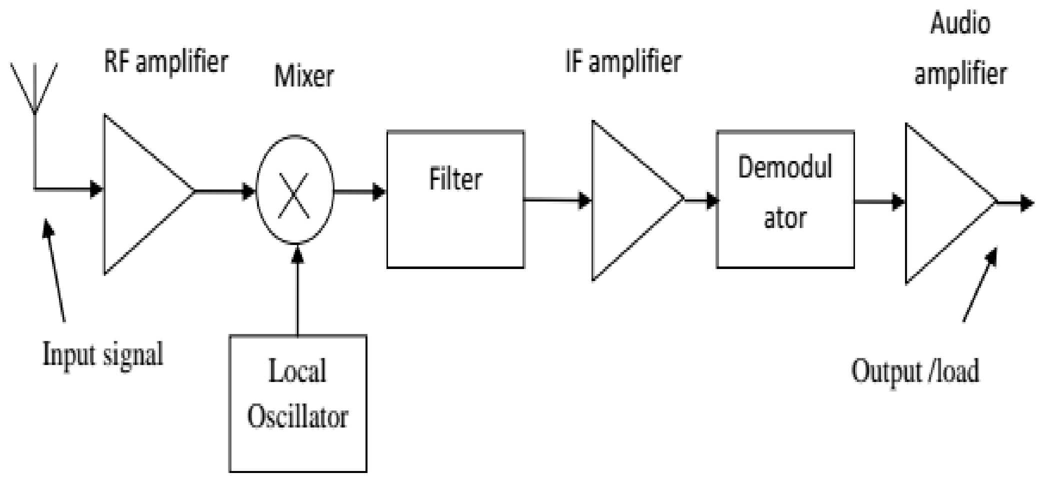

Figure 11: A Block diagram of Superhetrodyne Receiver (Source: RavikanthKanna, 2011).

Bin Yu (2010) investigated on a wireless system for multi-channel transmission of electroencephalographic (EEG) Signals. The project involved miniaturized wireless data acquisition and real-time signal analysis system for monitoring and analysis. This signal records the electrical activity of the neurons within the brain. Thereby physiological and pathological information could be collected and used to diagnose and treat brain diseases like movement disorders, migraine variants, catatonia or patients with coma. Figure 12 below shows the LT2510 transceiver module is simple to use and do not need any programming as implemented by Bin Yu.

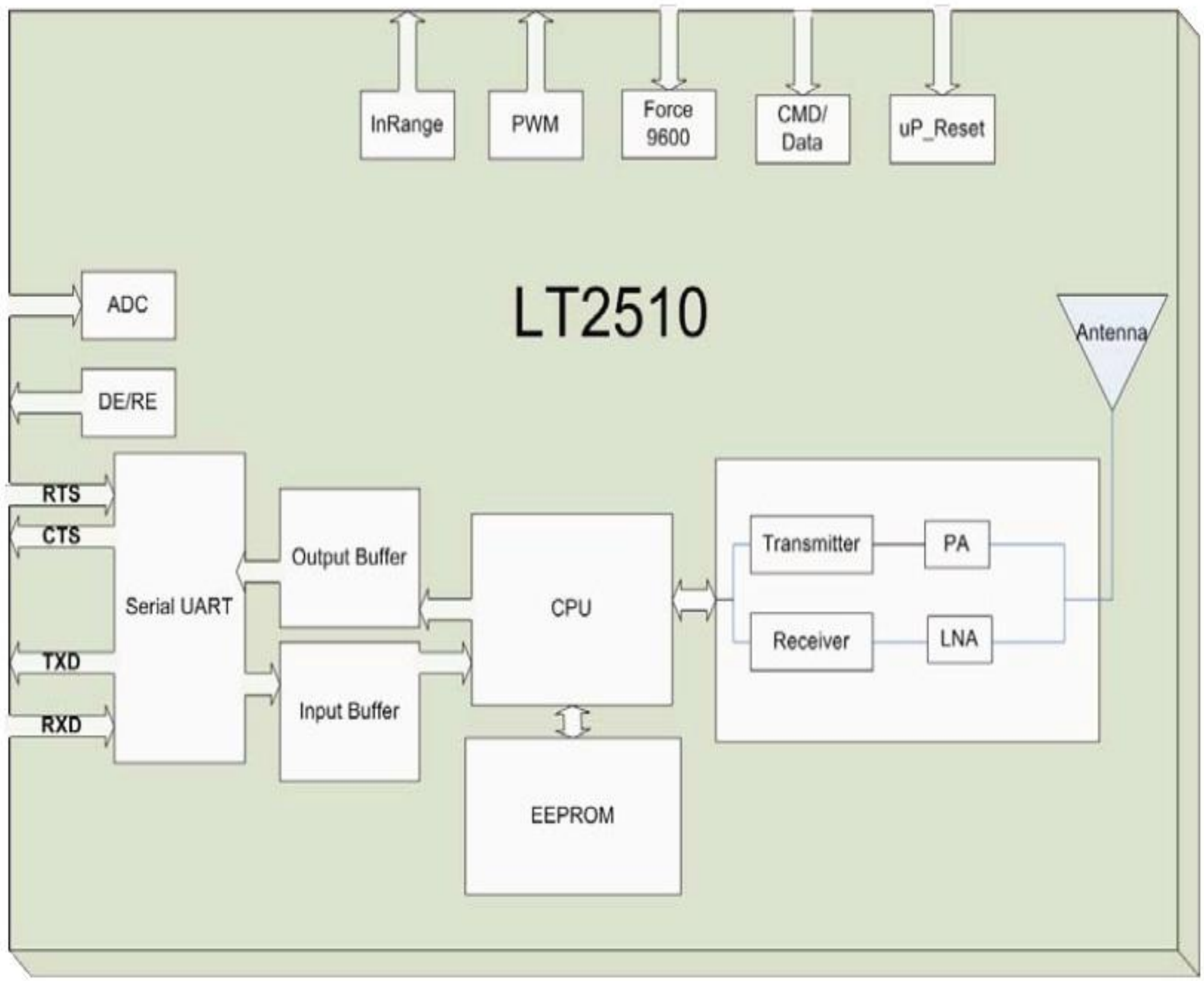

Figure 12: Functional block diagram of LT2510 (Source: Bin Yu, 2010)

2.7.1 Noisy-Chanel Coding Theorem (Shannon Theory)

The Noisy-Channel Coding Theorem (Shannon Theorem) is the most important theorem for the of information theorems. This theory presupposes that a message input into a noiseless channel can be distinguished from the output message. In retrospect, when noise or interference is experienced or introduced to the communication, the end result is that a message at the channel input which experiences a lot of noise and interference can produce the same output message.

This is achieved through implementing a plain coding system like a repetition code or even a linear error correcting code such that it simultaneously reduces the rate, R, of transmission.

Shannon further showed that a code exists such that the rate of transmission can be approximately equal to the message capacity of the channel (Michael Macon, 2015).

The Shannon theory of data compression and transmission allowed the ability for efficient transmission of data as well as growth of various informational sciences that included other disciplines such as Probability, Statistics, Computer Science, and its child disciplines like, Information Theory provides guidance for the development of various network communications, data storage and propagation, and other information technologies (Sergio Verd´u, 1998). In mathematical theory of communication, simple coordination from the central devices includes the following;

a) Lossless data compression methods: This involves specifications for amount of information within in a source and within the algorithms as well.
b) Develops optimal compression efficiency as shown by the theory.
c) The Shannon theory indicates channel capacity or bandwith as well as the amount of goodput vis s vis the bandwidth. This is important information which encounters it. transmitted through a noisy channel.
d) This involves specification for of lossy data compression:

The most critical loss is that of information rate and reproduction fidelity (Sergio Verd´u, 1998).

2.7.2 Information Theory

On the onset, the major importance of information theory was to provide a mathematical model depicting the theory of communication though establishing the fundamental tenets on the performance of various communication systems (Cheny and Fady, 2005). The information theory was initiated with the work of Claude E. Shannon who stated that it is possible to send data at a fixed rate through a noisy communication channel. In addition, it was observed that random sources of data for example music, wireless or electric singles as speech, music or image signals have a limit to the extent at which they cannot be compressed without distortion. This he proclaimed is as the theory of complexity the source entropy. Shannon abstract mathematical models have today enabled critical and important use of applications including;

i) Statistical Sciences like quantum information theory)
ii) Computer science (computability, algorithmic complexity, resolvability)
iii) The Probability theory (deviations in mega data, or various limit theorems)
iv) General Statistics (like hypothesis tests, estimations, and general correlation) (Po-Ning Cheny and Fady Alajajiz, 2005)

2.7.3 The Cisco PPDIO Methodology

The Cisco Prepare, Plan, Design, Implement, Operate, and Optimize (PPDIOO) methodology provides a continuous flow of key transition phases that take place during the building or setting up of a network. Each step indicates which key steps are required for a successful network to be set-up and operated. This top-down strategy to network design suits the network infrastructure transition towards the network application needs. The PPDIOO methodology steps are as follows;

2.7.3.1 The Prepare Phase

In this Prepare phase, the organization establishes its core requirements and develops a suitable network strategy, consequently proposing a high-level conceptual architecture that can support the network. Here the various technologies that can support the proposed architecture are identified. This prepare phase also creates a business case to that commensurately matches and justifies the budgets.

2.7.3.2 The Plan Phase

This Plan phase identifies the various network requirements that meet the network goals, facilities, and user needs. This phase involves assessing the network, identifying gaps and loopholes. It also compares and evaluates various best-practice in network models, and matches with the operational environment. A project plan is consequently developed to manage the tasks, responsible personnel or users, timetables and deadlines, resources required to draw-up the design and final implementation. The project plan is done within the scope, budget, and resource parameters with the original business needs.

2.7.3.3 The Design Phase

This network design involves the developed of the network on the basis of technical and business requirements covered in the previous lifecycle phases. The network design phase provides a comprehensive and detailed design that is commensurate to the current business and technical needs. The purpose of the design arrived at this stage is to relay high availability, scalability, security, reliability, flexibility and performance. The design phase includes network topology diagrams, addressing plan, transmission media and both end and intermediary devices involved in the set-up. Once the design phase is approved, the project can now transition to the implement phase.

2.7.3.4 The Implement Phase

This involves the actual laying down and setting-up of the network. Devices and media are procured, installed, configured and calibrated, in accordance to design specifications. In this phase, new devices are added onto the network, replace or upgrade the existing infrastructure. The project plan should be followed exclusively during this phase so as to avoid loopholes. Any un-planned network changes should be adversely communicated and documented in time and with authorities before commencement so that necessary approvals are given to proceed. Each of the steps during the implementation phase should include a description, detailed implementation guidelines, estimated time to be taken for implementation, rollback steps in case of a failure, and any additional network information.

2.7.3.5 The Operate Phase

This Operate phase details the process of maintaining the network daily operational and ensuring that is performing optimally. The processes involved during the operations include monitoring and managing network components, performing switching and routing maintenance, managing software and hardware upgrades, monitoring and managing general network performance as well as device performance, as well as identifying and correcting network faults. This operate phase tests the suitability of the proposed design before handover. During this operation phase, network management stations should monitor the general flow of data by recording the bandwidth, throughput and goodput. Basic network performance should also be monitored and recorded. Fault and error detection, error correction, and performance monitoring also provide critical data to enable optimization of the network.

2.7.3.6 Optimize Phase

The final Optimize phase requires constant network monitoring and management where bottlenecks are identified and resolved so as to have a healthy network. The Optimize phase may involve upgrading of the network or modifying the network design. In cases where the network general health is affected, there is then the need to improve performance issues, or to resolve various issues within the OSI layer. The Figure 13 below shows the Cisco PPDIO lifecyle.

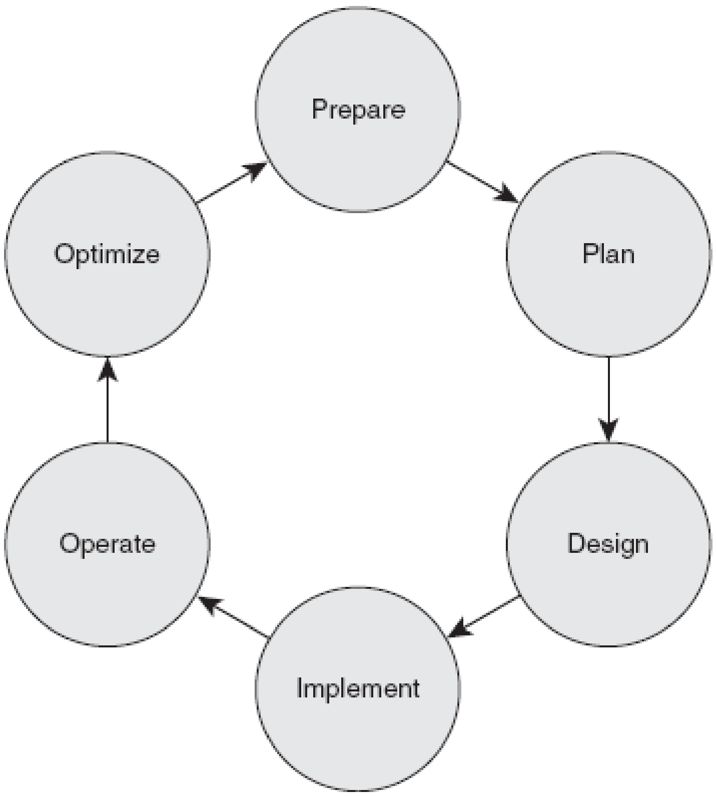

Figure13: The Cisco PPDIO Lifecycle (Source: Cisco 2014)

2.8. Conceptual Framework

A Zigbee based remote Water meter reading and meter sensing system is therefore proposed as a solution to the challenges of meter reading and water meter measurement in Kenyan water and sewerage companies' distribution points. These distribution points are categorized into (i) Residential homes/water meters for purposes of billing and; (ii) Various water supply distribution points along the water pipeline.

The system will utilize the Zigbee Mesh network to transmit meter readings wirelessly from residential areas to the companies' central office where the data on consumption will be analyzed for billing and other planning purposes. The water meters at various distribution points along the pipeline will transmit data logs wirelessly to the central office as well. A software system will consume, analyze, bill appropriately and provide reports on status of water meter along the infrastructure. An overview of the proposed system is presented in figure 14

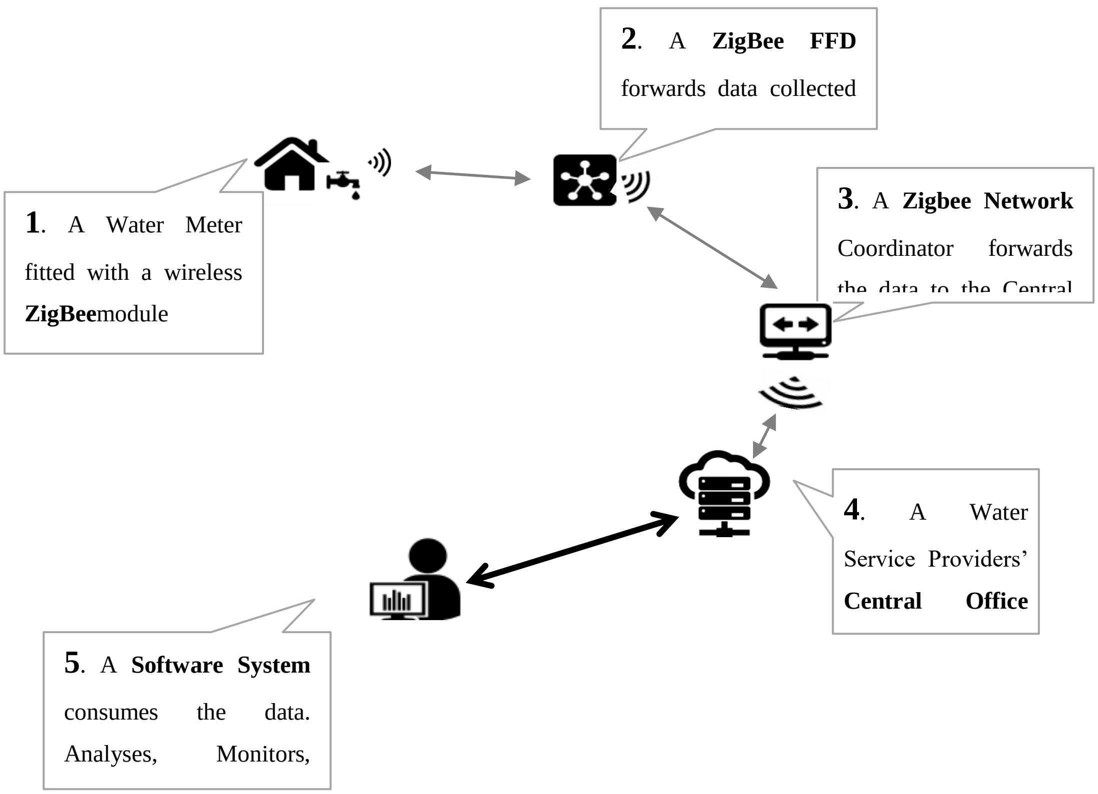

Figure 14: A diagram showing the residential device, intermediary devices and the system user at the water company.

The technical model will have the following components;

1. The domestic Mesh WPAN made up of water meters and;
2. A gateway router to forward data to the cloud.
3. The WPAN-to-WAN that relays on their behalf to the water service providers Central Office (CO) and;

The Networks

a) The Domestic Mesh Wireless Personal Area Network

This will be composed of several water meters with an embedded zigbee module. The module will be a reduced function device that will capture water meter data logs and relay the same to a Full Functional Device FFD. The modules will have a unique IPv6 address but will share the same IPv6 multicast address within the WPAN. The major advantage here is that individual meters do not need a single (expensive) connection to the Central Office, they will forward their data through the FFD to the Network Coordinator which will in turn re-route traffic to the WAN on their behalf. While such a network can accommodate over 65,654 for prototype purposes, they'll be limited to devices within one estate/flat. Figure 15 below describes the technical architecture.

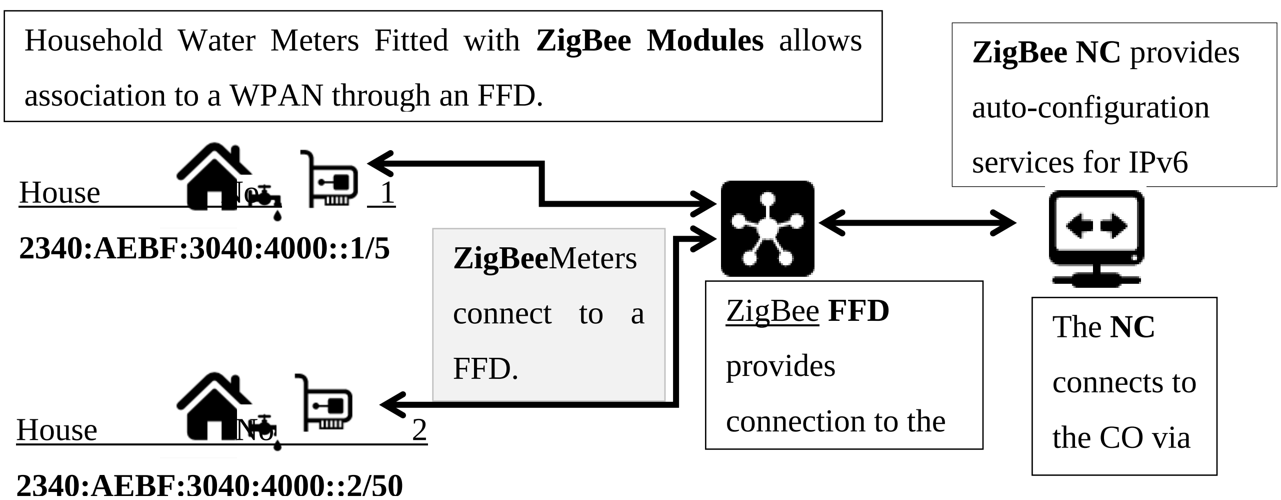

Figure 15: A House Meter to WPAN Connection

b) The WPAN-to-WAN Connection

This will provide the Network Coordinator (NC) with WAN connectivity so as to relay data to the Central Office (CO). Therefore it will limit the need to have every water meter speaking directly to the CO, rather via the NC. The NC will also monitor to see which devices have joined the network, as well as which devices are OFF in real time. WAN connectivity can be implemented using various ways with GSM being most appropriate Figure 16 below describes the WPAN-to-WAN connection.

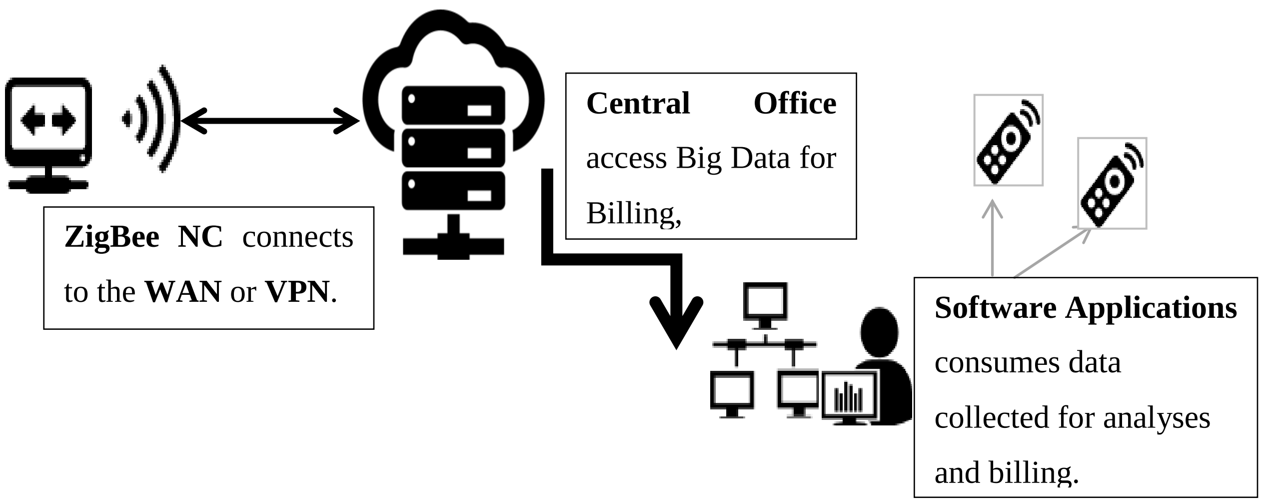

Figure 16: WPAN-to-WAN Connectivity

Zigbee networks support mesh topologies that provide multi-path connections. Thus, for purposes of enhancing reliability through redundancy, A WPAN can forward its data through an external FFD that connects devices in a different WPAN. Thus provide multi-path connectivity to the WAN incase of downtime. The figure 17 below shows the WPAN-to-WAN connection. It also further describes the multi-path ability of zigbee network topologies.

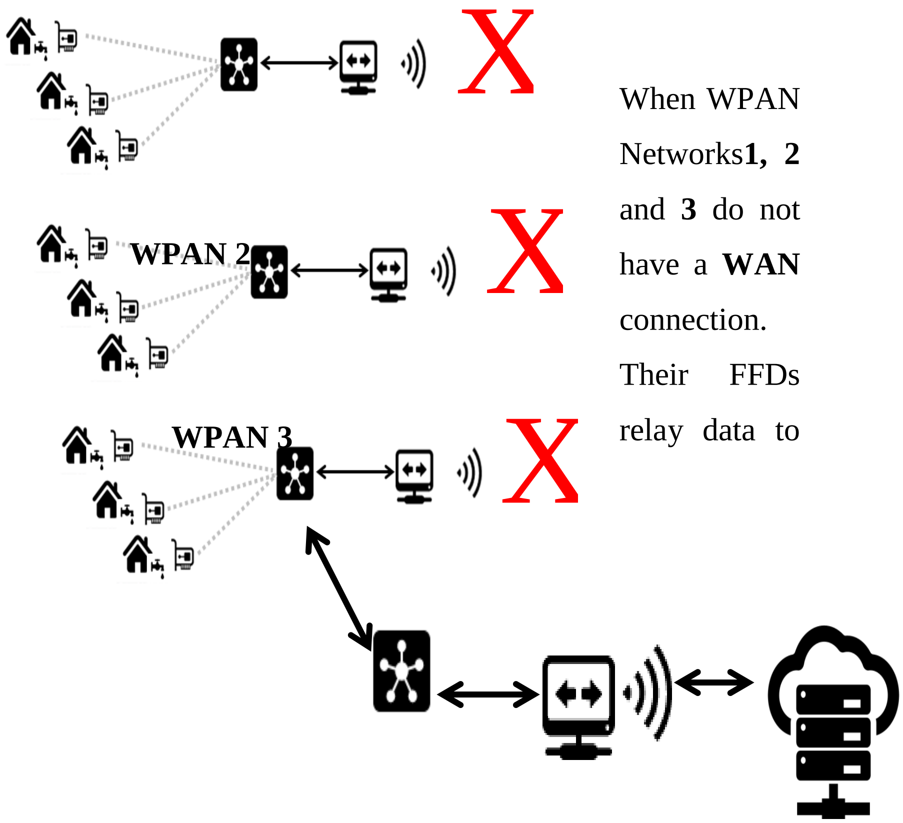

Figure 17: Multi-Path Connectivity in a Mesh Network Topology Environment.

To monitor water meter over the various water distribution points, each transfer point will be fitted with a FFD to enable backward compatibility to each other.

Water meter data analysis Software system

The software system to be developed will comprise of the following modules;

1. The data collection module – This module will interface with the data collection networks to be developed.
2. The data analysis module – This module will analyze the data collected and generate the following;
    a. Reports of the units consumed at the various meter readers for billing purposes.
    b. Reports of the water meter at various points in the water distribution network. These will be required for monitoring of water losses, pipe blockages and possible siphoning.
    c. Graphs of the network to enable the companies to detect devices that are not transmitting data or otherwise not on the network.

The data export module – This module will enable export of data to other systems that may require it for billing or for the development of applications that require it

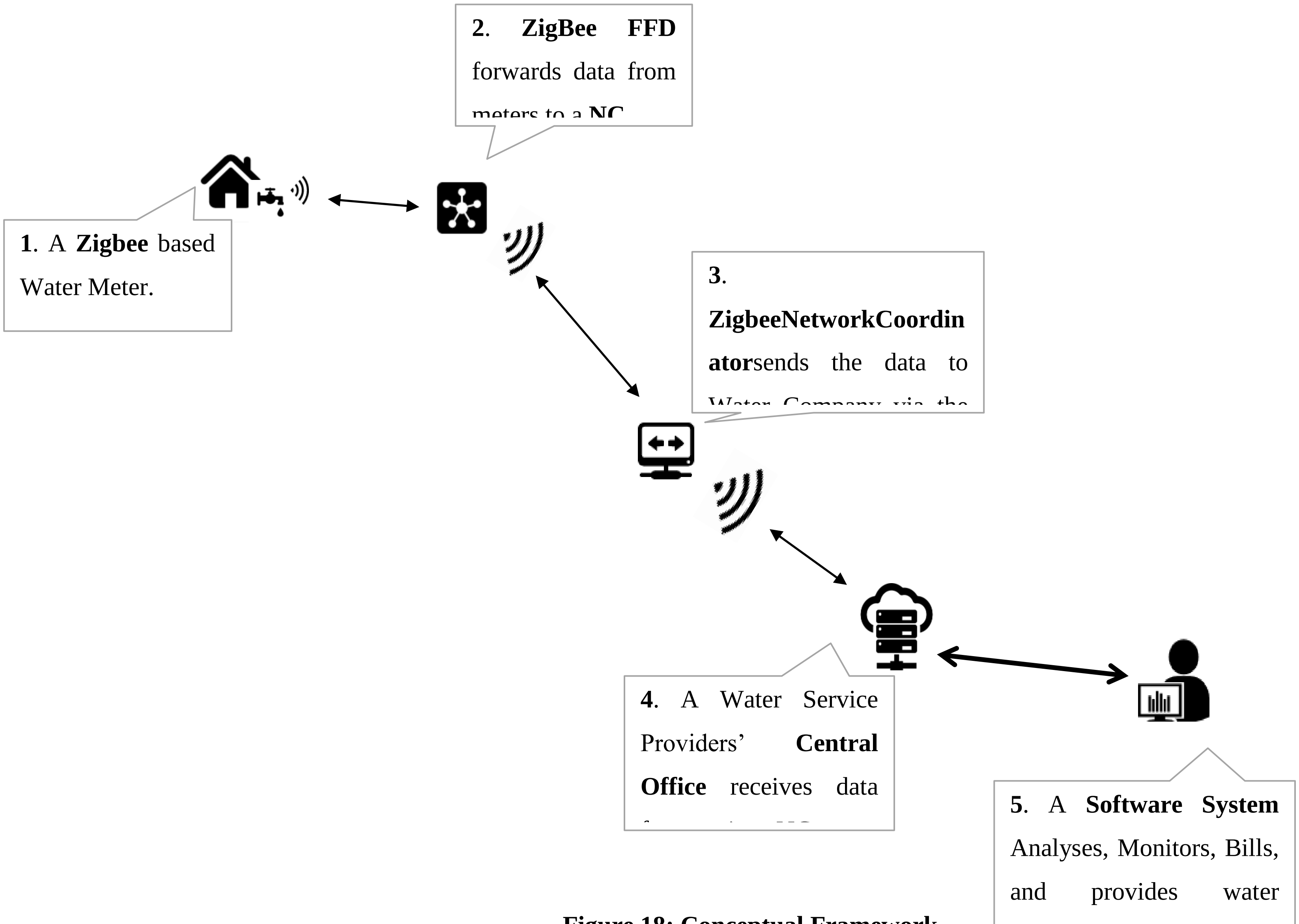

Figure 18: Conceptual Framework

2.9 Conclusion

This chapter presented a discussion on activity sensors, WPAN, mesh networks, 802.15.4 and Zigbee models. The theoretical and conceptual frameworks for the study were also be presented and discussed.

CHAPTER THREE
METHODOLOGY

3.0 Introduction

This chapter discussed the methods that were used in the network design and implementation of the scalable Zigbee model to create a Wireless Sensor Network.

3.1 PPDIOO Research Design

The research design chosen was Prepare, Plan, Design, Implement, Operate, and Optimize. PPDIOO methodology that defines the continuous life-cycle of services required for a network (Cisco, 2010). The prototype explicitly simulated a real life model of a WSN and remote data loggers. This methodology was ideal as it aided in lowering the total cost of network ownership, increasing network availability, improving business agility and speeding access to applications and services. Figure 19 describes the PPDIOO network design and implementation methodology.

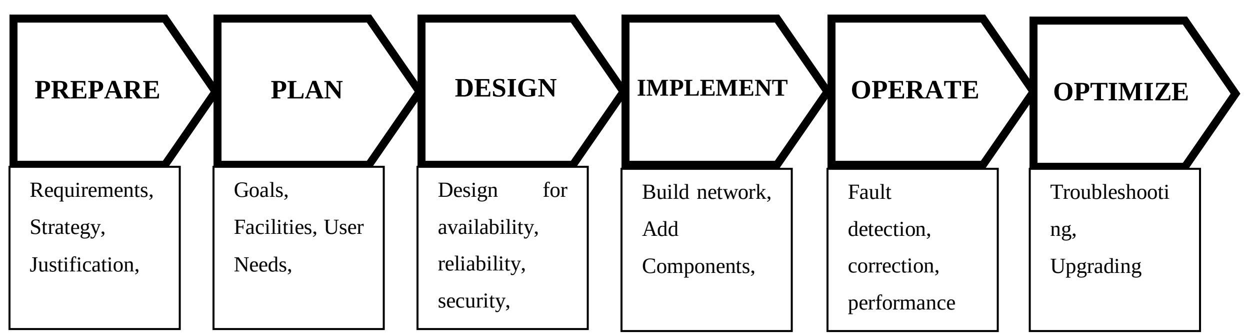

Figure 19: Prepare Plan, Design, Implement, Operate, and Optimize Network Design and Implementation methodology (Source: Cisco).

The prepare stage involved establishing network requirements, developing a network strategy, and proposing a high-level conceptual architecture. The prepare phase established a financial justification for network strategy by assessing the business case for the proposed architecture. The Planning stage involved identifying initial network requirements based on goals, facilities and user needed. It also involved characterizing sites and assessing any existing networks and performing a gap analysis to determine whether the existing system infrastructure, sites, and the operational environment had the ability to support the system. The design stage took the initial requirements that were derived in the planning phase to drive the activities of the network design specialists. The network design specification was a comprehensive detailed design that met current business and technical requirements, and incorporated specifications to support availability, reliability, security, scalability, and performance. The design specification was the basis for the implementation activities. During implement stage, the network was built or additional components were incorporated according to the design specifications. Operation is the final test of the appropriateness of the design. The operational phase involved maintaining network health through day-to-day operations, including maintaining high availability and reducing expenses. Fault detection, correction, and performance monitoring. The Optimize stage involved proactive management of the network. Troubleshooting was critical when proactive management cannot predict and mitigate failures. In the PPDIOO process, if performance does not meet expectations, new applications are identified to support organizational and technical requirements (Cisco 2010).

3.2 Model Location:

The zigbee prototype was be done under the auspices of Kabarak University and specifically the Library water meter point. Due to costs associated with acquisition of equipment, the prototype was limited to this site, from which remote connection and data collection was be carried out.

3.3 Model Design:

The design of a Zigbee WPAN network was be addressed using IANA licensed unicast global addresses of 2340:AEBF:3040::/48 network further subneted into the following sub-networks;

a) WSN Remote WPAN Subnet 1 - 2340:AEBF:3040:0000::/50
b) WSN Remote WPAN Subnet 2 - 2340:AEBF:3040:4000::/50
c) WSN Remote WPAN Subnet 3 - 2340:AEBF:3040:8000::/50
d) WAN Subnet 5 - 2340:AEBF:3040:C000::/50

3.4 Prototype Evaluation and Validation

After the model was designed and developed, the data propagation performance testing was carried out to evaluate data sets received from the end devices. To accomplish this, traffic was captured using NS2 and analyzed for validity and reliability. In order to validate the model, the prototype was tested using various tools. ICMP echo request was seek to test basic connectivity between the various sub-networks. The traceroute command verify multi-path ability to verify that Zigbee end devices are on a mesh network with varying paths to the coordinator. Multipaths ensure that the WPAN is self-healing. Packets can then be captured using wireshark and evaluated for various sets. Figure 20 below shows packets capture from wireshark.

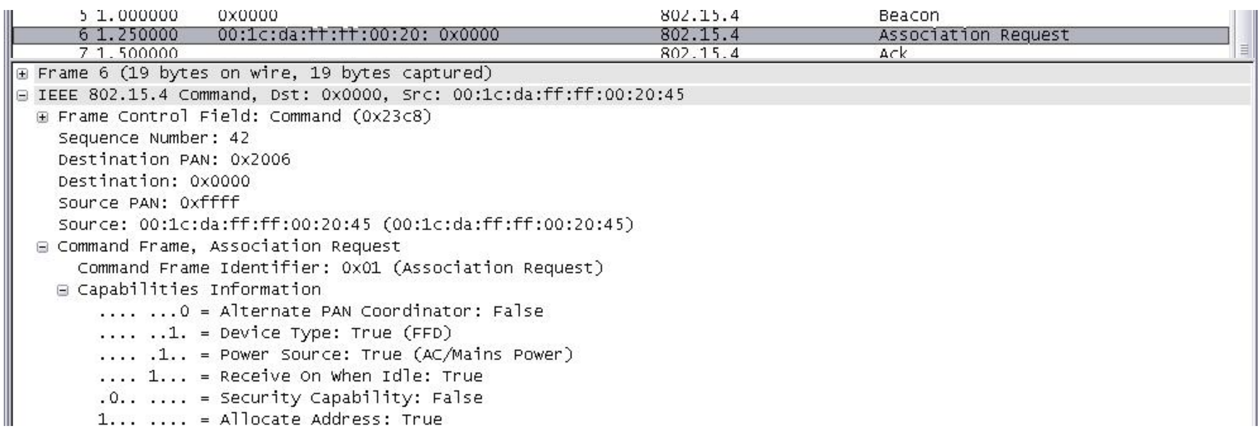

Figure 20: Packets capture from Wireshark (IEEE_802.15.4, 2015, August 26).)

3.5 Water Meter Data Analysis Software System

A software system consumed data collected from the zigbee network. The developed web based system comprised of the following modules;

1. The data collection module – This module interfaced with the data collection networks developed.
2. The data analysis module – This module analyzed the data collected and generated the following;
    a. Reports of the units consumed at the various meter readers for billing purposes.

b. Graphs of the network that enabled detection of devices that not transmitting data or otherwise not on the network.

3. The data export module – This module enabled export of data to other systems that may require it for billing or for the development of applications.

The figure 21 shows the various inter-relation between the software modules.

Figure 21: Water Meter Data Analysis Software Modules.

3.6 Software Development Methodology

The system was developed using Adaptive Software Development (ASD) process of Agile software development. The characteristic nature of ASD being mission focused, feature based, iterative, risk driven and most importantly change tolerant. The nature of the project was such that various components of the software would change and evolve thus a rapid and flexible development process like ASD was suitable. Figure 18 describes the use of Agile's Adaptive Software Development.

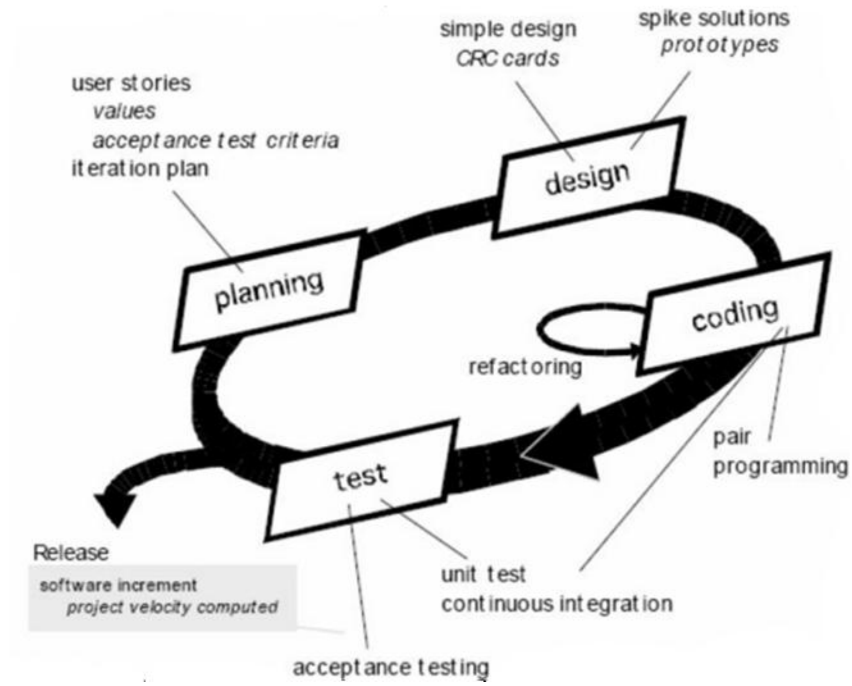

Figure22: Adaptive Software Development (Roger S. Pressman)

3.7 Conclusion

This chapter described the PPDIOO approach and methodology that guided the conduct of the study. The Agile's Adaptive Software Development approach was used in the development of the software system.

CHAPTER FOUR
PROTOTYPE DEVELOPMENT AND RESULTS

4.1 Introduction

This chapter discusses prototype development process, various water meter data sets, data collected results, model, system design, limitations, challenges, results of the evaluation of the Zigbee network.

4.1.1 Weaknesses of Existing Methods and Technologies in Water Data Collection

Existing water data collection methods include manual reading/inspection of water meters, GSM fitted meters, Bluetooth, wired Ethernet, onsite memory repository and 6LoWPAN. GSM with General packet radio service (GPRS) enable sim-cards produces a very expensive solution mainly aimed at corporate and factory clients. Bluetooth technology while very similar to zigbee consumes high amount of energy and power. 6LoWPAN lacks readily available devices and supporting peripherals to implement it while Ethernet based data collection methods are cumbersome and effort consuming solutions.

4.1.2 Weaknesses of Existing Methods and Technologies used by NAWASCO

The Nakuru Water and Sanitation Company has 35,128 customers. Water billing raw data collection process is tedious and error prone. Meter Readings are fed manually into an android phone application software – Meter Reader Pro 1.2.2. There are faults experienced as a result of manual reading and keying in thus necessitating manual inspection of transcripts by zonal chiefs so as to enable even further manual adjustments. The Table 1 below displays the various processes of data collection as per the interview with the Nakuru Water and Sanitation Company’s ICT Manager.

4.1.3 Weaknesses of Existing Methods and Technologies at Kabarak University

Kabarak University where the prototype was implemented has several water metering points across its water infrastructure, mainly being student’s hostels, administration block, kitchen, library, various schools and departments. However water administrators perform manual reading of water meters so as to establish amount of water consumed by every department. This process is manual, tedious and error prone. The borehole is also located 3 kilometers away adding to the taxing process of transport provision. This translates into the need for fuel consumption among other requirements. The prototype was thus set-up to particularly collect water flow data remotely at the library water meter outlet.

Table 1: Current Data Collection Methods by NAWASSCO

No	Process	In Charge	Number	Duration (days)	Totals Taken (days)
1	Physical Inspection of Meters	Field Agents	35	4	4
2	Submission of Entries	Field Agents	35	2	5
3	Inspection and Adjustment of Transcripts	Zonal Chiefs	5	7	12
4	Re-printing of adjusted transcripts	Zonal Chiefs	5	1	13
5	Final Approved Bills	Commercial Manager	1	1	15
Total Number of Days taken					**15**

4.2. Design of a Scalable Zigbee Mesh WPAN Prototype:

The design of the prototype followed the PPDIOO approach and methodology so as to help guide the conduct and suitability of the final product. Two Topologies (Topology 1 and Topology 2) were designed to evaluate the various ways a real life experiment would occur. For purposes of this project, Topology 1 was simulated extensively since the actual project would take this shape and design. Topology 1 thoroughly emulated the actual project and thus aided prepare and anticipate expectations of the live project. Data from Topology was further examined and reviewed.

4.2.1 Topology 1

A first prototype network was set-up to simulate direct forwarding of data from RFD 0 (First water meter) to Collector 1 (FFD 2 Coordinator) through the Collector (Internet gateway) without multi-hops. The figure 23 below shows the topology 1 design to which a commensurate script was written and compiled.

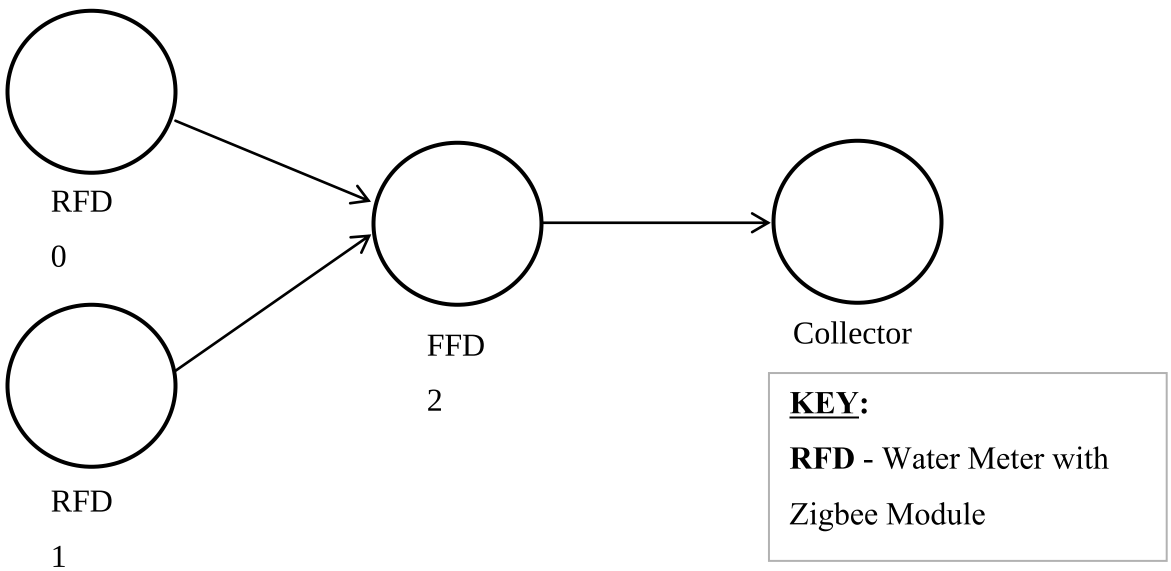

Figure 23: The Topology 1 Design for NS 2

4.2.2 Simulation Requirements

The simulation was set-up with two (2) RFD nodes, RFD 0 and RFD 1 under one FFD 2 and gateway router (Collector 1)that forwards data to the internet (NAWASCCO). The stub half-duplex link between 0-to-C1 and 1-to-C1 have 2 Mbps of bandwidth and 10 ms of delay. The stub between FFD2-Collector is a full-duplex connection with 20 ms of delay. RFD 0 is set up to use transport layer TCP protocol while RFD (1) uses User Datagram Protocol (UDP). The nodes transmit packets with 1KiloByte of data.10 instances of packet transfer are measured with 5 seconds of play.

4.2.3 Topology 2

The figure 24below shows the topology 2 design to which a commensurate script was written and compiled.

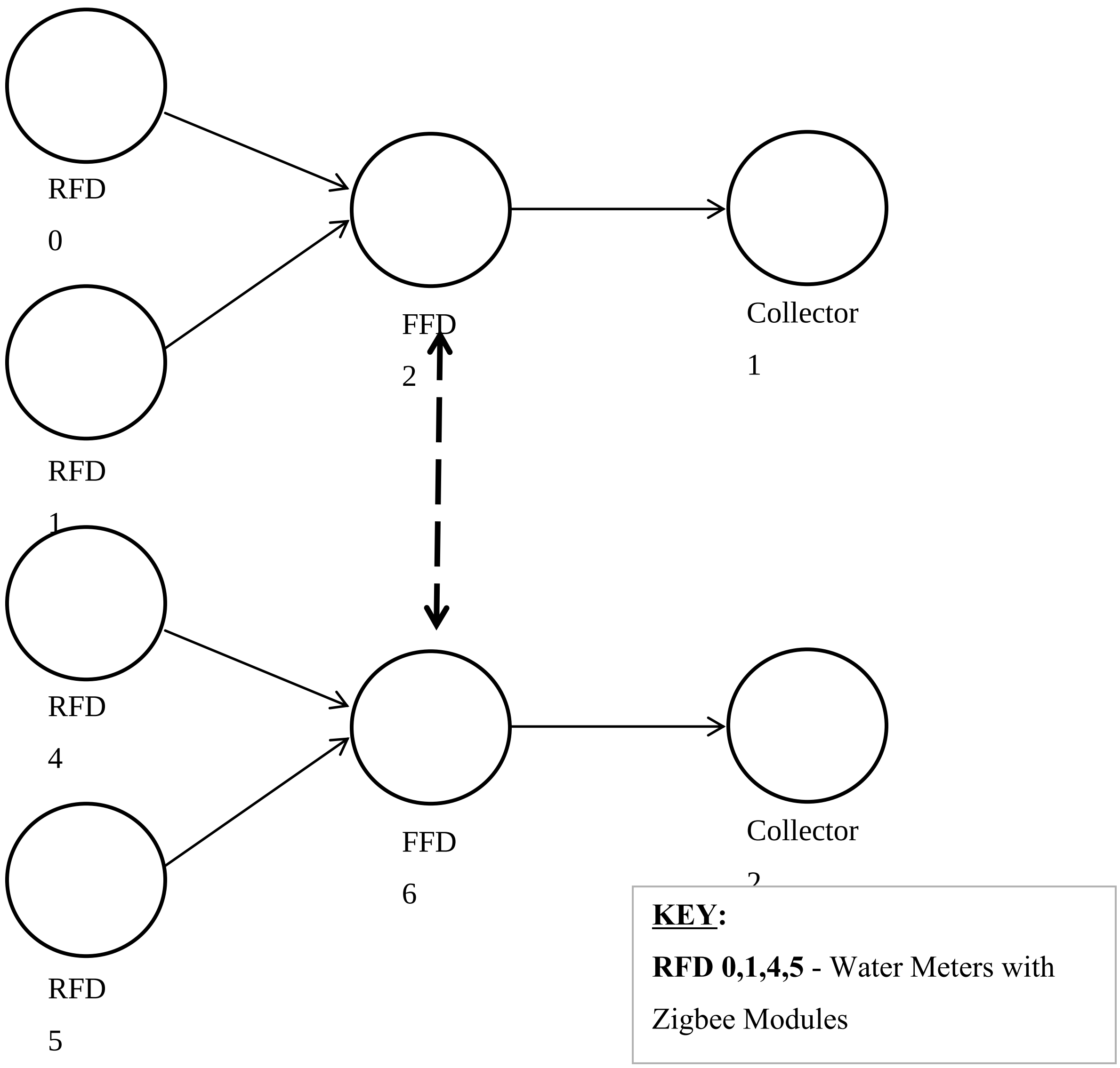

Figure 24: The Topology 2 Design for NS 2

4.2.4 Simulation Requirements

Using four (4) RFD nodes, Node 0 (A), Node 1 (B), Node 4 (C) and Node 5 (D) under two (2) FFDs and two (2) data collectors (Collector 1 and 2) that forwards data to the exit router (NAWASCCO). The stub half-duplex link between A-to-C1 and B-toC1 has 2 Mbps of bandwidth and 10 ms of delay. The stub between C1-to-NAWASCCO/Internet is a full-duplex connection with 20 ms of delay. Node 0 (A) is set up to use transport layer TCP protocol while Node (1) uses User Datagram Protocol (UDP). The nodes transmit packets with1KiloByte of data.10 instances of packet transfer are measured with 5 seconds of play. There is a full-duplex connection between FFD 2 and FFD6 to allow multi-path connectivity incase of downtime at C1 and/or C2 and vice versa.

4.2.5 Simulation Topology Implementation

A simulation script was set-up to define a network topology of four nodes, two RFDs and one FFD. The simulation was executed repeatedly for 5 seconds.

4.2.6 Simulation Script for the Topology 1

The Table 2 below shows the simulation script for topology 1.

Table 2: Simulation TCL Script

```
set ns [new Simulator]

set nf [open out.nam w]

$ns namtrace-all $nf

proc finish {} {

 global ns nf

 $ns flush-trace

  close $nf

  exec namout.nam&

 exit 0

}

set n0 [$ns node]
```

```
set n1 [$ns node]

set n2 [$ns node]

set n3 [$ns node]

$ns duplex-link $n0 $n2 2Mb 10ms DropTail

$ns duplex-link $n1 $n2 2Mb 10ms DropTail

$ns duplex-link $n2 $n3 2Mb 20ms DropTail

$ns duplex-link-op $n2 $n3 queuePos 0.5

set tcp [new Agent/TCP]

$ns attach-agent $n3 $sink

$ns connect $tcp $sink

$tcp set fid_ 1

set cbr [new Application/Traffic/CBR]

$cbr attach-agent $udp

$cbr set type_ CBR

$cbr set packet_size_ 1000

$cbr set rate_ 1mb

$tcp set class_ 2

$ns attach-agent $n0 $tcp

set sink [new Agent/TCPSink]

$cbr set random_ false

$ns at 0.1 “$cbr start”
```

```
$ns at 5.1 "$cbr stop"

$ns at 5.1 "$ns detach-agent $n0 $tcp ; $ns detach-agent $n3 $sink"

$ns at 5.0 "finish"

puts "CBR packet size = [$cbr set packet_size_]"

puts "CBR interval = [$cbr set interval_]"
```

While other technologies depend on a peer-to-peer connection between source and destination, the Zigbee protocol enable several devices (up to 300 for this prototype) to connect within one WPAN. The simulation was proved to show ability of several zigbee devices connecting to send packets via a single coordinator and consequently via a single gateway. The Figure 25 below shows Topology 1 on Network Simulator 2 (NS2) on Ubuntu Linux prior to packet propagation between the stub links. Zigbee meters (RFD 0 and RFD 1) form a WPAN coordinated by a Zigbee Coordinator (FFD 2) and consequently forward packets via internet gateway (3).

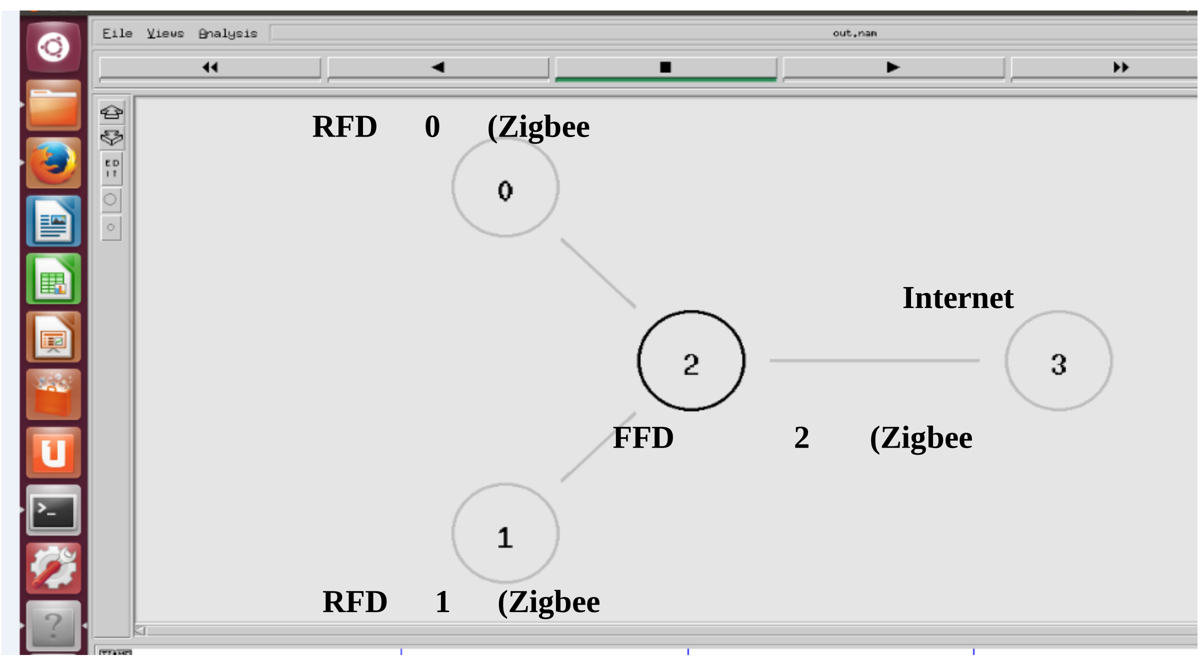

Figure 25: Network Topology 1 on NS 2 with all devices forming a WPAN

The Figure 26below shows the Topology 1 on Network Simulator 2 (NS2) on Ubuntu Linux with data packets coming only from one device RFD 1 to Collector only.

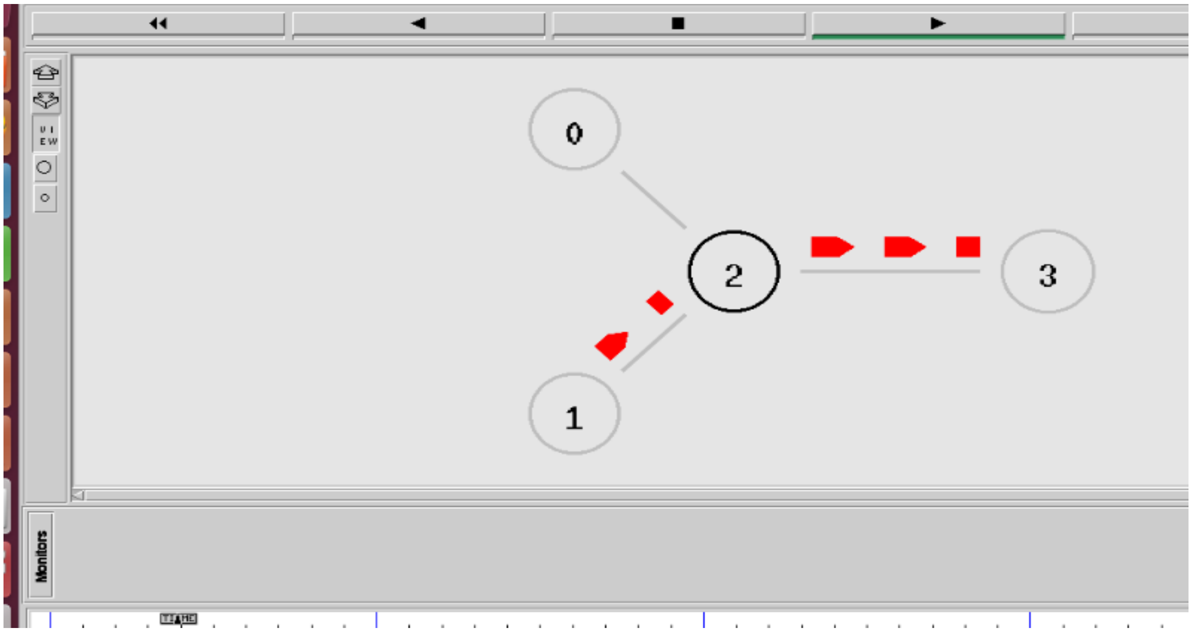

Figure 26: Network Topology 1 on NS 2 with Single Node Propagation.

The Zigbee network on Topology 1 allowed propagation of multiple devices concurrently within a single network. The Figure 27 below shows data packets from both RFD 0 and RFD 1 sending to the Collector and consequently to the Internet gateway.

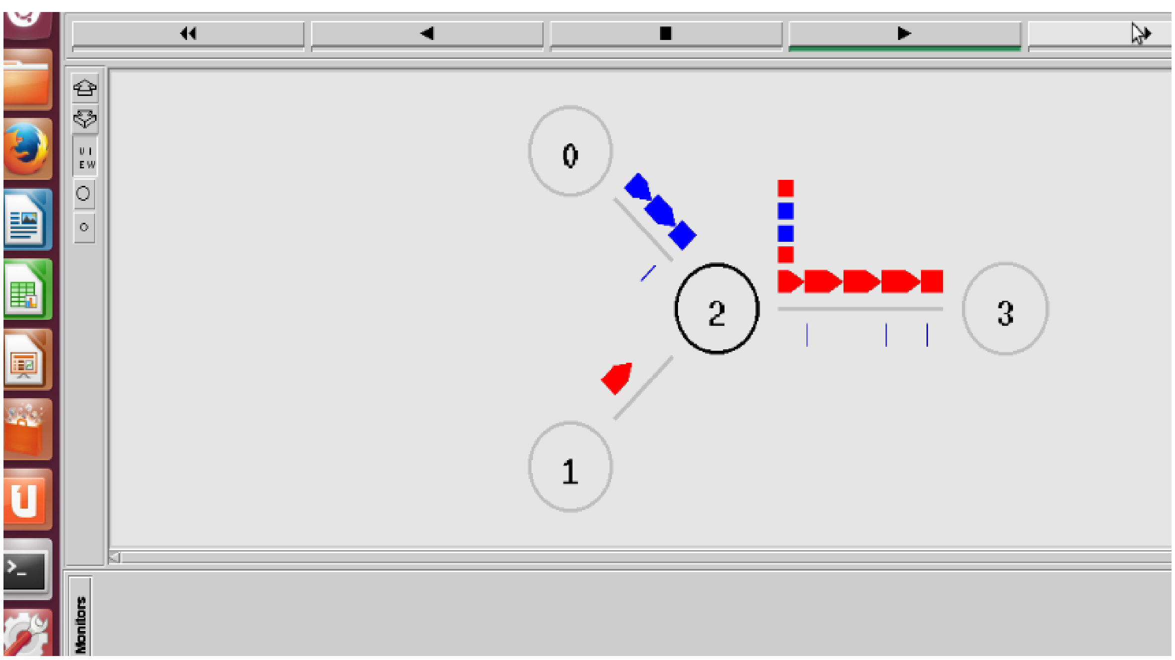

Figure 27: Network Topology on NS 2 with all nodes propagating.

4.3 Performance Evaluation of the Simulated Zigbee Network

The table 3 below displays the data sets captured from the topologies. 10 entries were captured from every node in a period of 5 seconds.

4.3.1 Comparative Analysis of Transmission Time

Analysis was computed that was showing a comparative analysis of transmission time as shown in table 3

Table 3: Various Data Sets from Varying Connections

Statement	N	Mean	Latency
i)Packets travel time From RFD 0 to Collector (Topology 1)	10	1.8000	.78881
ii)Average time by RFD 1&2to Collector 1 (Topology 1)	10	2.0000	.81650
iii)Average time in A/B via Collector 2 when Collector 1(Topology 2)	10	16.4000	1.77639

From the findings from Topology 1 the average time taken by RFD 0 takes to send packets via collector 1 to the internet gateway router is 1.8 *ms* with a latency of 0.788. Similarly, the average time taken by the two zigbee devices RFD 0 and RFD 1 via collector 1 to to the internet gateway router is 2.0*ms* with latency of 0.816**.**Similar simulation was carried out to demonstrate the behavior of data delivery via a back-up collector so as to emulate multi-hope capability in Topology 2.The average time was 16.4 *ms* with a latency of 1.77 Finally, Average time taken by the two zigbee devices RFD 0 and RFD 1 via a secondary collector when the primary collector internet router lacks connectivity, the average time taken was 19.30*ms* with a latency of 0.80

In comparison with Table 1 shown previously, there is a great disparity on the time taken to collect data using current manual methods as opposed to the zigbee technology based method. The turnaround time between normal to zigbee is a ratio of 1:77760000 seconds.

4.3.2 Comparative Analysis in the Connection Types

The Figure 28, a bar graph below show the transmission time taken by the RFDs in transmitting data to the internet gateway.

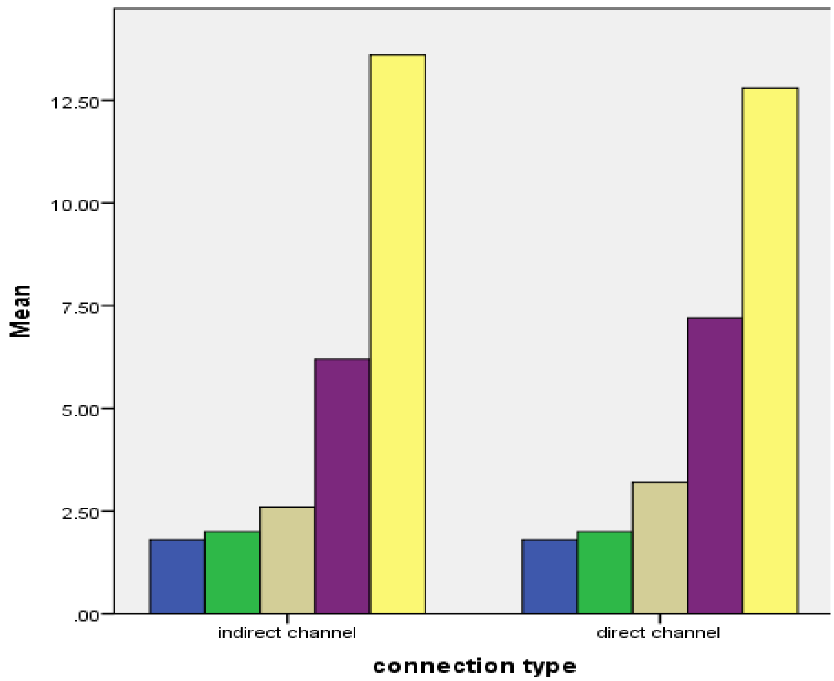

Figure 28: Connection Comparison on Direct and Multi-Hop Topology 2

The simulation results indicated above show that data can be sent by RFD 0 to the internet gateway with minimum transmission time when it is via direct channel (1.8 *ms*). When data is sent through a subsidiary collector i.e collector 2 its transmission time increases (14.9 *ms*)

4.3.3 Average Comparison in Latency in Data Transmission

The figure 29 below shows mean transmission time of packets by the nodes under varying conditions: Direct versus multi-hop channel and without channel interference.

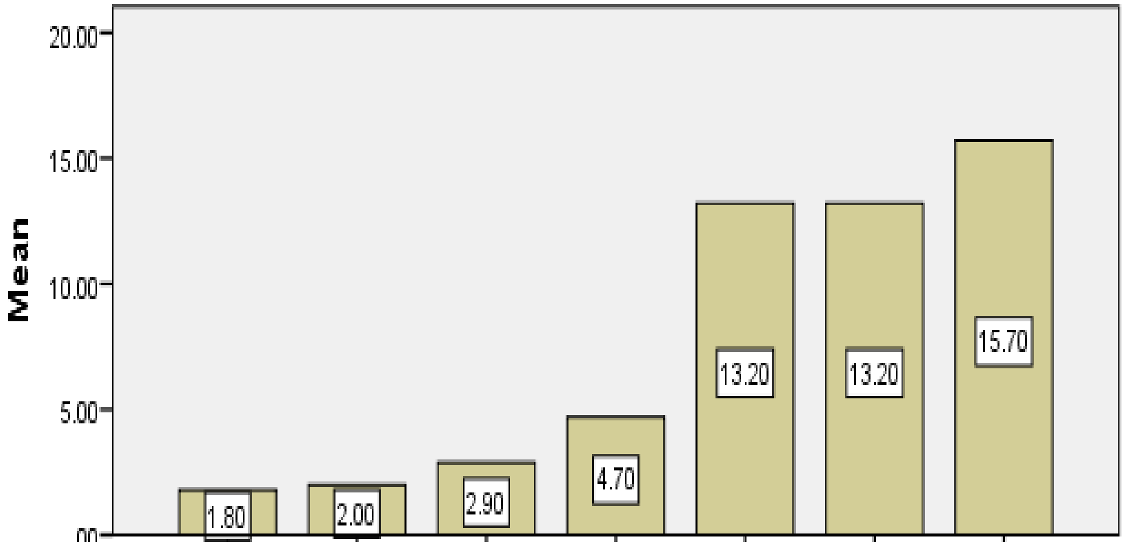

Figure 29: Mean Transmission Time of Packets

It was noted that the time taken by RFD 0 to transmit data directly to the first internet gateway using Collector 1 is 1.807 *ms*. In indirect channeling the time taken by the same RFD 1 via collector 2 to Node3 is 2.90 *ms* without interference.

4.3.4 Average Time Taken by A/B/C via Direct Channel

The figure 30 below shows average time taken by RFD 0 to send packets via direct channel.

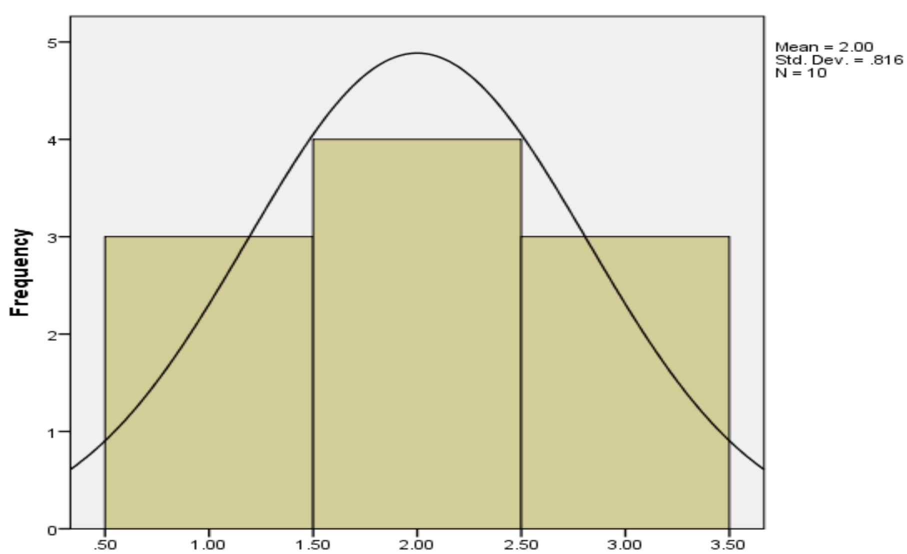

Figure: 30: Transmission time in Direct Channel from RFD 0 to Internet Gateway

From the results above, with 10 simulations transmitted, the transmission time of 2.*0ms* had the highest frequency of 5.Simulations that was considered as outliers included those that yielded 0.5 *ms* and 3.5 *ms* transmission time with a minimum frequency of 1

4.3.5 Average Time Taken via Multi-Hop

The figure 31below shows the average time taken by two RFD 0 and RFD 1 via multi-hops on collector 2 to the internet gateway.

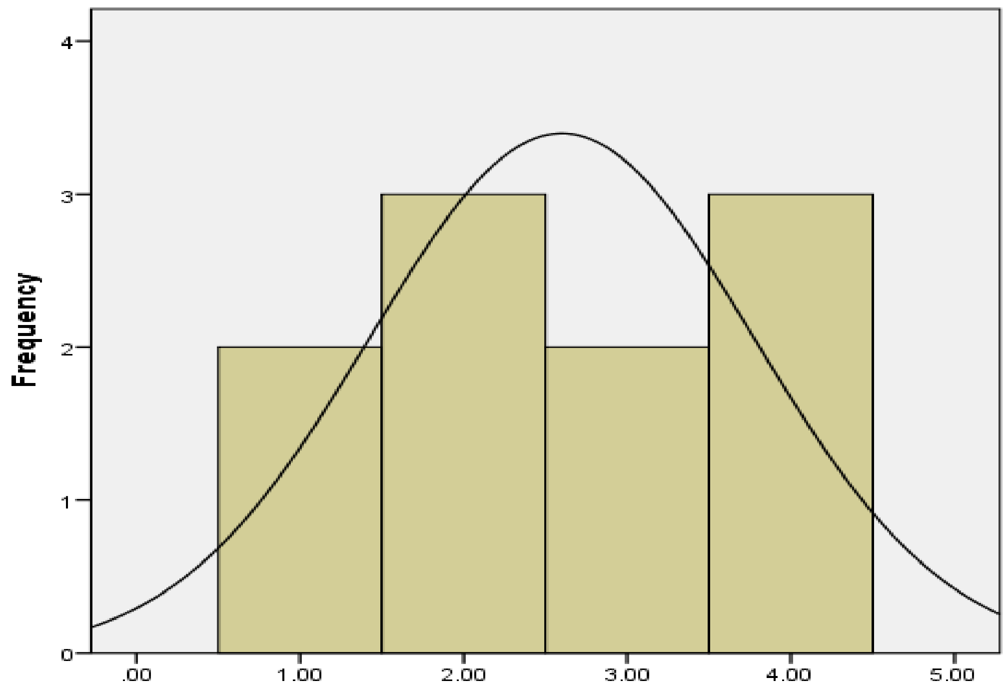

Figure: 31: Data Transmission Time via Single Hop On Topology 1

The figure above shows the average time taken by two RFD 0 and RFD 1via a multi-hop on collector 2 to the internet gateway. It was noted that out of 10 simulations, the maximum transmission time was 2.60 *ms* with highest frequency of3.5.However,there was two outliers who had 1.0ms and 4.0ms with frequencies of 2 and 3 respectively.

4.3.6 The Relationship between Channel Type and Time Taken for Transmission of Data

The study attempted to find out the relationship direct connection and time taken for transmission of data. The results are tabulated as shown below:

Table 3: The relationship between direct connection & time taken for transmission of data

		Time taken in RFD 0 via collector1 to Gateway
Direct channel	Pearson Correlation	-.408
	Sig. (2-tailed)	.000
	N	10

The findings of the analyzed data indicated that there exist a weak negative and statistically Significant relationship between direct channel and Time taken in by RFD 0 via collector1 to Node3 ($r=-0.408$; $p<0.05$).In other words, when meter readings are sent directly to Node3 via A direct channel the time to be taken reduces.

4.3.7 The Relationship between Channel type and Time Taken for Transmission of Data

The study attempted to find out the relationship between multi-hop connection and time taken for transmission of data. The results are tabulated as shown below:

Table 4: The Relationship between Multi-Hop and Time Taken for Transmission of Data

		Time taken by RFD 0 via collector 2 to internet
Indirect channel	Pearson Correlation	.134
	Sig. (2-tailed)	.000
	N	10

The findings indicated that there exist a positive and statistically significant relationship between the number of multi-hops and time taken by node A via collector 2 to Node3 ($r=0.134$; $p<0.05$). Interpretively, as the data is transmitted through consequent multi-hops, the transmission time taken will considerably increase.

4.4 Equipment for the Set-up

The project network design involved setting up of a live water meter within Kabarak University and particularly at the library water meter point, in promiscuous mode so as to avoid interference with legacy meter reading set-up. The project was based on the conceptual framework design achieved using the PPDIO network design methodology.

Modbus is an open, serial communication protocol that supports a Master-to-Slave connection for serial communication. It mostly uses RS-232 or RS-485 serial cable communication. It is a widely accepted protocol due to its ease of use and reliability. Modbus RTU is the most common implementation available for Modbus and as thus was best for this project implementation. Modbus RTU for serial communication was thus used to make use of a compact, binary representation of the water pulse data for protocol communication. In this case it was best for converting Water Meter Pulses to (Modbus) Messages.

The RTU modbus arrangement allows for data with a cyclic redundancy check checksum as an error check mechanism to ensure the reliability of data. The Modbus message was transmitted continuously without inter-character hesitations with messages frame delimiters separated by idle silent discrete phases.

The flow process describes actual transmission of data in the figure 32 show below.

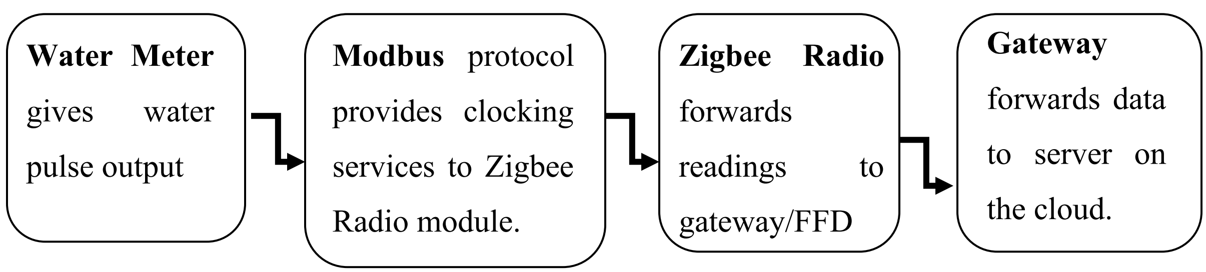

Figure 32: Water Pulse Reading from Meter to Cloud.

4.4.1Implementation of a Scalable Zigbee live Set-Up

Connection management between the modbus and zigbee radio was propagated using RS-485 Modbus interface for devices. Modbus modules had 12 pulse counting registers which were used to read and reset. The Modbus RTU unit supports 3 configuration modes for inputs. The configuration of the input pulse conversions and the modbus settings are done manually and configuration built-in pre installation. While the units meter pulse counter modbus communication speed is selectable, a clock rate of 9600 was set. The table 5 below shows object types provided by a modbus slave device to a modbus master device

Table 5: Object Types supported by Modbus Protocol.

Object Type	Access	Size
Coil	Read-Write	1-bit
Discrete Input	Read-Only	1-bit
Input Register	Read-Only	16-bits
Holding Register	Read-Write	16-bits

The figure 33 shows GSM fitted gateway router

Figure 33Gateway Router fitted with Zigbee Radio module and GSM gateway

The figure 34 below shows the water meter fitted with a modbus transmission

Figure 34: Water Meter with a Modbus Protocol transmission

The modbus connection integrated with a low power radio frequency module to the water meter via RS-485. The zigbee module is specifically chosen as a Reduced Function Device. This meant that the RFD would only operate on selected IEEE 802.15.4 MAC layers, thus enabling low power consumption and also since it demands energy only while transmitting data. The RFD was then connected to a router or gateway. The RFD however has ability to join a mesh network of more than 65,000 nodes. However in this study, the recommended network size is 200 so as to allow efficient propagation of data to the cloud. Therefore, this particular ZigBee architecture was designed so that RFD takes very short transmission time to propagate data. The primary functions of the zigbee module was;

a) To joins or leave a network
b) Transfer water data to the gateway.

The figure 35 below illustrates Gateway router interfaces-GSM AND RF interfaces

Figure35: Gateway Router Interfaces-GSM and RF Interfaces

The figure 36describes the flow chart that describes capture of data from the water meter to the zigbee radio module.

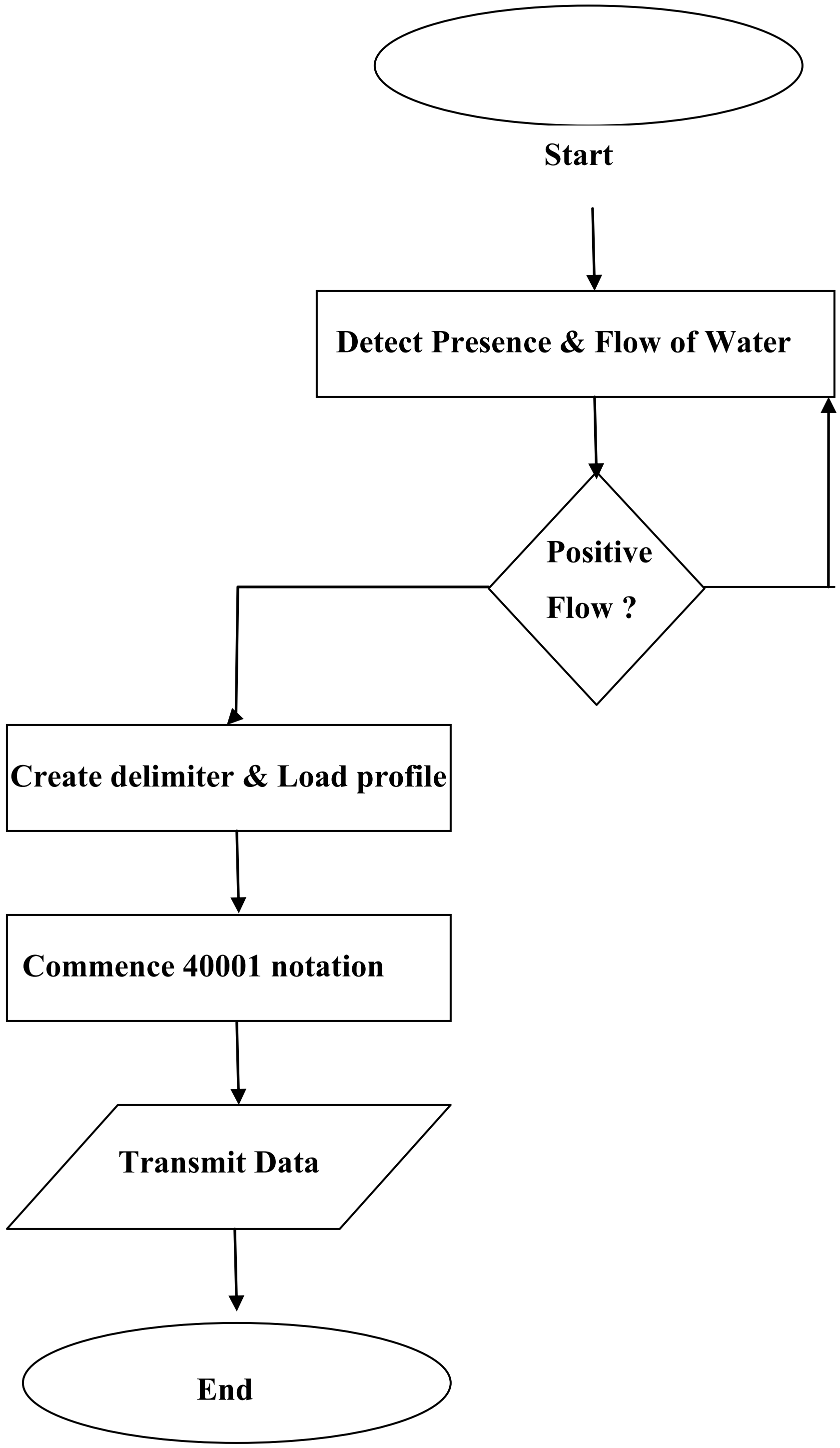

Figure 36: Water flow Data Propagation Flow Chart.

Data is then received by the zigbee radio module which is in turn forwards the data to a Zigbee gateway. A scalable mesh network supporting other zigbee RFD within its radius can be supported.

4.4.2 Zigbee Device Specifications.

The Zigbee module used supports inbuilt mesh network for hopping of data. The interfaces supported for integration of are as follows;

a) A PWM / Pulse input using RS 485 for 4-20 mA interface.
b) Proximity scan interface sensor / pulses measure the water flow and generates the metering data.

The RFD zigbee device module had a primary task of converting the data into logical meter reading while ensuring errors were finished by use of cyclic redundancy checks that enabled reliability of data. The RFD consequently transfers the data on wireless zigbee RF to the gateway. The gateway is strategically placed within radius so as to collect packets from the RFD. The gateway is a Fully Functional Device thus it has ability to form a network and also assign addresses to devices joining its network. Data collected from the RFD and by extension water meters would then be forwarded to the cloud. GSM was found to be the most fitting connection model for this project due to its ease of use.

The table 6 describes the technical specifications of the zigbee module.

Table 6: Zigbee Module Specifications

No	Item	Specifications
1	Frequency	433 / 868 / 915 865-867MHZ
2	Transmit power	16 (3 to 16 dBm)
3	RF data date	200 kbps
4	Baud rate	11,500 baud
5	On-board antenna	Whip Antenna
6	Communication range	> 1 Km (LOS)> 80 mtrs
7	Supply voltage	3.3 - 5 V DC
8	Supported topologies	Mesh
9	RF standard	IEEE 802.15.4g
10	Interface options	UART / TTL / RS485
11	Interface Connector	SMD soldered / Berg

The figure 37depicts the architecture of a zigbee reduced function device.

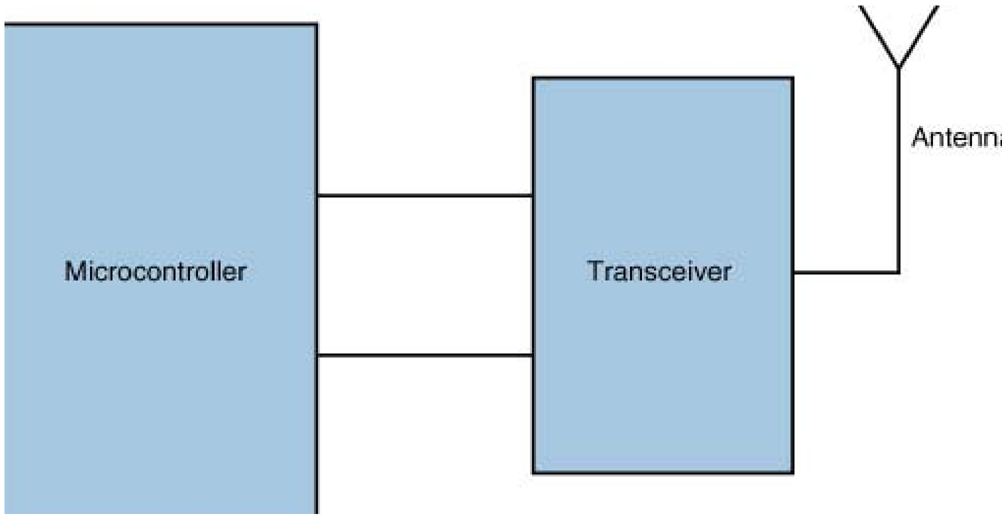

Figure 37: A Zigbee Reduced Function Device Architecture

4.4.3.Zigbee Module Modes of Operation

The zigbee module normally operates in four modes, namely;

a) Transmit Mode.
b) Receive Mode.
c) Sleep Mode.
d) Command Mode.

The zigbee module will always remain in idle mode if there's neither data to transmit nor none to receive as well. While in this state, the zigbee module normally checks for data intermittently. The module normally changes from idle to transmit mode, immediately it receives discrete data for packetization. Before transmission, the module will check to ensure that the paths to the destination and the 16-bit network address have been identified and mapped. In occasions where the address is neither identified nor mapped, a dynamic search begins until when the address cannot be mapped, it is then dropped. Zigbee uses a reliable transport mechanism to ensure data is delivered through acknowledgements. If an acknowledgement is not received commensurate to data sent, the zigbee device resends the data packet.

4.5Performance Evaluation of The Zigbee Model

The zigbee network successfully propagated water flow data from the water meter via gateway for the period of the test done Monday 10th October, Tuesday 11th October and Wednesday 12th October 2016.

Water flow data collected was propagated in the process shown in the figure 38below;

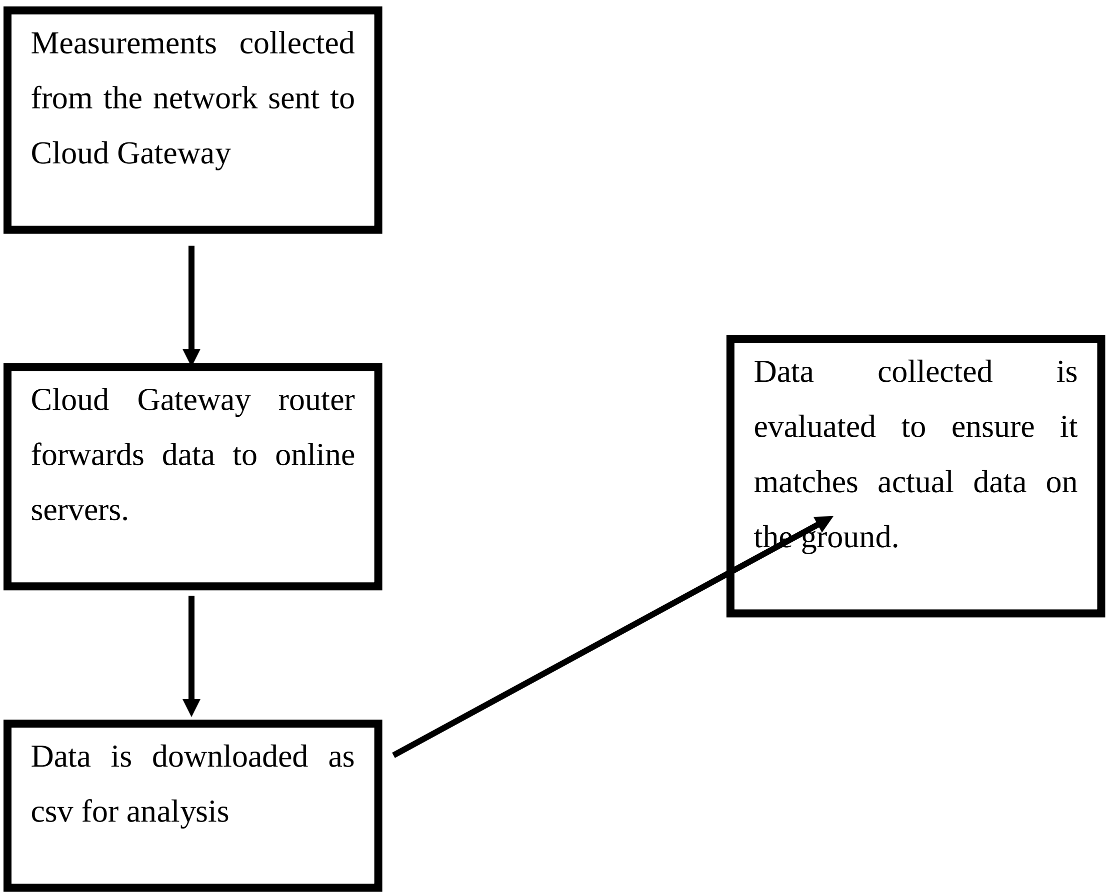

Figure 38: Data Collection and Evaluation Loop

4.5.1 Conclusion on Data Collection

The zigbee network successfully collected and propagated data from the water meter and this data was received instantaneously within periods of 1 second. This data was accessed from the cloud solution provider servers. The information was delivered via a web portal http://greenlightt.monitormymeter.com/Control/Index/historyDataView

4.5.2 Water Flow Data Captured by Data Transmission per Period

The data was then downloaded in .csv and further imported into a Microsoft Excel spreadsheet where evaluation was performed. From the recordings shown, the meter recorded water flow data for the periods as shown below in figure 39 and figure 40 below;

#Name	Date time	Water flow (Liters)		
Meter 1	10/10/2016 14:18	34657.37		
Meter 1	10/10/2016 14:17	34651.96		
Meter 1	10/10/2016 14:16	34646.54		
Meter 1	10/10/2016 14:15	34641.13		
Meter 1	10/10/2016 14:14	34635.71		
Meter 1	10/10/2016 14:13	34630.30		
Meter 1	10/10/2016 14:12	34624.88		
Meter 1	10/10/2016 14:11	34619.47		
Meter 1	10/10/2016 14:10	34614.05		
Meter 1	10/10/2016 14:09	34608.64		
Meter 1	10/10/2016 14:08	34603.22		
Meter 1	10/10/2016 14:07	34597.88		
Meter 1	10/10/2016 14:06	34592.25		
Meter 1	10/10/2016 14:05	34587.05		

Figure 39: Data Recordings Monday 11th October 2016

#Name	Date time	Water flow (Liters)		
Meter 1	11/10/2016 10:39	35092.09		
Meter 1	11/10/2016 10:38	35085.18		
Meter 1	11/10/2016 10:37	35078.27		
Meter 1	11/10/2016 10:36	35071.36		
Meter 1	11/10/2016 10:35	35064.45		
Meter 1	11/10/2016 10:34	35057.54		
Meter 1	11/10/2016 10:33	35050.63		
Meter 1	11/10/2016 10:32	35043.72		
Meter 1	11/10/2016 10:31	35036.81		
Meter 1	11/10/2016 10:30	35029.90		
Meter 1	11/10/2016 10:29	35022.99		
Meter 1	11/10/2016 10:28	35016.08		
Meter 1	11/10/2016 10:27	35009.17		
Meter 1	11/10/2016 10:26	35002.26		

Figure 40: Data Recordings Tuesday 12th October 2016

4.6 Data Collection and Monitoring

Data from the cloud server downloaded into csv and imported into a web-based system for purposes of providing more comprehensive reports. The imported water meter data is accessed and viewed from the web portal address below for purposes of providing more comprehensive reports;

www.kirori.me.ke

A web based system was chosen as the best case application that allows access of data from any form of computing device – PC, mobile devices with a simple data connection.

Users are required to log-in into the system and view records that match their records as shown in the figure41below. This also enables global access without the need for desktop applications other than a browser.

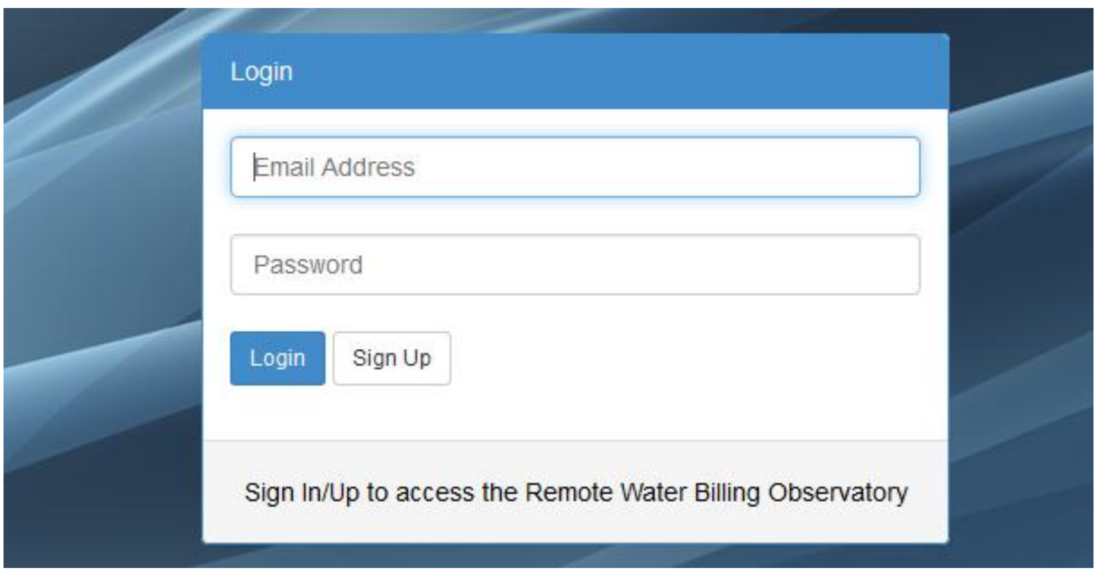

Figure 41: Log-In to the Online Water Billing Observatory

Users who have not logged-in to the system would be required to do a simple registration as shown in the figure 42 below

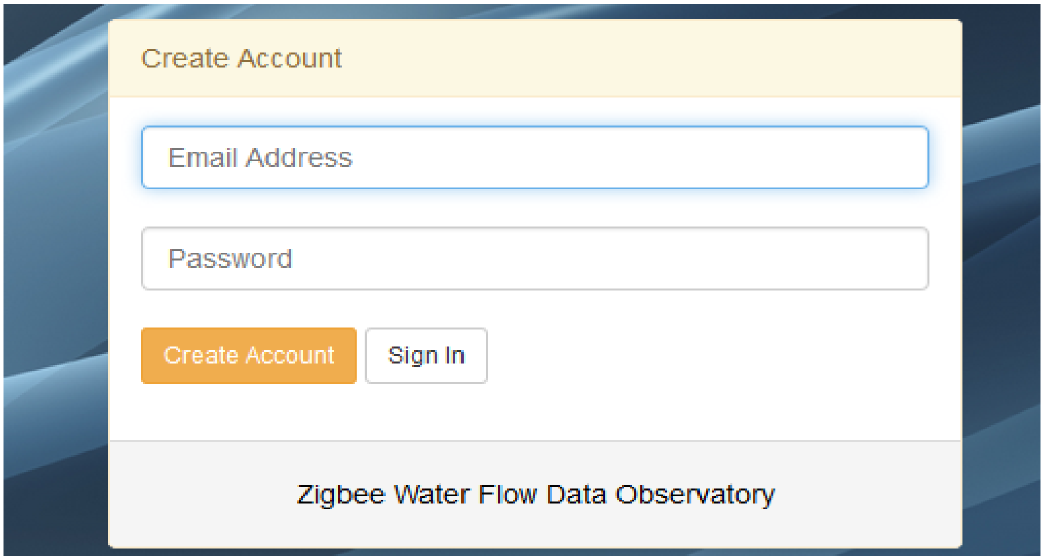

Figure 42: Account Creation Interface

The portal allows users to view the following critical aspects of the project;

i) Choose/Select particular water meter to view its water flow data.

ii) Access account history so as to view water flow data over a period of time.

iii) View general water flow data reports

The figure 31, 32 and 33 below displays the sequence of events that a user will meet while accessing the online system.

On successful access, the user will view an array of connected devices within the zigbee mesh network as shown in figure 43 below.

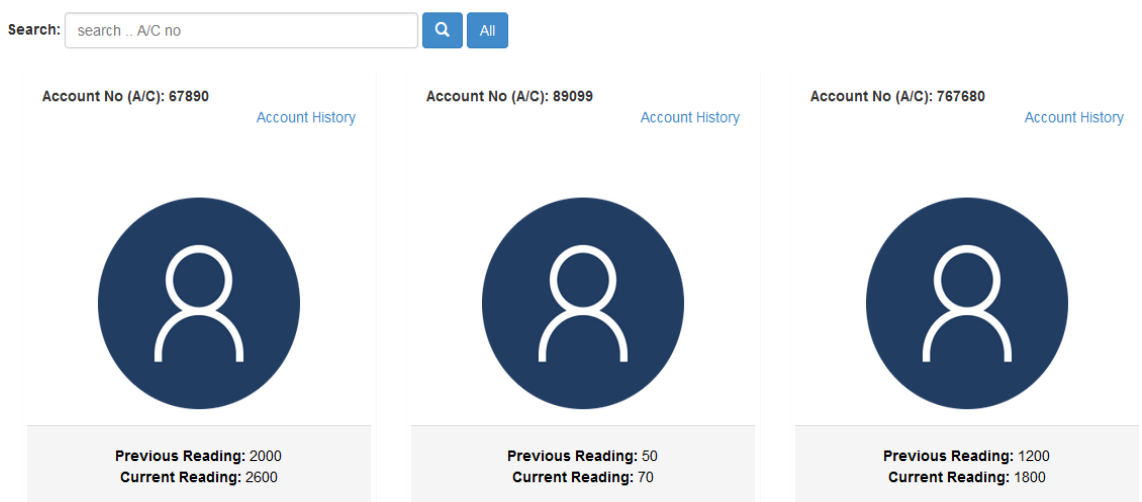

Figure 43: Available Devices in the Zigbee Mesh Network

The user can view truncated readings, current and previous as well as search for water meter by entering it's values on the search engine. Further water flow data history records and details can be accessed from the Account history. This has the following meter data; Date records are received, Account No, Meter No, Previous meter Reading, Current meter Reading, total Consumption for the period, Morning Reading and Evening Reading, Today (current day of access), current Week, current Month and Year.

Further, the datasets downloaded as .csv from the online portal was imported into a Microsoft Excel spreadsheet and consequently graphs were derived from the recordings below. The graphs derived describe various water flow data sets collected by the network as shown in figure 44below.

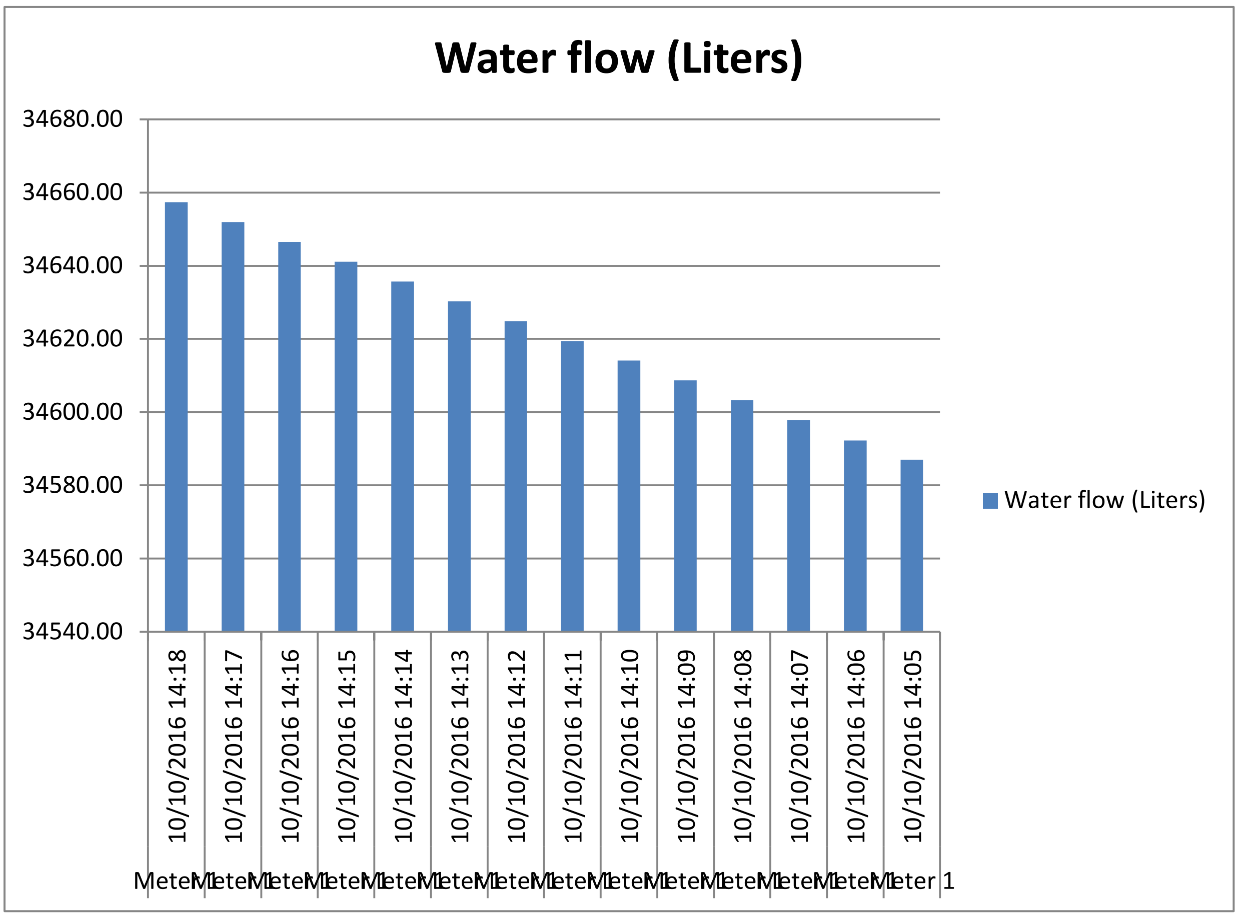

Figure 44: Graphical Description of Water Flow 10th October.

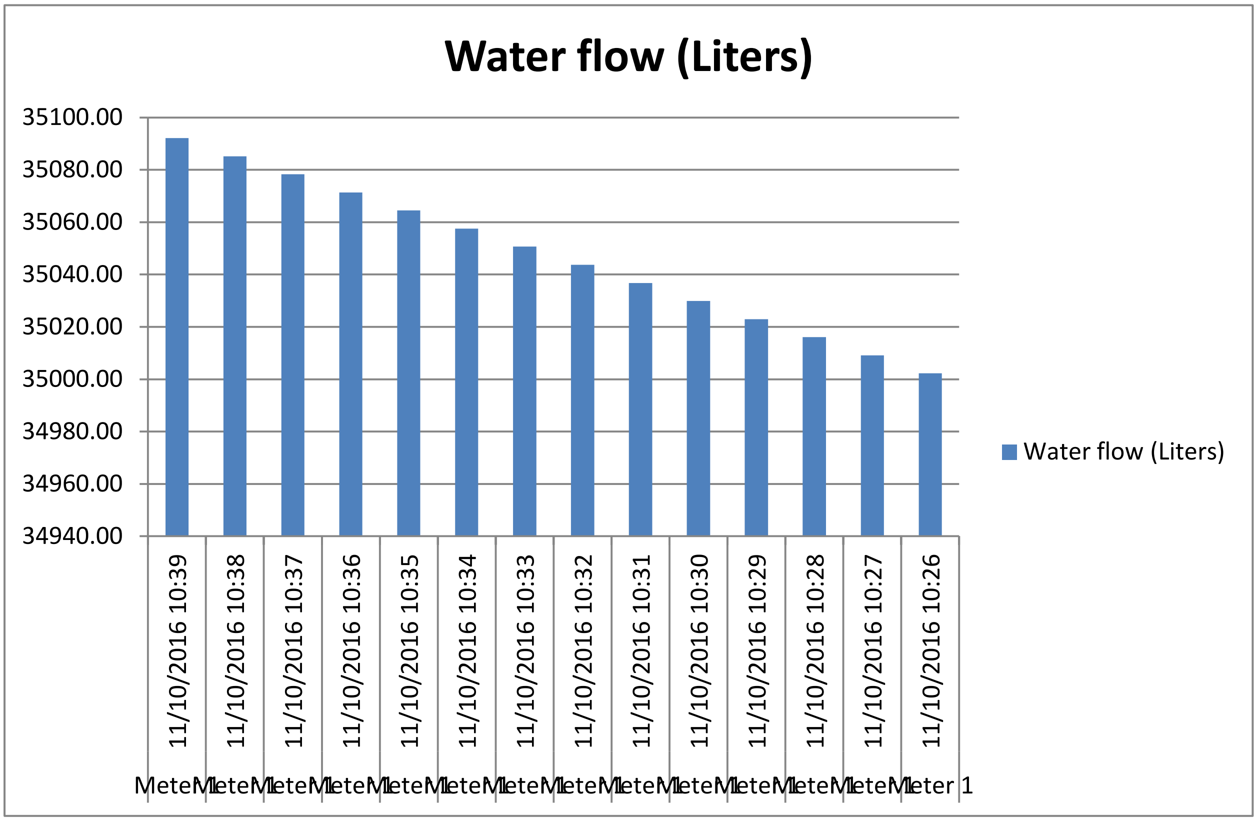

Figure 45: Graphical Description of Water Flow 11th October.

The .csv datasets were further archived as SQL databases for further flexible storage and manipulation. A mySQL database was used due to its ability to provide ACID (atomic, consistent, isolated, durable) transaction support, high-performance and most importantly tremendously fast data insert capability.

CHAPTER FIVE
CONCLUSIONS AND RECOMMENDATIONS

5.0 Introduction

This chapter provides conclusion and recommendations on the research on Zigbee networks that involved a model development, prototype development, actual physical set-up and final results of the overall program. It also provides further areas of study.

5.1 Conclusion

This study was guided by the inadequacies and weaknesses of manual collection of water flow data within various water and sanitation companies in Kenya. While there has been an attempt to implement technological solutions for harnessing of water data from clients residences, these technologies have their own challenges as well. The study revealed that Zigbee based networks are yet to be implemented in the light of their glaring advantages over competing technologies.

To achieve a conclusive comparison study, a scalable zigbee water meter network was setup and data logged from the prototype in real time. In addition, data was successfully populated and analyzed and proved further that this technology is a viable solution. There is considerable and invaluable contribution towards error-free, timely, efficient collection of water flow data remotely using a zigbee network. It is imperative that the study is scaled further to enable various water service utilities implement this technology based billing. There were logistical and bureaucratic hurdles were faced as well as challenges in accessing requisite devices. There is also need to further investigate security mechanisms for better confidentiality, authentication and availability of the zigbee system.

5.2 Established Weaknesses of Existing Methods and Technologies in Collecting and Harnessing Data from Water Meters?

The study established that there numerous bottlenecks and inefficiencies in the use of current methods of data collection through use of field agents. Corruption, human errors during meter reading are generally experienced instances of meddling with water meters was also experienced. Furthermore the billing process took too long.

This scenario does necessitate the use of technology so as to have a reliable, cost-effective and efficient way of water flow data collection.

For this experiment, the first Topology design was used as it would effectively meet objectives of the study as well as propagate data in accordance to set criteria.

5.3 Design of a Scalable Zigbee WPAN Model for Remote Water Meter Reading

The PPDIO model was used to design the zigbee wireless personal area network. Since it supports a continuous lifecycle, the various stages in Preparation, Planning, Design, Implementation, Operation and Optimization all worked in sync towards the objectives and final project as follows;

a) Connecting Water Meters to a Zigbee module
b) Connecting Zigbee module to Gateway
c) Propagating data to the cloud

While the resultant network deviated somewhat from the original design, the above objectives a,b,c were all achieved.

The resultant network was a real life model prototype of a WSN which remotely logged data to a repository. This methodology was ideal as it aided in lowering the total cost of network ownership, increased network availability, flexibility and speeding access to applications and services.

5.4 Implementation of Zigbee Mesh WPAN Prototype for remote Water Meter Reading

The zigbee network was implemented by setting up various hardware peripherals within set criteria. Modbus protocol was used to capture water flow from the meters and convert measurements into discrete values. A reduced function module was then used to capture the discreet signals from the water meter and consequently relay this data to the zigbee gateway router. The set up was done within Kabarak University.

5.5 Performance of a Zigbee Mesh Network

The zigbee network was able to successfully propagate water flow data efficiently and reliably. Data was captured remotely and effortlessly per second and viewed remotely from the web. Datasets from the network would then be reviewed and prepared for purposes of producing necessary reports.

The network was easy to deploy, it had excellent performance even with high proliferation of other mobile and wireless signals. It had an appropriate and reliable data transfer and bit rate with very low power consumption in the process.

5.5.1Equipment Challenges during the Study

With Zigbee and RFC 802.15.4 field being a relatively new area of study, there remains a dire deficiency of easily accessible equipment for setting up of such projects.Vendors neither did not have appropriate devices nor peripherals with commensurate specifications to meet requirements for this study.

5.5.2 Challenges will Local Government Bureaucracy

Limitations in bureaucracy at Nakuru Water and Sanitation Company produced bottlenecks in accessing water infrastructure owned and operated by NAWASCO thus having to implement the pilot prototype under the auspices of Kabarak University Library.

5.5.3Mechanical and Logistical Challenges

Mechanical flaws like air lock, irregular flow and intermittent pumping times were experienced during the period of the study.

5.5.4Future Research Areas on Security

There is need to look at composition and inclusion of a ZigBee trust center so as to provide security management, security key distribution, and device authentication. A zigbee trust center (ZTC) will be critical to ensuring proper security mechanism and data protection is propagated. Various security components should be examined in authentication and data encryption for data integrity. There is a great need to look at 128bit AES encryption for securing Zigbee networks.

5.5.5 Future Research Areas on Energy

There is a need to evaluate use of solar powered gateway routers to limit need for electrical wiring and reduce energy needs of the set-up and promote green energy as well.

5.5.6 Comparison with results from other Technologies

There is a wide variety of solutions for water meter connectivity with a view of remote logging of data. These varying technologies include Bluetooth, Wi-Fi, or Infrared that can be implemented towards automation of meter reading. While these technologies have a short propagation range, they however require interconnectivity with other solutions for purposes of forwarding data to the internet / cloud. The technologies include;

a) Short Range Radio Frequency (RF)
b) Global System for Mobile Communications (GSM)
c) Worldwide Interoperability for Microwave Access (WiMAX)
d) Long Term Evolution (LTE) commonly referred to 4G.

The table 7 below shows the comparison between a project implemented in Bluetooth against zigbee in a November 2007 study by Lee, Su, and Shen.

Table 7: Comparison Chart: Bluetooth (BLE) Vs. ZigBee (Source: Lee, Su and Shen.)

	Bluetooth (BLE)	ZigBee
Network type	Personal area network (PAN), which supports few nodes	Local area network (LAN), which supports many nodes
Range*	77 meters	291 meters
Operating system	Android, iOS, Windows 8, OS X	Not currently compatible
Topology	Mesh and star	Mesh only
Throughput	270 kbps	250 kbps
Modulation	Frequency-hopping spread spectrum (FHSS)	Direct-sequence spread spectrum (DSSS)
Transmit power	10 mW	100 mW

Another study involved investigating the differences in various network topologies, . Various simulations revealed that once a number of nodes surpassed normal network maximum, there was delay experienced. These delays would increases significantly irrespective of logical topology implemented. The lower the number of nodes (50) and the use of network topologies such as tree or mesh helps alleviate this problem and results in lower network delays. Generally packet loss for the logical topologies in all networks was between 0.0% to 0.14% for 10 to 70 devices while the success rate was between 23% to 48% where there was higher device density. (Marais, Malekian, Ning and Wang, 2016).

In a comparative study of Bluetooth, ZigBee and Wi-Fi, Wi-Fi devices were seen to be least affected by other wireless technologies operating within the same locale concomitantly such as ZigBee and Bluetooth. In retrospect ZigBee and Bluetooth suffers noticeably from micro-waves emanating from Wi-Fi devices. It was then found best to configure ZigBee devices to operate on more than the classic four ZigBee channels (Challoo, Oladeinde, Yilmazer, Ozcelik and Challoo, 2012).

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APPENDIX I

RESOURCE CONNECTION

```
<?php

//milele123

// assigning variables

$dbhost = "localhost";

$dbuser = "kirori_kirori";

$dbpass = "g3tp@55wd";

$dbname = "kirori_waterbiils";

// connecting to the server localhost

$con = mysql_connect($dbhost, $dbuser, $dbpass);

  if (!$con) {

     die('cannot connect to the server' . mysql_error() );

  }

//variable for accessing database

   $db = mysql_select_db($dbname, $con);

            if (!$db) {

            die ('database not found' . $DB_NAME . ': ' . mysql_error());

            }

?>

<?php
```

```
// assigning variables

$dbhost = "localhost";

$dbuser = "dev_mindo";

$dbpass = "kirori@28";

$dbname = "dev_waterbiills";

// connecting to the server localhost

$con = mysql_connect($dbhost, $dbuser, $dbpass);

  if (!$con) {

     die('cannot connect to the server' . mysql_error() );

  }

//variable for accessing database

   $db = mysql_select_db($dbname, $con);

            if (!$db) {

            die ('database not found' . $DB_NAME . ': ' . mysql_error());

            }

?>
```

BILLING DASHBOARD

```
<?php

            //confirming user sessions

            session_start();

            if(!isset($_SESSION["sess_user"] )) {

            header("location:../waterbilling/error.php");
```

```
	}else{


?><!doctype html>
<html lang="en">
	<head>
		<meta charset="utf-8">
		<meta name="viewport" content="width=1024">
		<title>water reports month of June and May</title>
		<link rel="stylesheet" href="css/bootstrap.min.css">
		<link rel="stylesheet" href="css/common.css">
		<link rel="stylesheet" href="css/03.css">
		<style>
		.navbar-inverse .navbar-nav > .active > a, .navbar-inverse .navbar-nav > .active > a:hover, .navbar-inverse .navbar-nav > .active > a:focus{
			color:#FFF;
			background:none;
		}
		</style>
	</head>
	<body>
```

```
<nav class="navbar navbar-inverse">

<div class="container-fluid">

<div class="navbar-header">

<button type="button" class="navbar-toggle collapsed" data-toggle="collapse" data-target="#navbar" aria-expanded="false" aria-controls="navbar">

<span class="sr-only">Toggle navigation</span>

<span class="icon-bar"></span>

<span class="icon-bar"></span>

<span class="icon-bar"></span>

</button>

<a class="navbar-brand" href="#" >Water Billing</a>

</div>

<div id="navbar" class="navbar-collapse collapse">

<ul class="nav navbar-nav navbar-right">

<li class="active"><a href="../waterbilling/default.php" class="active">Dashboard</a></li>

<li class="active" class="active" class="active"><a href="simulator.php">Simulator Device</a></li>

<li class="active" class="active"><a href="reports_bar.php">Reports</a></li>

<li class="active"><a href="logout.php">Logout</a></li>

</ul>



</div>
```

```
</div>

</nav>

                <div id="wrapper">

                        <div class="chart">

                                <h2>Water Report May & June M1,M2,M3 ...</h2>

                                <table id="data-table" border="1" cellpadding="10" cellspacing="0" summary="The effects of the zombie outbreak on the populations of endangered species from 2012 to 2016">

                                        <caption>Readings in consumption </caption>

                                        <thead>

                                                <tr>

                                                        <th scope="col">M1</th>

                                                        <th scope="col">M2</th>

                                                        <th scope="col">M3</th>

                                                        <th scope="col">M4</th>

                                                        <th scope="col">M5</th>


                                                </tr>

                                        </thead>

                                        <tbody>


                                                <tr>
```

}

```
<?php

include("connection.php");

$select = mysql_query("SELECT * FROM records_history
WHERE month='5' OR month='6'  ") or die ('No table found' . mysql_error() );

$num = mysql_num_rows($select);

        while($row = mysql_fetch_assoc($select)) {

                $fr = $row['Consumption'];

                echo "<td>".$row['Consumption']."</td>";

        }
```

```
                        ?>
                                                </tr>

                                                <!--<tr>
                                                        <td>7090</td>
                                                        <td>6080</td>
                                                        <td>6240</td>

                                                </tr>-->
                                                <tr>
                                                        <th
scope="row"><center>January</center></th>

                                                </tr>
                                        </tbody>
                                </table>
                        </div>
                </div>

                <!-- JavaScript at the bottom for fast page loading -->
```

```
			<!-- Grab jQuery from Google -->

			<script src="js/jq-1.11.3.js"></script>



			<!-- Example JavaScript -->

			<script src="js/03.js"></script>



		</body>

</html>

<?php

		}

?>

REPORTS

<?php

		include("controllers/header.php");



?>



<div class="container">



		<br />
```

```
<table border="1">

    <thead>

        <tr>
                    <th colspan="12"><center><h2>Measure of
water used annualy</h2></center></th>

        </tr>

    </thead>

    <tbody>

        <tr>

            <td><b>January</b></td><td          width="100%"><img
src="image/bar.png" height="40px" width="50%"></td>
                    </tr>
                <tr>
                    <td><b>February</b></td><td><img
```

```
src="image/bar.png" height="40px" width="10"></td>

                    </tr>
                    <tr>
                                        <td><b>March</b></td><td><img
src="image/bar.png" height="40px" width="10"></td>

                    </tr>
                    <tr>

                         <td><b>April</b></td><td><img          src="image/bar.png"
height="40px" width="10"></td>

                    </tr>
                    <tr>

                         <td><b>May</b></td><td><img          src="image/bar.png"
height="40px" width="1"></td>

                    </tr>
                    <tr>
```

```
<td><b>June</b></td><td><img src="image/bar.png"
height="40px" width="10"></td>

</tr>

<tr>

<td><b>July</b></td><td><img
src="image/bar.png" height="40px" width="10"></td>

</tr>

<tr>

<td><b>Aughust</b></td><td><img src="image/bar.png"
height="40px" width="10"></td>

</tr>

<tr>

<td><b>September</b></td><td><img src="image/bar.png"
height="40px" width="10"></td>

</tr>

<tr>

<td><b>October</b></td><td><img src="image/bar.png"
```

```
height="40px" width="10"></td>

                    </tr>

                    <tr>

                        <td><b>November</b></td><td><img src="image/bar.png" height="40px" width="10"></td>

                    </tr>

                    <tr>

                        <td><b>December</b></td><td><img src="image/bar.png" height="40px" width="10"></td>

                    </tr>

                    <tr>

                        <td colspan="12"><center><b>Water used in (Gallons)</b></center></td>

                    </tr>

                </tbody>
```

```
	</table>

</div>

<?php

	include("controllers/footer.php");

?>

<?php

//milele123

// assigning variables

$dbhost = "localhost";

$dbuser = "kirori_kirori";

$dbpass = "g3tp@55wd";

$dbname = "kirori_waterbiils";

// connecting to the server localhost

$con = mysql_connect($dbhost, $dbuser, $dbpass);

  if (!$con) {

     die('cannot connect to the server' . mysql_error() );

  }

//variable for accessing database

   $db = mysql_select_db($dbname, $con);

	if (!$db) {

	die ('database not found' . $DB_NAME . ': ' . mysql_error());
```

```
        }
?>
<?php


// assigning variables
CONNECTION CREDENTIALS
$dbhost = "localhost";
$dbuser = "dev_mindo";
$dbpass = "kirori@28";
$dbname = "dev_waterbiills";
// connecting to the server localhost
$con = mysql_connect($dbhost, $dbuser, $dbpass);
  if (!$con) {
     die('cannot connect to the server' . mysql_error() );
  }
//variable for accessing database
   $db = mysql_select_db($dbname, $con);
        if (!$db) {
        die ('database not found' . $DB_NAME . ': ' . mysql_error());
        }
?>
```

```
<?php

	//confirming user sessions

	session_start();

	if(!isset($_SESSION["sess_user"] )) {

	header("location:../waterbilling/error.php");



	}else{



?><!doctype html>

<html lang="en">

	<head>

		<meta charset="utf-8">

		<meta name="viewport" content="width=1024">

		<title>water reports month of June and May</title>

		<link rel="stylesheet" href="css/bootstrap.min.css">

		<link rel="stylesheet" href="css/common.css">

		<link rel="stylesheet" href="css/03.css">

		<style>

		.navbar-inverse .navbar-nav > .active > a, .navbar-inverse .navbar-nav > .active > a:hover, .navbar-inverse .navbar-nav > .active > a:focus{

			color:#FFF;

			background:none;
```

```
                    }

                    </style>

          </head>

          <body>


<nav class="navbar navbar-inverse">

<div class="container-fluid">

<div class="navbar-header">

<button type="button" class="navbar-toggle collapsed" data-toggle="collapse" data-target="#navbar" aria-expanded="false" aria-controls="navbar">

<span class="sr-only">Toggle navigation</span>

<span class="icon-bar"></span>

<span class="icon-bar"></span>

<span class="icon-bar"></span>

</button>

<a class="navbar-brand" href="#" >Water Billing</a>

</div>

<div id="navbar" class="navbar-collapse collapse">

<ul class="nav navbar-nav navbar-right">

<li class="active"><a href="../waterbilling/default.php" class="active">Dashboard</a></li>

<li class="active" class="active" class="active"><a href="simulator.php">Simulator Device</a></li>
```

```
<li class="active" class="active"><a href="reports_bar.php">Reports</a></li>

<li class="active"><a href="logout.php">Logout</a></li>

</ul>



</div>

</div>

</nav>

        <div id="wrapper">

            <div class="chart">

                <h2>Water Report May & June M1,M2,M3 ...</h2>

                <table id="data-table" border="1" cellpadding="10"
cellspacing="0" summary="The effects of the zombie outbreak on the populations of endangered
species from 2012 to 2016">

                    <caption>Readings in consumption </caption>

                    <thead>

                        <tr>

                            <th scope="col">M1</th>

                            <th scope="col">M2</th>

                            <th scope="col">M3</th>

                            <th scope="col">M4</th>

                            <th scope="col">M5</th>
```

```
</tr>

</thead>

<tbody>


<tr>


<?php



include("connection.php");


$select = mysql_query("SELECT * FROM records_history WHERE month='5' OR month='6'  ") or die ('No table found' . mysql_error() );


$num = mysql_num_rows($select);


while($row = mysql_fetch_assoc($select)) {



$fr = $row['Consumption'];
```

```
                                        echo "<td>".$row['Consumption']."</td>";

                                }

                ?>
                                        </tr>

                                        <!--<tr>
                                                <td>7090</td>
                                                <td>6080</td>
                                                <td>6240</td>

                                        </tr>-->
                                        <tr>
                                                <th
scope="row"><center>January</center></th>

                                        </tr>
                                </tbody>
                        </table>
                </div>
```

```
                    </div>



                    <!-- JavaScript at the bottom for fast page loading -->



                    <!-- Grab jQuery from Google -->

                    <script src="js/jq-1.11.3.js"></script>



                    <!-- Example JavaScript -->

                    <script src="js/03.js"></script>



          </body>

</html>

<?php

          }

?>
```

REPORTS

```
<?php

          include("controllers/header.php");



?>
```

```
<div class="container">

        <br />

        <table border="1">

            <thead>

                <tr>
                                <th colspan="12"><center><h2>Measure of water used annualy</h2></center></th>

                </tr>

            </thead>

            <tbody>

                <tr>

                    <td><b>January</b></td><td width="100%"><img src="image/bar.png" height="40px" width="50%"></td>
```

```
                                    </tr>

                              <tr>

                                    <td><b>February</b></td><td><img
src="image/bar.png" height="40px" width="10"></td>



            </tr>

            <tr>

                                    <td><b>March</b></td><td><img
src="image/bar.png" height="40px" width="10"></td>



            </tr>

            <tr>



                  <td><b>April</b></td><td><img         src="image/bar.png"
height="40px" width="10"></td>



            </tr>

            <tr>



                  <td><b>May</b></td><td><img           src="image/bar.png"
height="40px" width="1"></td>



            </tr>
```

```
<tr>

<td><b>June</b></td><td><img src="image/bar.png"
height="40px" width="10"></td>

</tr>
<tr>
<td><b>July</b></td><td><img
src="image/bar.png" height="40px" width="10"></td>
</tr>
<tr>

<td><b>Aughust</b></td><td><img src="image/bar.png"
height="40px" width="10"></td>

</tr>
<tr>

<td><b>September</b></td><td><img src="image/bar.png"
height="40px" width="10"></td>

</tr>
<tr>
```

```
                <td><b>October</b></td><td><img src="image/bar.png"
height="40px" width="10"></td>

            </tr>

            <tr>

                <td><b>November</b></td><td><img src="image/bar.png"
height="40px" width="10"></td>

            </tr>

            <tr>

                <td><b>December</b></td><td><img src="image/bar.png"
height="40px" width="10"></td>

            </tr>

            <tr>

                <td colspan="12"><center><b>Water used in
(Gallons)</b></center></td>

            </tr>

        </tbody>
```

```
        </table>
</div>
<?php
        include("controllers/footer.php");
?>


 <!DOCTYPE html>
 <html lang="en">
 <head>
 <meta charset="utf-8">
 <meta http-equiv="X-UA-Compatible" content="IE=edge">
 <meta name="viewport" content="width=device-width, initial-scale=1">
 <meta name="description" content="waterbilling software online, online portal water services">
 <meta name="author" content="vincent chebon">
 <!-- The above 3 meta tags *must* come first in the head; any other head content must come *after* these tags -->
 <link rel="icon" href="../../favicon.ico">
 <title>User Billing Software</title>
```

```
<!-- Bootstrap core CSS -->

<link href="css/bootstrap.min.css" rel="stylesheet">

<script src="js/jq-1.11.3.js"></script>

<script src="js/jq-ui.js"></script>

<script src="js/bootstrap.min.js"></script>

<script src="js/bootstrap-datetimepicker.min.js"></script>

<link href="css/bootstrap-datetimepicker.min.css" rel="stylesheet">

<link href="css/smoothness.css" rel="stylesheet">

<script type="text/JavaScript">

$(function() {

$( "#pckdate" ).datepicker();

});

 <!DOCTYPE html>

 <html>

 <head>

 <meta charset="utf-8">

 <meta http-equiv="X-UA-Compatible" content="IE=edge">

 <meta name="viewport" content="width=device-width, initial-scale=1">

 <!-- The above 3 meta tags *must* come first in the head; any other head content must come
```

```
*after* these tags -->

<link rel="stylesheet" type="text/css" href="css/bootstrap.min.css">

<script type="text/javascript" src="js/bootstrap.min.js"></script>

<script src="js/jq-1.11.3.js"></script>

<title>Login</title>

<style type="text/css">

.container{

flex-direction: column;

justify-content: center;

width: 100%;

min-height: 100%;

padding-top: 200px;

}

body{

background-image: url("image/water.jpg");

background-size: 100% 100%;

background-attachment: fixed;

}
```

```
</style>

</head>

<body>

<div class="container">

<div class="row">

<div class="col-sm-4"></div>

<div class="col-sm-4">

<div class="panel panel-primary">

<div class="panel-heading">Login</div>

<div class="panel-body">

<form method="post" class="form-group" action="login.php">

<input type="email" name="username" id="username" placeholder="Email Address" class="form-control" autofocusrequired/><br />

<input type="password" name="password" id="password" placeholder="Password" class="form-control" required/><br />

<input type="submit" name="login" class="btn btn-primary btn-sm" value="Login"/>

<a href="signup.php" class="btn btn-default btn-sm">Sign Up</a>

</form>
```

```
</div>

<div class="panel-footer">Sign In/Up to access the Remote Water Billing Observatory</div>

</div>

</div>

<div class="col-sm-4"></div>

</div>

</div>

</body>

</html>

 </script>

 <script type="text/JavaScript">

 $(function() {

 $( "#pckdate1" ).datepicker();

 });

 </script>

 <!-- IE10 viewport hack for Surface/desktop Windows 8 bug -->

 <link href="css/ie10-viewport-bug-workaround.css" rel="stylesheet">

 <!-- Custom styles for this template -->
```

```
<link href="css/dashboard.css" rel="stylesheet">

<style>
.navbar-inverse .navbar-nav > .active > a, .navbar-inverse .navbar-nav > .active > a:hover, .navbar-inverse .navbar-nav > .active > a:focus{
color:#FFF;
background:none;
}
</style>
</head>
<body>
<nav class="navbar navbar-inverse navbar-fixed-top">
<div class="container-fluid">
<div class="navbar-header">
<button type="button" class="navbar-toggle collapsed" data-toggle="collapse" data-target="#navbar" aria-expanded="false" aria-controls="navbar">
<span class="sr-only">Toggle navigation</span>
<span class="icon-bar"></span>
<span class="icon-bar"></span>
<span class="icon-bar"></span>
```

```
</button>

<a class="navbar-brand" href="#" >Water Billing</a>

</div>

<div id="navbar" class="navbar-collapse collapse">

<ul class="nav navbar-nav navbar-right">

<li class="active"><a href="../waterbilling/default.php" class="active">Dashboard</a></li>

<li class="active" class="active" class="active"><a href="simulator.php">Simulator Device</a></li>

<li class="active" class="active"><a href="reports_bar.php">Reports</a></li>

<li class="active"><a href="logout.php">Logout</a></li>

</ul>

</div>

</div>

</nav>

<div class="container">

<br />

<div class="row">

<div class="col-sm-12">
```

```
</div>

</div>

<div class="row thumbnail">

<form method = "POST" action="simulator.php">

<div class="col-sm-3 text-center">

</div>

<div class="col-sm-3 text-left">

<img src="image/water_meter_digital.jpg" width="100%" alt="Digital Meter Reading">

<p class="text-right"><b>First Reading</b></p>

<input type="number" name="ac" class="form-control" placeholder="Account Number" required/><br />

<input type="date" id="pckdate" name="sdate" class="form-control" placeholder="First Reading Date: yyyy-mm-dd" required/><br />

<input type="number" name="p_reading" class="form-control" placeholder="Previous Reading" required/><br />

<input type="number" name="mrn_reading" class="form-control" placeholder="Morning Reading" required/><br />

<input type="number" name="month_r" class="form-control" placeholder="Month" required/><br />
```

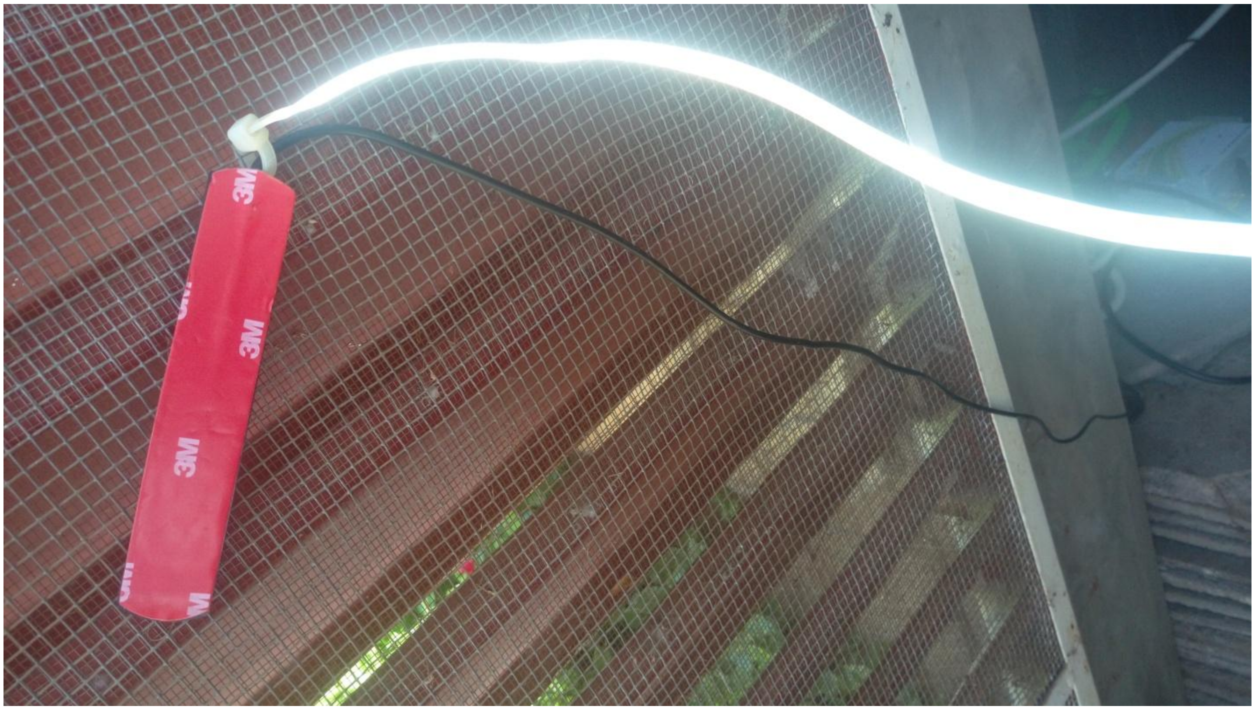
```
<input type="number" name="yr" class="form-control" placeholder="Year" required/>

</div>

<div class="col-sm-3 text-right">

<img src="image/water_meter_digital.jpg" width="100%" alt="Digital Meter Reading">

<p><b>Second Reading</b></p>

<input type="date" id="pckdate1" name="edate" class="form-control" placeholder="Second Reading Date: yyyy-mm-dd" required/><br />

<input type="number" name="c_reading" class="form-control" placeholder="Current Reading" required/><br />

<input type="number" name="eve_reading" class="form-control" placeholder="Evening Reading" required/><br />

<input type="number" name="today" class="form-control" placeholder="Today" required/><br />

<input type="number" name="week" class="form-control" placeholder="Week" required/><br />

<select type="number" name="day" class="form-control" placeholder="Week" required>

<option>--Select Day--</option>

<option>Monday</option>

<option>Tuesday</option>

<option>Wednesday</option>
```

```
<option>Thursday</option>

<option>Friday</option>

<option>Saturday</option>

<option>Sunday</option>

</select>

<br />

<br />

<input type="submit" name="send" class="btn btn-primary btn-sm" value="Send" />

<a href="../waterbilling" class="btn btn-default btn-sm">Go Back</a>

</div>

<div class="col-sm-3 text-center ">

</div>

</form>

</div>

</div>

<!-- Bootstrap core JavaScript

================================================== -->

<!-- Placed at the end of the document so the pages load faster -->
```

```
<!-- Just to make our placeholder images work. Don't actually copy the next line! -->

<script src="js/vendor/holder.min.js"></script>

<!-- IE10 viewport hack for Surface/desktop Windows 8 bug -->

<script src="js/ie10-viewport-bug-workaround.js"></script>

<!-- JavaScript at the bottom for fast page loading -->

<!-- Grab jQuery from Google -->

<script src="js/jq-1.11.3.js"></script>

<!-- Example JavaScript -->

<script src="js/03.js"></script>

</body>

</html>
```

APPENDIX II

GSM AERIAL TO CLOUD



APPENDIX III

BATTREY POWERED ZIGBEE MODULE

APPENDIX IV

ZIGBEE TO GSM ROUTER FOR DATA PROPAGATION

APPENDIX V

RESEARCH AWARD FROM NATIONAL COMMISSION FOR SCIENCE, TECHNOLOGY AND INNOVATION

NACOSTI

NATIONAL COMMISSION FOR SCIENCE, TECHNOLOGY AND INNOVATION

Telephone: +254-20-2213471,
2241349, 3310571, 2219420
Fax:+254-20-318245, 318249
Email:dg@nacosti.go.ke
Website: www.nacosti.go.ke
When replying please quote

9th Floor, Utalii House
Uhuru Highway
P.O. Box 30623-00100
NAIROBI-KENYA

Ref: No.

NACOSTI/RCD/6TH CALL/INNOV/100

Date:

27th April, 2016

Kirori Mindo,
Kabarak University
Private bag-20157,
KABARAK.

RE: SCIENCE, TECHNOLOGY AND INNOVATION GRANT (INNOVATION)

I'm pleased to inform you that National Commission for Science, Technology and Innovation (NACOSTI) has awarded you a research grant for your **Innovation project**.

The NACOSTI has approved an amount of Kenya shillings Six Hundred Thousand only (Ksh **600,000**) towards your project titled ***"A zigbee based remote water meter reading and flow sensing system."*** Your awarded Innovation grant will be disbursed on yearly instalments.

Find the enclosed ***Research Grant Contract Form (NACOSTI/ST&I/CONTRACT/FORM 1C)*** that should be duly completed. In the contract form, provide clearly itemized yearly budget in the format provided and attach grant acceptance letter if you take up the offer.

Your duly signed contract form and acceptance letter should be sent back to reach us not later than **6th May 2016** for our further actions.

DR. MOSES K. RUGUTT, PhD, HSC.
DIRECTOR GENERAL

cc Vice Chancellor, Kabarak University