2018

Leveraging TV white apace to monitor game conservation environments

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Leveraging TV White Space to Monitor Game Conservation Environments

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Submitted in partial fulfilment of the requirements of the Degree of Master of Science in Mobile Telecommunications and Innovation (MSc. MTI) at Strathmore University

Faculty of Information Technology

Strathmore University

Nairobi, Kenya

June, 2018

DECLARATION

I declare that this work has not been previously submitted and approved for the award of a degree by this or any other University. To the best of my knowledge and belief, the dissertation contains no material previously published or written by another person except where due reference is made in the dissertation itself.

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ABSTRACT

Installation of camera-traps by the conservancies has been gaining interest in the recent years here in Kenya. This is due to the increased scientific need to carry out wildlife research and also monitor the movement patterns of the wild game as a way of helping to address issues such as human-wildlife conflict and poaching. This is also gaining traction by the safari camps to enhance customer experience. The implementation of these camera-traps poses a limitation of remotely accessing the camera feeds. This is majorly caused by a challenge of connectivity as many of these game environments are located in rural environments of Kenya.

The focus of this study was to find out and establish the best approach of implementing a camera-trap that allows remote access of feeds in the game environments while leveraging on the connectivity that can be provided through deployment of Television (TV) White Space network. Through the use of questionnaires, an online survey was conducted in a select conservancy and a safari camp to investigate the challenges and the technology state within these environments that limit the adoption of networked game cameras. Various secondary sources were also studied to understand the existing connectivity technologies in the realm of the Internet of Things (IoT). The study used a combination of hardware and software technologies in realising the model in a TV White Space environment.

A networked game camera prototype that delivers video feeds on a remote mobile interface was developed. The camera prototype utilised a programmed Raspberry Pi camera and the System-On-Chip to relay the gathered feeds in real-time to the mobile interface. The mobile interface developed in this case was an Android-based mobile-web. This was tested by ordinary users in a Wi-Fi environment, TV White Space connectivity experts and conservation officers.

***Keywords**: Internet of Things (IoT), Machine to Machine (M2M), Raspberry Pi, TV White Space, Dynamic Spectrum Access (DSA)*

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LIST OF ACRONYMS

AET	-	Amboseli Ecosystem Trust
CA	-	Communications Authority
DSA	-	Dynamic Spectrum Access
FM	-	Frequency Modulation
GE	-	General Electric
GSM	-	Global System for Mobile Communications
GSMA	-	GSM Association
IERC	-	IoT European Research Cluster
IoT	-	Internet of Things
ITU	-	International Telecommunications Union
IP	-	Internet Protocol
ISM	-	Industrial, Scientific and Medical Radio band
ISP	-	Internet Service Provider
KWCA	-	Kenya Wildlife Conservation Association
LCG	-	Laikipia County Government
LCT	-	Lamu Conservation Trust
LWF	-	Laikipia Wildlife Fund
LPWAN	-	Low Power Wide Area Network
M2M	-	Machine to Machine Communication
MMWCA	-	Maasai Mara Wildlife Conservancies Association
MNO	-	Mobile Network Operator
NRT	-	Northern Rangelands Trust
RISC	-	Reduced Instruction Set Computer
RLWCA	-	Rift Lakes Wildlife Conservancies Association
SD	-	Secure Digital
SDR	-	Software Defined Radio

SoC	-	System-on-Chip
SORALO	-	South Rift Association of Land Owners
TCG	-	Tsavo Conservation Group
TTWCA	-	Taita Taveta Wildlife Conservancies Association
TV	-	Television
TVWS	-	TV White Space
UHF	-	Ultra-High Frequency
VHF	-	Very High Frequency
VSAT	-	Very Small Aperture Terminals
WSD	-	White Space Device (s)

DEFINITION OF TERMS

TV White Space	The unused TV channels between the active ones in the VHF and UHF spectrum. They are typically referred to as the "buffer" channels, previously placed between active TV channels to protect broadcasting interference.
White Space Device(s)	This is a certified wireless device that can be used without an exclusive broadcast license in the RF spectrum below 700MHz. These devices use underutilised, unlicensed portions of the spectrum called white space.
LoRa	Long range, low power digital wireless data communication IoT technology that uses license-free sub-gigahertz radio frequency bands like 169 MHz, 433 MHz, 868MHz (Europe) and 915 MHz (North America).
Raspberry Pi	The Raspberry Pi is a single-board, low-cost, high-performance computer first developed in the UK by the Raspberry Pi Foundation.
LoRaWAN	A Media Access Control (MAC) standardised layer developed to extend the LoRa physical communication layer onto Internet networks.
Machine to Machine Communications	This refers to a communication that happens when two or more fully automated computer systems interchange data without any human involvement.
Dynamic Spectrum Access	This is a new spectrum sharing paradigm that allows secondary users to access the abundant spectrum holes or white spaces in the licensed spectrum bands.
Sigfox	This is a narrowband (or ultra-narrowband) technology. It uses a standard radio transmission method called binary phase-shift keying (BPSK), and it takes very narrow chunks of spectrum and changes the phase of the carrier radio wave to encode the data
Narrow Band-IoT	This is a Low Power Wide Area Network (LPWAN) radio technology standard developed to enable a wide range of devices and services to be connected using cellular telecommunications bands

Cognitive Radio	This is a radio in which communication systems are aware of their internal state and environment such as location and utilisation on RF spectrum at that location
Low Power Wide Area Networks (LPWAN)	A Low-Power Wide-Area Network (LPWAN) or Low-Power Wide-Area (LPWA) network or Low-Power Network (LPN) is a type of wireless telecommunication wide area network designed to allow long range communications at a low bit rate among things (connected objects), such as sensors operated on a battery
3rd Generation Partnership Project (3GPP)	This is a collaboration between groups of telecommunications standards association whose work has been to make a globally applicable third-generation (3G) mobile phone system specification based on evolved GSM specification within the ITU scope.
System on Chip (SoC)	A system-on-a-chip integrates almost all the computer components into a single silicon chip. Along with a CPU, an SoC usually contains a GPU (a graphics processor), memory, USB controller, power management circuits and wireless radios (WiFi, 3G, 4G LTE and so on). Some like the Raspberry Pi C have an Ethernet port.
Very Small Aperture Terminals (VSATs)	This is a satellite communications system that serves home and business users. A VSAT end user needs a box that interfaces between the user's computer and an outside antenna with a transceiver.
None-Line-of-Site (NLOS)	A feature of connectivity (in this case TV White Space) to travel round hills, through trees/vegetation and penetrate building without a need of setting up an alignment of the transceivers to provide the connection link.

ACKNOWLEDGEMENT

First and foremost, I would like to thank our Almighty God for His grace and goodness during the entire period of this work.

I would also like to extend my gratitude to my supervisor Dr. Joseph Sevilla together with Dr. David Crawford and Mr. Malcolm Brew (from the University of Strathclyde) who offered their invaluable assistance, guidance and support towards the completion of my dissertation. Your support is greatly appreciated.

Special thanks goes to my family for their unending support and encouragement.

Last but not least I would like to acknowledge my friends and classmates for their input, thoughts and knowledge-sharing throughout this dissertation. Great thanks to the Mawingu Networks team especially Mr. Paul Kagiri, Mr. Job Ndege and Mr. Edwin Amakobe for allowing me to study, prototype and run tests with your resources.

May God bless you all.

CHAPTER 1: INTRODUCTION

1.1. Background

Kenya has over ten conservancies and over twenty five safari camps (Zijlma, 2017). Most of these conservancies and safari camps are situated along the Great Rift Valley. Some of them are also found in other counties such as Marsabit and Meru counties. These conservancies emerged to create natural habitats for wildlife in reserved areas due to the decline of wildlife population that began to be experienced in Kenya in 1970 (Wambugi, 2015). On the other hand, safari camps emerged to provide tourists and guests with comfortable lodging environments anytime they get to visit the conservancies. Endangered species such as Black rhinos, Grevy Zebras, African wild dogs, elephants, as well as animals such as lions, cheetahs, leopards, bat eared fox are among the conserved species in these ecosystems (KWCA, 2016).

Out of all these conservancies and safari camps, only a fraction of them have a stable Internet connection. This is due to the fact that most of them are located away from the major cities in the country such as Nairobi, Mombasa and Kisumu. They are hence described as being located in the rural areas of Kenya. A number of them have started initiating adoption of the cellular data infrastructure provided by Safaricom and Airtel mobile network operators to enable them efficiently carry out their office work. In addition, others such as the Sentinel Mara camp, have already gone an extra mile to implement VSAT technology in their ecosystem to improve the desired guest experience in accessing the Internet.

As these conservancies and safari camps accentuate their efforts of adopting a digital infrastructure in their ecosystems, pressing issues such as poaching and wildlife research are pushing for quicker implementation. For example, conservancies such as Ol Pejeta have already set up a number of camera-traps to boost their status of technology in gaining insight into the behaviour of the wildlife species found in their environment. A camera trap is an automated digital device that takes a flash photo whenever an animal triggers an infrared sensor embedded onto this digital device (Wearn & Glover-Kapfer, 2017).

This landscape generally demonstrates that a less tech-savvy state currently exists in the conservancies and the safari camp environments. On one hand it presents a scenario of activities happening in these ecosystems requiring less use of technology while on the other, it indicates an existing gap as well as existing challenges in adopting and implementing the desired technology.

1.1.1. The Emerging Landscape of the Internet of Things Technology in Kenya

For the past three years, we have experienced an exponential take-off of the concept of Internet of Things (IoT) the world over. A number of global companies such as Amazon, Google, General Electric (GE), Cisco and Bosch are already making huge investments to this technology (Orenstein, 2016). They are equally reaping huge returns from the same technology. For example, in 2013, GE made an approximate investment of $200 million in developing an IoT platform called Predix. Towards the second quarter of 2016, GE posted a revenue of $33.5 billion with 50% of these coming from Internet of Things (IoT). Almost similar reports are also being posted by Cisco (Orenstein, 2016).

The Internet of Things (IoT) is defined by the International Telecommunication Union (ITU) and IoT European Research Cluster (IERC) as a dynamic global network infrastructure with self-configuring capabilities based on standard and interoperable communication protocols where physical and virtual "things" have identities, physical attributes and virtual personalities, use intelligent interfaces and are seamlessly integrated into the information network. This definition essentially presents the stack of IoT which begins at the sensing level through connectivity to the cloud, providing an infrastructure that links the physical and the digital world (Vermessan & Fries, 2016).

The adoption of IoT in Kenya is already experiencing a rapid growth of the numbers in the early adopters set of the life cycle of technology adoption. There is also a growing trend of innovators in maker spaces such as iHub. This is translating into a new wave of growth of start-ups that get to develop solutions befitting different domains by use of IoT technologies. Chimera IoT and Illuminum Greenhouses are examples of IoT start-ups in Kenya currently developing solutions for smart homes and agriculture respectively (Ng'etich, 2016) .

The emerging IoT landscape in Kenya is gradually laying a framework of collaborative IoT where different players are selectively providing services under their traditional blocks of business. Companies that provide sensors through a resale point such as Nerokas, are improving their service through bulk shipping to be able to reach the growing demand in the market. Telecommunication companies such as Safaricom are embedding new connectivity layers and standards to their infrastructure to be able to achieve the low power wide area network (LPWAN) connectivity desired for reliable IoT deployment. Similarly, cloud giants such as Microsoft are already working with commercial companies, in this case, M-KOPA to realise the value of data in the IoT ecosystem (Mulligan, 2016).

1.1.2. The Emerging Innovation of TV White Space on the Spectrum

Innovation is defined as the process of translating an idea or invention into a good or service that creates value or for which customers will pay. A report published by the International Environmental Law Research Centre (Kameri-Mbote, Mony, Murungi and Nyawira, 2016) points out on the need of the Communications Authority (CA) to embrace technological innovation to ensure use of spectrum in order to reach an equilibrium of “sustainable consumption” despite its finite nature. The CA seems to have already heeded to this call and is already creating a platform of innovation by adopting use of Television (TV) White Space through implementation of a geo-location database.

Television White Space (TVWS) refers to the frequencies made available for unlicensed use at locations where the spectrum is not being used by licensed services such as television broadcasting. They can be described as the unused broadcasting frequencies (470-790 MHz in ITU Region 1 and 470-698 MHz in ITU Region 2) in the wireless spectrum. Television networks leave gaps between channels for buffering purposes, and this space in the wireless spectrum is similar to what is used for 4G systems. Hence it can be used to deliver widespread broadband Internet.

National and International bodies assign different frequencies for specific uses. They also license the rights to broadcast over these frequencies. The process of allocating these frequencies is what creates a band plan. In Kenya, the national body mandated to license all broadcasting systems and manage the frequency spectrum is the Communications Authority of Kenya (CA). The CA carries out national co-ordination to ensure harmonious sharing of frequencies by various users and services. It also performs international and regional frequency co-ordination to avoid harmful interference of frequency users in different administrations. The services that require frequency licenses from the Communications Authority (CA) include: TV and FM radio broadcasting, cellular mobile telecommunication, satellite communications, aeronautical and maritime radio services as well as emergency and disaster communication services (CA, 2017). The authority plans frequencies for use by various services every four years following results from the World Radio Conference (GSMA, 2017).

Currently, the Authority permitted Mawingu Networks, Microsoft and Jamii Telecommunications to jointly conduct pilot tests on use of TV white spaces using cognitive radio technology to enable spectrum sharing in the vicinity of Nanyuki and Kalema (Ndege, 2015). This trial implementation was able to provide affordable access to fast broadband connectivity in the areas of Nanyuki and Kalema. The project, dubbed as the Mawingu project successfully connected schools, hospitals, libraries and Red Cross leveraging TV white space technology in the rural of Laikipia and Nyeri counties.

1.1. Problem Statement

The adoption of networked digital game camera technology to allow remote monitoring, protection and wildlife research faces a number of challenges globally. Some of these challenges include limited access to power, poor signal strength of the network and cost of the connectivity provided by the cellular network operators (Wearn & Glover-Kapfer, 2017).

In Kenya, the quest of the conservancies and safari camps to improve wildlife monitoring in their ecosystems through the use of the networked game cameras faces one major challenge: Connectivity. An article on the Safari Guide Africa (2015) shows that most of the conservancies and safari camps in Kenya are located in rural areas and experience poor signal strength from the cellular broadband connection. Hence, this cannot reliably guarantee installation of networked game cameras to wirelessly relay captured feed to a remote mobile interface in order to achieve the objective of an improved approach of remote game monitoring.

The current installation of camera-traps by a number of the conservancies in Kenya demonstrates admirable effort to enhance their way of monitoring the game as well as carrying out wildlife research through the use of cameras. The camera-traps deployed in some of the conservancies so far only capture triggered images and store them locally in an SD card (Amin & Wacher, 2015). This clearly indicates the level of the connectivity challenge faced in the adoption of the digital camera technology as the installed camera traps have to be physically checked from time to time to have a view of the feed, in this case, images captured after a given period of time.

1.2. Research Hypothesis

The deployment of TV White Space connectivity in the game environments can reliably provide a connectivity infrastructure for networked game cameras.

1.3. Research Objectives

The following research objectives will serve as guidance to this study.

1. To study the existing challenges in conservancies and safari camps in adopting use of networked cameras for monitoring their environments.
2. To research on various related works done on deployment of IP-based cameras and the existing connectivity infrastructure used in an Internet of Things (IoT) implementation stack.
3. To design, implement and test a prototype that uses low-cost electronic components including a camera that can remotely provide the feed on a mobile interface leveraging TV white space technology.
4. To validate the implementation of the IP-based camera prototype solution in a TV white space deployed environment and the developed Android-based application that streams video feeds in real-time to the user.

1.4. Research Questions

This research is expected to answer the following questions:

1. What are the existing challenges in adopting the usage of networked cameras for monitoring the conservancies and safari camps in Kenya?
2. What are the existing connectivity implementations in IoT ecosystems to allow deployment of IP-based camera monitoring systems?
3. How can we model a prototype using low-cost electronic components with a camera that can make use of TV white space connectivity technology to transmit feed?
4. Does the IP-based camera prototype provide a reliable connectivity case of using TV White Space technology and delivering the video feeds to a mobile interface?

1.5. Scope and Limitations

This research focuses on the study of existing technology infrastructure in conservancies and safari camps in Kenya. This includes the current technologies already existing to foster monitoring of the wildlife, wildlife research and improvement of the tourism experience in the safari camps alongside the challenges faced. It also focuses on the significance of the adoption of the emerging technology innovation through the development of a solar-powered prototype made up of a low-cost IP-based camera together with infrared sensors. The IP-based camera developed here is expected to provide real-time video feeds on an Android mobile interface to demonstrate a more reliable approach of carrying out wildlife research in the conservancies as well as an advanced tourism experienced in the safari camps.

The prototype developed here has been tested in a TV white space deployed environment to demonstrate the reliability of the signal strength provided by this infrastructure if implemented in the game environments. In this case, tests were carried out at the Mawingu Networks station in Nanyuki where the existing base stations were flashed with new firmware to implement the new TV white space connectivity with a geo-location database from Nominet. The research also partly covered network design and optimisation methods for enabling affordable Internet access with Dynamic Spectrum Access techniques.

1.6. Significance of the Study

This study suggests a solution that will help improve the research on wildlife and wildlife related issues such as the human-wildlife conflict. It also suggests the implementation of innovative technologies that can help improve the tourism experience in the safari camps. The study also envisions to help address the major problem of poaching through the deployment of the type of camera technology intended to be prototyped here. In addition, it also intends to set a new ground of adopting innovative techniques that can guarantee flexible utilisation of the spectrum to provide Internet access to the conservancies and safari camps.

CHAPTER 2: LITERATURE REVIEW

This literature review begins by describing the general state of conservancies in Kenya. It then covers the current technologies being developed for the conservancies in an effort to combat poaching and advance wildlife research in Kenya. It also gets to cover the advances of the Internet of things (IoT) technology and the existing framework of connectivity provided through dynamic spectrum access alongside the current impact experienced from these advances.

2.1. Overview of Conservancies and Safari Camps in Kenya

Wildlife conservation in Kenya is an important component of the national economy, contributing significant value to the country through tourism, employment, community development, food production and scientific research among other sectors. It contributes nearly 14 per cent to Kenya's Gross Domestic Product. Consequently, it is among the top earners of the country's foreign exchange. Indeed, lions, leopards, elephants, rhinos and all our famous wildlife, can be described as the unsung heroes of the Kenyan economy. This is largely attributed to the work done by conservancies such as the Ol Pejeta who not only diversify the income stream but they also work to maximise the productivity of the land through the conservation of wildlife species (SBS, 2012).

Conservancies are large tracts of land, often adjoining National Parks and Reserves that eco-tourism operators rent from local communities or private ranches. The agreement is based on the understanding that the rented land is not used for grazing cattle or farming but left alone for the exclusive use of wildlife and a small tourist population armed with cameras. In the 1990s, Kenya's most popular safari destination, the Maasai Mara, was suffering from declining wildlife and a surplus of tourists. A creative way of dealing with this problem had to be formed. The Founder of Porini safari camps, Jake Grieves-Cook persuaded 70 Maasai families to set aside 3,200 hectares of their land exclusively for wildlife. This became the Ol Kinyei Conservancy, the first community-owned sanctuary to be established on the rangelands adjoining the Maasai Mara National Reserve. This paved way for a host of other conservancies in the Mara ecosystem and other places such as Amboseli. Lewa Wildlife Conservancy, one of the biggest conservancies in Kenya, was among the first to be formed back in 1995 within the Mara ecosystem (Zijlma, 2017).

Safari camps on the other hand are lodges used by tourists while visiting the conservancies. Foreigners and locals in search for amazing outdoor and wildlife activities get to have camping adventures and the luxury that comes with them while staying in these camps. There is a wide range of luxurious camps in Kenya that provide the desired safari adventures. Some of these camps include: Lake Elementaita Serena, Mahali Mzuri, Oldarpoi Mara camp, Ol Pejeta, Sentinel Mara among many others.

In practice the crucial difference between Conservancies and Government protected areas is the control of tourism and accommodation. The prolific expansion of properties in the National Parks and Reserves has had a negative impact on the wildlife and ecosystems. The result has been a deteriorating safari experience of reduced wildlife numbers, herds of minibuses, damage to flora by off-road driving as well as litter and pollution. Hence, the formation of conservancies was initiated to help address issues such as poaching, human-wildlife conflict, deforestation as well as climate change. Endangered species such as the African elephants, black rhinos and Grevy's zebras hence are able to be safeguarded in these conservancies. Conservancies such as the Ol Pejeta harbour the African elephant, African wild dog, Jackson's hartebeest and Grevy's zebra among other species such as cheetahs, lions, leopards and hippos to achieve their mission of safeguarding vulnerable species (KWCA, 2016).

All the conservancies in Kenya are registered with the Kenya Wildlife Conservancies Association (KWCA). The Kenya Wildlife Conservancies Association is a landowner led national membership organisation that serves the interest and collective voice of community and private conservancies. They work to create an enabling environment for conservancies to thrive by advocating for the right laws and incentives and supporting them through sharing information and building capacity. Table 2.1 shows the distribution of tourism facilities in Conservancies by Region in Kenya in 2016.

Table 2.1 Distribution of Number of Facilities in Conservancies by Region in Kenya

Region Area(RA)	No. of Conservancies	No. of Camps	No. of beds	No. of Jobs	Total Incomes
Amboseli Ecosystem Trust (AET)	18	10	112	568	-
Maasai Mara Wildlife Conservancies Association (MMWCA)	19	42	817	1,301	-
South Rift Association of Land Owners (SORALO)	9	1	14	51	-
Laikipia Wildlife Fund (LWF)	9	35	484	1,250	-
Northern Rangelands Trust (NRT)	33	6	83	845	58,841,746
Rift Lakes Wildlife Conservancies Association (RLWCA)	29	36	327	225	-
Taita Taveta Wildlife Conservancies Association (TTWCA)	19	6	518	-	-
Tsavo Conservation Group (TCG)	2	-	-	-	-
Lamu Conservation Trust (LCT)	2	-	-	40	-
Athi-Kapiti Wildlife Conservancies Association (AKWCA)	10	-	-	-	-
Western	13	6	42	-	-
Totals	163	142	2,397	4,280	

Source: KWCA, 2016

2.2. Types of Conservancies in Kenya

Table 2.2 shows the various types of conservancies as classified by the Kenya Wildlife Conservancies Association (KWCA).

Table 2.2 Types of Conservancies in Kenya

Private Conservancy	Group Conservancy	Community Conservancy
A Conservancy set up on private land by a private individual or corporate body for the purpose of wildlife conservation.	A single Conservancy created by the pooling of land by contiguous private land-owners for the purpose of wildlife conservation.	A Conservancy set up by a community on community land.

Sanctuary	Game Ranch	Game Farm
An area of land and water managed by government, community, individual, or private entity for conservation of one or more species of wildlife.	Keeping of wildlife under natural extensive conditions with the intention of engaging in wildlife conservation, recreation and trade.	Rearing of wildlife in an enclosed and controlled environment for wildlife conservation, trade and recreation.

Source: KWCA, 2016

2.3. The Growth of the Conservancies

Kenya Wildlife Conservancies Association (KWCA) has a membership of 113 private, group and community conservancies established in 28 counties. These non-state protected areas have over 40 years of history in Kenya, with the first "conservancies", Solio Ranch, Ol Jogi, Sangare , Sergoit and Sanctuary farm established in the 1970's to protect rhinos and other wildlife species. In 1972, the Taita Hills Sanctuary was established to protect elephants.

These private initiatives to establish conservancies were started to conserve or rescue highly endangered species (e.g. rhino, hirola), to increase financial returns from landholdings by deriving benefits from wildlife either through photo-tourism or cropping which was done between the late 1990s to early 2000s. Third party agreements with landowners (often with conservation NGOs) was also carried through setting aside land for wildlife in return for a range of benefits (often social-welfare services ranging from bursaries to infrastructure), or simply because of the desire of the landowner to conserve wildlife

The first time the term conservancy was used to describe non-state protected areas appeared in 1995 with the establishment of Lewa Wildlife Conservancy (a private conservancy) and Namunyak Community Conservancy (a community conservancy). The conservancy movement has since blossomed with 22 conservancies being established in the 90s, 57 in the 2000s and 69 by 2010. The highest number of conservancies was established in 2013 coinciding with the time the Wildlife Act 2013, was gazetted and KWCA was established (KWCA, 2016).

The foundations of the first private conservancies began in 1953 with Sergoit Farm. With the evolution of conservation policies, these ranching lands and farms, across the country were over time converted to conservancies. Community conservancies were first established in 1984, with the formation of Kitirua, but it was the establishment of Kimana in 1992, Namunyak and Koiyaki Lemek Wildlife Trust in 1995 and II Ngwesi in 1996 that really catalysed the growth of the community conservation model.

The first group conservancy established was Olchorro Oiroua Conservancy (6,903 Ha) in 1992. This was followed by Golini Mwaluganje (6,500 Ha) in 1993 and Ol Kinyai (6,629 Ha) in 2004. The growth of group conservancies peaked in the 2000s. Figure 2.1 shows the trend in the growth of conservancies in Kenya from 1953 to 2016.

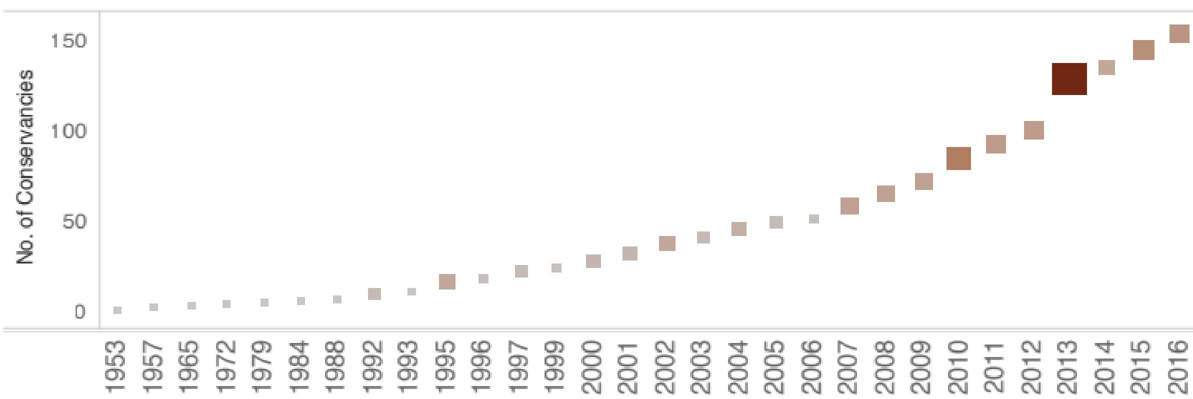

Figure 2.1 The Growth Curve of the Conservancies in Kenya

Source: KWCA, 2016

The five largest conservancies include Melako, Malkhalakhu, Lokichar, Shurr and Biliqo-Bulesa. These conservancies occupy 43% of the conservancies land. The total area covered by the first 16 conservancies to be set up hence is over 100,000 Ha. Among the largest conservancies are the emerging conservancies in Turkana and West Pokot Counties. Lokichar, Lochakula, Kainuk and Katilu in Turkana County experienced development challenges following the withdrawal of NRT in supporting the establishment of these conservancies (KWCA, 2016).Table 2.3 below shows the five largest conservancies by land size in Kenya.

Table 2.3 The Largest Conservancies by Land Size in Kenya

Conservancy	Size (Ha)	% of Total Size (Ha)
Melako	550,669	14%
Malkhalaku Conservancy	480,830	9%
Lokichar	453,692	7%
Shurr	419,071	7%
Biliqo-Bulesa	380,464	6%
Total	**2,643,101**	**43%**

Source: KWCA, 2016

Figure 2.2 shows the conservancies covering over 100,000 hectares in Kenya.

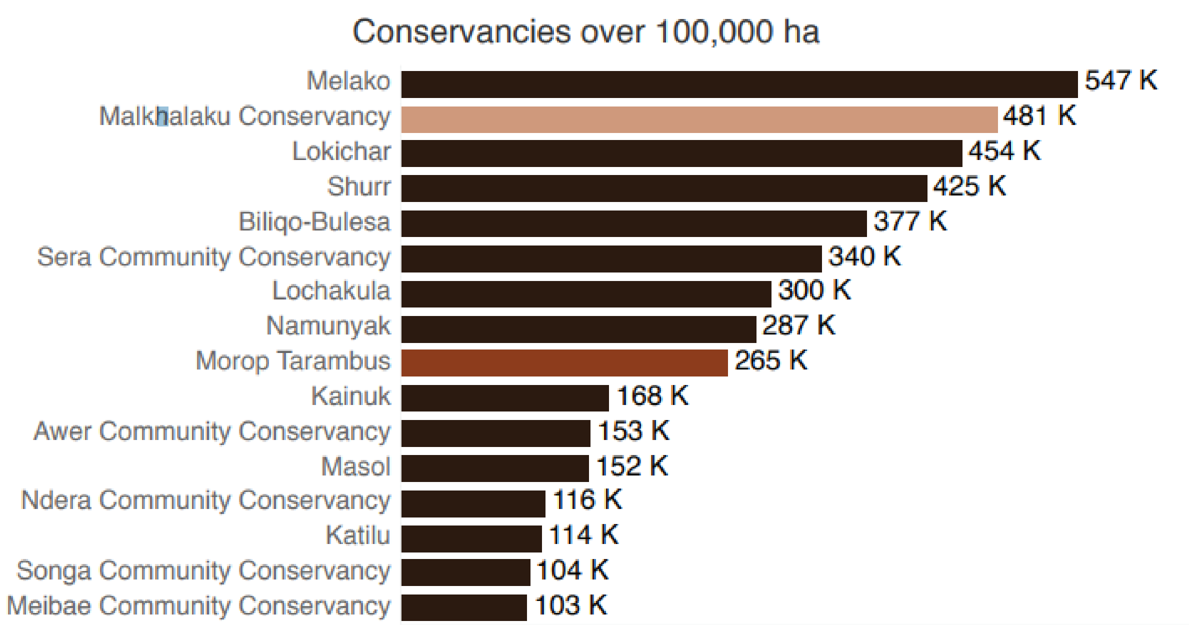

Figure 2.2 Conservancies Covering over 100,000 ha

Source: KWCA, 2016

2.4. Conservancies and Counties in Kenya

Counties are central in ensuring the long-term sustainability of conservancies both in a technical and financial capacity. The conservancies also play a government role in planning and development, while helping counties achieve their development objectives. Kajiado county hosts the highest number of conservancies (25), followed by Taita Taveta county (25) and Narok (16). Although Marsabit county only hosts 5 conservancies, these cover the largest extent (1.4 million Ha) followed by Turkana which occupied a 1.04 million land in size with 4 conservancies. Tana River occupies 674,000 Ha in 4 conservancies (KWCA, 2016). Figure 2.3 shows number of conservancies and their average land size per county.

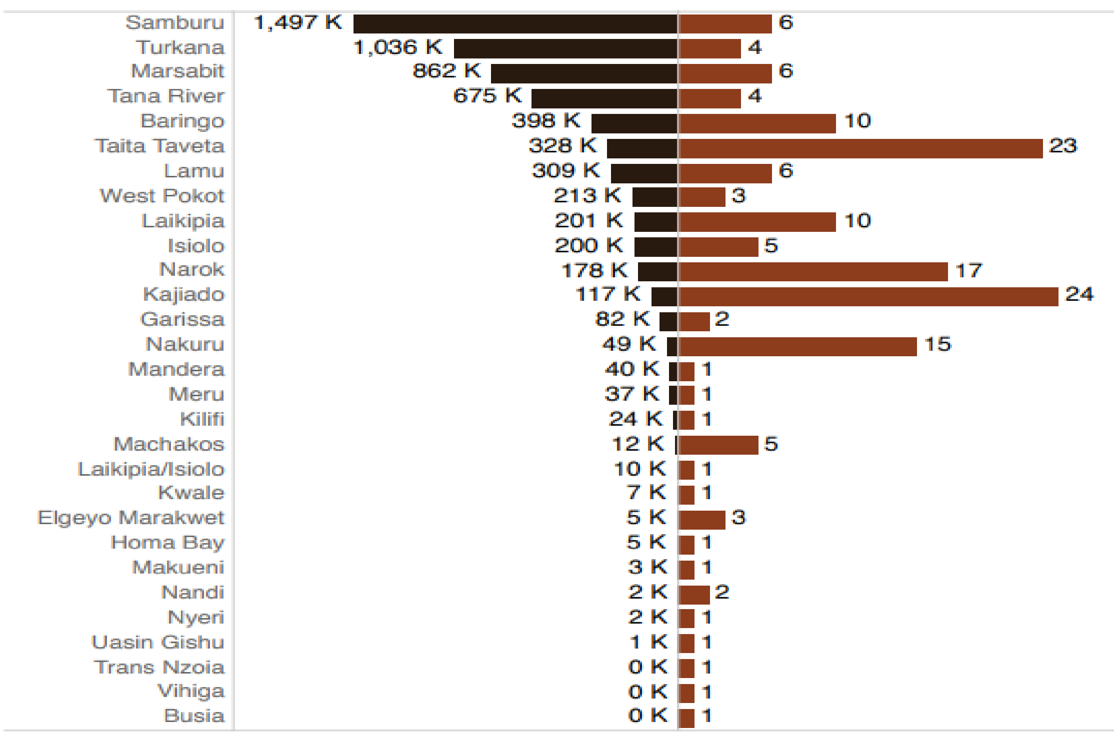

Figure 2.3 Conservancies by County in Kenya

Source: KWCA, 2016

2.5. Conservancy Rangers

KWCA in partnership with KWS has developed Standard Operating Procedures (SOPs) for wildlife scouts (conservancy rangers) to standardise security operations and management of rangers within conservancies. Out of the 2,991 conservancy rangers working in conservancies, 1,102 have undergone ranger training at the KWS Law Enforcement Academy. 579 conservancy rangers operate in Laikipia County, 400 in Kajiado and 306 in Narok Counties. KWCA has also played a central role in circulating and supporting conservancy rangers' trainings and ensuring that they are recognized within the security regulations of the Wildlife Act 2013. KWCA works with other stakeholders to coordinate and support the scout network. An estimated annual income of Kshs 45 Million is earned by the rangers employed in conservancies. Conservancies are a good source of jobs for youth majority of whom do not have formal education to access employment in formal sectors (KWCA, 2016).

2.6. Conservancies Contribution to Wildlife Conservation

A study published in 2016 by Ogutu et al., used DRSRS aerial survey data to depict wildlife densities and trends across the country. It indicated that almost 30% of the wildlife found in Kenya was hosted in Narok County. The proportion of national wildlife populations between 1977 and 2016 were also found to substantially increase in Laikipia and Taita Taveta counties. Within the southern rangelands, data indicates that an average of 56% of wildlife population is found outside of national parks and reserves (Table 2.7.1). These studies depict the importance of these counties and regions for conservancy development and wildlife conservation. The study also reports a national annual population decline of 68% between 1977-2016 (KWCA, 2016). Table 2.4 shows the wildlife distribution inside and outside of parks in 2012.

Table 2.4 Wildlife Distribution Inside and Outside of Parks in 2012

County	Protected Area	Species	Inside			Outside			County	
			Pop. Est.	Density	% (In)	Pop. Est.	Density	% (Out)	% (In)	% (out)
Narok	Masai Mara NR	Elephant	1059	0.61	38	1721	0.11	62	35	65
		Wildebeest	92735	53.02	55	74502	4.64	45	-	-
		Zebra	16986	9.71	31	38361	2.39	69	-	-
		Giraffe	317	0.18	16	1712	0.11	84	-	-
Kajiado	Amboseli NP and Chyulu Hills NP	Elephant	362	0.5	25	1061	0.05	75	20	80
		Wildebeest	5538	7.59	26	15483	0.72	74	-	-
		Zebra	5186	7.11	16	27402	1.27	84	-	-
		Giraffe	532	0.73	10	4601	0.21	90	-	-
Machakos and Makueni	Tsavo West NP and Ngai Ndethya NR	Elephant	66	0.1	72	26	0.002	28	7	93
		Wildebeest	-	-	-	2313	0.17	100	-	-
		Zebra	276	0.43	10	2497	0.19	90	-	-
		Giraffe	79	0.12	13	547	0.04	87	-	-
Kitui	Tsavo East NP and Kitui South NR	Elephant	1306	0.16	92	109	0.005	8	77	23
		Zebra	1478	0.18	91	148	0.01	9	-	-
		Giraffe	1727	0.21	62	1079	0.05	38	-	-
Taita-Taveta	Tsavo East and West NP	Elephant	6501	0.62	81	1488	0.22	19	75	25
		Zebra	8108	0.78	73	3036	0.45	27	-	-
		Giraffe	1203	0.12	58	875	0.13	42	-	-
Tana-River	Tsavo East NP	Elephant	521	0.18	83	109	0.003	17	21	71
		Zebra	1056	0.36	34	2063	0.06	66	-	-
		Giraffe	381	0.13	12	2690	0.07	88	-	-
Total			145,417			181,822			44	56

Source: KWCA, 2016

2.7. Conservancies Contribution to Protecting Endangered Species

In addition to supporting large numbers of wildlife, conservancies are hosts to global populations of some of the world's most endangered species such as the Black and White Rhinos, Grevy's Zebra, Hirola, Wild Dog, Giraffes and Elephants (Ali & Businge, 2015).

2.8. Safari Camps

The Great Wildebeest Migration, is one of the "Seven New Wonders of the World". Nowhere in the world is there a movement of animals as immense as the wildebeest migration. Over two million animals migrate from the Serengeti National Park in Tanzania to the greener pastures of the Maasai Mara National Reserve in Kenya during July through to October (adventures, 2015). This experience, among other wildlife adventures experienced by tourists are made possible through abode in the safari camps. Safari camps provide an intimate experience away from hordes of minibuses and crowds of tourists to the tourists visiting the various conservancies. This set of tourists get to have a number of activities such as game drives, nature walks and visiting of the local communities which are not possible in the National Game parks and reserves. Safari Camps, therefore provide luxury accommodations in small privately tented camps which also provides tourists with a chance to be able to view the various species of wild animals within the related conservancy (Ojo, 2015).

2.9. Challenges Facing Conservancies in Kenya

Even as various stakeholders running the conservancies in the different counties in Kenya continue to safeguard wildlife while improving the country's economy, they still face quite a number of challenges. This challenges range from government support to help advance wildlife research for improved conservancy ecosystems to the issues of human-wildlife conflicts and poaching. Other challenges also include climate change (KWCA, 2017). Some of these challenges are discussed below.

2.9.1. Human Wildlife Conflict

Human Wildlife Conflict (HWC) is a major threat to wildlife conservation and conservancies since wildlife species causing conflicts are attacked and killed by affected persons. The conflicts continue to increase on lands outside most protected areas with high incidences reported in the Taita Taveta/Tsavo; the Mara and the Amboseli and Laikipia/Samburu/Maralal regions.

Figure 2.4 gives an indication of the Number of conflicts reported to KWS from 2011 -2015. An average annual increase of 86% of HWC have been reported to KWS. This is high considering many cases go unreported (KWCA, 2016).

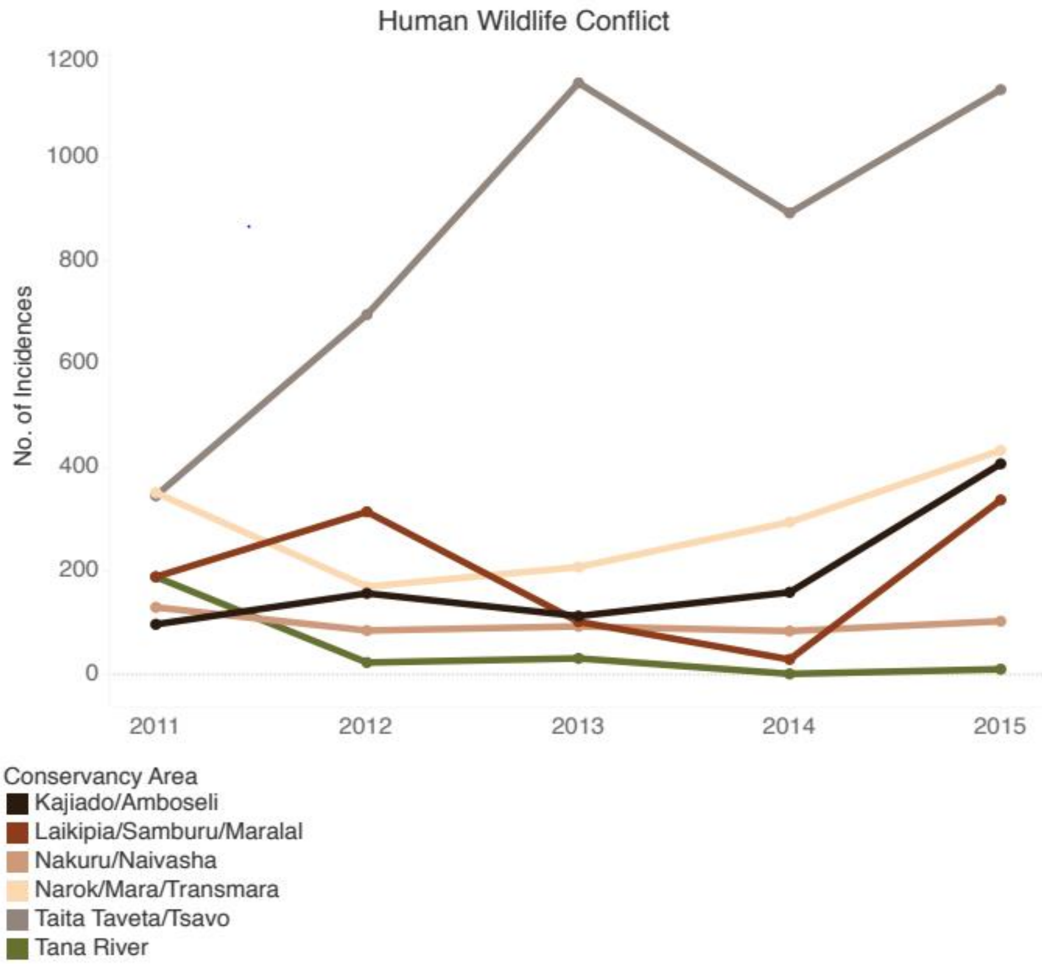

Figure 2.4 Human-Wildlife Conflicts Trend from 2011 to 2015

Source: KWCA, 2016

2.9.2. Poaching

Laikipia's Rhino sanctuaries prides itself as a rhino country. It hosts 49% of the Kenya's black rhino and 70% of the white rhino populations. It hence has approximately 540 rhinos. In addition, a breeding programme for the Northern White Rhino was established almost a decade ago in Ol Pejeta Conservancy. Only two of these type of rhino remain in the world (LWF, 2018). The rhino sanctuaries of Lewa, Solio, Borana, Ol Pejeta and Ol Jogi conservancies lead the way in Kenya's rhino conservation efforts. As we celebrate the efforts of these conservancies, they still face the enormous challenge of poaching. During the period of 2008-2013, the upsurge in rhino poaching incidents in Laikipia was indeed dramatic. There was a rise in the number of rhinos killed in 2006 to 2013 from 3 animals to 59 (LWF, 2018).

2.10. Wildlife Research

Wildlife studies vary in their invasiveness and impact on the animals being studied. Wildlife research is usually conducted with free-living animals in their natural habitats or with wild-caught animals in various captive settings (e.g. laboratory, zoo, conservancies, aquarium, and sanctuary). Many wildlife studies focus on conservation and management, with the aim of learning about the ecology of a population in the field. In such cases, minimising disturbances to the animals is important for the scientific validity of the research as well as for good animal welfare (NC3R, 2018).

Conservancies and Safari camps provide a reliably free environment to study wildlife. This is due to the openness of the environment within which the wild animals roam. The setup of the conservancies and safari camps through the adoption of the emerging technologies such as use of camera traps also allow wildlife research without disturbing the normal animal activities. For a physical human observation, animals easily abandon their territories and home ranges leading to inaccurate collection of data in the animal study. Hence, wildlife research is calling for use of more technology to be able to accurately study the animals remotely as well as view the points of conflict between the surrounding humans and the wildlife (Henriette, 2016).

2.11. Overview of Various Technologies Implemented in the Conservancies

2.11.1. Overview of the Conservancies' Internet Connectivity Landscape

Internet connectivity has been cited as a key facility to influence traveller destination decisions. This is already driving the Safari Camps to install access points that can allow their guests to access the Internet while in the conservancy areas. Although the entire concept of visiting the conservancies and safari camps is meant to have tourists enjoy a game experience and get away from their normal work life, the desire to update their experience on social media makes the provision of broadband WiFi access an essential hospitality facility in these environments. In Kenya, Safaricom and Airtel, the two biggest mobile network operators are currently providing a good 3G network for some of the remote conservancies and safari camps. However, the connection is only stable in areas within the safari camp lodges. As one moves away from the lodges, the connection becomes slower. The same is experienced for the more remote conservancies such as the conservancies away from the Maasai Mara (Jeff, 2015).

Some of the Safari Camps are turning to the implementation of Very Small Aperture Terminals (VSAT) technology to be able to provide the desired strength of connectivity to their visiting customers. Although the implementation of this eats an extra budget of the conservancies and the safari camps to meet their requirements.

The need for a reliable Internet connection goes beyond the use by the tourists visiting these ecosystems. Wildlife researchers and the conservancies as well as the safari camps are also the beneficiaries of a properly installed and connected infrastructure. Notably, these ecosystems are also aware of the impact a relatively cheaper and reliable connection can provide them. This will help them in their fight against poaching, human-wildlife conflict and in their wildlife research. Nocturnal creatures such as the Aardvark and the bush baby as well as a properly installed surveillance system are also pushing the implementation of an improved customer experienced in the Safari camps (Zijlma, 2017). The nocturnal creatures can be viewed on a mobile interface through the use of installed cameras which leverage a reliable network or Internet connection.

2.11.2. Implemented Technologies

2.11.2.1. Camera Traps

Camera trapping is an increasingly popular method to study wildlife. While there are several types of camera-traps, all models have the same basic principle: a photo (and/or video) camera protected with some sort of weather proof housing, coupled to a mechanism that allows the camera to be triggered automatically when an animal moves in front of it (Ancrenaz et al., 2012). There are two main types of camera traps: analogue and digital. The modern digital camera trap is simply a digital compact camera sensor wired up to a passive infrared sensor which is able to "see" the infrared radiation given out by warm blooded animals. However, any camera which is triggered by an animal to take pictures can be classified as a camera trap. This could include cameras triggered using any of a whole range of different methods, such as trip-wires, pull-wires, pressure plates, lasers or microwave sensors. Other names for camera traps include game cameras, scouting camera or trail cameras (Wearn & Glover-Kapfer, 2017).

Camera-traps are generally regarded as non-invasive, they can gather information on a range of species simultaneously and continuously, over large survey areas and for several months at a time. The digital camera-traps usually do not have a separate camera unit, but record the photographs digitally onto a memory card (SD card). In addition, some camera-traps have the ability to record video. Camera-traps have the invaluable advantage of working independently of an observer once they have been set up – at least as long as their batteries and picture storage (either film, or today mostly digital SD cards). Camera-traps do not have to be accessed on a daily basis.

This technology has currently been implemented in places such as the Danum Valley Conservation Area, Sabah in Malaysia (Ancrenaz et al., 2012), India, Mongolia, California and Florida in the United States of America (CSF, 2018). In Kenya, this implementation has already begun at the Lewa Wildlife Conservancy in Northern Kenya. The general idea is to be able to collect data from the cameras to help further the understanding about the type and numbers of wildlife species which pass through a particular fence gap. The camera-traps at the Lewa Conservancy are expected to take high-resolution photographs at night using infrared flash technology. The cameras are placed on either side of a 30m gap in Lewa's 140-kilometre-long protective game fence. The traps are housed in defensive metal boxes ad surrounded by high voltage electric wires to deter inquisitive elephants from “investigating”. In this case, understanding why animals move between a conservancy like Lewa and open rangelands is important for their protection and conservation (Davidson & Chege, 2013).

Figure 2.5 shows an example of a model of a camera-trap developed by Bushnell installed on a tree.

Figure 2.5 Model Camera-trap on a Tree

Source: Wildlifekate, 2017

2.11.2.2. Real-Time Game Cameras

The advances in wireless and camera technology has revolutionised the way game is monitored in the Nature Conservancy at Maui, Hawaii in the USA. Movement of the wild animals is digitally recorded and wirelessly transmitted in near real-time to the game manager’s smart phone. This new imaging technology is giving conservation crews unparalleled tools to remotely track the behaviour of feral animals such as the axis deers. In a fairly inexpensive ecosystem, images are collected on digital, motion and heat activated cameras that transmit immediately on cell phone networks. All the conservancies are expected to do is to set up an account with the cellular company. The cameras are also embedded with other sensors that can record pertinent information such as date and temperature and stamps this information on the images. These images are then sent to the smart phone either in an email or via text message (Lederman, 2018)

2.11.2.3. Use of Anti-Poaching Mobile Applications

The use of mobile applications to curb anti-poaching is gaining much popularity lately in assisting conservancies safeguard their conserved species. One notable example developed in Kenya on this, is the launch of the Wildlife Information and Landscape Database (WILD) App. The WILD App was developed by Strathmore University through its @iLabAfrica Research Centre (iLabAfrica, 2016).

A partnership bringing together @iLabAfrica- Strathmore University, United States Agency for International Development (USAID) and a number of other conservancies such as World Wildlife Foundation (WWF), Mara Elephant Foundation, David Sheldrick Wildlife Trust among others formed an Anti-Poaching Consortium. The aim of this consortium was to help report poaching and human-wildlife incidences through a cloud-based data collecting application that makes use of the smart phone's GPS sensor. This Android-based mobile application basically tracks a patrol unit's movement using the GPS software. While on patrol, game scouts can record information on incidences that occur, such as poaching, animal mortality, human-wildlife conflict, illegal human activity, community service, wildlife sightings, and climate data among other information. This information is hence accessed by administrators to implement evidence-based management decisions such as re-organising patrol routes to cover areas with higher incidences of poaching.

Another mobile application implemented to boost the fight against poaching is the Project Poacher which was developed for the National Wildlife Crime Unit in the United Kingdom (UK). The application was developed for the three platforms: iOS, Android and Windows to be used by people in reporting cruelty to animals and wildlife (Brien, 2016).

2.11.2.4. Adoption of VSAT Technology

The term Very Small Aperture Terminal (VSAT) refers to a small fixed earth station. VSATs provide the vital communication link required to set up a satellite based communication network. VSATs can support any communication requirement be it voice, data or video conferencing (Maral, 2003). VSATs are connected by radio frequency (RF) links via a satellite, with a so-called uplink from the station to the satellite and a so-called downlink from the satellite to the station.

The overall link from station to station, sometimes called hop, consists of an uplink and a downlink. A radio frequency link is a modulated carrier conveying information (Maral, 2003).

The VSAT comprises of two modules – an outdoor and an indoor unit. The outdoor unit consists of an Antenna and Radio Frequency Transceiver (RFT). The antenna size is typically 1.8 metres or 2.4 metres in diameter, although smaller antennas are also in use. The indoor unit functions as a modem and also interfaces with the end user equipment like standalone PCs, LANs or Telephones. With this kind of architecture, Internet connection is hence provided in various facilities through the indoor unit (Maral, 2003).

Figure 2.6 shows the implementation architecture of a VSAT technology showing the interconnection of the satellite to the outdoor and indoor unit up to a user's terminal.

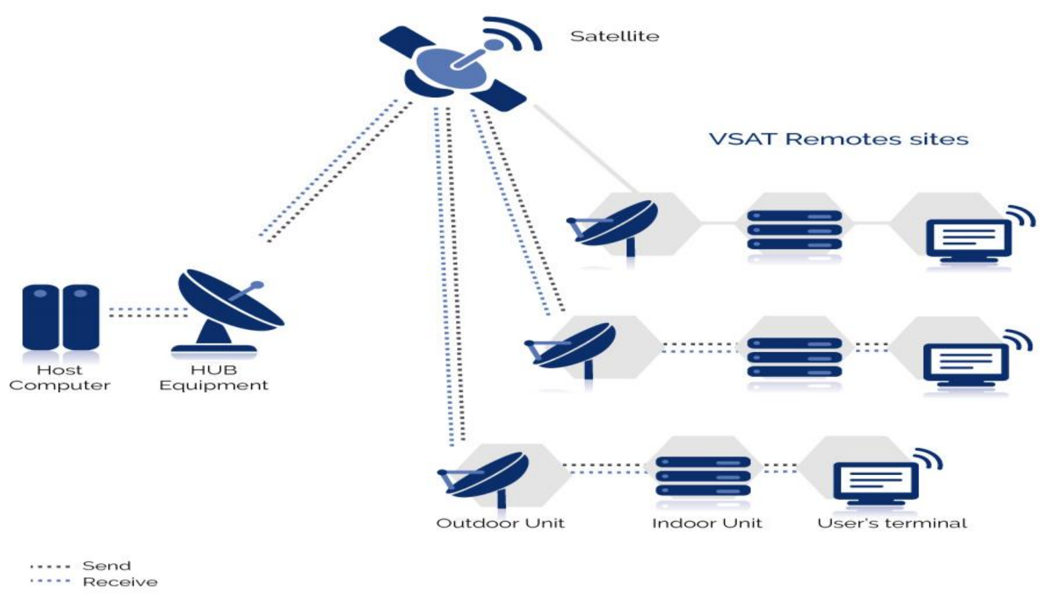

Figure 2.6 Implementation Architecture of VSAT Technology

Source: Qantsat, 2015

In Kenya, Indigo Telecom, Skynet and the Space Engineering Limited are the three known providers of Internet services through the VSAT satellite technology. Skynet have already set up a connection link to one of the Safari Camps in Kenya, the Sentinel Mara Camp. Their infrastructure is claimed to provide an elite network with high-download accelerate to 18Mbps with provision of various capacities to run applications such as Voice over Internet Protocol (VoIP), Video and Data.'

The price ranges of the Skynet VSAT service ranges from a minimum of Ksh. 6,300 for a 20GB bundle balance which provides speed rates of 5Mbps to a maximum cost of Ksh. 51,120 for an unlimited access. Table 2.5 shows the retail prices for the Internet service from Skynet as at January 2018.

Table 2.5 Retail Prices for Internet Service from Skynet in January 2018

RETAIL PRICING

Call **0716 634622** or + **0716 634621**, email support@skynet.co.ke **or visit** www.skynet.co.kefor more details

Retail Packages	Service Type (Down / Up) – "up to speeds"	Bundle Allowance	Monthly Subscription Charge (exclusive VAT)
Click 20	5mbps/768kbps	20GB	KES 6,300
Click 30	5mbps/1mbps	30GB	KES 9,500
Click 50	7mbps/1mbps	50GB	KES 19,500
Click 100	7mbps/1.5mbps	100GB	KES 35,000
Click 200	7mbps/1.5Mbps	200GB	KES 52,300
Click Unlimited 1	1mbps/256Kbps	Unlimited	KES 35,000
Click Unlimited 2	2mbps/1mbps	Unlimited	KES 51,120
Sky 15	10mbps/1mbps	15GB	KES 5,000
Sky 25	10mbps/1mbps	25GB	KES 9,900
Sky 35	10mbps/1mbps	35GB	KES 12,500
Sky 40	10mbps/1mbps	40GB	KES 15,000
Sky 50	10mbps/1mbps	50GB	KES 21,500
Sky 75	10mbps/1mbps	75GB	KES 28,520
Sky 125	10mbps/1mbps	125GB	KES 39,300
Sky 250	10mbps/2mbps	250GB	KES 66,720
Sky 350	10mbps/2mbps	350GB	KES 90,120
Sky Unlimited	1mbps/512kbps	Unlimited	KES 51,120

Source: Skynet, 2018

2.12. Implementation of TV White Space to Guarantee IoT Development

The discussion covered above on the deployment of Remote Game Cameras using the cellular network already presents an Internet of Things (IoT) case of implementation. Internet of Things (IoT) represents the concept of computers and machines with sensors which connect to the Internet to report status and accept control commands. The phrase "Internet of Things" was first used in 1999 by Kevin Ashton while he was working at Massachusetts Institute of Technology's (MIT's) Media Centre although the technology had been around before then. A related sister technology to the IoT is the Machine-to-Machine (M2M) Communications. Machine-to-Machine communications has been in existence for many decades, often using dedicated networks that eventually converged to the Internet, giving rise to the usage of the Internet of Things in the industrial sector (Norris, 2015).

In the IoT ecosystem, the buzz is around the interconnectivity achieved by the various objects embedded with sensor technology. This interconnection is created to achieve the capability of the objects to sense, communicate and share information over public or private Internet Protocol (IP) networks. The interconnected objects have data regularly collected, analysed and used to initiate action, providing a wealth of intelligence for planning, management and decision making. The buzz for more connectivity has led to advances in the research for more reliable wireless techniques that can allow IoT devices and applications to network and exchange data more efficiently. One such research is the sharing of the spectrum to implement IoT systems that access the traditional spectrum bands used by the broadcasters. One such band is the FM Radio and the TV spectrum. The concept within which this type of implementation is housed is referred to as Dynamic Spectrum Access (DSA). Recent examples of DSA in action include the innovation of TV White Space pilot networks currently implemented in various parts of the world such as in the USA, UK, Singapore, Canada, Ghana, Malawi, Kenya and other countries (Stewart, Crawford, & Weiss, 2017).

The concept of Dynamic Spectrum Access allows devices to use unoccupied portions of the spectrum without interfering with the traditional licensed transmissions. These new technology enables a more flexible utilisation of spectrum that is not in use with traditional spectrum management techniques. TV white space constitutes a part of the unused TV spectrum which can be made available using innovative techniques such as DSA. Wireless devices can also use DSA techniques such as sensing and geo-location databases to learn about available TV channels for wireless communication which include IoT transmission of data. Use of cameras in an IoT implementation can hence leverage the connectivity provided by the TV white spaces to transmit feeds for remote access (GSMA, 2017).

The CA issued Microsoft East Africa Limited a trial authorisation to conduct a trial utilising TV white space technology in the vicinity of Nanyuki, Laikipia County on 19th August 2013 in a project dubbed the Mawingu project (LCG, 2014). The project, as a pilot, successfully connected schools, hospitals, libraries and the Red Cross leveraging TV white space (TVWS) technology in the rural of Laikipia and Nyeri counties. The TVWS technology was implemented in a point-to-multipoint fashion broadband connectivity.

The utilisation of the TV white space in its implementation is meant to deliver connectivity to solar powered Internet kiosks, or 'solar cybers' in rural communities. The Mawingu project, to date, provides connectivity to the surrounding high schools, county government offices and a number of restaurants at absolutely no cost. The trial of this project has demonstrated the technical viability of TV white space. There are no interference issues arising from the trial with a point-to-multi-point coverage of 14 kilometres being achieved from the TVWS base stations operating at only 2.5 Watts (LCG, 2014). Figure 2.7 shows how TV white space works while exploiting the DSA techniques.

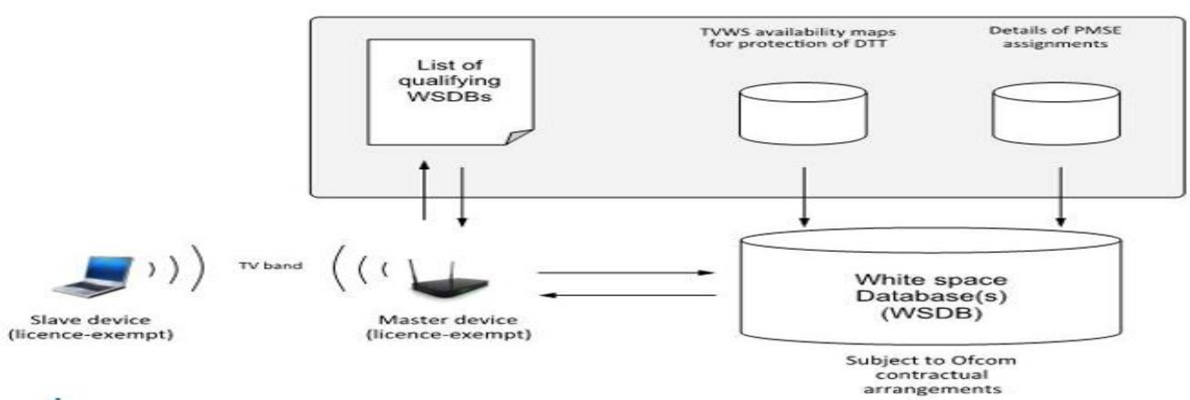

Figure 2.7 How TV White Space Works

Source: Ofcom, 2018

2.12.1. TV White Space Infrastructure with New DSA Rules

The term "white space" in the context of radio frequency spectrum management refers to portions of radio spectrum that are allocated for licensed use but are not assigned to a particular licensee or are allocated and assigned for licensed use but are not utilised by the licensees at all times or across geographical locations. There is a growing recognition that the white spaces in the bands traditionally allocated to television broadcasting (Television White Spaces) can be used to provide wireless broadband Internet access on a "no-interference no-protection" basis. A device that uses these white spaces is referred to as a white space device (WSD) or TVWS device (Carlson et al., 2013).

Available spectrum in broadcast bands has highly desirable propagation characteristics: signals transmitted over TVWS spectrum can travel long distances and penetrate walls and other barriers. As a result, TVWS technology is particularly suitable for delivering Internet access in rural and under-served urban areas (Carlson et al., 2013).

The coverage and throughput combination for the TVWS device investigated under this study is determined by:

i. The transmission power used by a device in a given location.
ii. The height and gain of the base station and client antennae.
iii. The specific channels of the UHF band used.
iv. Varying levels of absorption of the signals between base station and its client or clients which may be impacted by the presence of foliage or varied terrain.
v. The level of interference and noise that is present in the adjacent protected terrestrial TV channel.

To eliminate interference, the deployment of White Space Devices (WSD) for TVWS connectivity can properly be implemented through the use of a geolocation database. A geolocation database provides WSD devices with operating parameters for any given location (Carlson , et al., 2013). This include:

- Available white space channels.

- Transmission power limits applicable to the use of these channels, taking into account the location, height and configuration of the device.
- Duration for which the white spaces channels will be available (if necessary)
- Timeframe within which the device must re-register in order to receive updated information.

The methodology and algorithms employed by the geolocation database take into account the known transmission characteristics, that is, power output, frequency, antenna height, type, location and orientation of existing TV transmitters as well as the topography of the area, in order to model the radio propagation of every channel transmitted in that area. The database is then able to determine which channels are available for use (Carlson , et al., 2013). In this study, the geolocation database in-focus is from Nominet. Nominet provides dynamic spectrum access (DSA) management to guarantee no interference in the deployment of TVWS network.

The radio technology used in this study uses the Adaptrum providers who were the inventors of the first TVWS-based radio which incorporates Field Programmable Gate Arrays (FPGA) to implement the digital circuitry to execute the processing mechanism. These FPGAs use the Hardware Description Language to embed the desired logic onto the circuit.

The design of the radio technology in this study uses a band pass filter that ensures an extremely tight spectral mask which keeps the out of band signal spread to extremely low levels to avoid interference. The topology adopted by the Mawingu Networks assumes a star configuration with each station comprising of client premise equipment (CPE) and a Yagi-Uda type of antenna mounted outdoors and powered by an Unshielded Twisted Pair (UTP) cable that terminates into an indoor Power-over-Ethernet (PoE) adapter. Additional station devices include a Local Area Network (LAN) and ALIX board (Mikeka, et al., 2014).

2.13. Cognitive Radio and Dynamic Spectrum Access

Software Defined Radio (SDR) can act as a key enabling technology for a variety of other reconfigurable radio equipment. SDR can be defined as a radio in which some or all of the physical layer functions are software defined. A radio is any kind of device that wirelessly transmits or receives signals in the radio frequency (RF) part of the electromagnetic spectrum to facilitate the transfer of information. Radios exist in a multitude of items such as cell phones, computers, car door openers, vehicles and televisions.

Traditional hardware based radio devices limit cross-functionality and can only be modified through physical intervention. This results in higher production costs and minimal flexibility in supporting multiple waveform standards. By contrast, software defined radio technology provides an efficient and comparatively inexpensive solution to this problem, allowing multi-mode, multi-band and/or multi-functional wireless devices that can be enhanced using software upgrades (SDRF, Base Station System Structure, 2002).

Figure 2.8 shows a generalized functional architecture of a software defined radio.

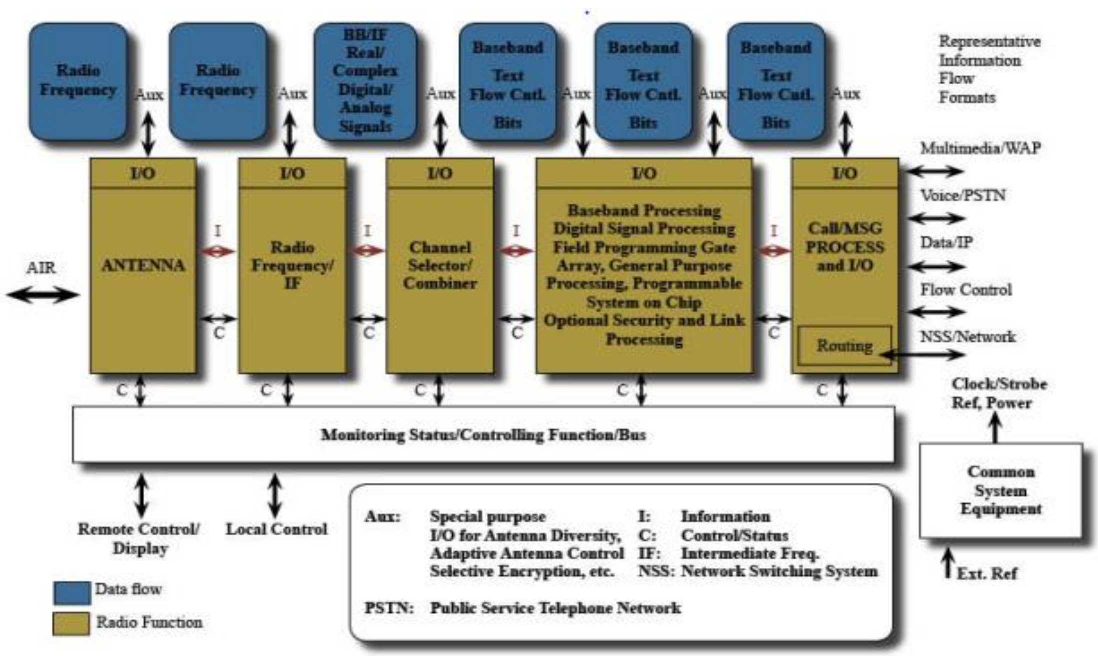

Figure 2.8 Generalised Functional Architecture of an SDR

Source: SDRF, 2002

2.13.1. Cognitive Radio

A cognitive radio is a radio in which communication systems are aware of their internal state and environment, such as location and utilisation on RF frequency spectrum at that location. They can make decisions about their radio operating behavior by mapping that information against predefined objectives (SDRF, Cognitive Radio Definitions and Nomenclature, 2008).

Cognitive radio is further defined by many to utilise SDR, Adaptive Radio and other technologies to automatically adjust its behaviour or operations to achieve desired objectives. The utilisation of these elements is critical in allowing end-users to make optimal use of available frequency spectrum and wireless networks with a common set of radio hardware. This will reduce cost to the end-user while allowing him or her to communicate with whomever they need whenever they need to and in whatever manner is appropriate (SDRF, Cognitive Radio Definitions and Nomenclature, 2008).

There are two major subsystems in a cognitive radio; a cognitive unit that makes decisions based on various inputs and a flexible SDR unit whose operating software provides a range of possible operating modes. A separate spectrum sensing subsystem is also often included in the architecture of a cognitive radio to measure the signal environment to determine the presence of other services or users. These subsystems do not necessarily define a single piece of equipment, but may instead incorporate components that are spread across an entire network. As a result, cognitive radio is often referred to as a cognitive radio system or a cognitive network (SDRF, Cognitive Radio Definitions and Nomenclature, 2008).

The cognitive unit is further separated into two parts as shown in figure 2.9. The first labelled the

"Cognitive engine" tries to find a solution or optimise a performance goal based on inputs received defining the radio's current internal state and operating environment. The second engine is the "policy engine" and is used to ensure that the solution provided by the "Cognitive engine" is in compliance with regulatory rules and other policies external to the radio.

Figure 2.9 shows the Cognitive Radio Concept Architecture.

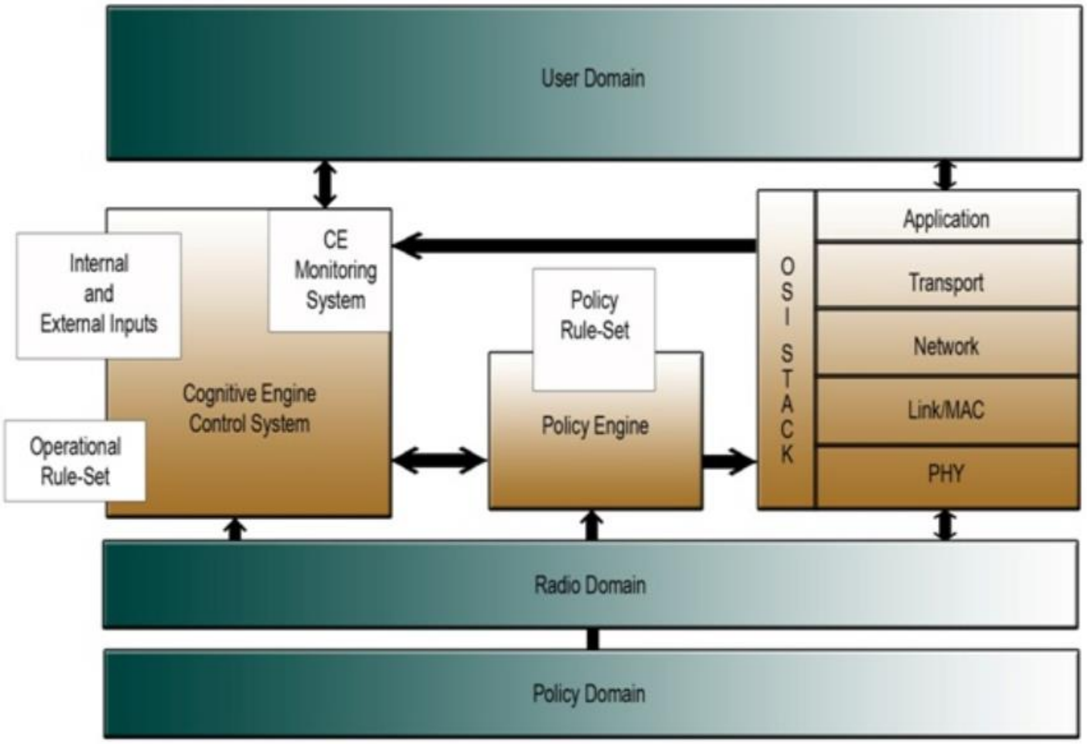

Figure 2.9 The Cognitive Radio Concept Architecture

Source: SDRF, Cognitive Radio Definitions and Nomenclature, 2008

2.13.2. Dynamic Spectrum Access

Dynamic Spectrum Access (DSA) is a new spectrum sharing paradigm that allows secondary users to access the abundant spectrum holes or white spaces in the licensed spectrum bands. DSA is a promising technology to alleviate the spectrum scarcity problem and increase spectrum utilisation. It allows devices to use unoccupied portions of the spectrum without interfering with the licensee's transmissions. This technique enables a more flexible utilisation of spectrum that is not in use with traditional spectrum management techniques. TV white space constitutes part of the unused spectrum in the TV band that can be made available using innovative techniques such as DSA. Wireless devices can also use DSA techniques such as sensing and geo-location databases to learn about available TV channels for wireless communication (Kameri-Mbote, Odhiambo, Muriungi, & Nyawira, 2016).

2.13.3. Enabling Architectures Supporting Cognitive Radio and Dynamic Spectrum Access

Support for cognitive radio and dynamic spectrum access requires a number of enabling technologies that are under development by the members of the Wireless Innovation Forum:

i. Information processing Architecture: A top-down model and a series of tools depicting the structure of complex systems to aid in defining, designing and selecting relevant cognitive radio processes is really important to help in understanding the current state of complex information systems.

ii. Modeling Language: Flexible and efficient communication protocols are required between advanced radio systems and subsystems to support next generation features such as vertical and horizontal mobility, spectrum awareness, dynamic spectrum adaption, waveform optimization, feature exchanges and advanced applications. A modeling language built on detailed use cases and defining the signaling plan, requirements and technical analysis of the information exchanges provides the basis for developing specifications and standards supporting these capabilities. Figure 2.10 shows a modeling language expressed in a formal declaration that is machine readable that is used to define the communications infrastructure of the cognitive radio.

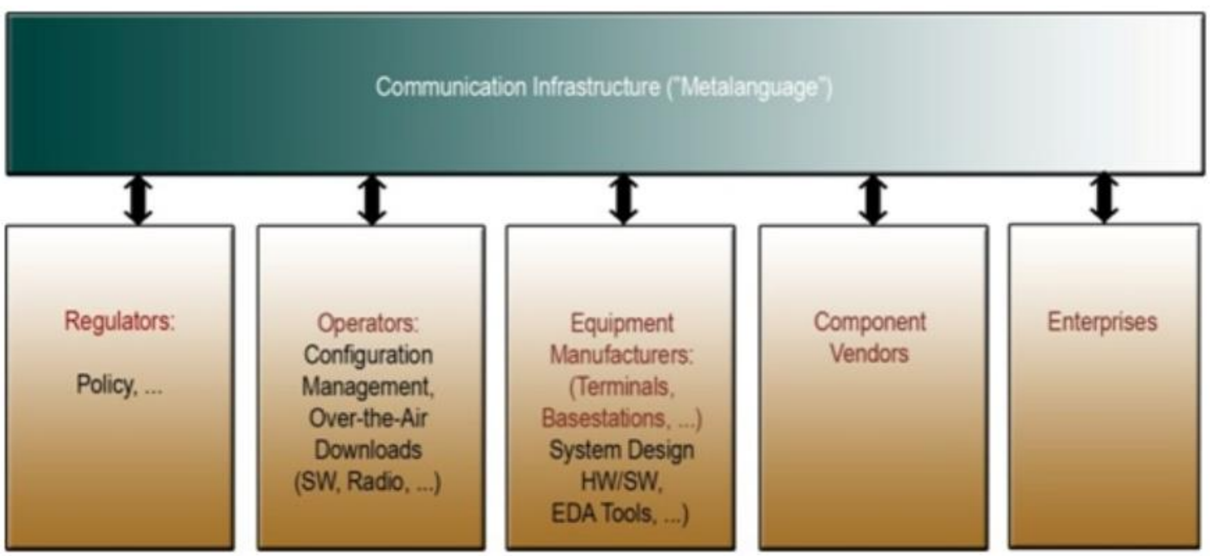

Figure 2.10 Modeling Language Diagram for a Communications Infrastructure of a Cognitive radio

Source: SDRF, Cognitive Radio Definitions and Nomenclature, 2008

iii. Radio Environment Map: Operation of a cognitive engine requires data and meta-data defining the spectral environment that a terminal is operating in at a given moment in time. Referred to as the radio environment map, this data can include information on spectrum economic transactions, dropouts, handovers, available networks and services. Data contained within the map is derived, in part, by capturing and synthesising measurements from many radios, and may be stored in a database that can be accessed remotely by the cognitive engine. Requirements for a database structure enabling this access including standardised database structures, data formats and functionality must be defined to support the flexibility necessary to accommodate current and future cognitive radio spectrum applications such as mobility, spectrum economic transactions, dropouts, handovers, available networks and services.

iv. Test and Measurement: Cognitive radios pose unique test challenges in quantifying the performance of critical functions such as spectrum sensing, interference avoidance, database performance and adherence to policy. Test methodologies supporting these challenges must be developed to consider a range of hardware platforms, protocols, algorithms, use cases and spectrum stakeholder requirements. Test equipment functionality and performance, test interfaces and test nodes must also be taken into account.

2.14. Adopted Trends in the Connectivity Infrastructures in Internet of Things (IoT)

The Internet of Things (IoT) is a collection of connected objects, embedded electronics, software, sensors and wireless connectivity protocols that collect and exchange information with applications through wireless networks connected to the Internet. It allows connected objects to remotely communicate and be remotely controlled through applications by leveraging existing internet infrastructures, combined with optimised wireless communication systems (Ducrot, et al., 2016).

Internet of Things (IoT) applications have diverse connectivity requirements in terms of range, data throughput, energy efficiency and device cost. WiFi has been cited as an obvious choice because in-building WiFi coverage is almost ubiquitous, but it is not always the appropriate choice.

Data transfer requirements for IoT vary from small, intermittent payloads like utility meters to large amounts of continuous data such as real-time video surveillance. Range requirements can span from very short distances for wearables to several kilometers for weather and agriculture applications (Parekh, 2017). One thing that is common is power constraint. IoT devices require constant connectivity but they may not always have continuous access to power source. This hence calls for a redesign of the components making up an IoT node for sustainable power supply and the desired connectivity.

A number of standards based and proprietary last mile connectivity options have evolved to service IoT and each has advantages and limitations. Table 2.6 presents a reference table of technologies available for IoT connectivity.

Table 2.6 Reference Table of The Various Technologies Available for IoT Connectivity

Technology	Network	Standards based or Proprietary	Range	Throughput	Energy requirement	Adoption
LoRa	LWPA	Proprietary (Semtech)	High	Low	Low	Moderate
NWave	LWPA	Proprietary (NWave)	High	Low	Low	High
RPMA	LWPA	Proprietary (OnRamp Total Reach)	High	Low	Low	High
SigFox	LWPA	Proprietary (SigFox)	High	Low	Low	Moderate
LTE-M	3GPP/LTE	Standards based (3GPP)	High	High	Low	Upcoming
NB-IoT	3GPP/LTE	Standards based (3GPP)	High	Moderate	Low	Increasing
NB-CIoT	3GPP/LTE	Standards based (3GPP- Huawei, Qualcomm)	High	Moderate	Low	Upcoming
NB-LTE	3GPP/LTE	Standards based (3GPP- Ericsson)	High	Moderate	Low	Upcoming
Bluetooth	Bluetooth	Standards based	Moderate	Low	Moderate	Limited Wearables
ZigBee	802.15.4	Standards based (802.15.4)	Low	High	Moderate	Limited PAN & Home
Thread	802.15.4	Standards based (802.15.4)	Low	High	Moderate	Upcoming
Z-wave	Proprietary	Proprietary (Sigma Design)	Low	Low	Moderate	Very Low Home Automation
WiFi	802.11	Standards based	Moderate	High	High	Very high
WiFi HaLow	802.11ah	Standards based	High	High	Low	Upcoming
HEW	802.11ax	Standards based	Moderate	High	Moderate	Upcoming

Source: Parekh, 2017

In this study, four major technologies of connectivity are covered. This include:

i. Wi-Fi;
ii. LoRa;
iii. Cellular Network – GSM/GPRS and Narrow Band IoT (NB-IoT) and
iv. SigFox.

2.14.1. Wi-Fi

Wi-Fi or 802.11, is a wireless protocol that was built with the intent of replacing Ethernet using wireless communication over unlicensed bands. Its goal was to provide off-the-shelf, easy to implement, easy to use short-range wireless connectivity with cross-vendor interoperability. With zero spectrum cost, there was little focus on spectral efficiency and with expected use of desktop devices, power efficiency was not critical (Parekh, 2017).

Devices with wireless adapters such as laptops, phones and now the IoT wireless modules use these adapters to translate data into radio signals and transmit them using their antennae. Those radio waves emanate outwards from the antenna and are received by the wireless router within their environment. The wireless router then converts the radio waves back into data and sends that data to the Internet using a physical connection. WiFi uses this wireless communication technique at frequencies of 2.4 GHz or 5 GHz. These frequencies are higher than the ones for cellular transmission to allow more data to be carried (McClelland, 2017). This mechanism hence is what drives the many WiFi modules implemented in the IoT ecosystem to transmit sensor data. In the implementation of IoT systems and solutions, Wi-Fi has its own pros and cons as listed in table 2.7.

Table 2.7 Pros and Cons of Wi-Fi in IoT

Pros	Cons
Low cost of infrastructure and devices	High power consumption
Ease of deployment	Moderate range
Points of presence	Spectrum congestion

2.14.2. LoRa

LoRa is a spread spectrum modulation scheme that uses wideband linear frequency modulated pulses whose frequency increases or decreases over a certain amount of time to encode information. The main advantages of this approach are twofold: a substantial increase in receiver sensitivity due to the processing gain of the spread spectrum technique and a high tolerance to frequency misalignment between receiver and transmitter (Semtech, 2013).

Several radio technologies co-exist to deploy Low Power Wide Area (LPWA) networks. Along with the Ultra Narrowband (UNB) protocol, LoRa and its MAC layer implementation, Long Range Wide Area Network (LoRaWAN), is the LPWA network solution currently gaining the most traction to support IoT applications and services (Ducrot, et al., 2016). Figure 2.11 shows the graph of power consumption against range of data transmission of LoRaWAN in comparison to Bluetooth low Energy (BLE), WiFi and the cellular network.

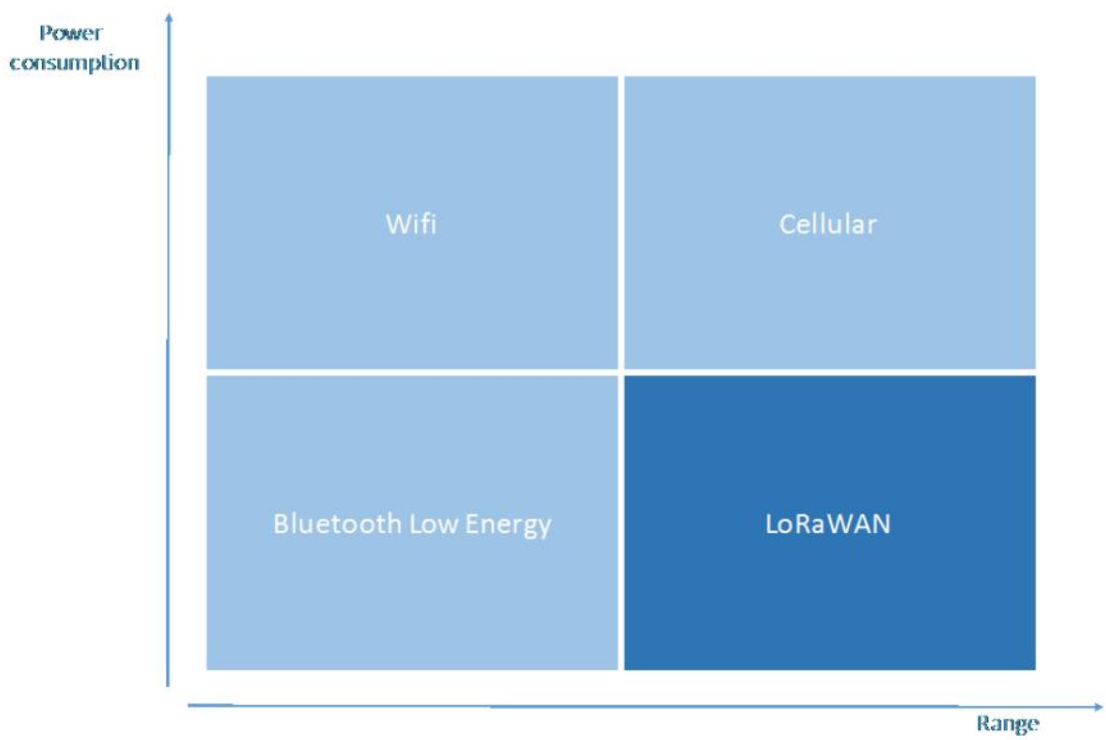

Figure 2.11 Graph of Power Against Range for Various Connectivity Technologies

Source: Ducrot, et al., 2016

LoRaWAN (LoRa for Wide Area Networks) specification is a Media Access Control (MAC) standardised layer developed to extend the LoRa physical communication layer onto Internet networks. This is based on the LoRa radio modulation technology that was invented in 2010 by a French startup called Cycleo. Cycleo was acquired by Semtech, a semiconductor company, in 2012. The specification of LoRaWAN is open sourced and supported by the LoRa Alliance. The LoRaWAN protocol also includes several key wireless network features such as End-to-End (E2E) and security, adaptive rate optimization, quality of service and other advanced communication applications (Ducrot, et al., 2016). A typical LoRaWAN network architecture is as shown in figure 2.12.

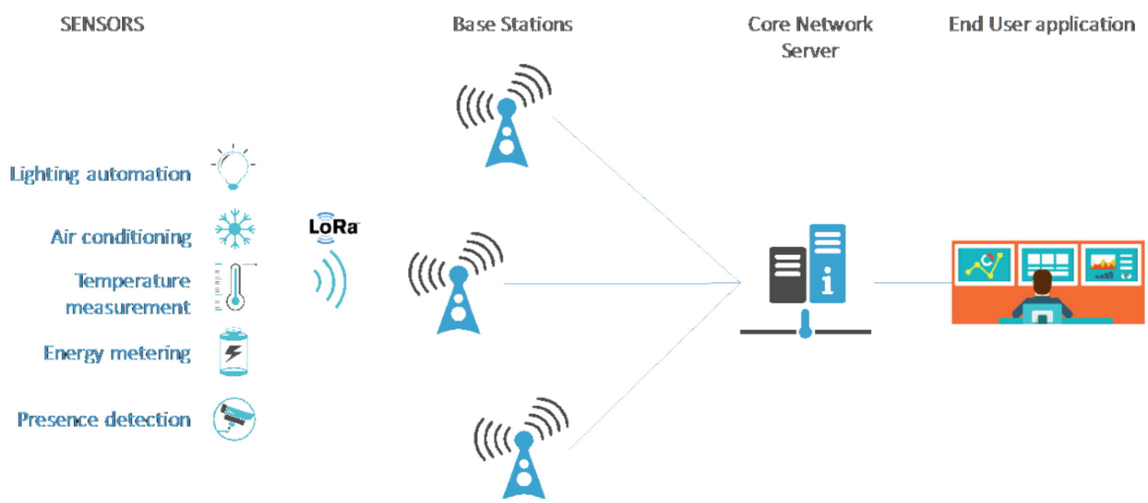

Figure 2.12 A Typical LoRaWAN Network Architecture

Source: Ducrot, et al., 2016

LoRaWAN networks are typically laid out as "star-of-stars" topology in which gateways relay messages between end-devices and a central core network server. All gateways are connected to the core network server via standard IP connections while end-devices use single-hop LoRa communication to one or many gateways. All communication is natively bi-directional, although uplink communication from an end-device to the network server is expected to be the predominant use case and traffic pattern.

Communication between end-devices and gateways is spread out on different frequency channels and data rates. The selection of the optimized data rate is a trade-off between the communication range and the message duration. Communications using different data rates do not interfere with each other. LoRa supports data rates ranging from 300 bps to 5 kbps for a 125 kHz bandwidth. In order to maximize both the battery life of each device and the overall capacity available through the system, LoRa network infrastructures reuse and Adaptive Data Rate(ADR) scheme to manage the individual data rates and RF output of each connected device. End-devices may transmit on any channel available at any time, using any available data rate, as long as the following rules are respected:

• The end-device changes channel in a pseudo-random fashion for every transmission. The resulting frequency diversity makes the system more robust against interference.

• In EU 868 ISM band, the end-device has to respect the maximum transmit duty cycle relative to the sub-band used and local regulations (1% for end-devices)

Adaptative Data Rate is the procedure by which the network instructs a node to perform a rate adaptation by using a requested data rate (and a requested TX Power in future LoRaWAN versions). Table 2.8 illustrates the Data Rate as function of the distance and the Spreading Factor (SF). As illustrated, LoRaWAN optimizes the communication data rate to minimize the airtime and power consumption of devices. Compared to fixed data rate of LPWA technologies, this optimization can lower average power consumption of a connected object by a factor of 100.

Table 2.8 LoRaWAN Protocol Spreading Factors Versus Data Rate and Time-on-Air

Spreading factor (at 125 kHz)	Bitrate	Range (indicative value, depending on propagation conditions)	Time on Air (ms) For 10 Bytes app payload
SF7	5470 bps	2 km	56 ms
SF8	3125 bps	4 km	100 ms
SF9	1760 bps	6 km	200 ms
SF10	980 bps	8 km	370 ms
SF11	440 bps	11 km	740 ms
SF12	290 bps	14 km	1400 ms

(with coding rate 4/5 ; bandwidth 125Khz ; Packet Error Rate (PER): 1%)

LoRaWAN uses licence-free spectrum, usually ISM (Industrial, Scientific, Medical) bands to communicate over the air. In Europe, ETSI regulates the ISM band access on the 868 MHz and 433 MHz bands. The usage of these bands is submitted to limitations: The output power (EIRP) of the transmitter shall not exceed 14 dBm or 25 mW and the duty cycle imposed in Europe by ETSI is limited to 1% (for devices) or 10% (for gateways) depending on the used sub-band.

The downside of LoRaWAN is that its data ranges from 0.3 kbps to 50 kbps per channel. The most common digital video formats for IP-based systems are MJPEG, MPEG-4 and H. 264 with bit rates that range from 130kbps with low quality MJPEG coding to 4 Mbps for 1920x1080 resolution. Hence LoRaWAN does not support video-based applications. It is suitable for the applications in the domains such as metering, real-time agricultural, leak detection or environmental domains and smart city applications such as smart lighting, smart-parking and smart waste collection (Adelantando, et al., 2017).

2.14.3. Cellular Networks

Cellular networks have undergone a revolution that can now provide better data and information services. They can also be used for wide-area Internet access. These are among the things that were described as future developments in telecommunications 15 years ago (Anttalainen, 2003). The third Generation Partnership Project (3GPP) standardised a set of low cost and low complexity devices targeting Machine-Type-Communication (MTC) in Release 13. In particular, 3GPP addresses the IoT market from a three-fold approach by standardising the enhanced Machine Type Communications (eMTC), the Narrow Band IoT (NB-IoT) and the EC-GSM-IoT (Adelantando, et al., 2017).

The cellular solutions for IoT, also known Cellular IoT is currently riding on 2G, 3G and 4G. 2G implementation basically provides an M2M environment for exchanged of data between machines and personal digital assistants via the Global System for Mobile (GSM) communications standard. It is also important to note that cellular IoT rides on licensed spectrum (Adelantando, et al., 2017). A General Packet Radio Service (GPRS) implementation on cellular IoT gets to allow the 2G networks to be used through data packages that enables the edge devices to communicate with the cloud by means of Attention (AT) commands. AT commands are instructions used to control a modem (Alam, 2015).

Several mobile operators are also pushing for cellular low power wide area networks such as Narrow Band IoT (NB-IoT) and Long Term Evolution category M1 (LTE-M) as well as 5G. Narrowband IoT is the "clean sheet" initiative by 3GPP, the standards body that writes cellular standards, to address the needs of very low data rate devices that need to connect to mobile networks, often powered by batteries (Hunn, 2016). In Nick's piece he points out that the 3GPP specification for NB-IoT has two competing variants, Huawei/Vodafone vs. Erikson/Nokia/Intel. Additionally, Erikson has stated that older 4G infrastructure based on Alcatel will not be backwards compatible with NB-IoT. This means that thousands of base stations would have to be changed for carriers to support NB-IoT.

NB-IoT technology is expected to ease the massive deployment of IoT by allowing an existing operator such as Safaricom to introduce NB-IoT within its small portion of existing network and available spectrum. This technology is designed to ensure that ultra-low end IoT applications including remote sensors, smart buildings and smart meters are supported. NB-IoT is designed for optimal co-existence performance with legacy GSM, GPRS and LTE technologies. It operates within a minimum system bandwidth of 180 kHz for both the downlink and uplink operations, respectively. Due to its choice of operation, it is possible for a GSM operator to replace one GSM carrier of 200 kHz with an NB-IoT application. On the other hand, an operator of the LTE network can as well deploy NB-IOT applications into an LTE carrier by means of allocating one of its Pseudorandom binary sequence (PRBs) of 180 kHz. The NB-IoT (Cat-NB1), is a pioneer technology towards building the 5G New Radio Network which is intended to enable new use cases for the IoT. It is foreseen that NB-IoT will continue to evolve towards 5G future requirements (Akpakwu, Silva, Hanke, & Abu-Mahfouz, 2017).

Research has shown that the future 5G mobile networks have to cater for the massive deployment of IoT with billions of connected smart objects and sensors that will be a global representation of the real world and to support the provision of mission critical IoT use cases, which will require real-time responses and automation of dynamic processes across different field of operations including vehicle-to-infrastructure , high speed motion, vehicle-to-vehicle (V2V), and as well as process control system. The 5G new radio network which is currently under consideration is expected to cater for both Massive and Critical IoT use cases as the demand for machine communications continue to grow extensively for connecting a massive number of smart devices with the benefits of using cellular networks. In light of this, further enhancements are currently being introduced in M2M and NB-IoT systems as specified in the current 3GPP Release-14 for cellular IoT, being the first normative phase for 5G standards. Currently, 3GPP standardization is working towards ensuring that further enhancements of KPIs are introduced into existing 4G networks to ensure that the 5G mobile network is designed from scratch in order to accommodate the growing span of the IoT use cases into the market, and minimizing the cost of developing new networks (Akpakwu, Silva, Hanke, & Abu-Mahfouz, 2017). In 3GPP Release-14, some of the expected key performance features and enhancements for M2M and NB-IoT systems highlighted for Massive and Critical IoT applications to be considered for discussion are briefly introduced as follows:

- General Enhancements to MTC
- Enhancements of NB-IoT
- NB-IoT RF requirement for co-existence with CDMA networks
- Release – 14 extensions for Cellular Internet of Things (CIoT)
- New band support for Release – 14 NB-IoT
- New services and Markets Technology Enablers

2.14.4. Sigfox

SigFox low power wide area network (LPWAN) technology offers a complete end-to-end connectivity solution which is based on their patented technologies by using ultra-narrowband (UNB). Since M2M communications requires a small amount of data to be transferred efficiently on a low bandwidth, SigFox suits such type of communication. This technology is deployed by using proprietary base stations which are configured with cognitive software-defined radios by connecting them to backend servers utilizing IP-based network infrastructure as depicted in Fig. 3. SigFox end devices connect to the network base stations by using a unique modulation scheme called Binary Phase Shift keying (BPSK) in an ultra-narrowband of 100Hz Sub-GHz Industrial, Scientific and Medical (ISM) band carrier. With UNB, SigFox technology provides higher sensitivity, ultra-low power consumption and long ranges by efficiently utilizing its bandwidth at the expense of limited data rates, which is adequate for IoT since most applications do not require high throughputs. SigFox networks use the unlicensed ISM band and as such its frequency of operation varies accordingly between 868 MHz and 915 MHz and enables wide coverage using line-of-sight communication. For instance, in rural areas, range up to 30-50 km and beyond can be achieved through frequency hopping, and this range is reduced to 3-10 km in urban locations due to the presence of obstacles. The SigFox network supports up to 12 bytes of packet size for each message using typical modulation including Gaussian Frequency-Shift Keying (GFSK) for downlink and Differential Binary Phase Shift Keying (DBPSK) for uplink transmission respectively.

Uplink messages are restricted/limited to 140 12-bytes messages per day which on the other hand conform to the regional regulations which states no use of license-free spectrum, while allowing 4 8-bytes messages per day for downlink transmission from the base stations to end connected devices. However, ultra-narrowband signals are susceptible to any aggressive bursts exceeding the duration of a bit (i.e. 10 ms), causing devices in a SigFox network to retransmit frames a number of times. This in turn increases the traffic load. Figure 2.13 shows an overview of SigFox MTC network.

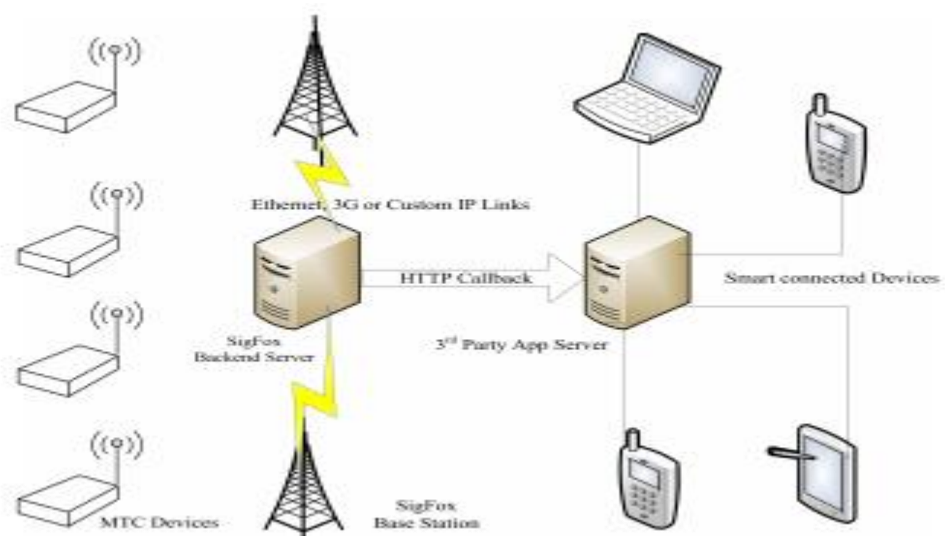

Figure 2.13 Overview of Sigfox MTC Network

Source: Akpakwu et al., 2017

Conclusions

Transmission of real-time video feeds requires a strong signal strength of the network. HD video feeds with a default resolution of 1920x1080 operate at 4 Mbps for high quality streaming. The technologies covered in this study such as LoRa, Sigfox, NB-IoT and the GSM/GPRS have their own merits and demerits in comparison with TV White Space in achieving real-time video streaming. LoRa, Sigfox and NB-IoT are all under the LPWAN family. The traditional set up of GSM/GPRS cannot reliably allow transmission of good quality video feeds especially on the 2G infrastructure. The 3G infrastructure has a good quality of service in this regard but the challenge of the coverage and the cost of data limits the adoption. LoRa technology, on the other hand, is only effectively in machine to machine communication. The protocol used by LoRa modulation technique is LoRaWAN. LoRaWAN uses licence-free spectrum, usually ISM (Industrial, Scientific, Medical) bands to communicate over the air. The downside of LoRaWAN is that its data ranges from 0.3 kbps to 50 kbps per channel. Hence LoRaWAN does not support video-based applications. Sigfox also operates in the ISM bands although uses binary phase-shift keying (BPSK). Its implementation requires a massive rollout of base stations and even its coverage in terms of signal strength does not guarantee live-streaming of feeds due to the spectrum size in use. NB-IoT on the other hand operates in the licensed spectrum band like TV White Space. The only difference on this, is that NB-IoT is on the cellular band while TV White Space on the TV band. The implementation of NB-IoT is limited by coverage and its adoption in Kenya has not been tested yet. The propagation characteristics of TV White Space discussed here in terms of signal strength and coverage especially in the areas where most conservancies are located makes the technology the most suitable in adopting live-streaming remote cameras.

CHAPTER 3: RESEARCH METHODOLOGY

3.1. Introduction

A methodology is defined as a set of procedures and techniques that are utilised within a particular discipline or applied to a particular branch of knowledge. Research methodology is a systematic way to solve a problem. It is a science of studying how research is to be carried out (Philominathat, Chinnathambi, & Rajasekar, 2013).

In this chapter, the methodology used in carrying out this research is discussed. It includes the usage of qualitative and quantitative methods to gather data on the status of the conservancies and the challenges that exist in adopting networked cameras to monitor these environments. The research also explains its usage of experiments to demonstrate a prototype that uses low-cost electronic components that can remotely provide captured video feeds on a mobile interface. The study also gathered information from secondary sources on various technologies that have been documented in this respect.

3.2. Requirements Phase

In this phase, the study focused on addressing the first two research questions of this study. The first question which seeks to investigate the existing challenges in the adoption of networked cameras for monitoring game environments was probed through the use of questionnaires and interviews.

An online questionnaire was sent to a representative at Ol Pejeta Conservancy and Sentinel Mara Camp. These two served as a sample of the population of the conservancies and safari camps in Kenya. This is due to the ease of accessibility of representatives from these two places physically and via email. The questionnaire sent to these representatives was shared with a team of at least five respondents in both of their stations. The questionnaire encompassed a set of questions that detailed an investigation on specific narrow questions which included the following:

i. Personal information of the respondents in terms of their duty and the period they have been at the environment (at the conservancy or safari camp)

ii. The usage of technology specifically the Internet.
iii. A response or view on the signal strength of the Internet connection
iv. An outline of a set of challenges that are experienced in this ecosystems in adopting a networked camera system.
v. Their view on camera installation at their environment for Wildlife monitoring.

The researcher visited the Ol Pejeta while at the Mawingu testbed to carry out an interview with a representative at the conservancy to seek a one on one engagement on the current implementation of the camera-traps and the challenges exhibited so far. This also included their feeling and understanding on implementing a TV White Space network and a networked camera system for monitoring the wild game.

In addressing the second question of this research which involves a deeper study on the various related works done on implementation of IP-based camera solutions including the type of connectivity used, this research scrutinised the existing secondary sources on this. Various journals, books, investigative reports and published implementations were studied alongside the existing drawback and recommended future works. This question was also addressed through inquiry by email to institutions and organisations that have implemented IP-based cameras in other countries. A questionnaire was also sent out to help provide a comprehensive report on the infrastructures implemented in such ecosystems.

3.2.1. Study Variables

The study variables include the location of the study, sample target population, type of research methods used, sampling strategies, research instruments, data collection analysis procedures used, all of which determine the viability of the research done.

3.2.1.1. Location of the Study

Mawingu Networks in Nanyuki was the location of the study. It was chosen because it is the only approved environment by the Communications Authority of Kenya for TV White Space implementation as at now. With Ol Pejeta conservancy being close to the location of study, it was easy to carry out a survey on the utilisation of the TV White Space to provide connectivity.

3.3. Design Phase

This phase probed the design of a prototype that combines usage of hardware to capture feeds through the cameras and transmit it through the TV white space devices as well as software implemented on top of the hardware, on the server side and the user interface. In the design of the hardware for sensing and communication, the following engineering design principles will be followed and keenly studied:

i. The technical reference documentations and data sheets to understand the power and signal requirements.
ii. Study of safety and security requirements, configurable settings such as the interfacing of the camera and the ARM-based System-On-Chip.
iii. The operational diagnostics as well as the mechanical, electrical, environmental and policy requirements of the TV White Space devices
iv. The testing principles of the various hardware components, sensors and cameras.

3.3.1. Software Design Methodology

The software modelling and design approach adopted in this research was Agile (Bjork, 2018). This methodology was used in this study to provide an iterative development approach in order to strictly and sensitively evolve the requirements to fit into the hardware that was used as well the user interface which was Android-based.

The three major steps of software development life-cycle, that is, planning, execution and delivery was broken down in the following design sub-phases aligning to the standard format of Agile software design methodology used here:

3.3.1.1. Requirements Gathering and Architectural Design

Under this design sub-phase, the first timebox of Agile development was built. This is the timebox that elicited the software requirements of the remote game monitoring system developed under this study. The programming environments, data flow diagrams and the overall architectural design of the server side and client side was crafted here including the overall high-level modelling of the system. Functional and non-functional requirements detailing the features and capabilities of the system to be developed as well as usability factors were gathered here including time slices for implementation.

3.3.1.2. Interface, Component and Data Structure Design

This sub-phase basically delved into the design of the system in terms of data flow, the bridge APIs that links the server side and the front-end and the interfaces for both web and Android platforms. Abstract specifications were also done here to understand the connection links and graphics in achieving a system that synchronises properly for the user and the interaction of the user and the system. The implementation of the data structure design involved mapping of the data of the users at the conservancies and safari camps in properly defined functions of the server side. In Agile format, this sub-phase fit into the timebox of design.

3.3.1.3. Algorithm Design and Software Development

Here, the system under this study was implemented in terms of development of algorithms and code. This timebox in Agile format is referred to as the development and testing phase. This sub-phase majorly dealt with the design of the algorithms meant to provide the services to the conservancy and safari camp users modelled in the system and technically implemented through the programming languages selected under the definition of requirements. The study used agile methodology for the software development life cycle. This is as illustrated in figure 3.1. This is due to the following reasons:

i. Rapid and continuous delivery of software to allow improvement of the software versions.
ii. People and interactions are emphasised rather than process and tools to have the users of the software relate to it.
iii. Continuous attention to technical excellence and good design.
iv. Regular adaptation to changing circumstances

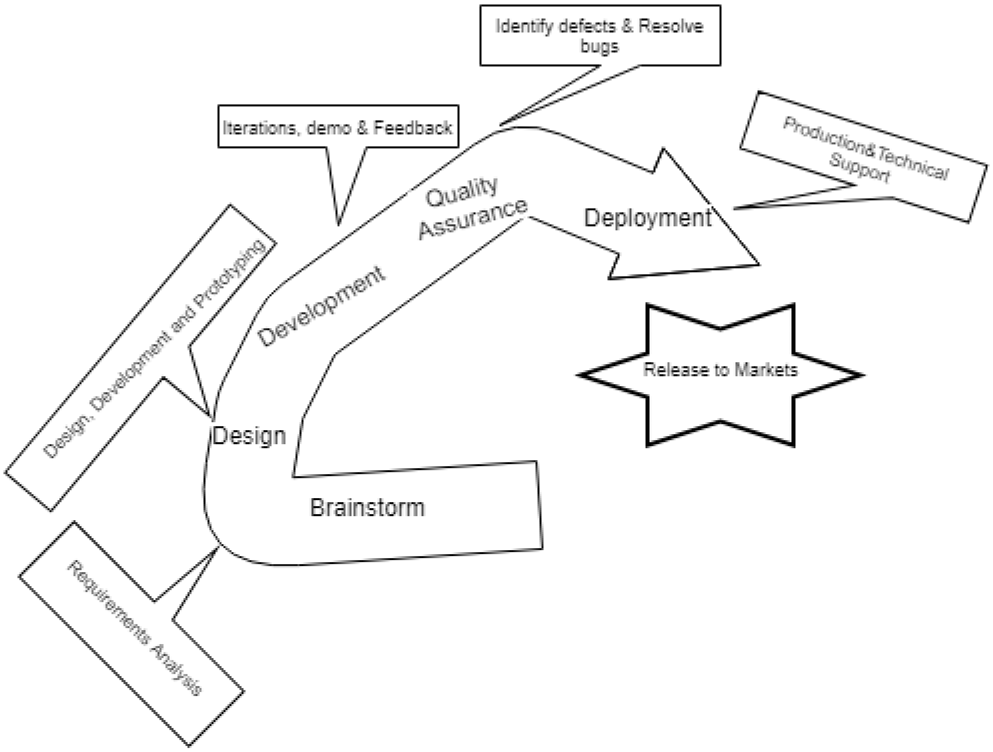

Figure 3.1 Agile Methodology

3.4. Implementation Phase

This phase delved into the implementation of the described prototype in this study. The prototype implemented here has both a hardware and a software element. The hardware element encompasses development of the side that captures feeds through the programmed cameras and the side that transmits the feeds. The software element implements the integration of the hardware to the server side and the front-end user interface.

In implementing the prototype under this study, the following are the sub-divisions of these components:

3.4.1. Hardware

The following hardware was used in this study:

i. An Arm-based Raspberry Pi System-on-Chip (SoC)
ii. Raspberry Pi camera module v2 on Camera Serial Interface (CSI)
iii. Connectors for the GPIO pins
iv. A mini-solar panel and a 7.4V battery
v. Adaptrum Radio modules for the TV White Space devices

3.4.2. Software

The following software was used in this research:

i. Conceptual modelling tool: draw.io (https://www.draw.io/)
ii. Wireframe and architecture design tool: Balsamiq (https://balsamiq.com/)
iii. Programming Languages: C, Python, PHP, Node.js and Java
iv. Server Side: A VPS storage from Microsoft Azure cloud.
v. Database: MySQL (https://www.mysql.com/) with apache server.
vi. Front-end/User Interface: Content Management System (CMS) with Mobile-Web for Android.

3.4.3. Implementation Tools

The following tools will be used for the implementation of the prototype under this study:

i. Visual Studio Code for software development of the hardware and Server side scripts (https://code.visualstudio.com/)
ii. Android Studio for Java development
iii. An online Control Panel for the Web Development

3.5. Prototype Evaluation and Validation Phase

Prototypes are experimental and incomplete designs which are cheaply and fast developed. Prototyping, on the other hand is the process of developing prototypes. It is an integral part of iterative user-centred design because it enables designers to try out their ideas and gather feedback (Greenberg, 1998). In this phase, the developed prototype was taken through compatibility and user tests as well as validation by a select set of the target users.

The compatibility test involved testing of the application on different Android versions, in this case Android Application Programming Interface (API) level 14 to 27. The testing was also done on Chrome, Firefox and Internet Explorer browser platforms.

Testing the reliability and speed of connectivity against other infrastructures such as Wi-Fi, cellular broadband and VSATs was carried out by a select group of people on the different infrastructures. Since the research was tested at a TV white space environment, a comprehensive report on the reliability and speed is provided for this study. The Wi-Fi tests were carried out at Strathmore University while the VSAT tests were given as a report from Sentinel Mara Camp through the shared questionnaire.

The user test was carried out randomly by a select group of three people at the Mawingu networks station and a group of seven people from both Ol Pejeta and Sentinel Mara Camp. This was done through a questionnaire to survey the level of satisfaction achieved in using the application. The developed application was also shared by a team of five people from Strathmore University.

The tests done at the Mawingu station as well as the overall report on the deployed networked camera system will be used to validate the hypothesis that leveraging the connectivity provided by TV white spaces can reliably guarantee remote monitoring of the game environments using networked cameras.

CHAPTER 4: SYSTEM DESIGN AND ARCHITECTURE

This chapter gives a detailed design structure of the proposed implementation under this study. The chapter examines the technical design, system architecture, functional and non-functional requirements gathered during the research phase and their design.

4.1. System Requirements

The requirements for a system are the descriptions of what the system should do, that is, the services that it provides and the constraints on its operation. These requirements reflect the needs of customers for a system that serves a certain purpose, in this case, guarantee real-time monitoring of the wildlife through use of networked game cameras riding on TV band for connectivity (Sommervile, 2011). In this research, the system requirements have been gathered from a survey done at the Ol Pejeta and Sentinel Mara Camp habitats on select individuals who serve as the end-user representatives of the prototype system that has been developed. They involve use of hardware components as well as software.

4.1.1. Functional Requirements

These are statements of services the system should provide, how the system should react to particular inputs and how the system should behave in particular situations. In some cases, the functional requirements may also explicitly state what the system should not do (Sommervile, 2011). In line with the objectives of this study, the functional requirements for the mobile interface here include:

i. User Registration – This is the first process the users at the various conservancies and safari camps will have to undertake before using the Mobile Application. A user could register with their Gmail account as well.

ii. Select the camera – This allows the users at the various conservancies or safari camps to select a specific camera in their habitat and view the feeds in real-time.

iii. Login/Logout – This allows the user to logout of the Application.

iv. View Feeds history – This functionality allows the user to view the stored feeds

4.1.2. Non-Functional Requirements

Non-functional requirements as the name suggests, are requirements that are not directly concerned with the specific services delivered by the system to its users. They may relate to emergent system properties such as reliability, response time and store occupancy. Alternatively, they may define constraints on the system implementations such as the capabilities of I/O devices or the data representations used in interfaces with other systems (Sommervile, 2011).

In this study, non-functional requirements are included in the entire ecosystem, that is, from the hardware, connectivity to the user interface. The non-functional requirements in this study include:

i. User Credentials – For both the administrator and the end user accessing the system.
ii. Availability and accessibility – Internet connection is required for use of the mobile-web interface and transmission of the feeds captured by the networked game camera.
iii. Performance and Reliability – The TV White Space infrastructure deployed has to guarantee continuous connectivity for user access of the feeds.

4.2. System Design

System design under this study refers to the data, application and technology architectures providing the information engineering ecosystem of the implementation of a networked game camera. This design implements an Internet of Things (IoT) stack that involves the four layers which include sensing, connectivity, data storage and end user visualisation through an Android-based mobile-web. Concepts of the architectural design, use case diagram and its descriptions, context diagram, data flow diagram, domain model, system sequence diagram and the entity relationship diagram used in this study are discussed under this section.

4.2.1. Architectural Design

This is concerned with understanding how a system should be organised and designing the overall structure of that system. It is the critical link between design and requirements engineering, as it identifies the main structural components in a system and the relationships between them

(Sommervile, 2011). In agile processes which is the one used in this study, it is generally accepted that the early stage of the development process has to establish an overall system architecture.

The overall architectural design of the system developed under this study is shown in figure 4.2.

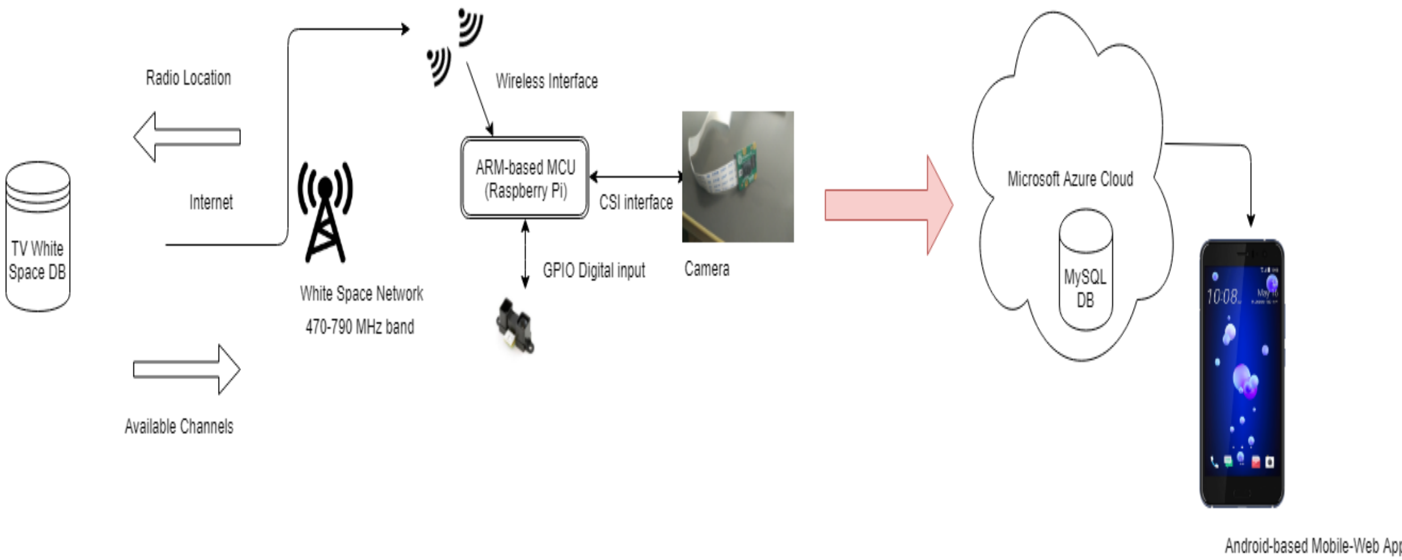

Figure 4.1 System Architecture of the Prototype Under Study

4.2.2. The Conceptual Model of the System

The following design diagrams elucidate the iterative implementation used in the development of the system under this study. They present an agile implementation of the data flows between the system and itself as well as its users. The diagrams covered here include the following:

1. Use Case diagram
2. Context diagram
3. Data Flow diagram
4. Partial Domain model
5. System Sequence diagram
6. Entity Relationship diagram

4.2.2.1. Use Case Diagram

In the development of the processes and data models for a networked game camera system that sits on top of TV white space connectivity, the system was broken down to add proper details to the definition of the requirements of this study. This was done through an outline of a set of activities that produce the interactive Android-based mobile interface that officers at the conservancies can use as well as visiting wildlife researchers at the safari camps.

Figure 4.3 shows the use case diagram of a networked game camera system under this research.

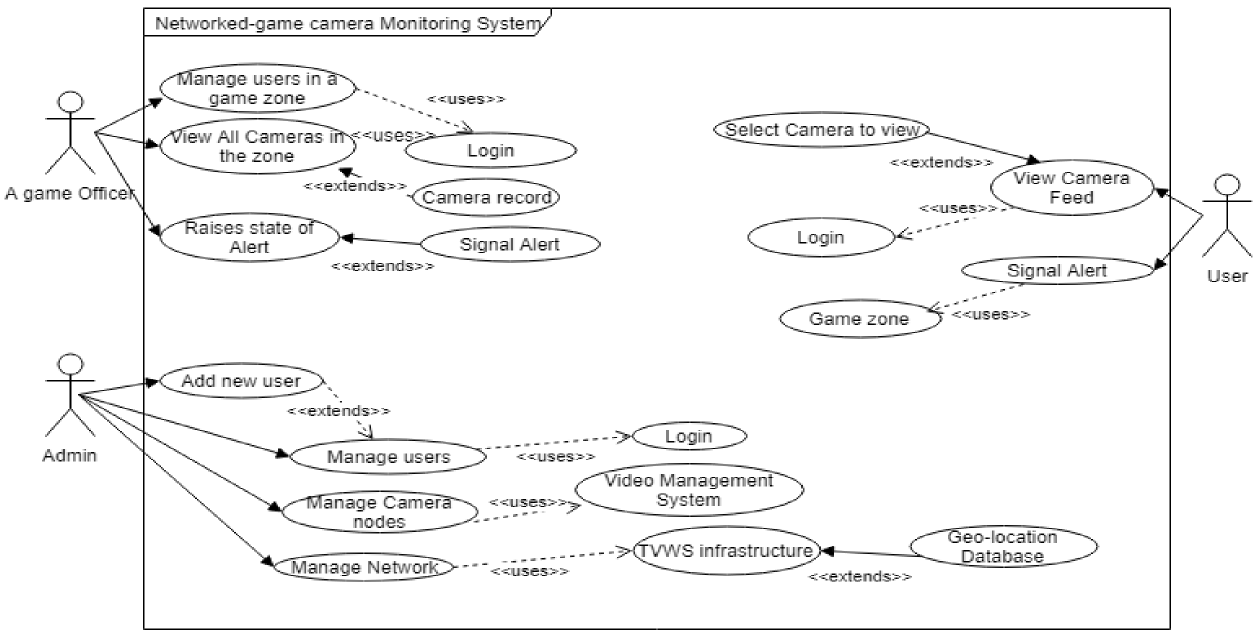

Figure 4.2 Use Case Diagram of a Networked Game Camera Monitoring System

4.2.2.1.1. Use Case Descriptions

View Camera Feeds

This use case gives details on the process of accessing the video feeds by a visiting tourist in a conservancy or a guest in the safari camp. Table 4.1 illustrates the description to this.

Table 4.1 View Camera Feeds Use Case Description

Use case Name	View Camera Feeds	Identifier: 1

Brief Description	User views feeds in a game zone	
Type	External	
Major Inputs: **User Credentials**	**Source** User	**Major Outputs** A List of camera interface
Preconditions	User credentials are confirmed by the back-end system	
Post Conditions	Camera provides real-time feed	
Flow of Events	1. User start the mobile App 2. The application presents an interface requesting for input fields for login 3. User enters the login details 4. The details are checked against the stored details in the database 5. The interface that has the various cameras is presented to the user	

Signal Alert Use Case

This use case enables the user to flag anything viewed in the conservancy or safari camp that requires immediate attention such as human-wildlife conflict or an abnormal behaviour identified on a viewed wild animal.

View All Cameras in a Zone

This is meant to be used by conservancy or safari camp officers to view the cameras attached to their station including a historical record of the feeds captured by these cameras.

Manage Camera Nodes

This use case presents an administrative data model of identifying all the cameras attached to the game officers in various nodes and their status in terms of functionality.

Manage Network

This use case still under the administrator actor describes the functionality of checking the available channels in use, the TV white space connectivity infrastructure signal strength and the interface to the geo-location database.

4.2.2.2. Context Diagram

This gives an overall flow of information between the entities in the system. It also describes the main components of the system under this research. Figure 4.4 shows the context diagram used in this study.

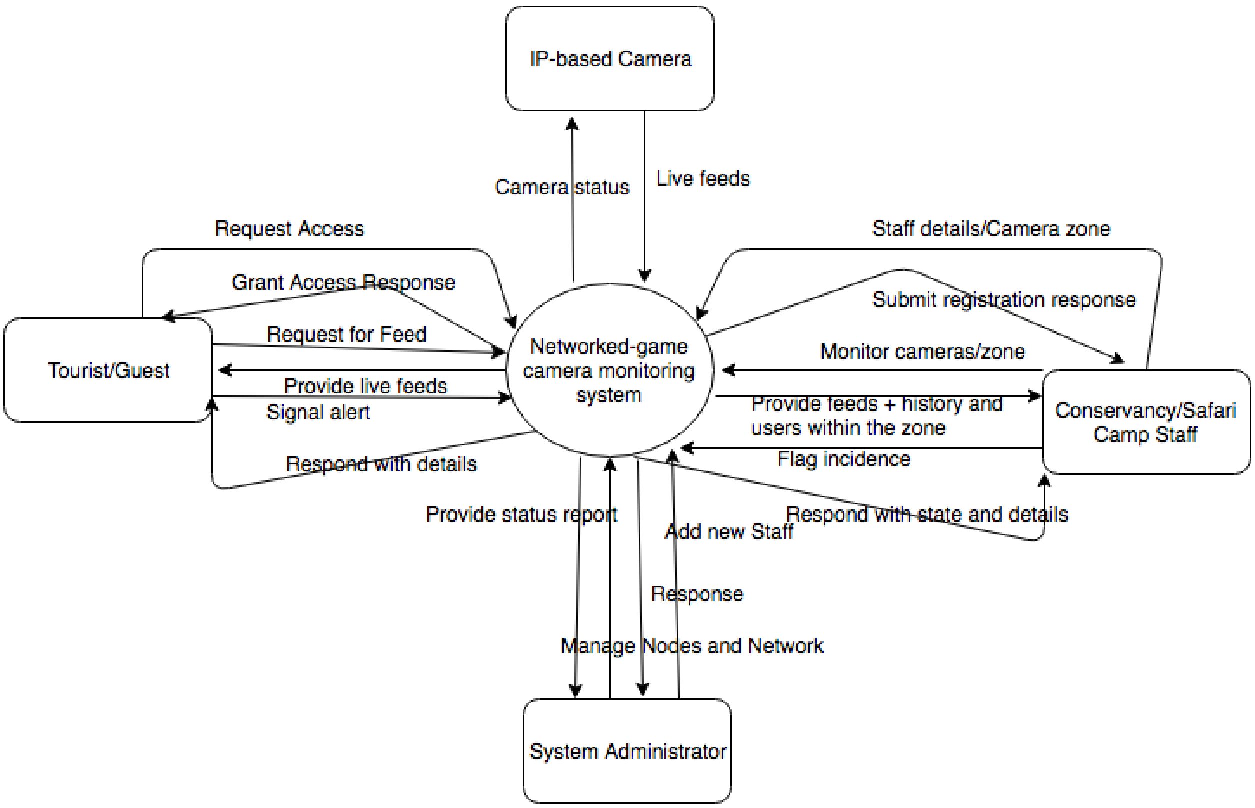

Figure 4.3 Context Diagram of The Networked Game Camera System

4.2.2.3. Data Flow Diagram

The information flow between the various components of the system under this study is as shown in figure 4.5.

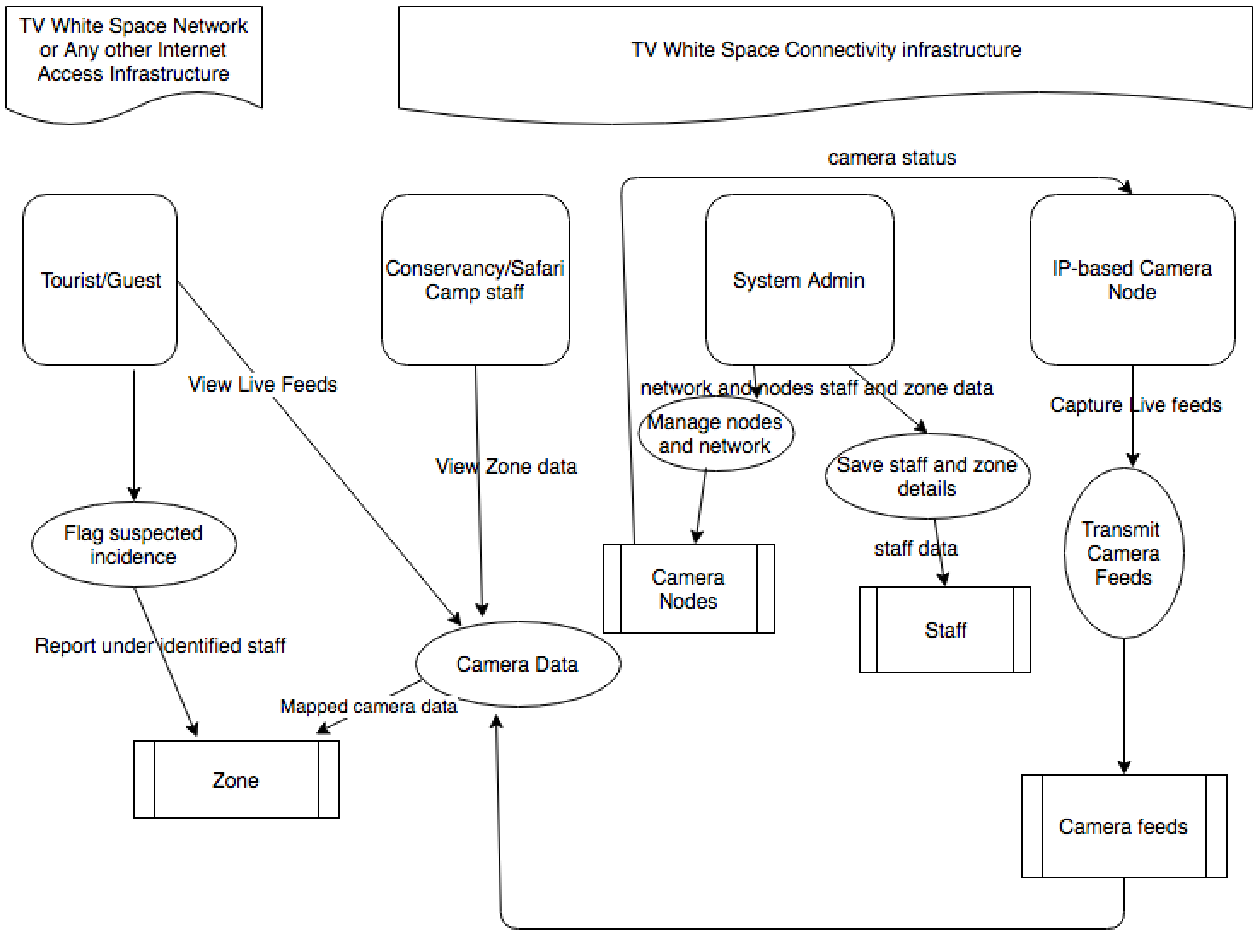

Figure 4.4 Data Flow Diagram

4.2.2.4. Partial Domain Model

Domain models identify the principle concerns in the system. These are defined using Unified Modelling Language class diagrams that include objects, attributes and associations (Sommervile, 2011). Figure 4.6 below shows the partial description of the objects, attributes and associations used in this study.

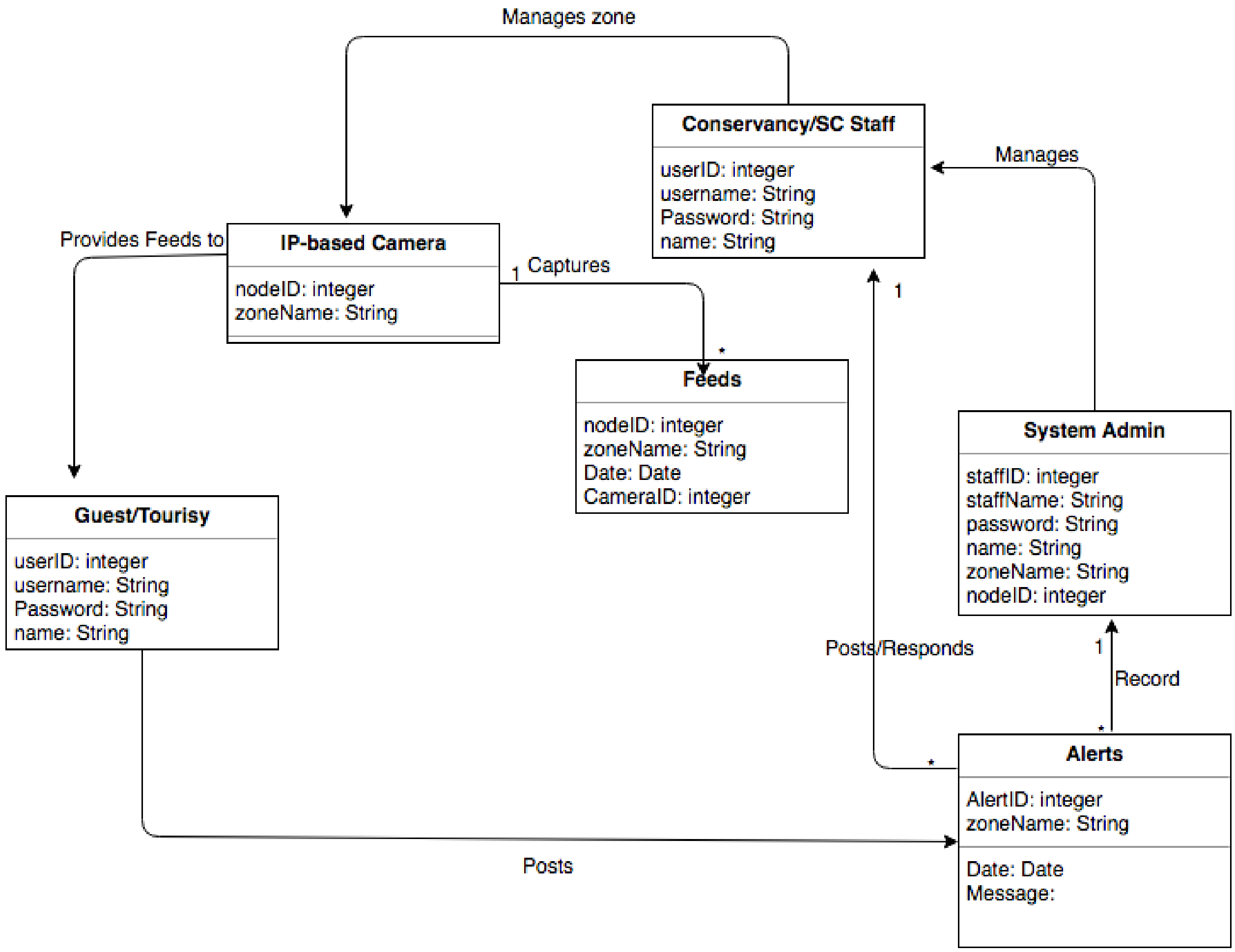

Figure 4.5 The Partial Domain Model of The System

4.2.2.5. System Sequence Diagram

Sequence diagrams show the interactions involved in a given system (Sommervile, 2011). In this system, the major interactions are as shown in figure 4.7. The actors in this system include the tourists or guests visiting the safari camps or conservancy, the staff in these habitats as well as the system administrator. All these actors interact with the networked-game camera monitoring system.

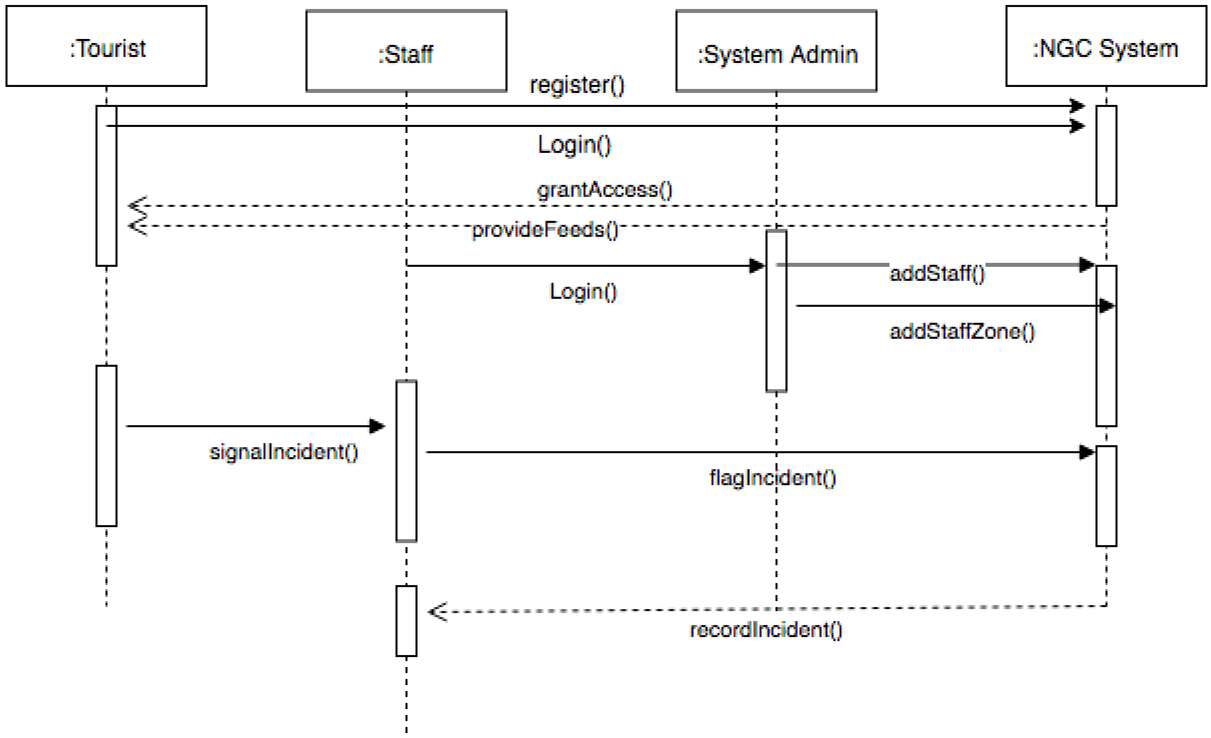

Figure 4.6 System Sequence Diagram of The System

4.2.2.6. Database Schema

A database schema is a skeleton structure that represents the logical view of the entire database. It defines how the data is organised and how the relations among them are associated. It formulates all the constraints that are applied on the data. It hence defines its entities and the relationship among them. In this study, the entities are as defined in table 4.2.

4.2.2.6.1. Entity Relationship Diagram

The system developed under this research uses the Sequential Query Language (SQL) approach of handling data for all the entities in the entire system. The approach covers the transactions which include the details of the visitors or guests, the staff in the conservancies and safari camps and the universal resource locators to the stored videos as well as the metadata. Figure 4.8 shows the entity relationship diagram.

Table 4.2 Entities and Their Definitions

Entity	Definition
Staff	The staff of a conservancy or a safari camp assigned to a particular section/zone.
Guest	A visitor in the conservancy or safari camp.
Zone	A section in the conservancy where a camera/cameras are installed.
Alert	A notification raised by a staff or guest based on a strange observation from the camera feeds.

4.2.2.6.2. Entity Relationship Diagram (ERD)

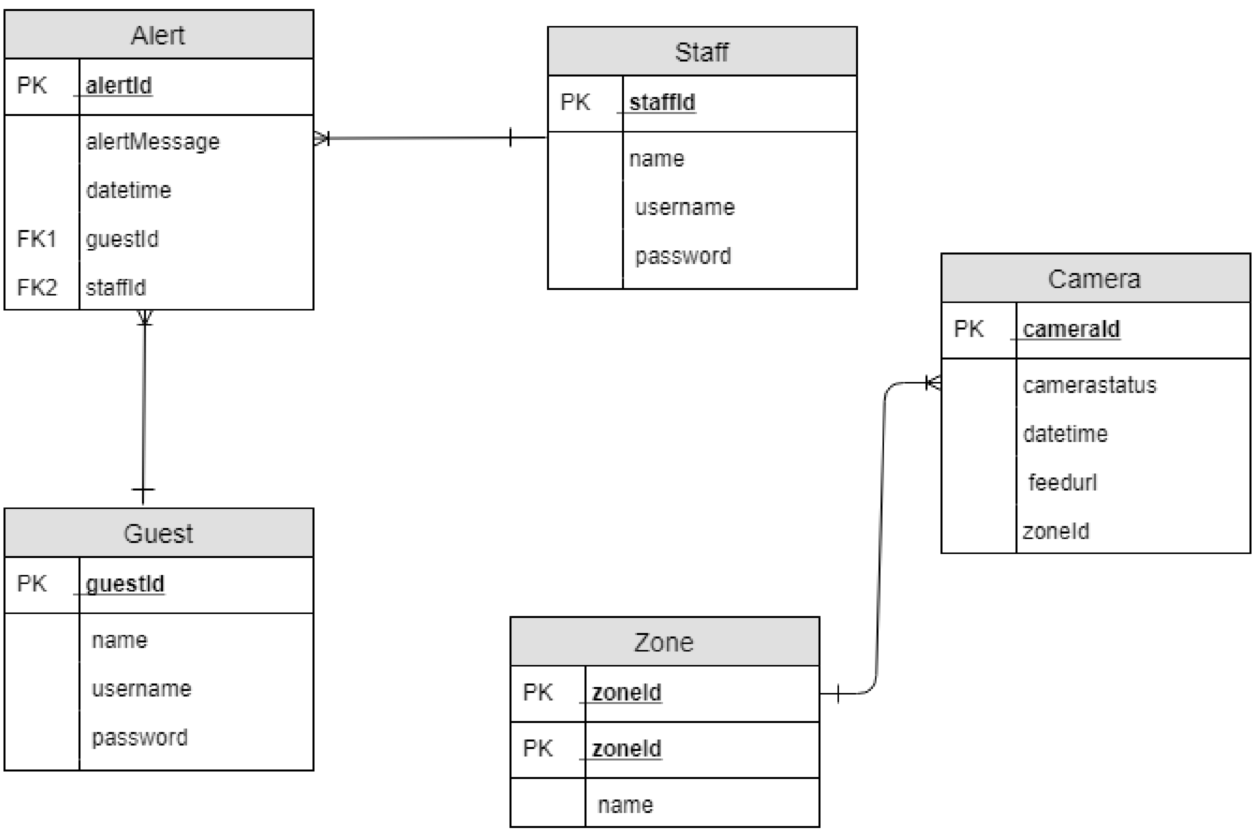

Figure 4.7 Entity Relationship Diagram

4.2.2.6.3. Description of Entities

The entities under this study form the tables used in the development of the database. They represent the nouns described in ERD of figure 4.8.

These entities are as described in table 4.3 with the various fields and the characteristics of the fields.

Table 4.3 Entities with their Fields and Characteristics

Table	Field	Characteristics
Staff	staffID	Primary Key (PK) of the staff table of type BIGINT. It cannot be NULL. The length is 40.
	Name	Name of staff. It is of type VARCHAR. Length is 40.
	Username	Username of staff. Type: VARCHAR. Length is 60.
	Password	Password used to authenticate staff in the database. Type: VARCHAR. Length is 50.
Guest	guestID	Primary Key (PK) of the guest table. It is of type BIGINT. Length is 40.
	Name	Name of guest. Type: VARCHAR. Length is 40.
	Username	Username of guest. Type: VARCHAR. Length is 60.
	Password	Password used to authenticate a particular guest. Type: VARCHAR. Length is 50.
Zone	zoneID	Primary Key (PK) of the zone table of type BIGINT. It cannot be NULL .Length is 40.

	Zonename	Name of a zone. Type: VARCHAR. Length is 50.
Cameras	CameraID	Primary Key (PK) of the camera table of type BIGINT. Length is 40.
	CameraStatus	An explicit selection of the status of the camera. Type: ENUM. It describes the camera as either working or not working.
	Feedurl	The url stored from the camera node. Type: VARCHAR. Length is 60.
	datetime	This is used to indicate the precise time feed is recorded and the url stored. It uses DATETIME type.
	zoneID	A Foreign Key (FK) that identifies the camera in a particular zone. This is NULL. It cannot be NULL.
Alert	alertID	Primary Key (PK) of the alert table of type BIGINT. Length is 40.
	alertMessage	A TEXT type of message entered by the guest or staff on reporting incidences.
	datetime	This is used to indicate the precise time an incidence was reported. It uses DATETIME type.
	guestID	A Foreign Key (FK) that identifies the guest that posted an alert/incidence message. This can be NULL.
	staffID	A Foreign Key (FK) that identifies the staff that posted an alert/incidence message. This can be NULL.

4.2.3. The Hardware Architecture

In the system development of this study, there is use of hardware to capture feeds in the deployed assumed zones and transmit the feeds to the software ecosystem. This system is uploaded with firmware and software to seamlessly guarantee real-time view of the camera feeds on the user interface end.

The hardware infrastructure encompasses the following components:

1. An ARM-based Raspberry Pi system-on-chip
2. Raspberry Pi camera module v2
3. A mini-solar panel of 5V, 2A output
4. Jumper wires for the GPIO connection
5. Adaptrum Radio modules.

Figure 4.9 illustrates the hardware architecture used in this study.

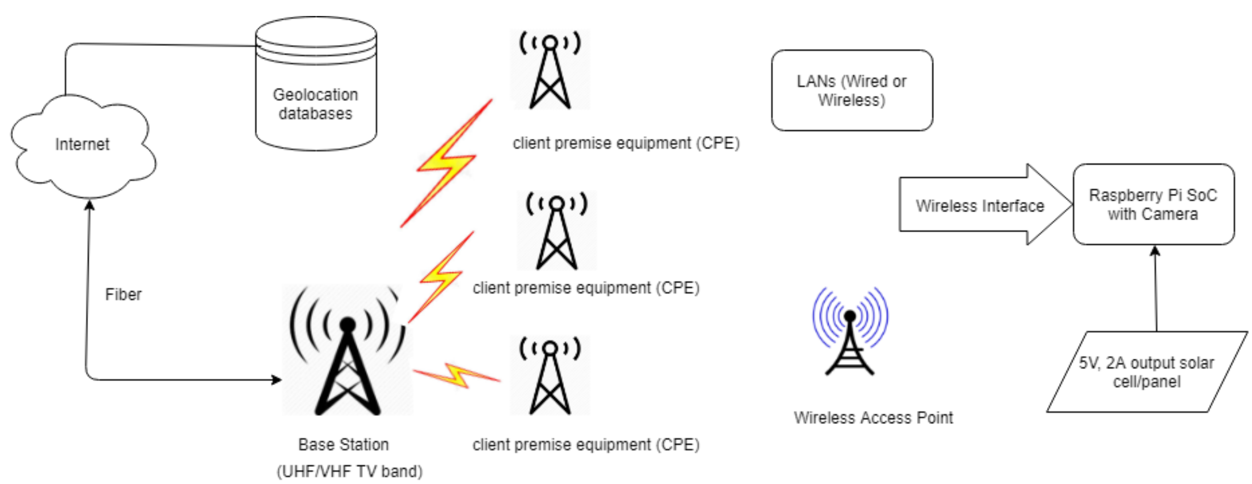

Figure 4.8 The Hardware Architecture of The System

4.2.3.1. The TV White Space Connectivity Infrastructure

The TVWS base station is an indoor device and has ultra-low power consumption compared with cellular base stations. It transmits using a huge monopole antenna mounted outdoors at a height based on rigorous computations or simulation per design coverage and link quality of the star topology. The speeds provided by the TVWS trials carried out in Nanyuki go up to 16 Mbps on a single 8 MHz TV channel at distances of up to 14 kilometres.

Figure 4.10 shows the Adaptrum ACRS1 equipment that was certified for use in the base stations at the Mawingu Networks.

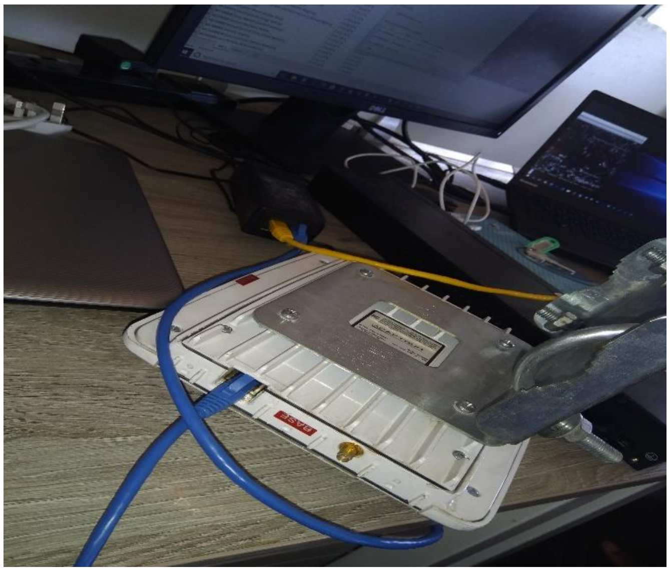

Figure 4.9 The Adaptrum ACRS2 Base Station

The implementation of the connectivity hardware using the Adaptrum TV white spaces base stations and clients is as shown in figure 4.11.

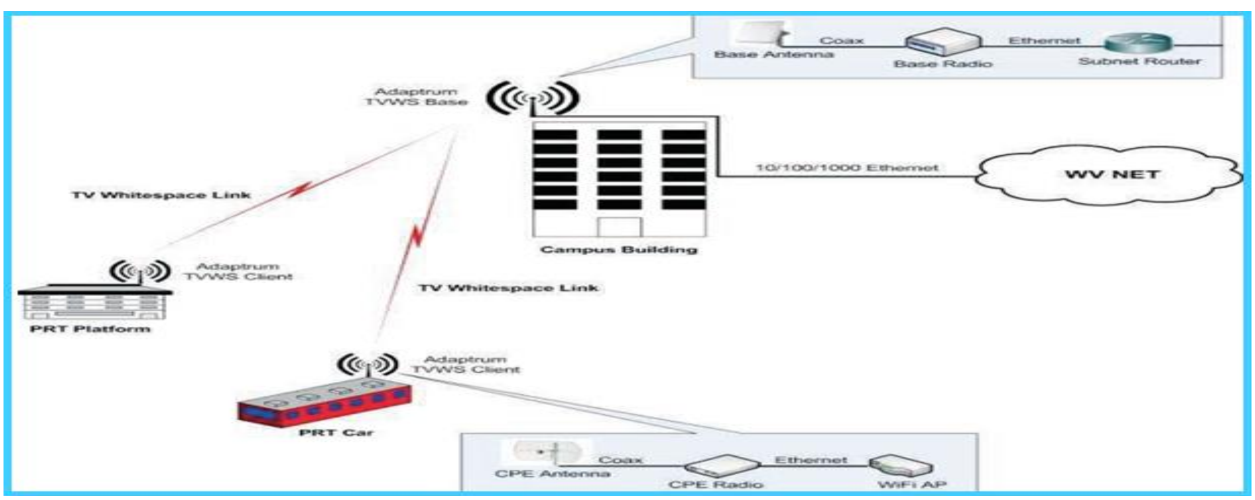

Figure 4.10 Connectivity Architecture of The Adaptrum Radio

Source: WVU, 2018

4.2.3.2. The Raspberry Pi System-On-Chip (SoC)

A Raspberry Pi is described as a system on a chip (SoC) which is a single microchip or integrated circuit (IC) that contains all the components for a system (Norris, 2015). SoCs are typically found on cell phones and embedded devices. For the Raspberry Pi, the SoC contains both an ARM processor for application processing and a Graphics Processing Unit (GPU) for video processing. The SoC is from Broadcom with the version BCM2837 used in this study. It contains a quad-core ARM Cortex-A53 running at 1.2GHz and a Videocore 4 GPU.

Four models of the Pi currently exist. While the four models are similar, the major differences are as listed in the table 4.3.

Table 4.4 Differences between Raspberry Pi Models

Model A	**Model B**	**Model C**	**Pi Zero W**
256MB RAM	512MB RAM	1GB RAM	512MB RAM
One USB Port	Two USB ports	4 USB Ports	1 USB OTG port
No Ethernet port	One Ethernet Port	Ethernet Port	No Ethernet port
700MHz single core CPU	900MHz quad core CPU	1,200MHz quad core CPU	1000MHz single core CPU
No built-in WiFi	No built-in WiFi	802.11n and Bluetooth	802.11n and Bluetooth 4.0
ARM1176JZF-S based CPU	ARM Cortex-A7 CPU	ARM Cortex-A53 CPU	ARM1176JZF-S based CPU

In the development of the networked game camera prototype under this study, the Raspberry Pi Model C has been used to handle the processing of the camera feeds. The Raspberry Pi model three is also the one used here to transmit the camera feeds for remote access using its wireless interface that rides on the broadcasted WiFi from the TV white space connectivity. This construction uses the Camera Serial Interface (CSI) of the Raspberry Pi.

Figure 4.12 shows a Raspberry Pi Model C used in the development of the system under this study.

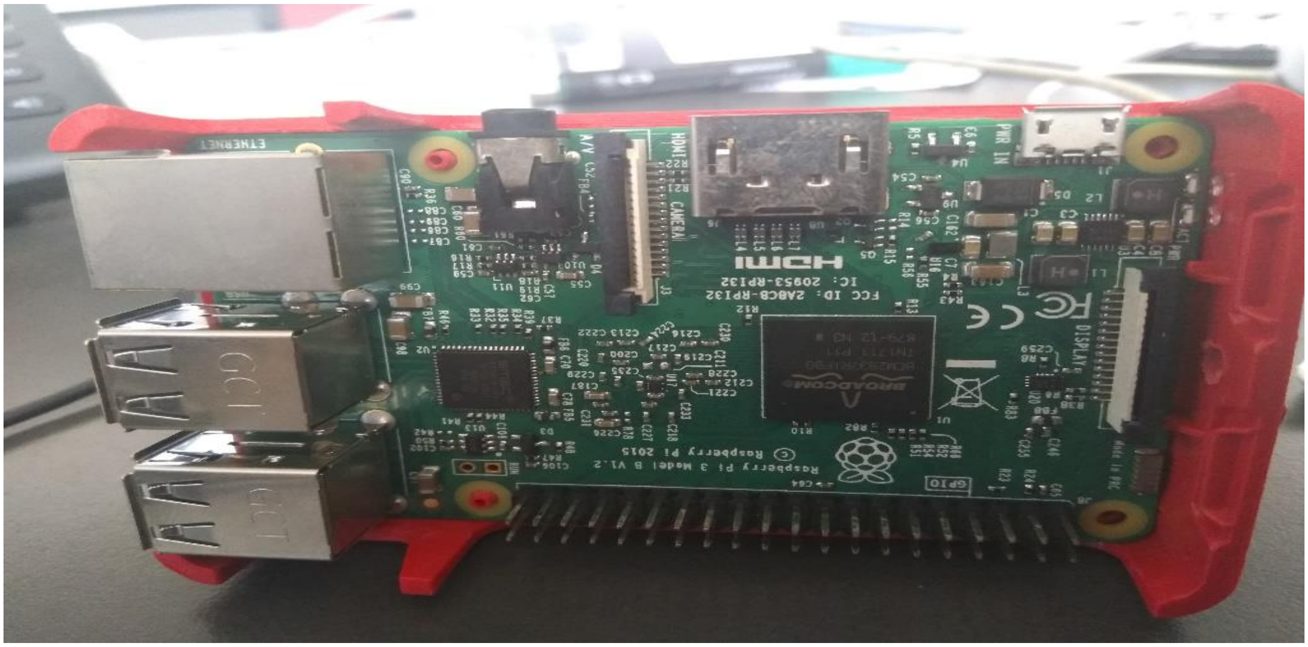

Figure 4.11 Raspberry Pi Model C SoC

4.2.3.3. The Raspberry Camera v2

The Raspberry Pi camera module version 2 (v2) features an 8 megapixel (MP), 25mm x 23mm x 9mm module. The micro-device is capable of 1080p video and still images that connect directly to the Raspberry Pi using the ribbon cable to the CSI port. It weighs 3g and uses an image sensor version from SONY whose version is IMX 219 PQ CMOS in a fixed-focus module. It is a plug-and-play-compatible device to the latest version of the Raspbian operating system making it perfect for time-lapse photography, recording video, motion detection and security application. In the latest version of Raspbian (Raspbian Stretch) which is the one used in this study, the camera has to be activated through the “sudo raspi-config” command.

Figure 4.13 shows this camera module used here.

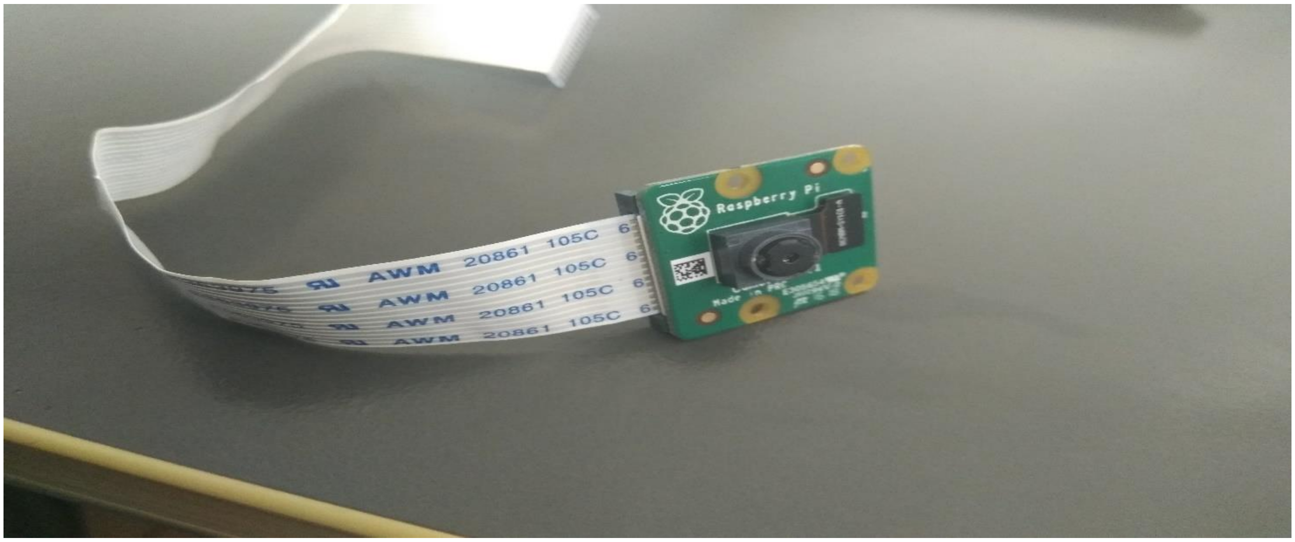

Figure 4.12 Raspberry Pi Camera v2 Module

Figure 4.14 shows the camera v2 module connected to the Raspberry Pi on the CSI port.

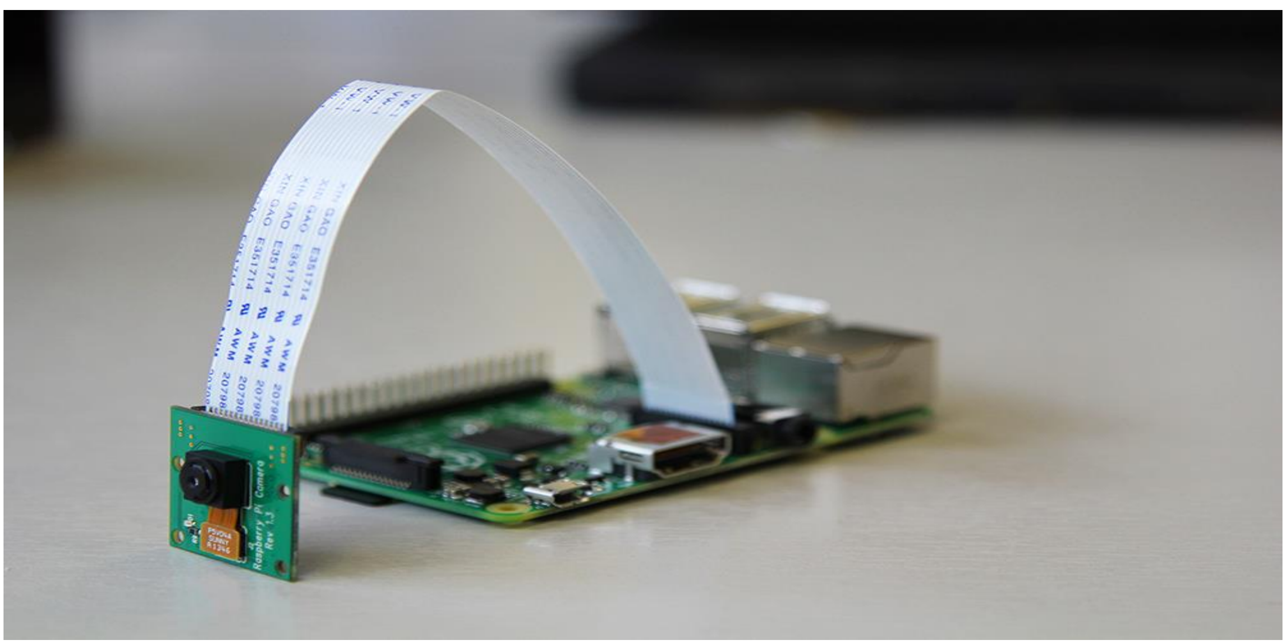

Figure 4.13 Camera Module Connected to the SoC

4.2.3.4. The Solar Panel of 5V, 2A output

In the implementation of electronics in an IoT ecosystem, electrical power is one of the major critical factors. For a sensitive System-On-Chip like the Raspberry Pi, this has to be handled delicately as well as ensuring the camera node can reliable run on deployment in an outdoor environment. The Raspberry Pi 3 model B used here requires an input voltage of 5V and a supply current of 2.5A. The addition of the camera module raises the power consumption to 2750mA as the camera module draws 250mA.

In order for the prototype developed under this study to work in an outdoor environment, proper power requirements have to be met. The study therefore adopts a 10W, 5V and 2A solar panel to power the camera node.

The solar panel used in this study is also connected to a rechargeable battery with a rating of 7.4V, 2200mAh.

Figure 4.15 shows the 10W solar panel with the 7.4V LiPo rechargeable battery.

Figure 4.14 10W Solar Panel with 7.4V LiPo Battery

4.2.3.5. Jumper Wires / Connectors

In the design of the prototype under this study, the use of jumper wires and connectors is crucial. The camera uses the ribbon connector to the Raspberry Pi while the connection of the solar panels and the LiPo battery utilises the jumper connectors. The jumper wires used are male-female although a part of it has been soldered to achieve the desired design.

Figure 4.16 shows an example of a set of jumper wires.

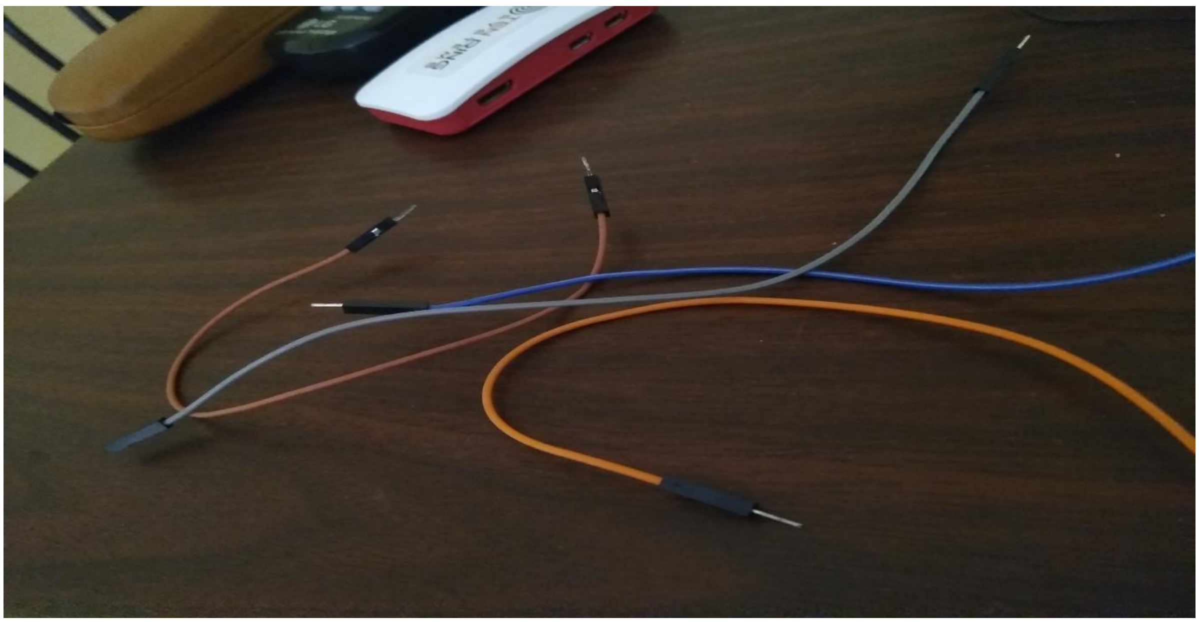

Figure 4.15 Jumper Wires

4.2.4. Wireframe Design

A wireframe is a low-fidelity, simplified outline of a product. Wireframes can usually be recognised by their distinctive block layouts, use of lines to represent text and other components. A wireframe can hence be described as a skeleton. It loosely shapes the product, providing a reliable idea of where everything will eventually go.

In this research, the wireframes developed are for the mobile-web application that can be used by the conservancy staff and visitors within the game environment.

The wireframe design of the sign up and sign in screens is as shown in figure A.2.

Figure 4.17 shows the dashboard interface

Figure 4.16 The Dashboard Wireframe

Figure 4.18 shows the camera feed wireframe interface

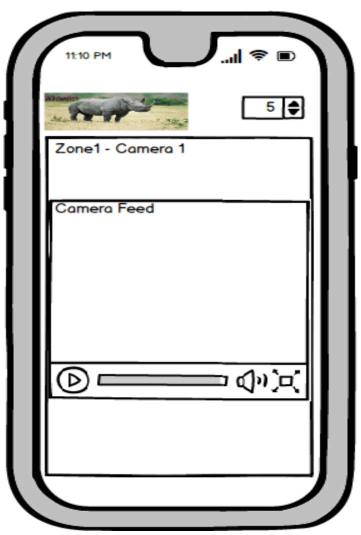

Figure 4.17 The Camera Feed Wireframe

Figure 4.19 shows the interface that users can use to report an incidence.

Figure 4.18 The Incidence Reporting Interface

4.3. Conclusions

In implementing the proposed system under this study, this section generally focuses on the design aimed at fitting in the requirements gathered from the user as well as the components needed for implementation. The section has outlined the hardware and software requirements of the study detailing the design models of the software as well as the data flow mechanisms necessary for the attainment of the value to the end user. This is necessary in aligning with the third objective of this study.

CHAPTER 5: SYSTEM IMPLEMENTATION AND TESTING

This chapter covers the implementation and testing of the prototype developed under this study. It describes the implementation of the designed hardware and software techniques to realise a game environment monitoring system that utilises TV white spaces connectivity. The implementation here focuses on the overall presentation of the networked-game camera system, the powering mechanisms and the programming developed both on the SoC to capture and transmit feed including the user access and interaction interface.

5.1. Implementation of the TV White Space Connectivity with the New DSA Rules Approach

The new model rules and regulations from the Dynamic Spectrum Alliance released and published in December 2017, outlines the approach of deploying Television white spaces. The first three rules which majorly address the existing issues in the adoption of the TV White Space include (DSA, 2017):

1. Permissible Frequencies of Operation

Here the White Space Devices (WSDs) are permitted to operate on a license-exempt basis subject to the interference protection requirements set forth in the rules. The WSDs are further directed to operate in the broadcast television frequency bands, as well as other frequency bands designated by regulators all as long as there is no interference to the licensed incumbent services.

2. Protection of Licensed Incumbent Services

This rule is strictly meant to protect the traditional TV broadcasters

3. Geolocation and Database Access

For proper utilisation of available channels and reliably protect the incumbent licensed TV services, this third rule recommends for the WSD to rely on geolocation and database access mechanism to identify the available frequencies.

In line with these model rules and regulations from the Dynamic Spectrum Alliance, this study implemented an Adaptrum base station (a WSD) that interacts with a geolocation database as part of ongoing work between Strathmore University, Communications Authority, Mawingu Networks among other partners. The WSD device used under this study was flashed with the latest binary and python-based firmware. This WSD can hence be viewed live in the Nominet's geolocation database and can hence select a list of available channels to avoid causing interference to the incumbent TV broadcasters. It hence had to be loaded with GPS co-ordinates under this study. A snippet of the python script embedded to the Adaptrum base station hardware is shown in Figure 5.1.

```
class PAWS:
    def __init__(self):
        self.etsiRulesetId = "ETSI-EN-301-598-1.1.1"
        # device characteristics
        self.device_serial_number = ""
        self.device_manufacturer_id = "Adaptrum"
        self.device_model_id = "ACRS2.0"
        self.device_category = "slave"
        self.device_emission_class = "1"
        self.device_type = "A"
        self.device_technology_id = "ACRS2.0-2014"
        # master device characteristics (for slaves)
        self.master_serial_number = ""
        self.master_manufacturer_id = "Adaptrum"
        self.master_model_id = "ACRS2.0"
        self.master_category = "master"
        self.master_emission_class = "1"
        self.master_type = "A"
        self.master_technology_id = "ACRS2.0-2014"
        # device horizontal location
        self.latitude = 0
        self.longitude = 0
        self.latitude_uncertainty = 0
        self.longitude_uncertainty = 0
        # master horizontal location (for slaves)
        self.master_latitude = 0
        self.master_longitude = 0
        self.master_latitude_uncertainty = 0
        self.master_longitude_uncertainty = 0
        # device vertical location
        self.height = 0
        self.height_uncertainty = 0
        self.height_ref = "AGL"
```

Figure 5.1 Snippet of a Python Script Flashed in The Adaptrum Base Station for DB Interaction

The Adaptrum new network architecture to be implemented for the future deployment of the TV White Space infrastructure with geolocation mechanism is as shown in figure 5.2.

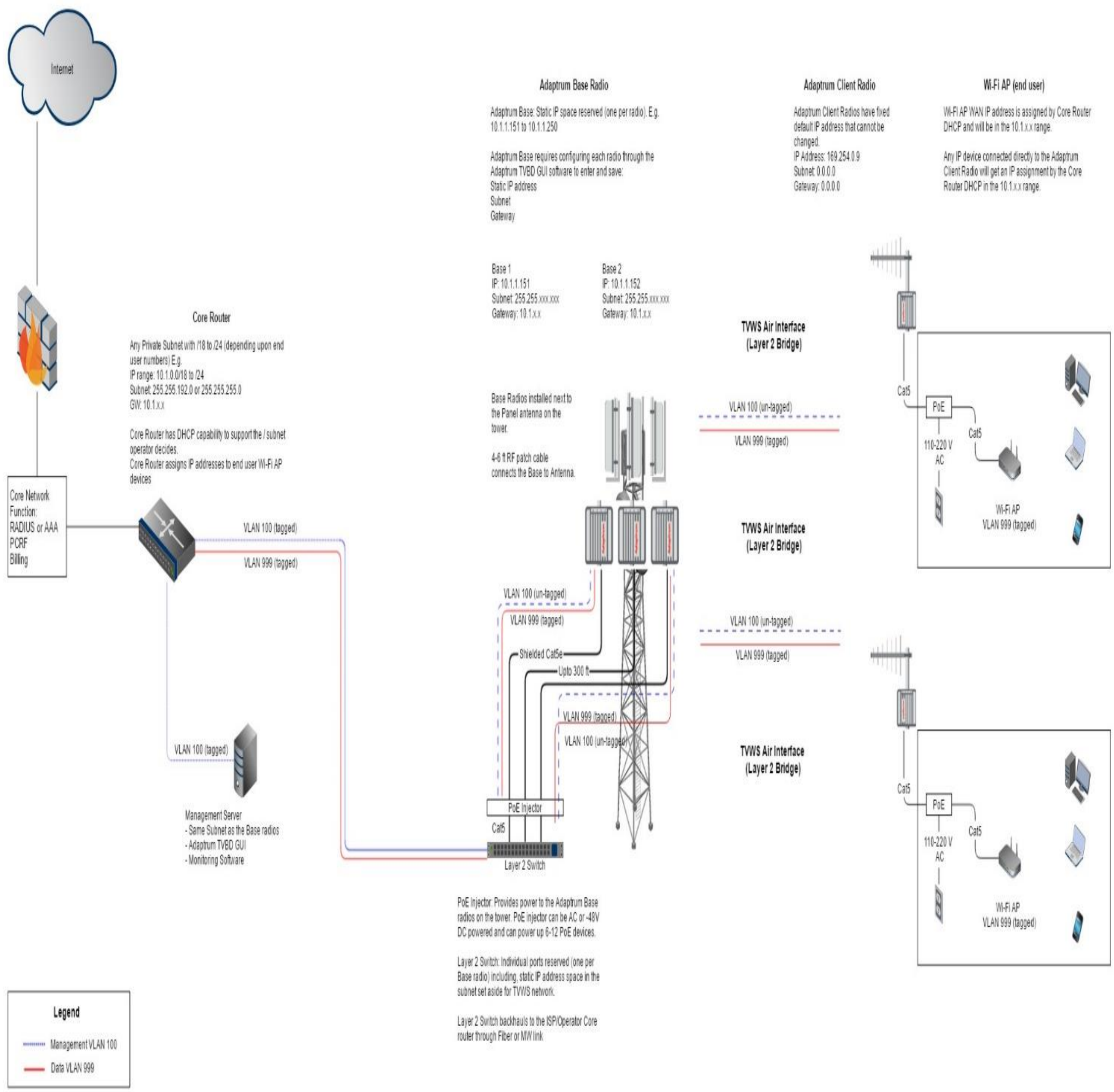

Figure 5.2 Adaptrum Network Architecture

5.1.1. Identification of Available Channels

Figure A.6 shows the search of available channels by the Adaptrum base station under the new DSA rules after uploading the new firmware.

5.2. Implementation of the IP-based Camera

In order to achieve the implementation of the IP-based camera, a Raspberry Pi camera module v2 was connected to the Raspberry Pi System-On-Chip (SoC) through the CSI interface. A python program was written on this SoC to capture feeds in real-time and provide access to them from an Android-based mobile-web application. The feeds are saved in the cloud with a mysql storage of the urls. The hardware implementation set up is as shown in figure A.7.

The code snippet of the Python Script, based on python3 that runs on the System-On-Chip for the camera to capture the feeds and relay them to a browser interface is shown in figure 5.5.

```
import sys
import io
import os
import shutil
from subprocess import Popen, PIPE
from string import Template
from struct import Struct
from threading import Thread
from time import sleep, time
from http.server import HTTPServer, BaseHTTPRequestHandler
from wsgiref.simple_server import make_server

import picamera
from ws4py.websocket import WebSocket
from ws4py.server.wsgirefserver import WSGIServer, WebSocketWSGIRequestHandler
from ws4py.server.wsgiutils import WebSocketWSGIApplication

###########################################
# CONFIGURATION
WIDTH = 640
HEIGHT = 480
FRAMERATE = 24
HTTP_PORT = 8082
WS_PORT = 8084
COLOR = u'#444'
BGCOLOR = u'#333'
JSMPEG_MAGIC = b'jsmp'
JSMPEG_HEADER = Struct('>4sHH')
###########################################
```

Figure 5.3 Code Snippet for the Camera Operation

5.3. The User Interface Implementation

The User Interface implemented under this study is accessible both from a web and mobile interface. The Web interface is an extension of a Content Management System (CMS) and displays under a view of a link referred to as a Wildwatch. The mobile interface is an Android-based App that gives a mobile-web view of the real-time streaming video feed from the networked cameras.

5.3.1. The Web Interface

The web interface implemented in this study extends a service of a personal project that allows people to book for vacation and other places of interest. A link referred to as "wildwatch" takes the user to the sign in window then to the camera feeds. Figure 5.6 shows a live video feed of the remote camera of the browser. Figure A.3 shows the web sign in interface for the user.

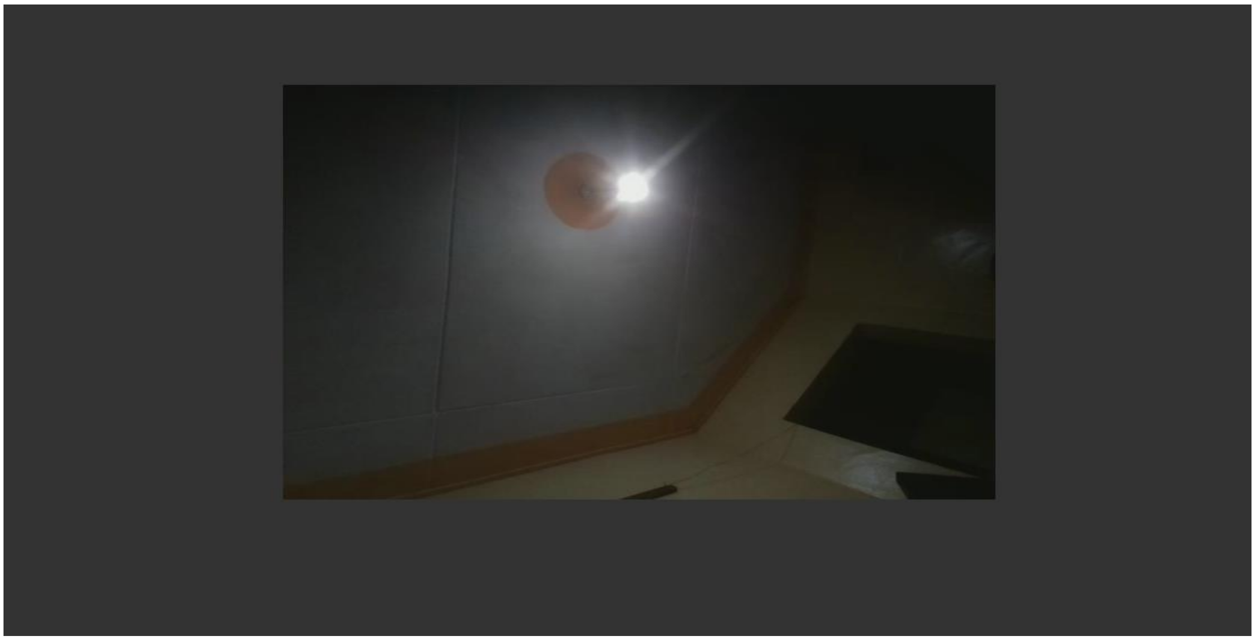

Figure 5.6 A Live Video Feed of The Camera on The Browser

5.3.2. The Mobile-Web Interface

The mobile App interface accesses the web interface. The Android-based mobile web App is referred to as "Wildwatch" under this study. It displays real-time video feeds from the camera programmed on the SoC. Figure 5.8 shows a live-feed streaming from the camera while 5.9 shows the App interface for the cameras and zones.

Figure 5.4 Screenshot a Live Stream of Feed on The App

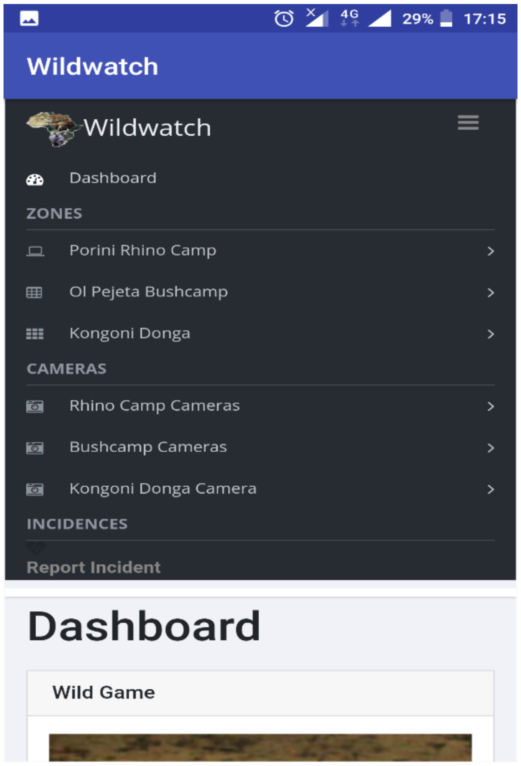

Figure 5.5 App Interface of The Cameras and The Zones

5.4. Prototype Testing

The functionality of the different components of the system was checked while testing the prototype. This was also carried out to validate the research hypothesis in this study.

5.4.1. Testing of the Connectivity

The current development under TV white spaces is still in progress to align with the new DSA rules. The tests done under this study are a representation of a research in progress that adopts the usage of a geolocation database to intelligently provide available channels through the cognitive radios. Table 5.1 outlines the test results of the previous infrastructure of the TV white spaces implemented without the real-time database integration for the channels at the Mawing Networks station in Nanyuki.

Table 5.1 Tabulated Major TVWS Trials Technical Results

1.	The Mawingu project has successfully demonstrated the technical viability of the TV White Space implementation with interference free point to mulyti-point coverage of up to 14 kilometres from TVWS base stations operating at only 2.5 Watts power.
2.	The infrastructure currently provides approximately 235km^2 of TVWS coverage using multiple 90 degree base station sector antennas.
3.	Speeds of up to 16 Mbps on a single 8 MHz TV channel at distances of up to 14 kilometres have been achieved in the trial implementations at Nanyuki
4.	No interference has been reported by the incumbent TV broadcasters with the equipment deployed during the trial period of TVWS implementation.
5.	The TV White Space technology can support various media protocols such as streaming videos, emails, File Transfer Protocol (FTP), Skype voice and video conferencing and high speed Virtual Private Network (VPN) services.
6.	The technology has been implemented in areas with no source of electricity with majority of the endpoints running on standalone solar power systems.

On Saturday 28th April 2018, tests were carried out to find out the speed of connectivity for the 20km distance of a link between Scott's pump and Cedar Mall (Mawingu Networks Headquarters). The speed discovered was 7 Mbps as shown in figure 5.11. This was done in line with the new DSA rules of the base stations interacting with the real-time geolocation database from Nominet.

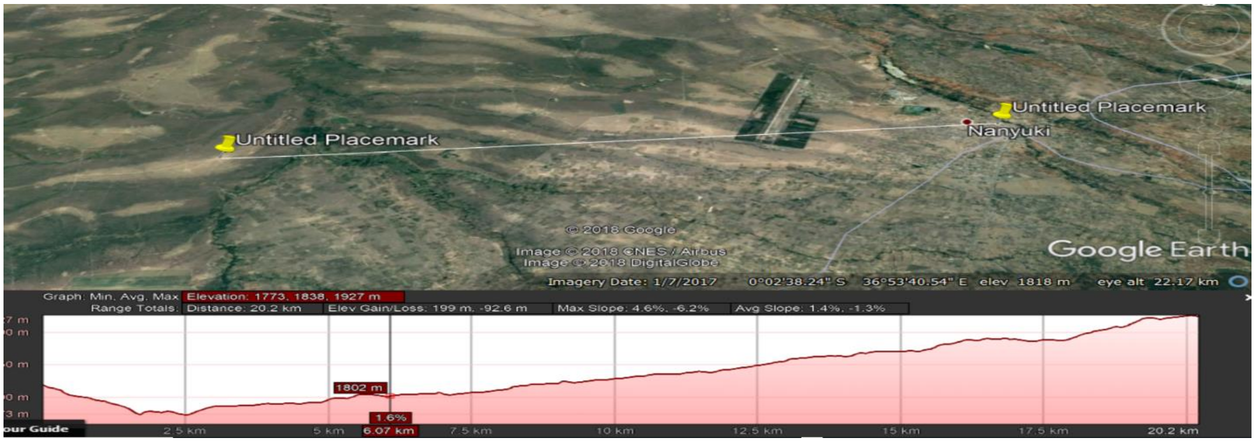

Figure 5.6 TVWS Test Between Scott's Pump and Cedar Mall (Mawingu HQ)

5.4.2. Testing of the IP-based Camera Hardware

The developed IP-based prototype deployed at the Mawingu Networks station streams video feeds in real-time. The camera designed and programmed uses the HTTP protocol alongside web sockets to load the real-time video feeds on the browser. Multiple users can access the feeds from the developed application although due to the constraints of an SoC in terms of the processor and main memory, at most 7 interfaces can reliably deliver these feeds without latency or jitter on a stable network connection.

5.4.3. Application Testing

Based on the third and fourth objectives of this study alongside the system design as well, the implemented user interface here is a mobile-web that delivers the real-time live feeds from the IP-based camera. The application has been tested by the team at the Mawingu Networks, Ol Pejeta and a select group of people at the Internet of Things Lab at @iLabAfrica.

The functionality tests carried out by the 15 users was through a survey that required participants to.

1. Launch the application
2. Log in to the application
3. Navigate through the Application
4. View Live-Feeds from the networked camera
5. Give feedback on navigation and functionality

5.4.3.1. General Information Gathering

A total of 15 users were involved in the testing of the developed system under this study. There were 7 game environments specialists from Ol Pejeta and Sentinel Mara Camp, 5 representatives from Strathmore University with 3 of them being students while the other 2 staff and the final 3 people were from the Mawingu Networks station. Table B.2 shows the total number of the respondents categorised in terms of their category of work.

5.4.3.1.1. Gender Composition

From the 15 users involved in the testing of the Application, 10 of them were male while 5 were female.

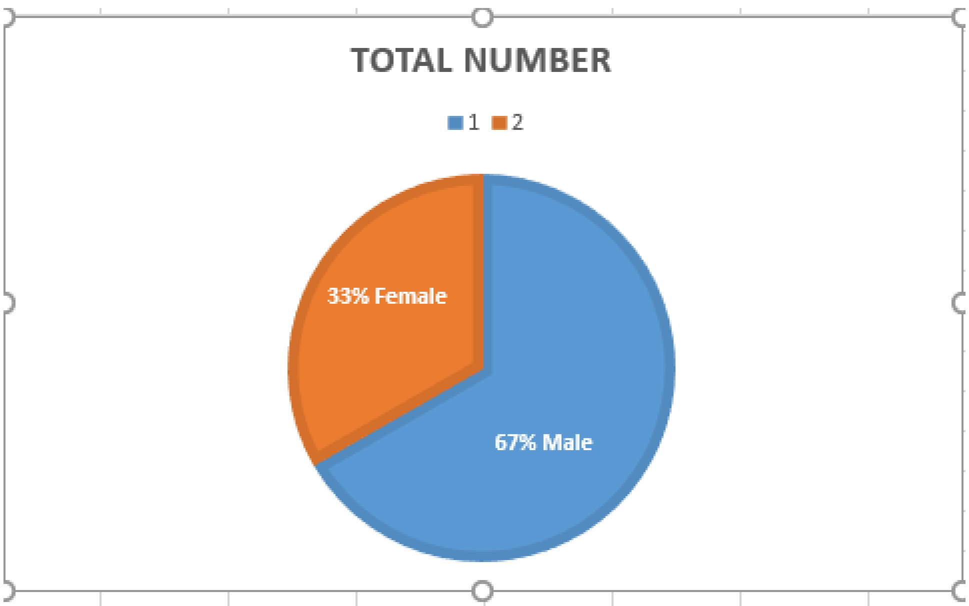

Figure 5.7 Respondents' Gender Distribution

Figure 5.11 shows the representation of the category of users involved in the application testing by gender in the sample population. The number of female respondents was a third of the entire sample population while the number of male respondents was twice that of the female respondents. Table D.2 shows this distribution by the exact numbers of the gender.

5.4.3.1.2. Age Representation

The representation of the sample population by age is as shown in the figure 5.12 below.

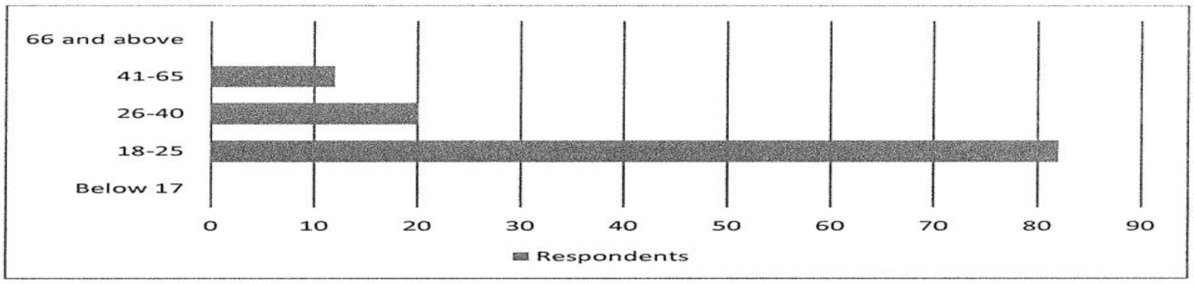

Figure 5.8 Age representation of The Users

5.4.3.2. Functionality Testing

This part involved testing the functionalities of the mobile-web application. This section focused mainly on the ability of the user to achieve the intended objective of the application. The functionalities tested among the users are as described in this section of the study. Table D.3 shows the tabular representation of the users' feedback on the ease of application use test.

5.4.3.2.1. Ease of Application Use Test

100% of the staff and students found the application easy to use. This is as shown in figure 5.13. Under the category of students and staff, no one found the application hard to use.

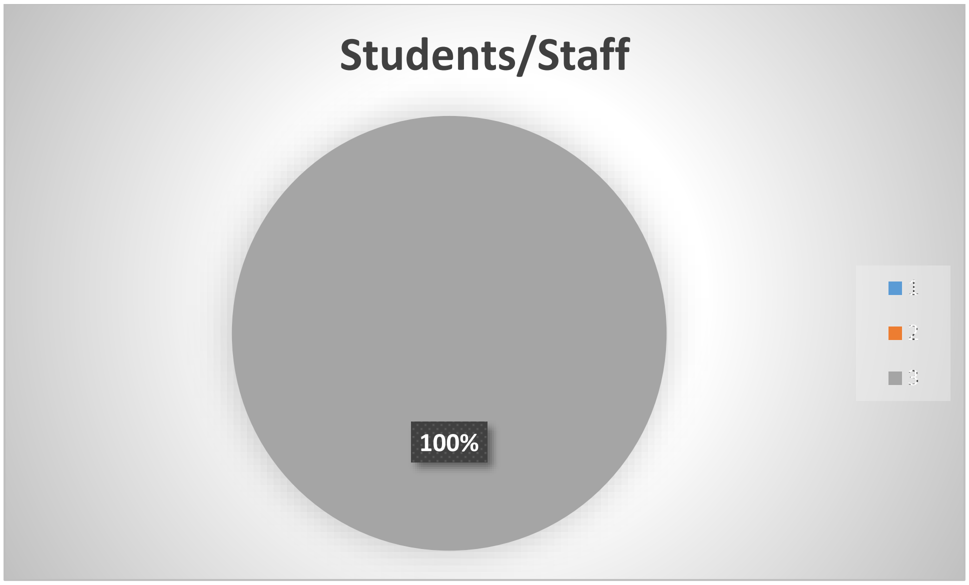

Figure 5.9 Student/Staff User representation on Application Use Test

100% of the network engineers at the Mawingu test bed also found the application easy to use. This is as shown in figure 5.14.

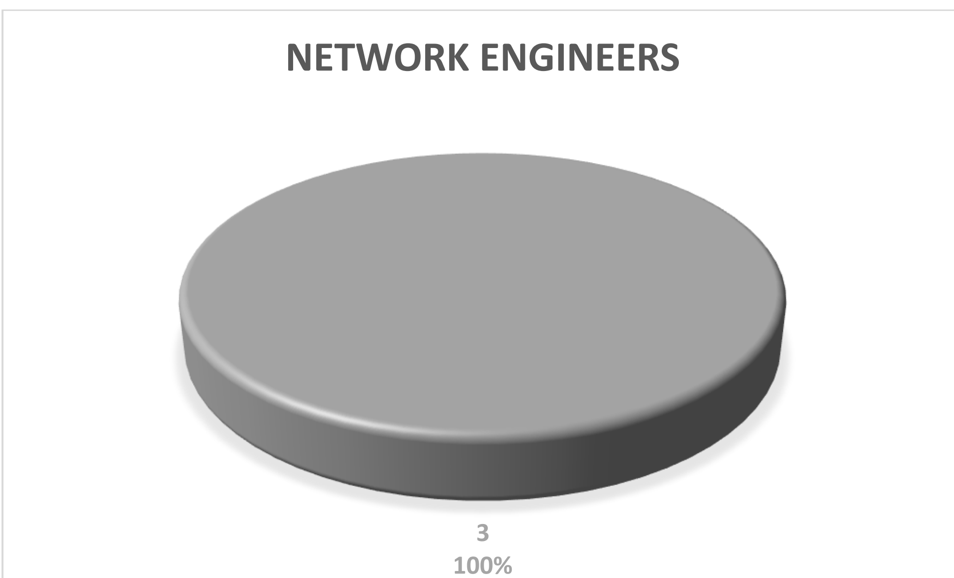

Figure 5.10 Network Engineers Percentage Representation on Application Usage

86% which is a representation of 6 people in the conservation environments found the application easy to use with only 14% which is a representation of 1 person finding the application a little hard to navigate through. This is as shown in in figure 5.15.

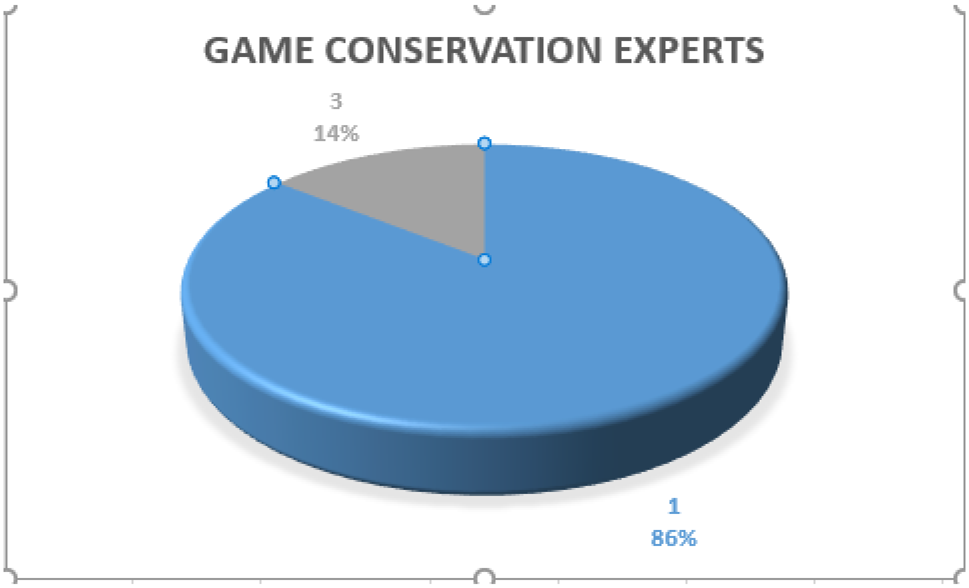

Figure 5.11 Game Conservation Experts Percentage Representation on Application Usage

5.4.3.2.2. Performance Test of the Application

Figure 5.16 demonstrate the respondents feeling of the performance of the Application. This was carried out through testing of precision, response and throughput of the Application. Through the activities of the Application such as signing in and retrieving feed from the camera. The excitement of remotely accessing feeds from a remote camera elucidated some impatience from the set of students testing the Application. Since the application also depends on the strength of connectivity on the end users end, the application might delay in delivering the live feeds if the connectivity is poor. 93% of the users found the applications response on performance to be reliable while the 7% felt that it needed to be faster on performance.

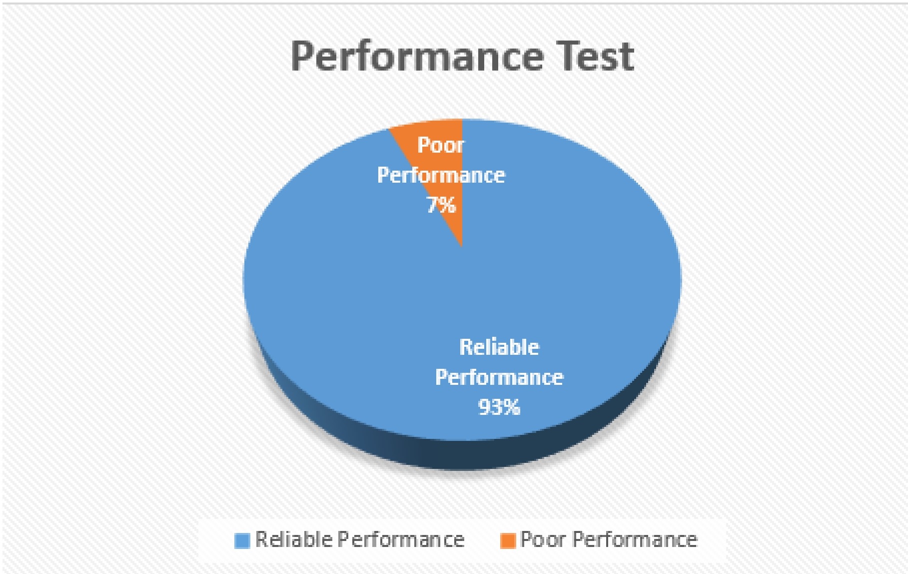

Figure 5.12 User Test for the Performance of the Application

5.4.3.2.3. Relevance of The Mobile Application

From the survey carried out at the two case environments under this study, that is Ol Pejeta and Sentinel Mara Camp, 100% of the respondents at Ol Pejeta found the application relevant while 50% of the respondents at Sentinel Mara Camp found the application relevant. This was investigated in line with the commercial benefit the application can provide to their ecosystems. Figure 5.17 and 5.18 show the pie chart representation of their feedback.

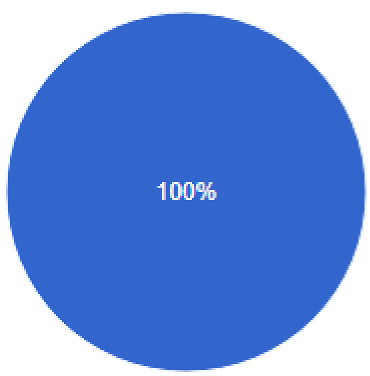

Figure 5.13 Percentage of Respondents from Ol Pejeta who found the Application Relevant

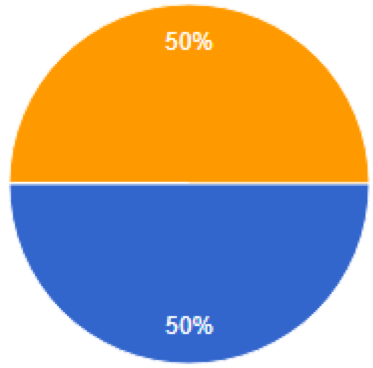

Figure 5.14 Percentage of Respondents at Sentinel Mara Camp who found the Application Relevant

CHAPTER 6: DISCUSSION OF RESULTS

In addressing connectivity as a problem experienced in the game conservation environments such as conservancies and safari camps, various approaches investigated under this study are explained in detail in this chapter. This study uniquely focused on the benefits that TV White Space connectivity can provide to the game environments in a way that can enhance the way wildlife is monitored to advance the usage of the traditional camera-traps through the adoption of networked game cameras. The game camera prototype discussed, designed and implemented under this study presents the need of affordable, reliable and stable connectivity to enhance the desired wildlife monitoring.

This chapter therefore runs a comparison of various connectivity infrastructures that can be adopted or have been adopted by conservancies to monitor wildlife and are being implemented by safari camps to improve customer experience. The comparison is juxtaposed with TV White Space to clearly paint a picture that proves the research hypothesis under this study. This includes a description of the entire setup of the networked camera system implemented here and its functionality on a TV White Space backhaul network.

6.1. Challenges Faced by the Conservation Environments in Adopting Networked-game cameras

The research carried out under this study in identifying the challenges faced by the conservation environments, that is, conservancies and safari camps involved use of a survey. An online-based survey was done through sharing of a google form with the team at the Ol Pejeta conservancy and the Sentinel Mara Camp. Ol Pejeta and Sentinel Mara Camp were selected to represent the population of the conservancies and safari camps respectively. Additionally, a visit to the Ol Pejeta conservancy was carried out to assess the state of technology as well as a one on one engagement on the current implementation of the camera-traps.

The results obtained from these two surveys are as outlined in table 6.1.

Table 6.1 Table Showing The Survey Results

Investigated Concepts	Ol Pejeta	Sentinel Mara Camp
Number of Responses	5	4
Category of Respondents	1. Management (1) 2. Technologists (2) 3. Officers (2)	1. Management (1) 2. Officers (2) 3. Technologists (1)
Period of Employment at the Station	6 years for the Management, 2 years for the Technologists, 10 and 3 months for the 2 officers respectively.	5 years for the management, 10 months for the officers and 1 year for the technologist.
Percentage usage of the Internet	100% of the work of the category of the respondents requires use of Internet	50% of the work of the category of the respondents require use of Internet
The rating of the current Internet speeds	Reliable	Fairly reliable
The level of technical skills	Fairly technical	Fairly technical
Connectivity infrastructure	Fibre	VSATs
Need for Networked-game Cameras	100% need it	50% need it
Use of Cameras will improve business		100%
Challenges:	1. Powering the cameras 2. Achieving a network that covers the whole conservancy of 360sq km. 3. A network that can support live streaming	1. Cost 2. Power Requirements 3. Unstable Internet Connectivity 4. Viewing animals on a Mobile Interface might

	4. Damage of the cameras by elephants 5. Cost of deployment 6. Interference from other devices	not be as fulfilling as watching them face to face 5. Mobile Viewing can easily kill the spirit of Safari

Ol Pejeta conservancy has already implemented a number of camera-traps on the edges of the conservancy fence which allows them to study a number of features about specific wild animals within this conservancy and their movement. An interview carried out with the Head of Technology points out that, this does not provide a proper way of addressing issues such human-wildlife and poaching including a closer way of studying the wildlife that live-streaming networked game cameras can help address. He also added that, it is a huge challenge to get the feeds from the SD cards of the camera-trap especially during the rainy season and sometimes there is a possibility that the images are not as clear as they would need them to be due to an unclear flash image captured.

The figures associated with the survey are found in the section of Appendix E of this study.

6.2. Connectivity Implementations of IP-based Camera Monitoring Systems

The survey carried out at Ol Pejeta as a sample representation of the conservancies and at the Sentinel Mara Camp for the safari camps, demonstrates the need of a reliable connectivity that can support live-streaming of the video feeds. For implementation of an IP-based camera system that is able to deliver feeds remotely in real-time to a mobile interface, connectivity with speeds of at least 1.5 Mbps is required. This can only be currently achieved on wired and wireless networks that are built with a backhaul of a fibre network and cellular networks currently implemented in 3G and 4G which are able to deliver speeds of upto 1.5 Mbps and 12-15 Mbps respectively. VSATs are able to deliver 2 Mbps speeds for uploads and 4 Mbps for downloads which are also reliable enough for video streaming.

Connectivity infrastructures such as Long Range Radio (LoRa), Bluetooth Low Energy (BLE), Narrowband Internet of Things (NB-IoT) and Sigfox studied under this research are only suitable for transmitting small payloads which make them suitable for transmitting data from sensors in the Internet of Things (IoT) space and not suitable for video streaming.

The implementation of the recommended networked game camera system under this study can hence be supported by the three infrastructures: Wi-Fi from backhaul fibre network, Very Small Aperture Terminals (VSATs) and 3G/4G based cellular broadband. These infrastructures present drawbacks in a number of factors regarding their deployment in a game environment for provision of connectivity necessary to support networked camera implementation. This drawback includes: the coverage area of the connectivity especially in the outdoor environment on a stretch of land such as the 360km^2 like the Ol Pejeta, the cost of implementing and deploying this connectivity as well as the operational costs, the signal strength of the deployed infrastructure among other factors as presented in table 6.2 relative to TV White Space.

Table 6.2 Comparison Table for TVWS, Cellular, Wi-Fi and VSATs

Factor	Wi-Fi	Cellular Broadband	VSATs	TVWS
Coverage Distance	32-100 metres for indoor placed routers	About 20 metres from a mobile hotspot	About 4km for a generic antenna size	Can cover up to 10 kilometres
Receiver Signal Strength Indicator	-72/-102 for Line of Sight and -99/-102 for Non-Line of Sight	-80 to -100 dBm -110 for LTE	+4dBm	-50/-89 for LOS and -62/-92 for NLOS
Cost	Depends on the backhaul network. Fibre network has a high initial cost for rural deployment	Most costly due to data costs and signal drop	High initial infrastructure cost and the cost of the service.	High initial cost: Cost of base stations but relatively cheaper compared to VSATs and

				Fibre connectivity.
Interference	Highly affected by buildings and walls especially the 5GHz Wi-Fi frequency	Highly dependent on the cellular infrastructure deployed. Rural areas likely not to have 3G/4G connectivity due to ROI needed.	Suffer from storm interferences	-Can penetrate walls, buildings and vegetation -Can easily cause interference to the incumbent TV services
Speed				
Reliability in rural areas	Reliable in indoor environments	Highly unlikely to experience 3G/4G speeds in the rural areas of the conservancies	reliable	reliable
IEEE Standards	IEEE 802.11ac and IEEE 802.11b/g/n	IEEE 802.11ac and IEEE 802.11b/g/n and 802.16 for WiMAX	IEEE 802.11	IEEE 802.11af

The implementation of IP-based cameras that leverages the various connectivity infrastructures discussed in table 6.2 has been carried out in various domains. At the Ol Pejeta,for example, the cameras already implemented are for surveillance and uses the cabled infrastructure through the Power Over Ethernet (PoE) technology. This has also been done in other institutions such as the government offices along Harambee Avenue in Kenya, Industrial area environments and a lot of other places including our institution, Strathmore University.

Networked game cameras have not been implemented in Kenya yet due to a number of factors with connectivity standing top of the list. The implementation of PoEs for the game environments would work but the major demerit would be the expensive cable infrastructure that has to be put up alongside other challenges such as setting up of mechanisms to power the infrastructure in the fields and the high chance of the wild animals knocking down all the devices linked to the cables.

Camera-traps that uses GPRS technology have been implemented in parts of California in the United States of America to intermittently transmit captured images after intervals of time. This has proven successful owing to the wildlife research desired in that ecosystem. The future work to be added on this implementation is to have real-time transmission of the camera feeds on deployment of reliable connectivity network.

6.2.1. Validation of the Research Hypothesis

Table 6.2 presents an interesting comparison of the available infrastructures that game environments have to consider for implementation of connectivity. Given the size of area covered by conservancies and safari camps, for example, the Ol Pejeta conservancy which covers 360sq. km and was visited under this research, it is paramount that connectivity to be deployed has to guarantee coverage of such an area.

The implementation of the other connectivity technologies described in table 6.2 requires setting up of more repeating infrastructure to achieve the desired connectivity in an area like Ol Pejeta compared to the usage of TV White Space which on estimation could use only five client stations and two masters that could cover an area of 400sq. km. The cost of setting up this infrastructure is relatively cheaper compared to VSATs, cellular broadband and Wi-Fi. In addition, the stability of the signal of VSATs, cellular broadband and Wi-Fi (from Fibre connectivity) in a rural area, where most conservancies are located, is hampered by geographical interferences such as buildings and vegetation. This will highly degrade the quality of the signal from these technologies. TV White Space, on the other hand, can operate in a non-line of sight (NLOS) while utilising the lower-frequency UHF signals that can penetrate obstacles and cover uneven ground without requiring additional infrastructure.

The backhaul network of TV White Space can cover a distance of up to 14km penetrating walls, buildings and vegetation. While the range will vary depending upon terrain and obstacles in each individual location, users can typically expect an area of high throughput extending 5-12 km from the base station. The throughput will also vary depending on terrain, obstacles, number of client stations and other factors although an average throughput of 12.3 Mb/s can be achieved at the lowest implementation of infrastructure.

The tests carried out at the Mawingu station show that TVWS broadband can support download speeds of 50 Mbps or more which is sufficient enough to allow transmission of video feeds from networked game cameras to a mobile interface. The camera prototype developed under this study is able to produce an output of a HD video whose default resolution is 1920x1080 at a bitrate of 17Mbps which fits into the provision of the TVWS speeds. The large coverage area that TV white space can span through its base station and client infrastructure while staying resilient to obstacles also demonstrate that this is a reliable connectivity in the game environments. This connectivity can hence be leveraged to implement networked game cameras that can provide feeds in real-time to various user interfaces and even stored the feeds in the cloud.

6.3. Implemented IP-based Camera System in this Study

The IP-based camera designed, implemented and tested in this dissertation can be deployed in any network that supports streaming protocols. This can be deployed in a Wi-Fi environment with a fibre backhaul network or any other, cellular broadband connectivity that is implemented with Wide Code Division Multiple Access (WCDMA) protocol that contrives High Speed Packet Access (HSPA) mobile protocol, VSATs and TV White Space.

In line with the objectives and context of this research, the implementation of the IP-based camera system will suffice in the game environments through deployment of the TV White Space connectivity infrastructure which can relatively guarantee cheaper cost of setup, speed of connectivity, RSSI and resilience of the radio waves to obstacles if interference to the incumbent TV services is properly addressed.

The IP-based camera system developed here uses an 8 MP camera with a resolution of 1024x768. The camera costs $40 and comes as a plug and play through the CSI interface. The feeds delivered are clear enough to be viewed on any mobile device. The transmission of the live-feeds is dependent on the strength of the signal of the network. The TV White Space connectivity provides downlink and uplink speed of approximately 3 to 7 Mbps. Figure 6.1 shows a snippet of the downlink speeds of the Adaptrum ACRS2 base stations as tested at Mawingu Networks.

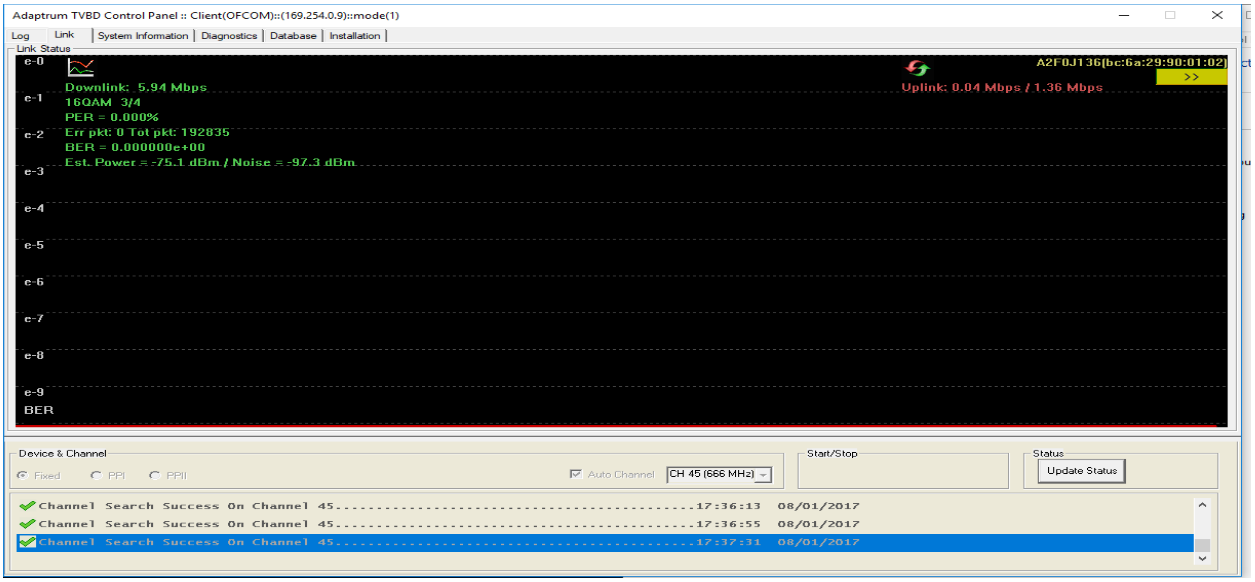

Figure 6.1 Screenshot of Downlink Speeds for Adaptrum ACRS2 Base Station

The application used by the user to access and view the live streaming of the feeds is Android-based. The App works well on API version 14 to 27 of the Android platform. The application was developed to accommodate that range of APIs due to the majority of the devices used by users having support for these APIs. The API names of these Android names are as shown in table 6.3 with the latest version (API 27) not included. The latest API version of Android Oreo.

Table 6.3 Android API versions (From API 14) and Their Code Names

Code name	Version	API level
Nougat++	7.1 and 7.1.1	API level 25
Nougat	7.0	API level 24
Marshmallow	6.0	API level 23
LOLLIPOP_MR1	5.1	API level 22
Lollipop	5.0	API level 21
KitKat	4.4 – 4.4.4	API level 19
Jelly Bean	4.3.x	API level 18
Jelly Bean	4.2.x	API level 17
Jelly Bean	4.1.x	API level 16
Ice Cream Sandwich	4.0.3 – 4.0.4	API level 15, NDK 8
Ice Cream Sandwich	4.0.1 – 4.0.2	API level 14, NDK 7

CHAPTER 7: CONCLUSIONS AND RECOMMENDATIONS

7.1. Conclusions

TV White Space infrastructure provides a way of utilising spectrum in an efficient manner to guarantee affordable Internet connectivity for rural areas. This connectivity is critical for the development of any game camera solution that can enhance wildlife research and help boost efforts in dealing with human-wildlife conflict and poaching for the conservancies and safari camps. Conservancies and Safari camps are environments that are largely located in rural areas of Kenya and face a number of challenges such as connectivity, poaching, human-wildlife conflicts which hamper their economic success. This hence poses a challenge in the approach of designing a proper connectivity infrastructure for them to improve their game monitoring methods. Other wireless network options such as fibre optics, cellular broadband and Very Small Aperture Terminals (VSATs) are slowly being implemented to reach out to these rural areas but still have their challenges in terms of signal strength, interference and cost of deployment.

The connectivity provided through TV White Space has its own challenges as well. The biggest challenge is the utilisation of the spectrum in the TV band without affecting the incumbent services from the TV broadcasters including the constitution of a proper policy to accentuate the large scake deployment of the network. The coverage of the TV White Space connectivity, the speed of Internet access and the ability to penetrate buildings and vegetation on the other hand makes this connectivity reliable for the conservancies and the safari camps. These areas have huge tracts of land that has to be properly covered with connectivity to achieve live-streaming camera implementations as gathered by the survey.

Networked game cameras can comfortably be adopted by the conservation environments to monitor the movement of the wild animals in real-time as part of wildlife research and addressing the issues of poaching and human-wildlife conflict if TV White Space connectivity is effectuated.

7.2. Recommendations

7.2.1. Implications to Research and Policy

The implementation of TV White Space connectivity certainly requires the input of the Communications Authority of Kenya (CA) due to the usage of the licensed spectrum. The CA can help fast track the implementation of this connectivity in conservation habitats due to the economic benefit the conservation environments provide to the country. This can be done through collaborative research and development funded by the CA to the local universities and provision of resources and an efficiently enabling environment to deploy the WSDs.

7.2.2. Implications to Practice

The cameras used in this study are the low-cost do-it-yourself (DIY) camera type which do not provide the best resolution for viewing live-streaming feeds. For production deployment, high definition (HD) cameras with tilt, pan and zoom capability will be ideal but the power requirements have to be properly studied to achieve an efficiently low-powered camera for design aesthetics of the system in order to make use of miniaturised solar panels.

Development of the user interface application should also be scaled to accommodate the iOS platform as well other screen interface technologies. The development should also be optimised through a stable video management system (VMS) that will at least guarantee management of over 1000 cameras.

7.3. Suggestions for Future Research

For further work, spectrum space in the TV band should be investigated for provision of 5G and other services that will also be used by other verticals of Internet of Things (IoT) in the conservation environments.

Models of use and adoption of geolocation databases should be researched for proper policy formulation in using White Space Devices (WSDs)

Research should also be carried out on the implementation of low power systems for the white space devices as well as HD cameras to provide an efficiently solar-powering mechanism for the cameras.

Infrastructure security will also help in building a resilient ecosystem of these cameras to deter hackers from accessing information on the network of the game conservation environments. A proper research on Cybersecurity in this direction as part of the future work would really be important and beneficial.

Concepts of machine learning and artificial intelligence could be incorporated on the gathered feeds from the cameras to study the various patterns of the wild animals and even the facial structure to automatically identify, count and describe the animals.

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APPENDIX

Appendix A: Existing System Components and Modules

The System-on-a-Chip has a 3D printed mount that can be used with sticky material to mount the whole device on a tree or any building to directly point in an open field where the wild game is roaming. In this case, I used a double-sided tape for the mounts.

Figure A.1 Side View of the SoC packaged with the camera

Wireframe Designs and Web Interface

The sign up and sign in wireframes are as shown in figure A.2.

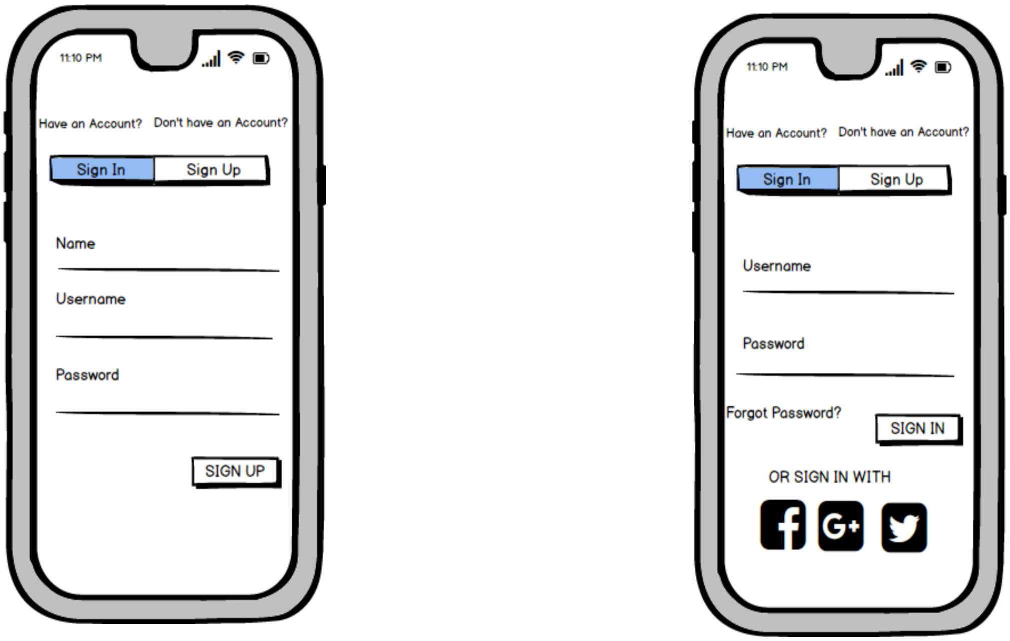

Figure A.2 Wireframe Sign Up and Sign In Screens

The web interface for signing up and signing in to the application is as shown in figure A.3.

Figure A.3 Web Interface for Sign Up and Sign In

Login Module

After registration by the user through use of Gmail or Facebook, the user is presented with a Login screen where she can as well login with Gmail or Facebook or through the credentials he/she used while registering. The Login module then allows the user to be able to navigate the App and access the various cameras placed at various nodes. This is as shown by the second figure of figure A.5.

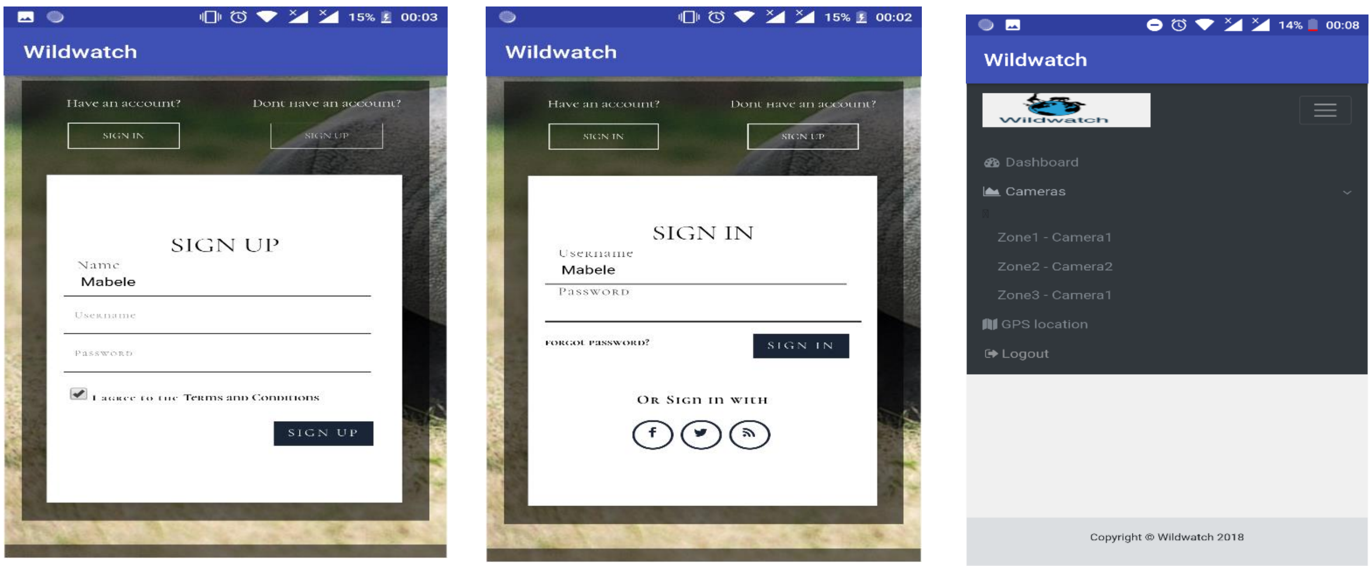

Figure A.4 Module for Accessing the Interface for Camera Feeds

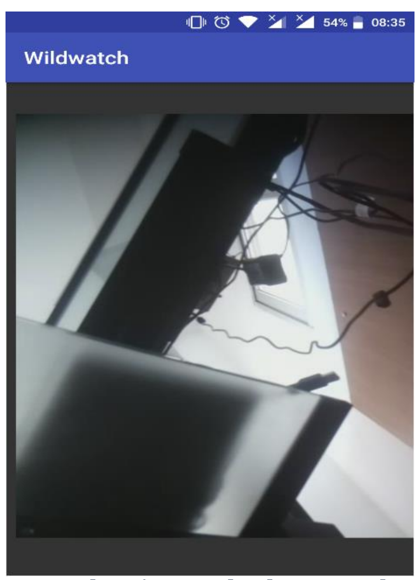

Figure A.5 The Live Feeds Shown on the App

Figure A.6 shows the search of available channels by the Adaptrum base station under the new DSA rules after uploading the new firmware.

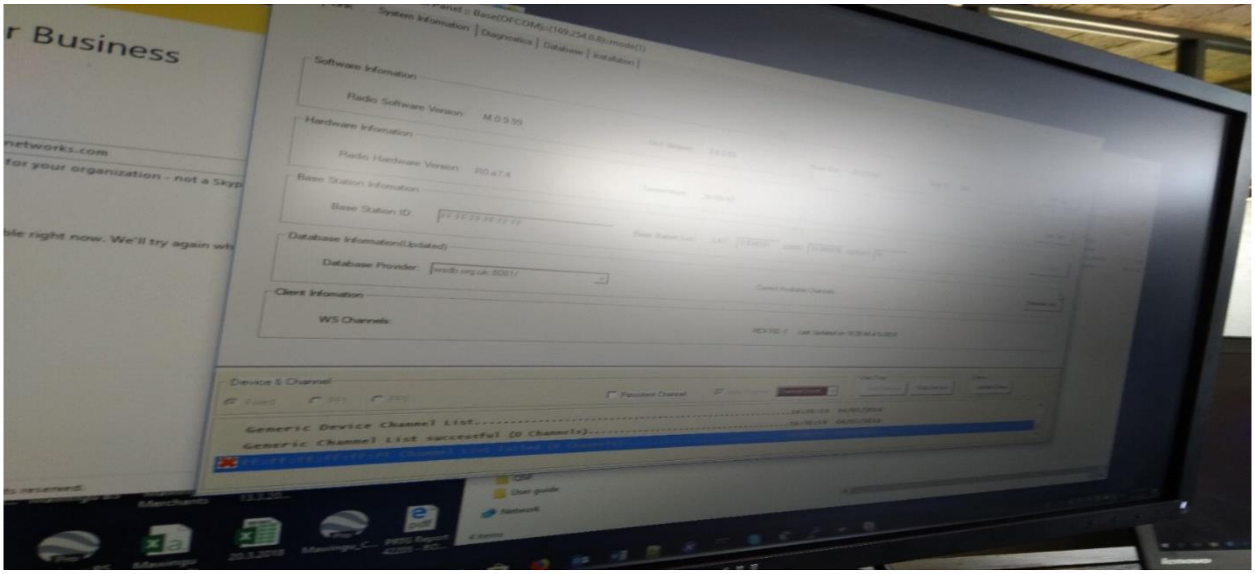

Figure A.6 Search Interface of The Available Channels on The New Firmware of The Adaptrum GUI

Figure A.7 The IP-based Camera Hardware Implementation

Appendix B: Survey Questionnaire

1. Survey Questionnaire on the Status of Connectivity and Installation of Networked Game Cameras at Sentinel Mara Camp

1. How long have you been at Sentinel Mara Camp?

Short answer text

2. Does your work involve use of Internet at the safari camp?

- Yes
- No
- Occasional use of Internet

3. If your answer to question 2 above is "yes" or "occasional use", how would you rate the Internet speeds at Sentinel mara camp on a scale of 1 - 5? 1 - very reliable 2 - reliable 3 - fairly reliable 4 - unreliable 5 - very unreliable

Short answer text

4. How would you describe your level of technical skills? 1 - Very skilled 2 - Skilled 3 - Fairly technical 4 - Not technical at all

Short answer text

5. If your level of technical skill is "1", "2" or "3", how would you describe the internet speeds provided by your Internet Service Provider?

Long answer text

6. What is your connectivity infrastructure?

- ◯ Cellular broadband e.g. Airtel, Safaricom, Telkom
- ◯ Fiber network
- ◯ VSATs

7. Would you enjoy an experience of viewing the wild animals movement at the Sentinel Mara Camp from your mobile phone?

- Yes
- No
- Am not sure

8. Do you think the use of networked game cameras (cameras that allow remote viewing of camera feeds) can help improve wildlife viewing/customer experience at Sentinel Camp?

- Option 1

9. If your answer to Q.5 above is "yes", what would you say are the challenges to be faced in implementing networked game cameras at the Sentinel Camp?

Paragraph

Thank you for your time in filling this questionnaire. Be assured that any information you have provided will be considered only for the purposes of this research and will be considered private and confidential.

2. Survey Questionnaire on the Status of Connectivity and Installation of Networked Game Cameras at Ol Pejeta Conservancy

1. How long have you been at Ol Pejeta?

Short answer text

2. Does your work involve use of Internet at the Conservancy?

- Yes
- No
- Occasional Use of Internet

3. If your answer to question 2 above is "yes" or "occasional use", how would you rate the Internet speeds at Ol Pejeta on a scale of 1 - 5? 1 - very reliable 2 - reliable 3 - fairly reliable 4 - unreliable 5 - very unreliable

Short answer text

4. How would you describe your level of technical skills? 1 - Very skilled 2 - Skilled 3 - Fairly technical 4 - Not technical at all

Short answer text

5. Would you enjoy an experience of viewing the wild animals movement in the Ol Pejeta conservancy from your mobile phone?

- ◯ Yes
- ◯ No

6. Do you think the use of networked game cameras (cameras that allow remote viewing of camera feeds) can help improve wildlife monitoring/wildlife research at Ol Pejeta?

- ◯ Yes
- ◯ No
- ◯ Am not sure

---

7. If your answer to Q.5 above is "yes", what would you say are the challenges to be faced in implementing networked game cameras at the Ol Pejeta conservancy?

Paragraph

Thank you for your time in filling this questionnaire. Be assured that any information you have provided will be considered only for the purposes of this research and will be considered private and confidential.

Appendix C: User's Questionnaire

<u>Demographics</u>

(Please tick where appropriate)

Name(Optional): ……………………………………………………….

Age: Below 18: ( ) 19-25 ( ) 26-40 ( ) 41-65 ( ) 66 and above ( )

Gender: Male ( ) Female ( )

Highest Education Level: Primary ( ) Secondary ( ) College/University ( )

<u>Part 1: Navigation Testing</u>

1. **Please perform the following tasks and respond to the questions that follow**

   i. Launch the "Wildwatch" App
   ii. Register by entering the requested details
   iii. Login to the application
   iv. Selection Camera in Zone 1

Please state if any of the screens crashes or has a problem with your access

………………………………………………………………………………………………

……………………………………………………………………………………………….

<u>Part 2: Functionality Test</u>

2. **<u>On a scale of 1-5, please rate the application on the listed functionalities: 1 being Very Poor and 5 being Very Good</u>**

   Very Good - 1 Fairly Good – 3 Poor - 4

   Good - 2 Very Poor - 5

a. <u>Ease of Use in terms of navigation</u>

b. Speed of Submitting Information

c. Presentation of video feeds

d. Relevance of the application

Part 3: Look and Feel Test

1. **On a scale of 1-5, please rate the application on the listed appearance screens: 1 being Very Poor and 5 being Very Good**

   Very Good - 1   Fairly Good – 3   Poor - 4

   Good - 2   Very Poor - 5

Table B.1 Application Rating Table

Screen	**Rating**
App icon	
Registration	
Login	
Home -- Dashboard	
Camera feeds view	

Appendix D: Testing Results

Table D.1 Sample Distribution by Respondent Category

Respondents' Occupation	Total Number
Staff and Students	5
Network Engineers / TVWS Specialists	3
Game Environment Officers	7
Total Population	**15**

Table D.2 Tabular Representation of Users Testers by Gender

Respondents	Total Number
Male	10
Female	5
Total Population	**15**

Table D.3 Tabular Presentation of the Feedback by Numbers on Ease of Application Use

Respondents' Occupation	Reliable Performance	Poor Performance
Staff and Students	5	0
Network Engineers / TVWS Specialists	3	0
Game Environment Officers	6	1
Total Number	**14**	**1**

Appendix E: Survey Results

Table E.1 Tabular Representation of Respondents by Numbers from the Conservation Areas

Conservation Environment	Number of Respondents
Ol Pejeta	4
Sentinel Mara Camp	3
Total Number of Respondents	**7**

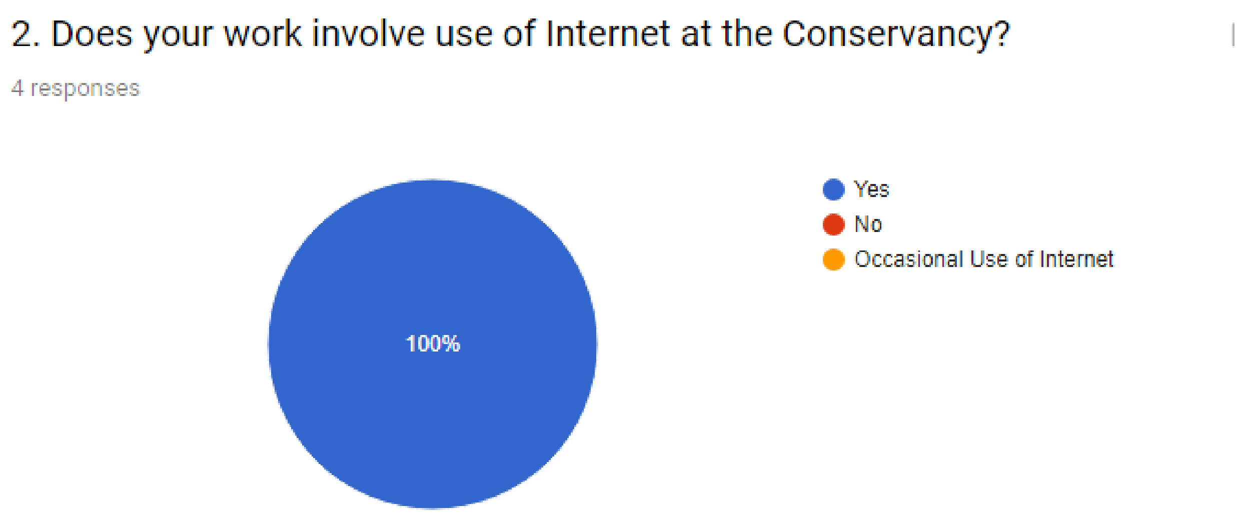

Figure E.1 Respondents Whose Work Involve Using The Internet at Ol Pejeta

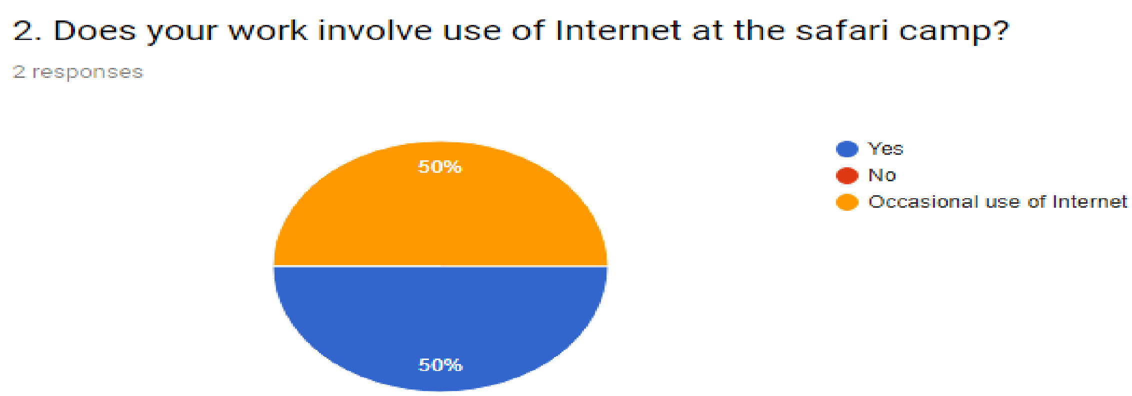

Figure E.2 Respondents Whose Work Involve Using The Internet at Sentinel Mara Camp

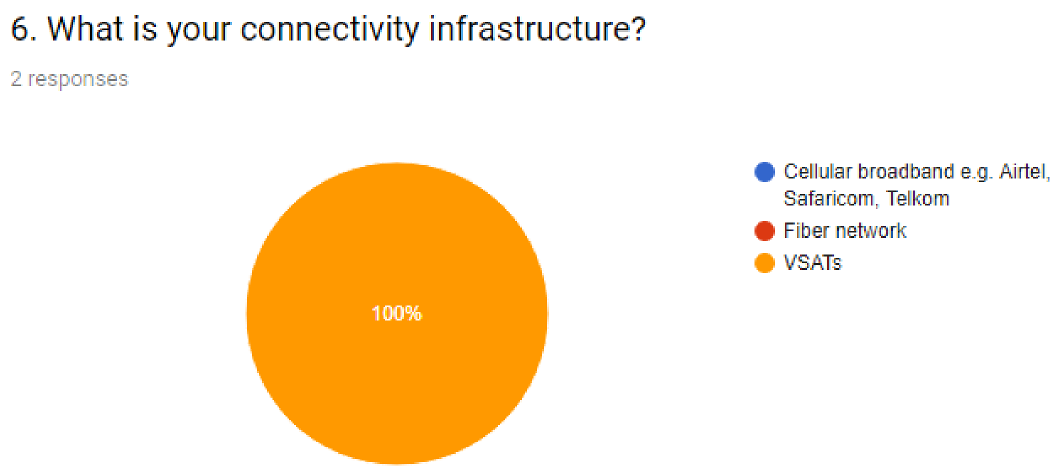

Figure E.3 Connectivity Infrastructure at Sentinel Mara Camp

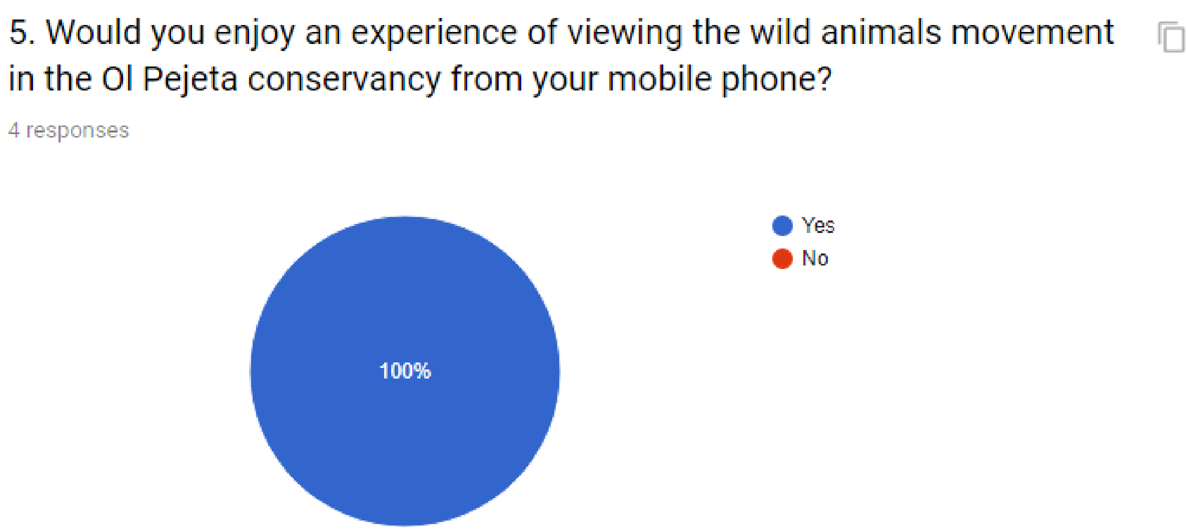

Figure E.4 Respondents at Ol Pejeta Who Would Enjoy Remote Viewing of The Wild Game

7. If your answer to Q.5 above is "yes", what would you say are the challenges to be faced in implementing networked game cameras at the Ol Pejeta conservancy?

4 responses

Powering the cameras, setting up the network to cover the whole conservancy - 360sq km, having the bandwidth to support said streaming

1. Olpejeta is a big ranch - Full network coverage can be a challenge
2. Cameras being damaged by wildlife - e.g elephants

1.There could be interference of other devices.
2.The bandwidth could be strained.
3.Cost

Network connectivity, maintenance

Figure E.5 The Challenges Cited by Ol Pejeta on Implementing Networked Game Cameras

9. If your answer to Q.5 above is "yes", what would you say are the challenges to be faced in implementing networked game cameras at the Sentinel Camp?

2 responses

cost, electricity requirements, disturbance to close to nature experience

1) Not having Internet available throughout the day could be a challenge.
2) Viewing animals on a mobile phone might not be as fulfilling as watching animals face to face.
3) Mobile viewing can easily kill the spirit of Safari

Figure E.6 The Challenges Cited by Sentinel Mara Camp in Adopting Networked Game Cameras