A wireless livestock tracking system based on real-time internet of things for theft prevention.

A Wireless Livestock Tracking System Based on Real-time Internet of Things for Theft Prevention

By

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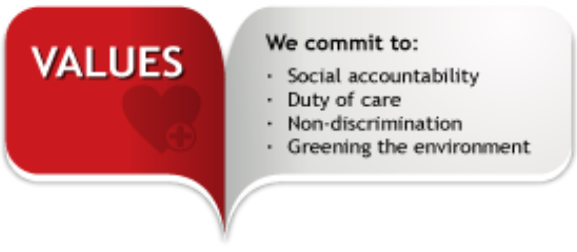

Declaration

I, Muzi Vincent Sandlana, hereby declare that this dissertation research study entitled, A Wireless Livestock Tracking System Based on Real-time Internet of Things for Theft Prevention, is my work. It is being submitted in partial fulfilment of the requirements for the Master of Computing Degree: Information Technology at Tshwane University of Technology, Pretoria. I further declare that all sources cited or quoted are indicated and acknowledged using a comprehensive list of references.

Signature Date

……. ……

Dedications

This study is dedicated to the memory of my late father, JN Sandlana. Although he was my inspiration to pursue my studies while I was very young, he did not see my graduation. This is for him.

Thanks to my academic advisor who guided me through this process, and to the committee that kept me on track.

I dedicate this dissertation to my 12th grade teacher who inspired my pursuit of ICT.

My sister Christinah helped me in all big and small things, as did my parents.

This dissertation is dedicated to my wife and daughters who encouraged me to pursue my dreams and to complete my dissertation.

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Abstract

The incessant problem of livestock theft poses a significant threat to the agricultural industry, necessitating the development of innovative and effective preventive strategies. In this study, a novel Wireless Livestock Tracking System (WLTS) is proposed, leveraging real-time Internet of Things (IoT) technologies to revolutionize livestock theft prevention. The proposed WLTS employs a robust IoT infrastructure, seamlessly integrating GPS sensors with LoRa wireless communication modules. LoRa technology, with its extended range and low power consumption, emerges as the cornerstone of this IoT-based solution, surpassing the limitations of Wi-Fi and Bluetooth-based systems. To facilitate real-time communication between farmers and their livestock, the system utilizes a single LoRa network receiver, capable of simultaneously handling multiple sensor nodes dispersed across the geographical area.

Simulation results obtained using the NS-3 simulator convincingly demonstrate the efficacy of the proposed WLTS in mitigating livestock theft. Real-time tracking capabilities empower farmers to promptly identify and recover stolen animals, minimizing losses and safeguarding their valuable assets. Geofencing alerts, proven to be highly accurate, further enhance the system's sensitivity to potential theft scenarios. Furthermore, the WLTS is equipped with a user-friendly interface accessible via online or mobile applications, enabling farmers to remotely monitor their livestock from anywhere. Additionally, data analytics capabilities are integrated into the system, enabling predictive analysis of probable theft trends based on historical data, further augmenting its intelligence and effectiveness.

The proposed WLTS stands as a testament to the transformative potential of IoT technologies in the agricultural sector, offering a comprehensive solution to the pervasive issue of livestock theft. The system's effectiveness has been rigorously validated through NS-3 simulations, highlighting its potential as a vital tool for enhancing agricultural security. The findings of this study pave the way for the practical implementation of the WLTS, revolutionizing livestock protection and safeguarding the livelihoods of farmers worldwide.

Keywords: *LoRa, communication, sensor nodes, low-power wide-area network, radio frequency identification, real-time Internet of Things.*

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List of Abbreviations

EPC - Electronic Product Codes

RFID - Radio Frequency Identification

LoRa - Long Range

LPWAN - Low-Power Wide-Area Network

WSNs - Wireless Sensor Nodes

WSN - Wireless Sensor Network

GPS - Global Positioning System

M2M – Machine 2 Machine

WLTS - Wireless Livestock Tracking System

Chapter 1: Introduction

1.1 Background Information to the Study

Farm animals that are raised in an agricultural context are known as livestock, perhaps most obviously sheep and cattle. The management and raising of domestic livestock, or farm animals for the goal of meat production and other products is known as livestock farming. The main drawbacks of traditional livestock farming are that the farmers are ignorant when the cattle are sick; it is challenging to track the whereabouts of cows since they do not keep to one place; and the traditional tracking procedure takes more time and is less dependable (Vigneswaria, Kalaiselvib, Mathumithac, Nivedithac & Sowmian, 2021).

Various indigenous people living in rural South African communities view cattle not only as a source of food but also as an important commodity that can be used in business deals and social ventures. Most rural South African communities view cattle as their only source of livelihood and sustainability, or as “living wealth”. Therefore, livestock theft can be a devastating event that threatens the livelihood of rural livestock farmers and their commercial endeavours (Geldenhuys, 2020).

Farmers frequently find themselves stuck in this situation without any answers. However, farmers create ways of labelling each animal, counting the herd before and after grazing, and enclosing the grazing area in order to prevent livestock theft. It is obvious that these methods fall far short of being sufficiently effective in addressing this issue on a large scale. Moreover, thieves are taking what they want by employing ever more advanced and cunning methods. Additionally, it appears to be nearly impossible and at best an arduous process to recover the stolen animals − they may

already have been slaughtered or sold. Governmental means thus far appear to be insufficient (Geldenhuys, 2020).

Livestock theft in South Africa causes a major problem to the livelihood of the farmers, more especially the ones owning small numbers of livestock. For example, in the Mpumalanga Province Nkomazi Local Municipality, which is close to eSwatini and Mozambique borders, livestock is being stolen and taken outside of the country. It thus becomes very difficult for the farmers to track their livestock, which leads to them losing a great deal of money. For underprivileged farmers, the impact of livestock theft is felt more harshly than on the commercial livestock owners. Indigent farmers own very small numbers of livestock; and this is their only way of making a living and feeding their families (Geldenhuys, 2020).

A November 2021 SAAI article written by Jess de Klerk states that livestock theft is an emotional matter for farmers; however, the full extent of its impact has yet to be known. Most farmers appear to be unconcerned about the issue prior to theft; only responding when someone steals from them. The majority of operations and patrols target the so-called runners, who are responsible for stealing the livestock. Farmers and the SAPS are expending vast amounts of energy, time, and resources to combat stock theft; however, they are currently waging a losing war.

In a study by Maluleke & Dlamini (2019), it is mentioned that every year, over 131 000 cases of stolen goods are reported. Every year, around 4 000 stock theft instances are reported in the Free State alone. A considerable proportion of stock thefts are not reported because farmers believe that nothing will be done in any event, implying that thousands more occurrences must be added to these figures. According to Statistics South Africa, around 70.7% of stock theft occurrences go unreported. The value of

animals taken in 2019/2020 is estimated by Maluleke & Dlamini (2019) to be roughly R1 179 458 600. Every day, around 182 cattle, 282 sheep, and 138 goats are stolen in South Africa.

Of recent years technology in the agricultural sector has been advancing, bringing forth solutions to most problems faced by farmers, including this study, of livestock theft. Solutions aim to increase productivity and safety of the livestock, making farming less burdensome for the farmers. Smart farming, animal tracking and habitat monitoring are some domains to be implemented using LoRa Communication and Internet of Things (IoT) with Wireless Sensor Networks (WSNs) (Ferreira, Viegas, Coimbra, & De Almeida, 2019).

The IoT, along with LoRa Communication can be a true answer to this problem which is being addressed in this study. First, theft must be detected and then it must be prevented by accurate analysis of livestock behaviour. Many solutions have emerged of recent years; however, generally they are designed for European countries and do not address the real constraints associated with the African rural context (Ferreira, Viegas, Coimbra, & De Almeida, 2019).

In this dissertation various types of real-time IoT solutions are suggested, not forgetting LoRa communication, which is the Low Power Wide Area Network's new communication technology (LPWAN). LPWAN emphasizes long-range communication with high-receiving sensitivity, allowing it to work effectively under noise interference or noise floor. LoRa communication can be used as a real-time communication tool to monitor or track livestock so that livestock theft can be prevented (Casas, Hermosa, Marco, Blanco, & Zarazaga-Soria, 2021).

LoRa is a low-power wireless communication system designed for long-distance communication. Furthermore, it offers low-data-rate connectivity over long distances. LoRa is a type of RF modulation technology which can communicate over vast distances of up to 15 kilometres in rural regions and up to 5 kilometres in urban areas. As this study seeks to bring solutions to farmers in the rural areas of South Africa, LoRa appears the best solution to this problem as it will allow farmers to see their livestock for distances up to 15km and to be able to cover that range in rural areas (Evans, 2022).

According to Dieng, Thiare & Pham (2017), utilizing cutting-edge technologies, such as those connected to the Internet of Things, could be a successful strategy for preventing and combatting cattle rustling by making it easier to identify and locate animals, manage farms and herds, manage grazing areas, study animal behaviour, predict thefts, etc. Technologies centred on the IoT, such as wireless sensors and actuators networks (WSAN), radio frequency identification (RFID), and Big Data, could help overcome the limitations of conventional solutions in the fight against cattle rustling (Akkaya & Younis 2006). The Internet of Things is not a new technology; rather, it is the advancement of several technologies that allows for the communication of all virtually connected items as well as the collection of additional data for use in improving systems.

The only way to prevent livestock theft is always to have the best method of tracking the livestock and ensuring that they are counted automatically. This will not be possible if livestock is counted manually − it will only be possible if identification methods such as EPC (electronic product codes) are used to identify the livestock. Such can also be used for receiving livestock information from various selected objects before forwarding that information to the data centre or data warehouse. The best system

being used for communication to connect to the livestock from servers and smartphones is the LoRaWAN network. This is a low-power WAN protocol which is low cost, mobile, and secure; and it also supports geolocation applications, which makes it possible to implement the real-time IoT livestock tracking system (Dieng, Thiare & Pham, 2017). This study is also looking more into outdoor livestock tracking systems as it is focusing on tracking or monitoring livestock while at the grazeland.

The research gap identified is that most researchers have developed a system which uses base stations that do not report in real-time. This study has reviewed the current tracking devices which are mostly collars worn by livestock. These are not fool-proof − thieves can easily remove them before taking the livestock. Dieng et al. (2010) further mentioned that the choice of technologies to prevent and combat cattle theft in the African context should be made taking into account specific criteria applicable to the rural areas; also the social conditions of farmers in this environment.

Most solutions are designed for urban but not rural areas. The number of IoT systems and devices rapidly increases, and IoT applications are becoming increasingly popular. For a large number of such applications, the ability to localize the devices is of additional value as it gives context to the application and increases usability and functionality (Casas, Hermosa, Marco, Blanco, & Zarazaga-Soria, 2021). This research study has designed a livestock real-time wireless tracking system which uses LoRaWAN along with RFID as an important enabler of IoT that can be used for livestock identification.

In this study, RFID is used to consolidate electromagnetic fields for the unique identification and tracking of livestock. LoRaWAN is an outdoor-based localization systems which provides the best solution to preventing livestock theft. The system

allows real-time communication between the livestock sensor nodes and the livestock owner connecting through the LoRa communication tools. This includes the LoRa gateway which is the link between the data source (sensors in the environment) and people. The gateway enables scale for the IoT and is a critical component in the chain that enables better visibility, cost reduction, resource input reduction, improved safety, and better decision-making. In addition to that, an outdoor tracking device will be mainly sensors worn by the livestock designed to fulfil the objective of the research.

1.2 Research Motivation

When the researcher's sister was married, the researcher's mother was given two cows by the in-laws as part of the *lobola* (bride price). In less than five months one cow went missing and it has not been seen since. When I, as researcher, was given the opportunity to work on this topic, I looked forward to solving this problem that many farmers face in the villages. Therefore, this study proposes a real-time IoT livestock tracking system using LoRa communication which will assist livestock owners to monitor the geographical location of their livestock in real-time. The interest in carrying out this research study is to develop a real-time wireless tracking system; also, to contribute to the IoT wireless networks field. In addition, the motivation behind this research study is to learn more about real-time IoT technologies that will assist in solving the problem of livestock theft, especially in rural areas of Mpumalanga Ehlanzeni. Previous studies have addressed the issue of livestock theft but not in real-time: most use technologies that do not respond in real-time; for the security of the livestock, however, this study will be addressing both issues, respectively.

1.3. Problem Statement

Most literature reviews have confirmed that the impact of crime on agricultural farms in South Africa is serious; the inadequacy of livestock wireless tracking systems in rural areas to combat livestock theft is a huge challenge. Such inadequacy of livestock tracking on rural areas farms is not only an issue in South Africa but also in neighbouring countries. Nothing much is being done to address livestock theft in rural areas. Some researchers internationally have proven that in the fields of criminology, penology, and more in the criminal justice system, there is a lack of attendance to cases in the stock-crime field; and there is total neglect in the rural areas and little done in urban areas (Jones & Smith, 2010; Marco, et al., 2021). The stock-theft report at a meeting held on the 11th and 12th of September 2018 by the National Red Meat Producers Congress stated that livestock stolen between 2013 and 2018 shows a huge increase on previous losses. This includes all types of livestock. In calculating the number of livestock units stolen in the country per day, the true horror of the situation becomes evident. The figures were as follows (Jones & Smith, 2010; Marco, et al., 2021):

1. Cattle: 178 stolen per day (365 days of the year)
2. Sheep: 249 stolen per day (365 days per year)
3. Goats: 115 stolen per day (365 days per year)

The statistics above show that South Africa as a whole, therefore, loses one economic farming unit per day. In some cases where people farm with limited numbers of livestock as in the rural areas, their livelihood is simply destroyed by this criminal behaviour, farming being their main source of income. This study will be viewing these problems and addressing them to prevent the increase in livestock theft in our country.

Such will be achieved by using the latest IoT technologies available such as LoRa, which is a LPWAN protocol presenting best securities to ensure success.

1.4. Research Questions

The main research question to address in this study reads as follows: How to develop a real-time IoT wireless tracking system using LoRa low-power wireless communication technology to prevent livestock theft in rural areas?

In order to answer the above main research question and provide a solution to the identified problem, this dissertation has adequately answered the following sub-questions:

1. What are the existing technologies used for livestock tracking?
2. How can the proposed real-time IoT wireless tracking systems using low-power wireless communication technology be designed to prevent livestock theft?
3. What is the effectiveness of the designed IoT livestock wireless tracking system?

1.5. Aim and Objectives

The main aim of this study is to develop a real-time IoT wireless livestock-tracking system using low-power wireless communication technology that helps to prevent livestock theft.

Objectives are:

1. To identify types of real-time IoT technologies considered useful for tracking livestock wirelessly.

2. To design a real-time wireless tracking system using low-power wireless communication technology that will be used to prevent livestock theft.
3. To evaluate the effectiveness of the designed IoT Livestock wireless tracking system.

1.6. Significance and Benefits of the Study

This study will benefit livestock farmers in the rural areas of Mpumalanga in the Ehlanzeni District, especially Nkomazi Local Municipality, which is close to the eSwatini and Mozambique borders.

The two areas in which ere the livestock owners will benefit from this research are:

i. Livestock theft prevention: The designed IoT livestock tracking system using low-power wireless communication technology will assist the livestock owners to locate their livestock and to count them in real-time per this system.
ii. This study is also a learning curve for livestock owners in rural areas who know nothing about IoT and real-time wireless networks.

1.7. Research Methodology

This study is attempting to developing a real-time IoT wireless tracking system using low-power wireless communication technology that prevents livestock theft in rural areas. To provide answers to all the research questions in this study, an experimental methodology is applied, with the following methods discussed below:

1.7.1 Literature review

This study is conducted using studies such as white papers, conference papers, documented IoT, LoRaWAN organizational information websites, journals, books, and

other internet sources. This study examined the conclusions after analysing the material gathered from the sources.

1.7.2 Modelling

Scientific models or mathematical models are used to design the proposed wireless tracking system. LoRaWAN gateways are used to test and implement the wireless connection between the livestock sensor nodes and the farmers' workstations. Such was implemented using the NS-3 simulation tool; at a later stage it will be tested in a real-time environment.

1.7.3 Simulation

The effectiveness of the proposed solution is measured using the NS-3 simulation tool. The NS-3 is an open-source event-driven simulation tool, designed specifically for research in computer communication networks.

Table I: Alignment of Research Questions, Research Objectives, and Research Methods

Research Questions	Research Objectives	Research Methods
1. What are the existing technologies used for livestock tracking?	To identify types of real-time IoT technologies considered useful for tracking livestock wirelessly.	Literature review
2. How can the proposed real-time IoT wireless tracking systems using low-power wireless communication technology be	To design a real-time wireless tracking system using low-power wireless communication technology that will be used to prevent livestock theft.	Modelling

	designed to prevent livestock theft?		
3.	What is the effectiveness of the designed IoT livestock wireless tracking system?	To evaluate the effectiveness of the designed IoT livestock wireless tracking system.	Simulations

1.8 Premises of the Research

Telecommunication Standardization Sector (ITU-T), IEEE 802.11 standard, and the International Organization for Standardization (ISO) 9001 model served as the foundation for our research. ITU-T was employed in this dissertation because it outlines how telecommunication networks operate and interact. In this dissertation, the IEEE 802.11 standard was used to construct network architectures and communication models. ISO 9001 was used to ensure quality during the algorithm design, implementation, testing, and inspection phases. All phases must be planned, controlled, and verified during the research, going forward.

1.9 Contributions of the Study

The contributions of the study are:

1. This real-time wireless tracking system which uses low-power wireless communication technology will provide the best, most accurate record-keeping and real-time decision-making for the farmers.
2. This proposes a real-time system, using LoRa which has benefits which are low range, low power and low-cost connectivity. Another key feature of LoRa and LoRaWAN is security for both devices and network.

3. This proposes a real-time wireless tracking system and livestock-theft prevention system preventing livestock theft by reporting and counting the livestock in real-time using IoT and LoRaWan technologies.

1.10 Ethical Considerations

No ethical clearance was required for this research. This is because data used in the study did not involve either directly or indirectly, any humans and animal information; it made use solely of a computer algorithm and simulations.

1.11 Organization of the Dissertation

The remainder of this dissertation is organized as follows: In Chapter 2, the research study presents the review of literature and overview of related work, wireless network protocols, and an overview of the simulation tools used which are the NS2 and NS3. Furthermore, this study discusses the various wireless communication network protocols used to solve the identified problem, as well as their gaps/limitations in the solution's implementation. This study also explains why IoT, LoRaWAN, LoRa Gateway, and Wireless Sensor nodes were chosen when designing the proposed real-time wireless tracking system. The proposed system uses low-power wireless communication technology to help livestock farmers track their livestock in real-time; and to know where they are and where they are going. In Chapter 3, the research study describes system design and presents the design of the proposed real-time wireless tracking system design and the wireless network protocols used. In Chapter 4, the system implementation of the real-time livestock wireless tracking system is presented. The chapter also presents the experimental set-up and the technologies used to implement the proposed solution. In Chapter 5, the research study presents

the evaluated results. Lastly, in Chapter 6, the research study provides a conclusion and suggestions for future work.

1.12 Summary

In this chapter, the background of the real-time wireless tracking system was presented. The motivation for this research study was to propose a real-time wireless tracking system using LoRa wireless communication network that will be used to track livestock. The proposed system must be able to count animals and allow their whereabouts to be known at all times by the livestock owners. To support the proposed system, a set of research questions has been identified and defined, which the dissertation answers per its objectives. In this dissertation, this study used the experimental technique and the following procedures to tackle the specified problem: literature review, modelling, implementation, and simulation. Furthermore, this study discussed the dissertation contributions. This study also gives a complete literature review and associated studies in the next chapter.

Chapter 2: Literature Review

2.1 Introduction

Primarily and most importantly, very little research exists that focuses solely on the combination of livestock theft prevalence and its prevention, in concert with the rural livestock farming practices. The simple reason would be that most developed countries do not need applications for this purpose, cattle rustling occurring very rarely and on isolated occasions (Gough, Oliver, & Thomas, 2012). Technology in the computerized agricultural sector around the world has been advancing at a steady pace to increase the productivity and efficiency of various farmland processes. With the advances in wireless sensor networks (WSNs) and the IoT, there is endless potential for their implementation in various domains, including habitat monitoring, wild-animal tracking, and smart farming (Stojkoska, Bogatinoska, Scheepers, & Malekian, 2018).

Abdul (2020) mentioned that the International Telecommunication Union Telecommunication Standardization Sector (ITU-T) has defined IoT as a vision with technological and societal implications: the IoT is defined as a global infrastructure for the information society, enabling advanced services by interconnecting (physical and virtual) objects, based on existing and evolving interoperable information and communication technologies. According to this recommendation, the IoT, by using sensing and communications capabilities, utilizes objects to serve various types of application needs while ensuring security and privacy.

Table II: The Elements (terms) of the IoT Paradigm

Term	Definition	Author(s)
Device	A piece of technology with the essential ability to communicate; and the supplementary skills to sense, act, collect, store, and process data.	Despa, Nama, Muhammad & Anwar, 2018
Things	Any objects of either the physical world (physical objects) or the information world (virtual objects); an infrastructure of interconnected objects, people, systems, and information resources together with intelligent services allows them to process information of the physical and the virtual world and react accordingly.	Ghosh, Chakraborty & Law, 2018

The need for the real-time livestock wireless tracking system to prevent livestock theft arises because in South Africa, especially in Mpumalanga, the municipalities are close to eSwatini and Mozambique. Rustling has therefore become a trend, an almost daily occurrence. Using LoRaWAN and the IoT technologies will assist livestock farmers to ameliorate this trend (Masuku & Motlalekgosi, 2021). Farmers must be able to track their livestock and always know when something is about to happen to them, thus being able to prevent it. This will be accomplished by using RFID which is the most important enabler of IoT that can be used for livestock identification. In this study, RFID is used to consolidate electromagnetic fields for unique identification and tracking of

the livestock. This study is also using the LoRaWAN outdoor-based localization system, this being the best solution to preventing livestock theft.

The structure of Chapter 2 is as follows: In Section 2.2 the research study presents an overview of wireless networks used in this study, including security requirements and problems. The real-time wireless livestock tracking system is appropriate for a variety of protocols and is utilized for such. The various wireless network protocols and wireless network classes are discussed in Section 2.3. Sensor nodes communicate with one another through application servers and the LoRa gateway to receive and transfer information, which is critical in real-time IoT technologies. To ensure smooth communication, it is vital to choose the correct technology. Following on, Section 2.4 focuses on a variety of technologies utilized in real-time IoT wireless systems. In Section 2.5 the research report discusses numerous types of security attack in real-time IoT wireless networks, along with their problems. In Section 2.5 the research study also provides an overview of existing livestock tracking systems. Finally, in Section 2.6, the study addresses related work before laying out the gaps discovered in existing solutions.

2.2 LoRa Wireless Communication Network

LoRa is a low-power wireless communication system designed for long-distance communication. Furthermore, it offers low-data-rate connectivity over long distances. LoRa is a type of RF modulation technology that can communicate over vast distances of up to 15 kilometres in rural regions, and up to 5 kilometres in urban areas. The highlight of the LoRa-based systems is how little electricity they demand. As a result,

these battery-powered devices can easily survive up to ten years (Liang, Zhao, & Wang, 2020).

2.2.1 LoRa's operational modes

According to Evans (2022), LoRa devices operate in the sub-gigahertz frequency range. Although the accessible bands are limited and subject to rigorous government regulations, they are still helpful for long-distance data transfer.

LoRa chips operate in specific bands, with frequencies varying by region. LoRa radio devices, for example, operate at 915-928 MHz in Asia and South America; while they function at 863-870/873 MHz in Europe. In South Africa it is recommend to use EU868, the 434MHz for LoRaWAN, not being used for other modern networks (Abdul, et al., 2019).

Sigfox is a French worldwide network operator formed in 2010. Sigfox creates wireless networks to connect low-power gadgets such as electricity meters and smartwatches that must be constantly on, and generating small amounts of data. With Sigfox it is also recommended to request that the chip manufacturer reprogramme the chip to meet the criteria of the given region, which is South Africa; in this case per the LoRa Alliance (Mekki, Bajic, Chaxel, & Meyer, 2018,).

2.2.1.1 LoRaWAN typical applications

This wireless technology has a wide range of applications. Its long-range and low-power features allow one to instal end points in a variety of locations. For example, whether installed inside or outside, LoRa WAN can still communicate with the gateway. Because of these qualities, the system is suitable for M2M and IoT applications. Some common applications of LoRa are (Yu, Zhu, & Fan, 2017):

a. Smart-metering in the automotive industry
b. Applications for utilities
c. Inventory management

In reality, LoRa technology can be useful everywhere that data control and reporting are demanded. Such technology is required to be outlined in this dissertation. The point is to control the data of livestock location and report to the livestock owners in real-time using this technology which is simple to set up and utilize. As a result, most individuals prefer LoRaWAN to alternative technologies. This study is using LoRaWAN technology for the above reasons; this will make it easy for the farm owners to manage their livestock and always to know where they are situated. Farmers will thus gain real-time notifications when their livestock move out of their geographical location.

2.2.1.2 LoRa device classifications

LoRa technology is classified into various categories. Thus, below, the study explores all the LoRa device classifications in detail. There are three different classes of end-point device to address the varying needs reflected in the wide range of applications: (Cheong, Bergs, Hawinkel, & Famaey, 2017; Carlsson, Anders, Kuzminykh, Franksson, & Liljegren, 2018).

- **Class A – Bidirectional and lowest-power end devices**

  All LoRaWAN end devices support this class. Class A communication is always initiated by the end device and is completely asynchronous. It enables bidirectional communication by sending one uplink transmission at a time.

  This uplink transmission is followed by two downlink windows. ALOHA protocol is used in Class A. Class A terminating devices can enter low-

power sleep mode and remain there for as long as the application specifies.

More crucially, no network is required for periodic wake-ups. The system denotes the lowest power mode of operation.

One concept only must be grasped. As previously stated, downlink communication is followed by uplink transmission determined by the end-device application. As a result, the network server must buffer downlink communication until the next uplink event.

- **Class B – Devices are synchronized to the network**

  These devices communicate with the network via periodic beacons. Beacons can communicate with an open downlink at predetermined intervals. Such enables the network to provide predictable latency downlink communication. However, it is possible to do so at the expense of some additional power usage.

  One does not need to be concerned about the extra power usage of the LoRaWAN as they can still be valid for battery-powered applications. Furthermore, the downlink latency can be configured for up to 128 seconds. As a result, it can be used for a variety of purposes.

- **Class C – Bidirectional lowest latency end devices**

  This feature keeps the gadget turned on even when it is not transmitting. Class A uplink is followed by two downlink windows; this becomes class C and reduces downlink latency still further. Class C has the shortest latency, downlink transmission able to begin at any time. This is primarily due to the network server assuming that the end-device receiver is open.

Class C is best suited for applications that require constant power delivery. The receiver in the end device consumes up to 50mW (megawatt). Battery-powered gadgets can move between classes A and C, but only for short periods of time.

Table III: Differences between Class A, Class B, and Class C

LoRa Class A	**LoRa Class B**	**LoRa Class C**
Bidirectional communications	Bidirectional communications with scheduled receive slots	Bidirectional communications
Small payloads, long intervals	Small payloads, a periodic beacon from the gateway	Small payloads
Battery powered	Low latency	No latency
End-device uplink initiates communication	Downlink initiates communication at scheduled times	A server can initiate transmission at any time
Unicast messages	Unicast and multicast messages	Unicast and multicast messages

Lowest power consumption	More power consumption than class A	Heavy battery drainage

With all the LoRaWAN device classes explained above, in this dissertation this study is using the Class A which is the bidirectional and lowest-power end-devices category, LoRaWAN endpoints having to support Class A implementation. The end device always initiates Class A communication. An uplink message can be sent by a device at any time. After completing the uplink broadcast, the gadget opens two short 'receive' (downlink) windows. There is a delay between the end of uplink transmission and the beginning of the receive windows (RX1 and RX2). Should the network server not react during these two receive windows, the following downlink will be transmitted after the next uplink.

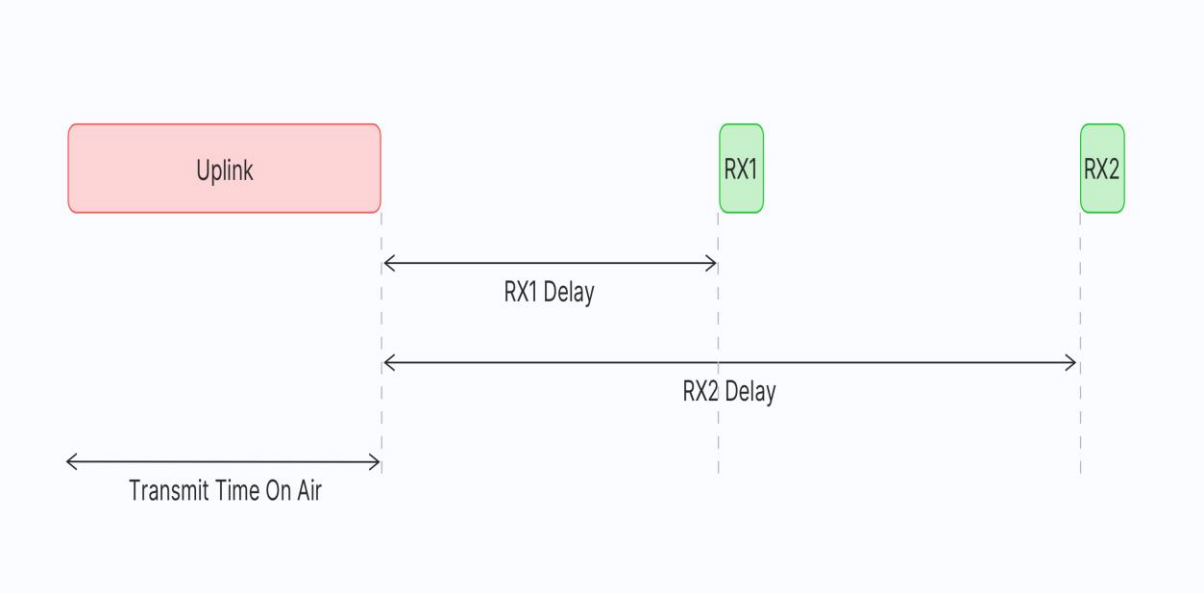


Figure 2.1. Class A receive windows

Once the downlink has been delivered, after the next uplink, the server can respond either during the first receive window (RX1) or the second receive window (RX2), but not on both. Consider the following three scenarios for downlink messaging.

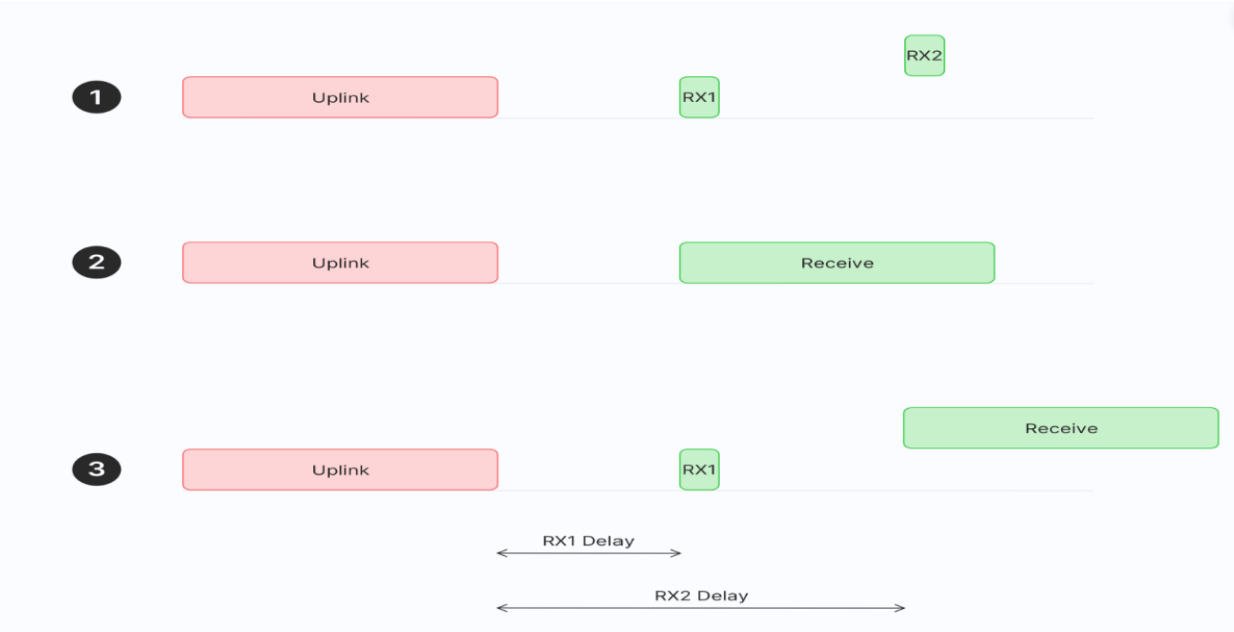


Figure 2.2. Behaviour of Class A receive windows

Case 1: The end device opens both receive windows, but neither receive window receives a downlink message.

Case 2: The end device receives a downlink during the first receive window, hence the second receive window is not opened.

Case 3: The end device opens the first receive window, but no downlink is received. As a result, it opens the second receive window and gains a downlink during that time.

The main benefits of using Class A end-devices are that they are often battery-powered, have the lowest energy consumption, spend the majority of the time in sleep mode, usually keep long intervals between uplinks, and have high downlink latency

(to receive a downlink, the end device must send an uplink). These benefits make class A the most preferable; it is also primarily used for environmental monitoring and animal tracking, which is our main objective in this dissertation. Location tracking is one of the most common uses of class A devices also forming part of this research. Other applications such as fire detection, water-leakage detection and earthquake early detection are also common use cases for Class A end-devices (Carlsson et al., 2018).

2.3 Overview of Real-time IoT Wireless Sensor Networks

WSNs are self-configured and infrastructure-free wireless networks that monitor physical or environmental conditions such as temperature, sound, vibration, pressure, motion, or pollutants; and cooperatively pass their data through the network to a central location or sink where the data can be observed and analysed. A sink, also known as a base station, serves as a link between users and the network. By injecting queries and gathering results from the sink, one can receive the required information from the network. A wireless sensor network typically consists of hundreds of thousands of sensor nodes. Radio signals allow the sensor nodes to communicate with one another. Sensing and computing devices, radio transceivers, and power components are all included in a wireless sensor node (Khalaf & Sabbar, 2019; Akkaya, & Younis, 2006).

Individual nodes in WSNs are resource-constrained by design: their processing speed, storage capacity, and communication bandwidth are all limited. After being deployed, the sensor nodes are responsible for self-organizing an adequate network infrastructure, which typically includes multi-hop communication. The inbuilt sensors then begin collecting data of importance. Wireless sensor devices also respond to

requests for specific instructions or sensing samples given from a “control site”. The sensor nodes can operate in either a continuous or event-driven mode. To gather location and positioning information, the global positioning system (GPS) and local positioning algorithms can be employed. Actuators can be added to wireless sensor devices to allow them to ‘act’ in response to particular situations (Gulati, Boddu, Kapila, Bangare, Chandnani, & Saravanan, 2022; Akkaya et al., 2006).

2.4 Wireless Sensor Nodes and Sensor Network Used

Sensor nodes communicate with one another through application servers and the LoRa gateway to receive and transfer information, which is critical in real-time IoT technologies. To ensure smooth communication, it is imperative to choose the most suitable technology. The best wireless sensor that this study is looking into is the LoRaWAN technology sensor which uses IoT. Before the study makes further progress, it is necessary to understand the concept of LoRaWAN sensors. First, IoT sensors are briefly explained. According to (Islam, Ray, & Pasandideh, 2020), IoT sensors are wireless devices that collect sensory data from their surroundings and detect abnormal changes in the environment, such as temperature and movement (which is the focus of this study), air quality, and lighting. These monitoring devices are intended to communicate with central hubs, gateways, and servers via nodes that are organized to support the user’s specific network goals.

LoRaWAN sensors are IoT devices designed to operate on LoRaWAN networks. Because of their ability to transfer data over long distances, these networks are especially useful for wireless sensors. They also have high-performance link margins that allow signals to penetrate below the radio frequency (RF) noise floor. Both of these features enable LoRaWAN to make network connections more accessible to IoT

sensors, particularly in remote areas where public access is limited (Islam, Ray, & Pasandideh, 2020).

For a variety of reasons, 2.4GHz protocols such as Wi-Fi, Zigbee, and Bluetooth are poor options for wireless sensors. Firstly, protocols that operate in the 2.4GHz band have low range and propagation through obstacles such as walls and floors. When the Wi-Fi router is in the basement and there is any form of blockage in the way, it is usual for people to have problems gaining a Wi-Fi connection on the second story of their home. Home automation systems that use protocols such as Zigbee will frequently have problems connecting to the next room (Germani, Mecarelli, Baruffa, Rugini & Frescura, 2019).

In open-air conditions, LoRa devices, on the other hand, can reach distances of many miles and work admirably over obstacles such as buildings or equipment. It is also evident that the 2.4GHz band is somewhat 'noisy', which means that 2.4GHz devices are competing for air time all around us, lowering link quality. LoRa is deployed in South Africa using the 868MHz ISM band (869.4 - 869.525MHz to be more specific for downlink as well as lower bands for uplink). This means that LoRa will not interfere with local Wi-Fi or most other wireless devices (Germani et al., 2019).

The security and key management of WIFI protocols are unreliable. For example, if the password on a Wi-Fi router is changed, all Wi-Fi devices must also be updated. The question arises how to update the password on a small battery-powered gadget with no user interface. Smartphones, TVs, computers, and other common Wi-Fi devices have screens that allow one simply to change the password; however, this is not the case with relatively simple battery-powered sensors. LoRaWAN, on the other hand, sets up and uniquely secures devices. The key originates at the sensor and has

a unique value that may be provisioned at the network server, which is common in the cloud, instead of a single password specified at the network server (Abul, 2020; Germani et al., 2019).

This dissertation further revealed that all Radio Bridge sensors have their own unique ID/Key pairs, allowing for easy security provisioning and management. Fourthly, power consumption is relatively significant for devices such as Wi-Fi, Bluetooth, Zigbee, and cellular devices. Not only is the transmitting power considerable, but the devices must also frequently communicate with a gateway or base station to stay connected. LoRaWAN devices, on the other hand, can go into a deep slumber and only transmit when a new event has to be sent. This provides for a very long battery life in most applications, in the order of 5-10 years. Such also assists in this regard; this study brings a solution that also requires low power and a longer duration of the battery, there being no time to frequently change batteries on the livestock. LoRaWAN also caters to long-range issues, which makes the LoRaWAN sensors the best sensor nodes to use (Aras, Ramachandran, Lawrence, & Hughes, 2017; Gokul & Sitaram Tadepalli, 2017).

2.5 Variety of Technologies utilized in Real-time IoT Wireless Systems

The IoT continues to promise us a smarter future: fridges that can replenish themselves by automatically ordering food from a local grocery store (in-fridge delivery included); bridges that warn oncoming cars about a frozen surface, or smart apparel that monitors your health and sends real-time data directly to your doctor's iPhone. While all of this may soon be within our grasp, the study must remain conscious of the vast machinery at work behind the scenes to make fantasies a reality. These fantasies

would never be realized were it not for the plethora of IoT technology that surrounds us (Farhan, Shukur, Alissa, Alrweg, Raza, & Kharel, 2017).

2.5.1 The excitement surrounding IoT technology

Computer technology has been available since the mid-twentieth century. However, the technology behind the IoT had been in development long before PCs were available to everyone. Since the second half of the nineteenth century, the science of telemetry (Greek tele = remote, and metron = measure) has been used to measure and collect weather data or to follow wildlife using wired phonelines, radio waves, and satellite communications. Despite its technical limitations, this technology set the groundwork for the concept of machine-to-machine communication (M2M), which, as connection solutions advanced, gave birth to the concept of the IoT as this study knows it today (McRae, Ellis, & Kent, 2018).

The IoT is a system of networked digital devices, machines, items, animals, or people that have unique IDs, having the ability to communicate and share data without requiring human-to-human or animal- or human-to-computer interaction. The IoT aspires to create smart environments in which individuals and entire societies can live in a wiser and more comfortable manner by bridging the gap between the physical and virtual worlds (McRae, Ellis, & Kent, 2018). As pompous as it may sound, the IoT has already become a part of our daily lives and will certainly remain so in the future. With all of this in mind, below is a brief overview of the machinery that powers the IoT world.

Along with the IoT technology stack, IoT technology consists of the following components. Given the diversity and sheer number of technology solutions that surround it, it might be difficult to navigate one's way through the IoT technological

maze. To simplify matters, this study divides the IoT technology stack into four main technology layers that are involved in making the IoT work (McRae, Ellis, & Kent, 2018).

These are as follows:

a. Device hardware

Devices are the objects that make up the 'things' in the IoT. Devices may take various sizes, shapes, and levels of technological complexity. Such depends, however, on the task they are required to accomplish inside the given IoT deployment, acting as an interface between the real and digital worlds. Whether a pinhead-sized microphone or a heavy construction machine, almost any material object (even those animate such as animals or humans) can be turned into a connected device by adding the necessary instrumentation (sensors or actuators along with the appropriate software) to measure and collect the necessary data. Sensors, actuators, and other telemetry equipment can, of course, function as standalone smart devices. The only constraint here is the actual IoT use case and its hardware requirements (size, simplicity of deployment and maintenance, reliability, useful lifetime, and cost-effectiveness) (Huh, Cho, & Kim, 2017).

b. Device software

This is what gives linked gadgets their 'smart' characteristics. Within the IoT network, software is in charge of creating connectivity with the cloud, collecting data, integrating devices, and executing real-time data analysis. Furthermore, device software provides application-level features for users to visualize data and to interact with the IoT system (Taivalsaari & Mikkonen, 2017).

c. Communication

After the device hardware and software are in place, another layer must be added to offer smart objects ways and means of exchanging information with the rest of the IoT world. While communications methods are inextricably linked to device hardware and software, they must be viewed as a separate layer. Physical connectivity options (cellular, satellite, LAN) and specialized protocols used in various IoT contexts (ZigBee, Thread, Z-Wave, MQTT, LwM2M) are included in the communication layer. Choosing the appropriate communications solution is an important aspect of building any IoT technology stack. The technology selected will impact not only how data is delivered to and received from the cloud, but also how devices are controlled and how they communicate with third-party devices. For the purposes of this dissertation, this study later goes into detail about some of today's communication options (Liang, Zhao, & Wang, 2020).

d. Platform

As previously said, the gadget can 'sense' what is occurring around it, communicating such to the user over a specialized communications channel thanks to the 'smart' hardware and software installed. An IoT platform is the place where all of this data is collected, managed, processed, analysed, and displayed in an understandable manner. Thus, what distinguishes such a system is not just its data gathering and IoT device-management skills, but also its ability to analyse and derive usable insights from sections of data provided by devices via the communications layer. Again, there are numerous IoT platforms on the market, with options based on project requirements, and factors such as architecture and IoT technology stack, reliability, customization properties, protocols used, hardware agnosticism, security, and cost-effectiveness. It is also worth noting that platforms can be installed on-premise or in

the cloud. The Coiote IoT Device Management platform is an example of such a platform that can be installed both on-premises and in the cloud. The same is true for another AVSystem IoT platform, Coiote IoT Data Orchestration (McRae, Ellis, & Kent, 2018).

2.6 An Overview of Existing Livestock Tracking Systems LoRaWAN Technologies

Only a few studies in the literature consider the problem of theft prevention. With the rapid development of wireless and embedded technologies, many new opportunities appear for monitoring and tracking mobile objects, including animals (Mobley, 2013). The first WSN-based systems for animal tracking were costly and were not operating in real-time. Just ten years ago, the cost of a collar was around $800 and data were sent twice per day. Over the last few years, the price of hardware has dropped drastically, while advances in communication technology have soared (Stojkoska, Bogatinoska, Scheepers, & Malekian, 2018).

The recent advances in animal-tracking technology have resulted in large volumes of data becoming available for analysis. Telemetry systems based on GPS is a relatively recent development for monitoring movement, or activity (Ungar et al., 2005), and resource use by medium- to large-sized animals. The GPS technology has enabled researchers to record the sequential movement patterns of animals and to compile datasets with many observations compared with older tracking techniques over a similar period of time (Gaur, Chand, Louhaichi, Johnson, Mishra, & Roy, 2013).

Gaur et al. (2013) stated that the use of GPS-enabled livestock tracking systems (LTS) can be used to monitor the activity of livestock (i.e., walked distance, speed, grazing and resting time; the habitat preferences; i.e., grazing sites and intensity and resting

sites; and thereby being able to assist the herdsman. In a few instances, the LTS was enhanced further with heat- and/or health-monitoring sensors − brand-new technology, such as those connected to the IoT (Maroto-Molina, Navarro-García, Príncipe-Aguirre, Gómez-Maqueda, Guerrero-Ginel, Garrido-Varo, & Pérez-Marín, 2019).

There are two kinds of GPS technology available for livestock monitoring: real-time and passive. Real-time GPS monitoring is used to keep an eye on livestock, having the ability to monitor spatial movements and spatial activities, information that can provide multiple benefits (Maroto-Molina et al., 2019). GPS live-monitoring data transmitted from livestock helps herders understand a great deal about how livestock interact with the precious land; and also gives them the ability to discover a farm animal's precise location. Passive GPS tracking systems gather information about livestock. The tracking collars are placed around the animal's neck as with a dog's collar; the herder can download the recorded tracking data by physically removing the collar as needed. The herdsman can look back and see how the livestock have moved. However, it is anticipated that as technology becomes more specialized and affordable, there will be a dynamic shift and drive toward real-time solutions (Tomkiewicz, Mark, Fuller, Kie, & Bates, 2010).

A South African product titled CelMax has been developed specifically for sheep stock-theft prevention. CelMax works by placing a collar device around the neck of a single sheep in a herd of 500. Sheep usually follow the actions of others; when one sheep behaves abnormally, the entire herd will behave similarly. When running at night is detected by the collar devices, it is assumed that someone is chasing the sheep, which could be a thief trying to catch a sheep. The device then sends an SMS to the farmer to let him know that the sheep are running and are probably being chased. The battery

life of this device ranges from 6 to 8 weeks and the whole device is very expensive (Stojkoska et al., 2018).

In 2009 another product titled the ProTagT or system was launched. This system works on the same principle as the CelMax system but uses base stations instead of an onboard GSM module to send an SMS to a farmer. These signals are forwarded to the base stations for analysis. Each of these tags has a battery life of 4 to 7 years and costs 10% of the GSM collar. According to Stojkoska et al. (2018), the first GPS-based animal tracking systems were used to store GPS locations locally; however, modern approaches are told of in the most recent studies which incorporate data-transfer techniques to send data at regular intervals in real-time or near-real-time, using radio communication, global systems for mobile communications (GSM), low-earth-orbit (LEO) satellites and ad-hoc networks, or even Bluetooth Low Energy (BLE).

2.6.1 Connectivity solutions within the IoT technology stack

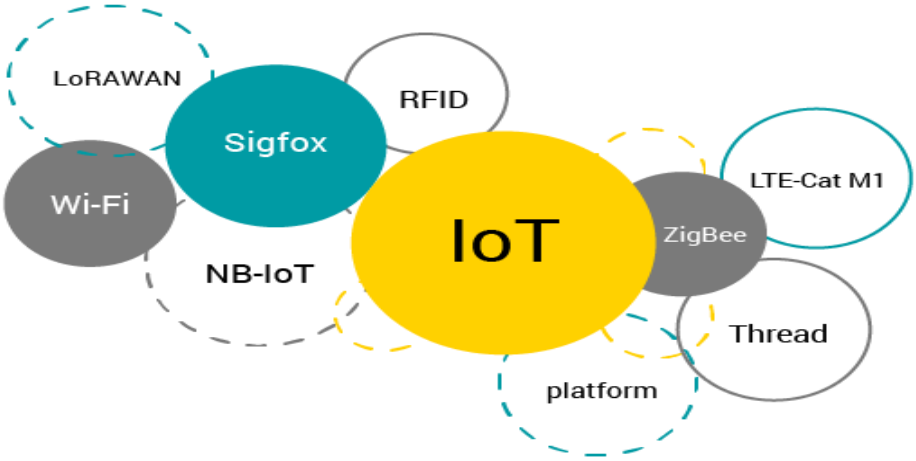


Figure 2.3. IoT technologies

As many real-world uses of IoT technologies as there are, there is no shortage of connectivity options to support them. Depending on the requirements of a certain IoT use case, each communication solution may provide distinct service enablement

scenarios while balancing power consumption, range, and bandwidth. For example, in designing a smart home, one might want to interface interior temperature sensors and a heating controller with one's smartphone so as to remotely monitor and modify the temperatures in each room based on current demands. In this situation, the IP-based IPv6 networking protocol Thread, which was specifically built for home automation, would be the best solution; the same applies to the solution of monitoring the livestock which is the best solution this study can present (Liang, Zhao, &Wang, 2020).

With so many communication standards and protocols to choose from, one would wonder why there is a need to build new ones − certain well-proven internet protocols have been in use for decades. The reason for this is that traditional internet protocols, such as transmission control protocol/internet protocol (TCP/IP), are frequently insufficiently effective and consume too much power to function efficiently within new IoT technology applications. The study provides a brief review of the key alternative internet protocols developed specifically for usage by IoT systems (Liang, Zhao, &Wang, 2020).

The review focuses on the most prevalent IoT radio technologies, which are classified according to the radio-frequency range attained by each solution: short range IoT radio solutions, medium-range solutions, and long-range wide area networks solutions (Sikimić, Amović, Vujović, Suknović, & Manjak, 2020).

2.6.1.1 Short range IoT network solutions

According to Sikimić et al. (2020), short-range IoT network solutions play a crucial role in enabling various applications and devices to connect and communicate within a localized area. These networks typically have a limited coverage range but offer advantages such as low power consumption, cost-effectiveness, and

suitability for small-scale deployments. Some popular short-range IoT network solutions are discussed below:

a) **Bluetooth**, being a well-established short-range connectivity technology, is often seen as the main answer for the future of the wearable electronics sector, such as wireless headphones or geolocation sensors; this is owing to its ubiquitous integration with smartphones. The Bluetooth low-energy (BLE) protocol takes extremely little power from the device and was designed with cost-effectiveness and low power consumption in mind. However, there is a catch − when frequently exchanging large volumes of data, BLE may not be the best answer (Sikimić et al., 2020).

b) **Radio-frequency identification (RFID),** one of the first IoT applications to be developed, provides positioning solutions for IoT applications. This is particularly so in supply-chain management and logistics, which require the capacity to determine object position inside buildings. RFID technology's future certainly extends far beyond simple localization services. Potential uses range from tracking hospital patients to boosting efficiency in healthcare to delivering real-time goods' location data to retail establishments thus mitigating out-of-stock situations (Sikimić et al., 2020).

c) **Wi-Fi**, based on IEEE 802.11, is the most widely used and well-known wireless communications protocol. Its widespread use in the IoT sector is hampered mostly by higher-than-average power consumption as a result of the necessity to maintain strong signal strength and quick data transfer for improved connectivity and reliability. Wi-Fi, as a crucial technology in the development of the IoT, provides a broad foundation for a dizzying number of IoT solutions; nevertheless, Wi-Fi must also be managed and employed in terms of

marketing, thus returning profits to both service providers and customers (Sikimić et al., 2020).

d) **ZigBee** is a widely used wireless mesh networking standard most commonly found in traffic-management systems, household gadgets, and the machine sector. ZigBee, which is based on the IEEE 802.15.4 standard, provides low data-exchange rates, low power operation, security, and reliability (Sikimić et al., 2020).

e) **Thread**, which was designed exclusively for smart home products, uses IPv6 connectivity to allow linked devices to speak to one another, access cloud services, and interact with the user via Thread mobile applications. Thread detractors argue that, given market saturation, adding another wireless communication protocol leads to increased fragmentation within the IoT technology stack (Sikimić et al., 2020).

When choosing a short-range IoT network solution, factors such as power consumption, range requirements, data throughput, security, and interoperability should be considered. Additionally, the availability of development kits, ecosystem support, and scalability should also be evaluated based on the specific application needs (Sikimić et al., 2020).

2.6.1.2 Long-range wide area networks (WAN) solutions

According to Silva, Neto, Oliveira, Rosário, Cerqueira, Both, Zeadally & Neto (2021) long-range wide area networks (WAN) solutions have gained significant attention in recent years due to the increasing need for connectivity in remote and challenging environments. These networks offer extended coverage and low-power, long-range communication capabilities, enabling connectivity for various

applications such as smart cities, industrial IoT, agriculture, and asset tracking. Below are some key discussions and considerations on long-range WAN solutions:

2.6.1.2.1 Technology options:

a) **Narrowband IoT (NB-IoT)** is a brand-new radio technology standard that ensures exceptionally low power consumption (10 years of battery power operation) and connectivity; with signal strength approximately 23 dB lower than in the case of 2G. This is the product of current 3GPP technologies. Furthermore, it makes use of existing network infrastructure, ensuring not only global coverage but also guaranteeing signal quality in LTE networks. In many circumstances, this enables the use of NB-IoT rather than options that require the creation of local networks, such as LoRa or Sigfox (Queralta, Gia, Zou, Tenhunen, & Westerlund, 2019).

b) **LTE-Cat M1** is a low-power wide-area (LPWA) networking standard used to connect IoT and M2M devices with medium data rates. It has a longer battery lifecycle and a greater in-building range than cellular technologies such as 2G, 3G, or LTE-Cat 1. Because CAT M1 is compatible with existing LTE networks, carriers do not need to create new infrastructure to deploy it. In comparison with NB-IoT, LTE Cat M1 is ideal for mobile use cases because it handles handover between cell sites much better and is quite comparable to high-speed LTE (Silva et al., 2021).

c) **LoRaWAN** is a low-power long range wide-area networking technology that supports massive networks with millions of devices, while consuming little power. LoRaWAN is a low-power wide-area network (WAN) protocol that aims

to provide low-power WANs with the features needed to allow low-cost, mobile, and secure bi-directional communication in IoT, M2M, smart city, and industrial applications (Silva et al., 2021).

d) **Sigfox** is made to provide an effective connection solution for low-power M2M applications that require modest amounts of data transfer but are too short for Wi-Fi range and too pricey and power-hungry for cellular range. Sigfox uses UNB technology, which allows it to manage modest data-transfer speeds ranging from 10 to 1,000 bits per second. Sigfox uses up to 100 times less energy than cellular communication technologies and has an average stand-by period of 20 years with a 2.5Ah battery. Sigfox proves suitable for a variety of M2M applications, including smart street lighting, intelligent meters, patient monitors, security devices, and environmental sensors, in providing a robust, energy-efficient, and scalable network capable of supporting communication between thousands of battery-powered devices across areas of several square kilometres. Sigfox is being used in an increasing variety of IoT technology solutions, such as Coiote IoT Application Enablement, to mention just one (Silva et al., 2021).

2.6.1.2.2 Coverage and range

a) Long-range WAN solutions are specifically designed to provide extended coverage in areas where traditional cellular networks may not reach. These networks use lower frequencies and higher transmit power to achieve long-range connectivity, enabling connectivity in rural or remote areas (Silva et al., 2021).

b) The coverage range of long-range WAN solutions can vary depending on factors such as transmit power, antenna placement, terrain, and

environmental conditions. It is important to assess the specific requirements of one's deployment and to conduct site surveys before determining the optimal range (Silva et al., 2021).

2.6.1.2.3 Power consumption

a) Long-range WAN solutions are designed to operate on low power, making them suitable for battery-powered IoT devices. The devices can remain operational for extended periods, ranging from months to several years, depending on the power requirements and battery capacity (Silva et al., 2021).
b) Efficient power management is crucial to maximizing the lifespan of devices in the field. Considerations include optimizing transmission intervals, duty cycles, and employing power-saving techniques such as sleep modes (Silva et al., 2021).

2.6.1.2.4 Network infrastructure

a) Long-range WAN solutions typically require the deployment of gateway devices that act as intermediaries between end devices and the central network server. Gateways receive and forward data from end devices to the network server for processing (Bagariang et al., 2019).
b) The number and placement of gateways depend on the desired coverage area and density of devices. Careful planning and network optimization are essential to ensure seamless connectivity and minimal signal interference (Bagariang et al., 2019).

2.6.1.2.5 Data rate and payload

a) Long-range WAN solutions offer lower data rates compared with traditional cellular networks. These networks are optimized for small and infrequent data

transmissions, making them suitable for applications that require periodic sensor data or simple control signals (Bagariang et al., 2019).

b) The payload size may also be limited, typically ranging from a few bytes to a few kilobytes. One must consider the data requirements of the application to ensure that the chosen solution can handle the necessary payload size (Bagariang et al., 2019).

2.6.1.2.6 Security

a) Security is a critical aspect of Long-Range WAN solutions, particularly when deploying IoT devices. Implementing encryption, secure device provisioning, and authentication mechanisms is essential to protect data integrity and prevent unauthorized access (Gebremichael et al., 2020).

b) It is important to choose solutions that provide robust security features and follow best practices for secure IoT deployments (Gebremichael et al., 2020).

2.6.1.2.7 Ecosystem and standards

a) One should consider the availability of an active ecosystem and community support for the chosen Long Range WAN solution. A vibrant ecosystem ensures access to a wide range of compatible devices, development tools, and support resources (Bansal & Kumar, 2020).

b) Standards organizations such as the LoRa Alliance and 3GPP (for NB-IoT) play a crucial role in defining specifications and ensuring interoperability. Choosing solutions aligned with established standards can provide long-term stability and compatibility (Silva et al., 2021).

These discussions highlight some key considerations when evaluating long-range WAN solutions. It is crucial to assess one's specific requirements, including coverage,

power consumption, data rate, security, and ecosystem support, before making an informed decision. Additionally, staying updated with advancements in the field can help leverage the latest technologies, and optimize IoT deployments (Silva et al., 2021).

To summarize, IoT technology has already come to stay in our homes, public spaces, offices, and factories. Given the breakneck pace of its development, it appears that the hackneyed IoT phrase ‘anything that can be connected will be connected’ is creeping ever closer to becoming our daily reality. As a result, the pertinent question should not be when this will occur, but rather how the connections should be created to ensure maximum efficiency while maintaining critical qualities such as security and cost-effectiveness.

Keeping this in mind, a deployment including a large number of low-power, low-bandwidth devices would necessitate the usage of LwM2M, a lightweight protocol created specifically for managing such resource-constrained machines. Overall, the main reason for LoRaWAN being used in this dissertation is the advantages of LoRaWAN namely, long range, low power consumption, scalability, cost-effectiveness, deep penetration, wide coverage, flexibility, and security. Such features make it a compelling choice for the IoT applications the study is working on, as it prioritizes long-range communication, battery efficiency, and cost optimization.

2.7 Overview of Real-time LoRaWAN Wireless Sensor Nodes

LoRaWAN (long-range wide-area network) is a wireless communication protocol designed for long-range, low-power communication between IoT devices. Real-time LoRaWAN wireless sensor nodes play a crucial role in various IoT applications,

including smart cities, agriculture, industrial automation, and environmental monitoring (Ghazali, Teoh, & Rahiman, 2021). An overview of these sensor nodes is given below.

2.7.1 Wireless communication protocol

LoRaWAN uses the LoRa modulation technique to achieve long-range communication, which can span several kilometres in open environments. This is particularly useful for applications in which devices are spread out over a wide area (Ghazali, Teoh, & Rahiman, 2021).

2.7.2 Low power consumption

LoRaWAN devices are designed to operate on low power, allowing them to run on batteries for extended periods (often several years) before needing replacement or recharging. This makes them suitable for remote or hard-to-reach locations (Ghazali, Teoh, & Rahiman, 2021).

2.7.3 Real-time capabilities

While LoRaWAN can be used for real-time applications, the protocol itself is not strictly real-time. However, the sensor nodes can transmit data at scheduled intervals or when triggered by specific events, providing near real-time information. In this case, when the livestock move beyond the geographical fence, the sensor nodes will be triggered and transmit the livestock data as per the scheduled intervals, which is in real-time (Ghazali, Teoh, & Rahiman, 2021).

2.7.4 Sensor integration

LoRaWAN sensor nodes can integrate various types of sensors, such as temperature, humidity, pressure, motion, proximity, and more. This allows them to monitor a wide range of environmental parameters. This study deals more with the motion sensors as

these look more to the real-time location of the livestock. Sensors are used to make sure that the owners of the livestock always know the whereabouts of their livestock. This is made possible by the use of sensor nodes which are integrated with the LoRaWAN gateway and application servers (Ghazali, Teoh, & Rahiman, 2021).

2.7.5 Edge processing

Some advanced LoRaWAN nodes can be edge processed, which means they can process data locally before transmitting it to a central server. This can reduce the amount of data sent over the network and enable quicker response times (Ghazali, Teoh, & Rahiman, 2021).

2.7.6 Security and gateway integration

LoRaWAN incorporates several security features, including AES-128 encryption, for secure communication between nodes and gateways. Data is thus transmitted over the network but protected from unauthorized access (Stranahan, 2020).

LoRaWAN sensor nodes communicate with gateways, which act as intermediaries between the nodes and the central network server. Gateways receive data from nodes and transmit it to the server, and vice versa. Integration with gateways is a critical part of a LoRaWAN network (Stranahan, 2020).

2.7.7 Scalability and application areas

LoRaWAN networks are highly scalable, allowing for the deployment of thousands of nodes in a single network. This makes LoRaWAN suitable for applications that require large-scale sensor deployments (Van den Abeele et al., 2017).

LoRaWAN sensor nodes find applications in various industries, including agriculture (for soil moisture and environmental monitoring), smart cities (for traffic management

and environmental sensing), industrial automation (for condition monitoring), and more (Van den Abeele et al., 2017).

2.7.8 IoT platforms and integration

The data collected by LoRaWAN sensor nodes is typically sent to IoT platforms for storage, processing, and visualization. These platforms provide tools for managing and analysing the data generated by the sensor nodes (Van den Abeele et al., 2017).

2.7.9 Cost-efficiency

LoRaWAN technology offers a cost-effective solution for wide-area IoT deployments, especially when compared with other wireless communication technologies such as cellular networks (Ugwuanyi, Paul, & Irvine, 2021).

It should be noted that the specific features and capabilities of LoRaWAN sensor nodes can vary between manufacturers and models. One must carefully select the right sensor nodes based on the requirements of the specific application desired (Ugwuanyi, Paul, & Irvine, 2021).

2.8 Related Work

Recent related works have proposed numerous livestock theft-prevention solutions that take into account various network protocols such as base stations, LoRa, wireless sensor networks, MAC and transport layer model, ALOHA access scheme, and medium access with a listen-before-talk (LBT) strategy at the physical layer (Telfor, 2018; Germani et al., 2019; Shah et al., 2019; Roberto et al., 2021; Maroto-Molina et al., 2019; Ojo et al., 2021; Stojkoska et al., 2018). This section briefly discusses existing real-time livestock theft prevention methods, as well as the gaps that have been discovered in these solutions.

2.8.1 Continuous livestock monitoring architecture

Germani, Mecarelli, Buruffa, Rugini, & Frescura (2019) designed an IoT architecture for continuous livestock monitoring using LoRa LPWAN. The architecture described in this work intends to analyse the status of dairy cattle in a cowshed or while grazing in near real-time using sensors implanted in smart collars. This paper also presented a small-scale sensor network dedicated to monitoring bovine vital parameters and cowshed environmental factors using LoRa LPWAN technology (Germani et al., 2019).

This solution was proposed in order to monitor the vital parameters of cattle and the environmental parameters of cowsheds using LoRa LPWAN technology. The reason for this proposed solution is also to ensure that farmers can monitor the status of dairy cattle during grazing using sensors.

This solution is developed with a large number of EDs that only need a single gateway, as well as the creation of a custom MAC layer that is adapted to the transmission intervals commonly used in this type of application. In particular, for LoRaWAN, the LBT-based technique was employed to allow for a greater number of EDs or a higher success rate. This method uses several gateways for scalability and can assign various frequencies and spreading factors to the EDs. The custom MAC with LBT capabilities was utilized to allow and reduce the number of data retransmissions required, as well as to lower the EDs' power consumption.

The small-scale sensor network results were tested using simulations to see how characteristics such as transmission time, number of EDs, use of CSMA/CA and LBT, and acknowledgments affect packet delivery rate and packet losses. Because of the modelling environment, channel occupation and transmission overhead

were thoroughly explored. Because of the large number of parameters that have been studied in a simulation, it was decided to limit the number of alternative scenarios by keeping some of them constant in each simulation (Germani et al., 2019).

2.8.2 Livestock monitoring using LPWAN

According to Casas et al. (2018), there is a great need for livestock monitoring; and this study offers a current method. Livestock farming is a major component of agriculture; agriculture, according to (Eli-Chukwu, 2019), has a significant role in long-term economic growth and structural transformation. This research discussed and outlined a system for livestock monitoring in remote and over large areas. Geographical issues must not be disregarded because livestock tend to travel large distances when grazing.

As a result, Casas et al. (2018) stated that the deployment of LPWAN Smart wearable technology and infrastructure will be a solution to the challenges that herders and farmers face. These technologies will aid in monitoring and data-logging. It was proposed to use UAVs and GNSS in tandem. The combination of the two will alleviate the constraints of UAVs that tally and thus account for livestock using image-processing techniques.

The proposal's goal was to observe and monitor livestock migration while also assessing the impact of these movements on biodiversity. Casas et al. (2019) believe that a tracking device equipped with a GNS receiver will be used to capture the locations of the animals while they are out grazing in the fields, downloading these locations once they have returned to their sheds in the evenings. The downloaded data will assist farmers in collecting relevant data, analysing animal behaviour, and registering herd status. Cattle owners will know whether a certain cow in the herd is

still alive or has died; or whether it has been hurt or captured, based on the animal's stationary location reading. Furthermore, the herders will know where to collect the livestock and return them to the kraal.

The second goal of the study was to address the societal concern over farm animal welfare, which citizens believe is necessary to address. Casas et al. (2018) revealed that in most European countries livestock husbandry is uncontrolled; according to Eeswaran (2022), this is also true in most African countries. Cattle are allowed to roam freely in huge enclosed rural regions.

Although herders maintain the livestock, they must also collect them for veterinary control and other purposes when the weather permits. This means that the herds people would have to travel long distances through the fields in search of animals. This not only affects the herders, but it also provides a platform for cattle thieves. Our suggestion for helping in this area is to virtually shorten the distance between animals and herders by introducing a wearable technological infrastructure equipped with inertial sensors, GNSS, and wireless communications.

The evaluation process was divided into two sections. The first stage is the laboratory test; and the final stage is the field test. The laboratory test occurs when the gadget is programmed to fine-tune parameters in order to attain a better range while maintaining the lowest power consumption number. Because it may be deployed in the field and laboratory for study, the wearable device proposed in this paper has proven to be a capable and versatile instrument for addressing the modern difficulties of vast livestock farming.

Field experiments show communication lines of up to 12km, allowing for coverage of wide areas with minimal infrastructure. A single receiver would theoretically serve a

45 km region. Low energy consumption estimates were reached by the use of the VQ compression model, which allows the wearable device to work throughout the season even if the animals are away grazing in the mountains. The usage of LoRa in this experiment enables long-distance point-to-point communications, with up to 12km achievable in a mountain environment.

The main users evaluated in this study were the herder and the animals, who have different needs. According to Fuentes et al. (2022), this test does not address livestock theft or the optimal internet protocol for ensuring that the livestock is constantly accessible to the owners. The LPWAN design presented in this study appears to disregard the consequences of cattle theft and real-time surveillance of livestock, which can have an impact on the desired output. In order to address difficulties of real-time livestock monitoring, thus allowing this study to produce more results, we should incorporate LoRaWAN and real-time IoT technologies into the design. Other options include the utilization of wireless sensor nodes, LoRaWAN Gateways, and invisible wearables by the livestock.

2.8.3 Livestock monitoring in agricultural sector using the Internet of Things

The research into a livestock monitoring system utilizing the IoT was demonstrated to the agricultural sector. The IoT is a network of interconnected computing devices, mechanical and digital machinery, items, animals, or people with unique identifiers and the ability to send data over a network without requiring human-to-human or animal- or human-to-computer interaction.

As agriculture is one of the most important sources of income in most countries, the paper proposed that farmers instal internet-connected sensors in their farms. Such sensors would collect ecological data that will assist farmers in monitoring livestock

via the web from outside the farm, allowing farmers to control farm environmental in remote locations. Aside from tracking livestock position, the monitoring solutions system uses internet sensors embedded into the livestock to collect and transmit data reflecting parameters such as temperature, humidity, and heartbeat. Farmers will be able to monitor the overall health of livestock using the information from these sensors.

This study recommended using the web to assist farmers in monitoring livestock health and tracking livestock whereabouts. The livestock monitoring system was created to collect ecological data and to assist farmers in tracking temperature, humidity, and heartbeat. Farm cattle are usually plagued by a variety of diseases; therefore, an IoT livestock monitoring system was utilized to detect abnormalities in livestock health, thereafter alerting the farmer, allowing farmers to monitor livestock from outside the farm.

The main reason for introducing the livestock monitoring system is to track the health and vitality of livestock in real time, enabling farmers to cure animals swiftly and to avoid the spread of illness or disease.

The livestock monitoring system was designed to be user-friendly, so that farmers who are unfamiliar with contemporary technologies can quickly and efficiently monitor their cattle. Data such as cattle position, temperature, humidity, and heartbeat were collected and transmitted via internet-connected sensors. Sensor data was sent to the Arduino Uno. The Arduino Uno takes data from the sensors before transmitting it; the signals from the sensors are delivered to the GSM module via the Arduino Uno Connection.

A GSM module is a device that receives information from GPS satellites, thereafter calculating the device’s geographical position; the GSM module is used to offer

livestock location. The GSM module maintains the SIM network connection and encryption, which is utilized for SMS notifications should the readings on the monitoring website be abnormal. For farmers to monitor the readings of their cattle, a user-friendly website was created; the website also keeps track of the database. Farmers are notified via email or SMS should there be a deviation from the normal range in their animals.

The research results were attained because the goal of the suggested paper was to remove most of the limitations and to present a user-friendly monitoring system that is guaranteed to deliver results for all livestock utilized in the agricultural industry. A website was created so that farmers could monitor their livestock and receive alert messages should there be a deviation from the normal range provided for the livestock via email or SMS. The website was also designed to keep a database of all the data collected.

The application employed supplied the precise location of the cattle; and the systems included a Wi-Fi module to ensure that sensors did not lose connection to the Arduino Uno, resulting in more efficient results.

Field range limits can be defined and added to the system so that if livestock escapes the farm grounds, farmers can be notified of their whereabouts. The applications utilized must offer the actual location of the cattle in real-time, and the system must also feature a built-in WI-FI module to avoid losing connection to the Arduino Uno. To improve the overall efficiency of the research, the system must be tested before implementation to minimize setbacks and outcomes with gaps.

2.8.4 Other studies conducted

According to research from CSIRO published in Australia in 2017, wireless sensor networks are described as a developing technology that is generating a large amount of scientific interest due to it gaining more data in real-time and as quickly as possible. More innovative work is coming from the use of wireless sensor nodes to monitor herd behaviour and their geographical information at all times, ensuring that grazing patterns of the livestock are seen.

According to Duranti et al. (2013), in a study by the Department of Engineering, a MAC and a transport layer model were used, different from the ALOHA access scheme that was used in LoRaWAN. This was implemented to avoid all unnecessary collisions that can occur between the radio packets; along with an acknowledgment (ACK)-based transmission policy implemented at the transport layer by performing the medium access with a strategy of listen-before-talk (LBT) at the physical layer.

The study by (Duranti et al., 2019) also implemented CSMA-CA in an unslotted way. In this model the channel is always checked to see whether or not it is sensed idle, and if it is, and no other LoRa ED are transmitting, the current transmission can be made to avoid a collision. It is also evident that if the channel is occupied, there is a need for a back-off time to be calculated randomly before the transmission can attempt to take place again.

The back-off time is always chosen randomly within the contention window, which starts right after a certain transmission decision. During the period of TCW, right up to the maximum value of the NCMA transmission attempt, the radio will then not send packets. According to the study on the transport layer, a further acknowledgment mechanism is also applied to further avoid the packets sending data at the same time.

In a study conducted by (Telfor, 2018) regarding real-time IoT structural design for wireless livestock tracking, it was said that the rapid development of wireless and implanted technologies has created more opportunities for monitoring and tracking mobile objects such as livestock; this study is looking into solving livestock theft by this research. Based on the study at hand it is evident that the first wireless sensor nodes systems for livestock monitoring were then expensive, and were not functioning exactly in real-time. The study also shows that the price of these systems has dropped massively; also, with the developments in the used technologies such is making it affordable for all farmers.

Recent studies show that the approach that was used previously to store GPS locations locally and to send data twice a day, which is the GPS animal tracking system, is now outdated. It cannot be functional in this research; it is not sending data as expected by the researchers which must either be fully in real-time or as close to that as possible when using low-energy GSM technologies such as Bluetooth. This study will be using real-time Internet of Things to certify that data is sent in real-time; the livestock will also always be checked and reported should they go beyond the geographical fence.

The literature review reflects insufficient studies that consider the issue of livestock theft and the solution to that problem in South Africa, especially in rural areas (Scheepers et al., 2017). CelMax has been developed to prevent the theft of sheep in South Africa. This product functions by the insertion of a collar device in one sheep; the system relies on other sheep following this sheep; the owner is then notified. The theory behind this is that sheep always follow one another. It is believed that when the collar-worn device detects the main sheep running, the device will send a notification to the farmer who will understand that someone is chasing the sheep. This device's

battery can run from 6 to 8 weeks; however, the disadvantage of this device is that it is too expensive for rural farmers to afford.

2.9 Overview of Wireless Network Simulators

Wireless network simulators are software tools that allow researchers, engineers, and students to model and analyse the behaviour of wireless networks in a controlled virtual environment. These simulators are crucial for studying and evaluating various aspects of wireless communication systems, including protocol performance, network design, and resource allocation. Researchers choose this network simulators because of their widespread usage; and most researchers use this simulator to validate their proposed solutions (Hussain & Saeed, 2013; Khana, Bilalb, & Othmana, 2012; Weingartner, Vom-Lehn & Wehrle, 2009). In this dissertation, this study only discusses the open-source network simulators. This study further discusses the reasons for NS-3 being preferred over other network simulators. Below is an overview of some popular wireless network simulators:

1. NS-3, or Network Simulator 3, is an open-source discrete-event network simulator used for research and education in networking. NS-3 allows researchers and developers to model and simulate various types of networks, including wired and wireless, allowing them to study their behaviour under different conditions.

   Here are some key features and aspects of NS-3:

   Discrete-event Simulation: NS-3 is based on discrete-event simulation, which means that events occur at distinct times. This allows for accurate modelling of complex network behaviour.

Modularity: NS-3 is designed to be modular, which means that various components of a network (e.g., devices, protocols) can be modelled independently before being combined to create a complete network simulation.

Protocol Support: NS-3 provides a wide range of built-in networking protocols, including TCP/IP, routing protocols (e.g., OSPF, BGP), wireless protocols (e.g., Wi-Fi, LTE), and more. Additionally, it allows users to implement and test custom protocols.

Wireless Networks: NS-3 is particularly known for its support for modelling wireless networks, including Wi-Fi, LTE, inter alia. This makes it a popular choice for researchers working on wireless communication technologies.

Python Bindings: NS-3 provides Python bindings, allowing users to interact with the simulator and to create simulations using Python scripts. This makes it more accessible and user-friendly for many researchers and developers.

Community and Documentation: NS-3 has an active community of users and contributors, which means that there is a wealth of resources, forums, and documentation available to help users get started and to troubleshoot any issues they encounter.

Open Source: Being open-source, NS-3 is free to use and can be modified and extended by the community. This encourages collaboration and innovation in the field of networking research.

Educational Use: NS-3 is widely used in educational settings to teach networking concepts and to allow students to gain hands-on experience with network simulations.

It is worth noting that since September 2021, NS-3 has been a widely used and respected tool in the networking research community. However, for the most up-to-date information on NS-3, including any potential changes or developments after September 2021, the official NS-3 website or community resources can be checked.

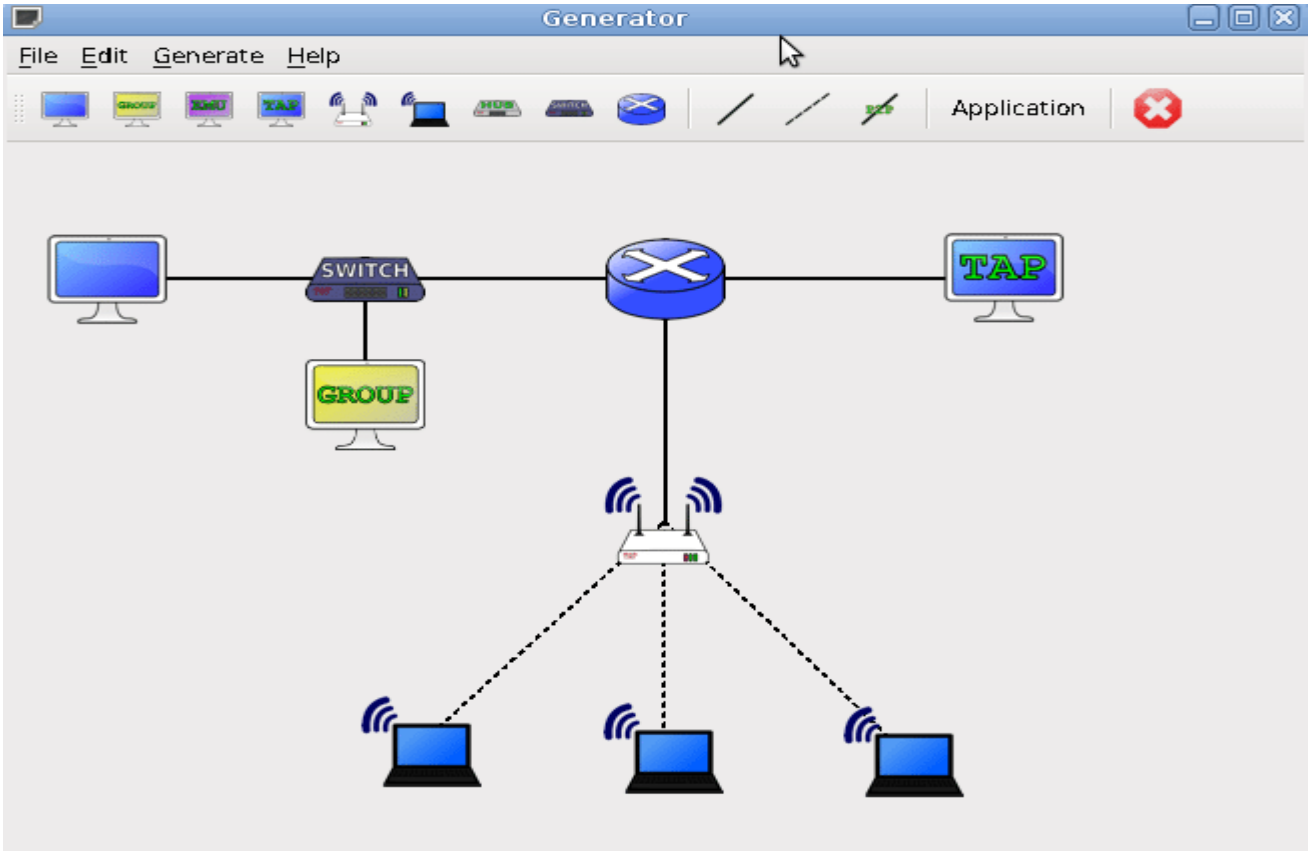


Figure 2.4. NS-3 simulation interface

2. OMNeT++ is a discrete event simulation environment. OMNeT++ is used for modelling, simulating, and analysing complex communication systems. The name OMNeT++ stands for Objective Modular Network Testbed in C++.

   Here are some key points about OMNeT++:

Discrete Event Simulation: OMNeT++ follows the discrete event simulation paradigm. This means that the simulation advances in small time-steps, and events (like message transmissions, arrivals, etc.) occur at specific times.

Modular Architecture: OMNeT++ is designed with modularity in mind. Models in OMNeT++ are represented as modules; and these modules can easily be combined and extended to create complex simulations.

Component-Based: The simulations in OMNeT++ are constructed using various components, including simple modules, compound modules, and channels. These components can be reused and combined to model complex systems.

C++ Programming Language: OMNeT++ is implemented in C++, which makes it powerful and flexible. Users define their models using C++, making it suitable for a wide range of simulation scenarios.

Extensible and Customizable: OMNeT++ provides an extensive framework for developing custom models and components. OMNeT++ supports various protocols and allows for the creation of new ones.

Community and Libraries: There is an active community around OMNeT++ which has a collection of libraries and models that can be used to speed up the development process.

Visualization and Analysis Tools: OMNeT++ provides tools for visualizing and analysing simulation results. This is crucial for gaining insights into system behaviour.

Application Areas: OMNeT++ is widely used in academia and industry for simulating and analysing communication networks, including wired and wireless networks, IoT systems, ad-hoc networks, vehicular networks, among many others.

Scalability and Performance: OMNeT++ is designed to handle simulations of various sizes. It can be used for small-scale experiments as well as large-scale network simulations.

Integration with Other Tools: OMNeT++ can be integrated with other tools like MATLAB, Python, and others for additional analysis and visualization.

Overall, OMNeT++ is a powerful tool for simulating and studying communication systems. It is particularly popular in academic research and in industries where understanding and optimizing network performance is crucial.

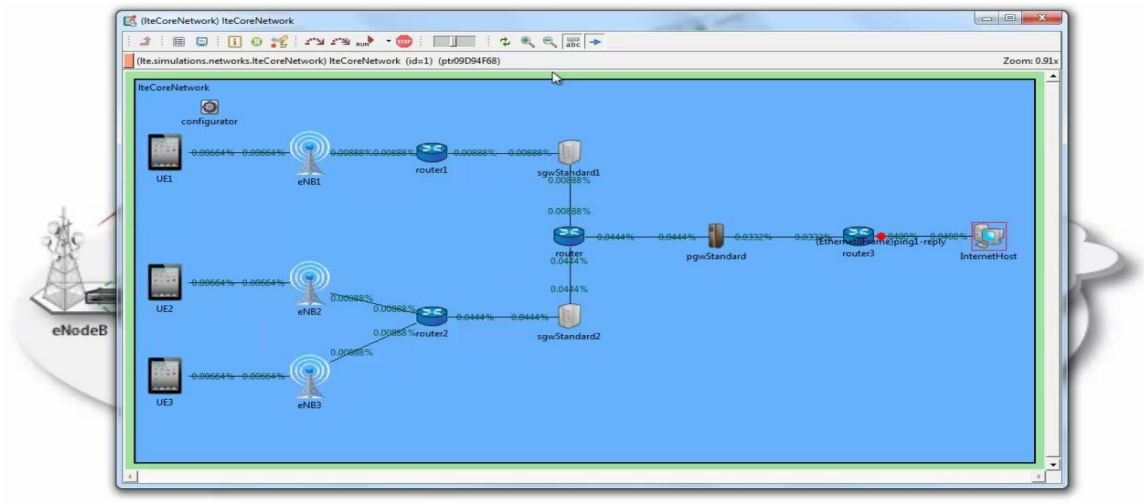


Figure 2.5. OMNeT++: simulator simulation interface

3. GNS3 (Graphical Network Simulator-3) is a widely used network simulation tool that allows users to simulate complex networks. GNS3 provides a graphical user interface (GUI) to design and configure virtual networks, making it an

excellent tool for network engineers, administrators, and students to practise and test network configurations without the need for physical hardware.

Here are some key features and aspects of GNS3:

Topology Design: GNS3 allows users to drag and drop various networking devices like routers, switches, and firewalls onto a virtual workspace. These devices can then be connected to create complex network topologies.

Device Emulation: GNS3 is capable of emulating various networking devices, including Cisco routers, switches, Juniper devices, and many others. This means that you can run real-time operating systems of these devices on your computer.

Integration with Real Hardware: GNS3 supports connecting to physical network equipment, allowing you to integrate virtual and real-world components in your simulations.

Packet Capturing and Analysis: GNS3 provides the ability to capture and analyse network traffic within a simulated environment, which can be useful for troubleshooting and monitoring purposes.

Integration with Virtual Machines: GNS3 can be integrated with virtualization platforms such as VMware and VirtualBox, enabling one to run virtual machines alongside network devices.

Community and Marketplace: GNS3 has a large community of users who contribute to the project. There is also a marketplace where users can share pre-configured virtual appliances and topologies.

Support for Multiple Network APIs: GNS3 supports multiple network emulation APIs including Dynamips, QEMU, VirtualBox, and Docker. This means it can emulate a wide range of devices and technologies.

Scalability: GNS3 can handle fairly large and complex network topologies, allowing for extensive testing and experimentation.

Support for Various Operating Systems: GNS3 is compatible with Windows, MacOS, and Linux, making it accessible to a wide range of users.

Learning and Training Tool: It is a popular choice for network engineers and students to practise and test configurations, learn new networking concepts, and prepare for certification exams.

Open Source and Community-Driven: GNS3 is an open-source project, which means it is constantly evolving thanks to contributions from the community. This also means it is often at the forefront of networking technologies.

It is worth noting that while GNS3 is a powerful simulation tool, it does not replace the need for hands-on experience with physical hardware in certain scenarios. It is most commonly used for testing, learning, and development purposes.

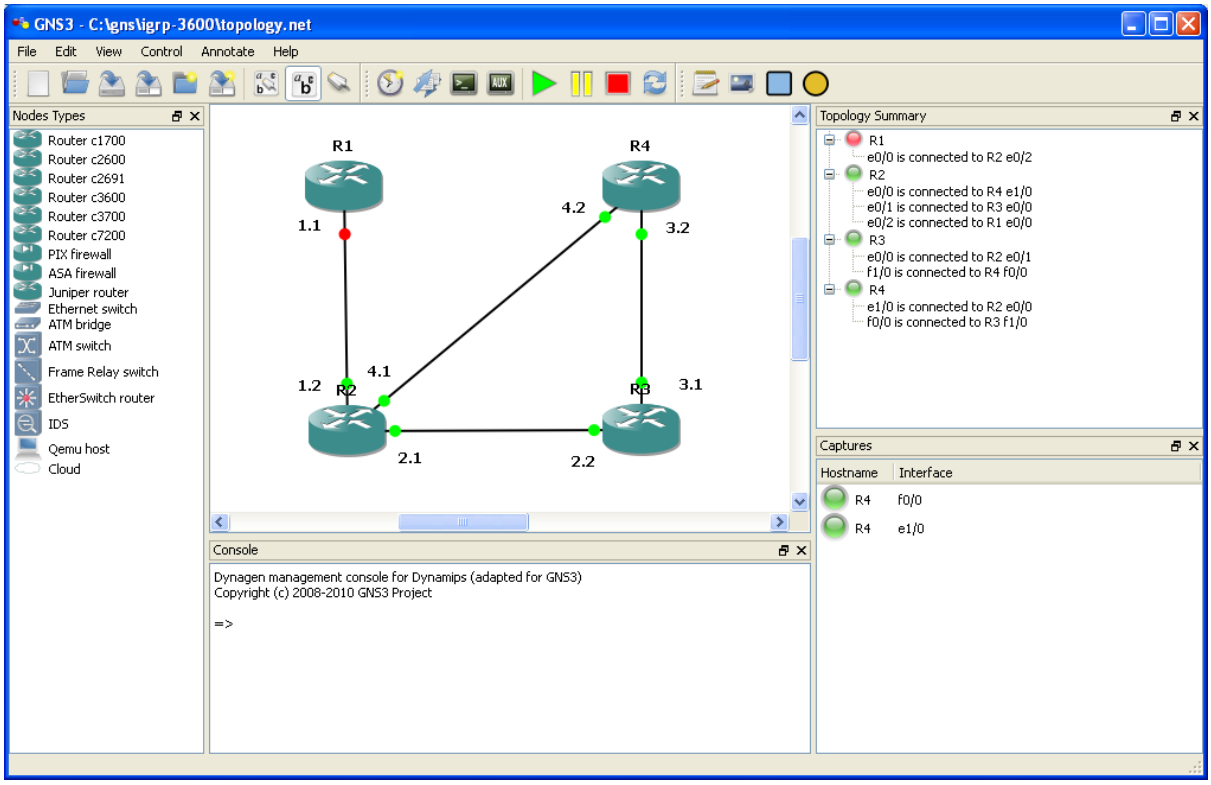


Figure 2.6. GNS3 (Graphical Network Simulator-3) simulation interface

4. OPNET Modeler, now known as Riverbed Modeler, is a comprehensive network simulation and modelling tool used for designing, analysing, and simulating various types of networks. It allows users to create network models and to evaluate their performance under different conditions and scenarios. Here are some key features and aspects of OPNET Modeler (now Riverbed Modeler):

   Network Modelling and Design: OPNET Modeler provides a graphical interface for building network models. Users can define nodes, links, protocols, and various network elements to represent real-world network scenarios.

Protocol Support: OPNET Modeler supports a wide range of communication protocols, including TCP/IP, UDP, BGP, OSPF, MPLS, and more. This enables users to simulate a diverse set of network environments.

Traffic Modelling: OPNET Modeler allows users to model various types of traffic pattern, such as constant bit rate (CBR), variable bit rate (VBR), and other custom traffic patterns. This is crucial for evaluating network performance under different traffic loads.

Application Behaviour Modelling: OPNET Modeler provides tools to model various application behaviours, allowing users to simulate how different applications interact with the network.

Wireless Networking Capabilities: The tool includes modules for simulating wireless networks, including technologies such as Wi-Fi, WiMAX, and cellular networks.

Statistical Analysis and Reporting: OPNET Modeler offers extensive statistical analysis capabilities, allowing users to collect and analyse performance metrics from simulations. It also provides tools for generating reports and visualizing simulation results.

Integration with Other Tools: OPNET Modeler may integrate with other tools and platforms, such as MATLAB and external databases, to enhance its capabilities and extend its functionality.

Scenario and Parameter Management: Users can define multiple scenarios and configure various parameters to study how different settings impact network performance.

Model Validation and Verification: OPNET Modeler allows users to validate and verify their models by comparing simulation results with real-world measurements or established theoretical models.

Educational and Research Use: OPNET Modeler is widely used in academia for teaching networking concepts and in research for simulating and analysing different networking scenarios.

Riverbed Acquisition: In 2012, OPNET Technologies was acquired by Riverbed Technology. As a result, OPNET Modeler was rebranded as Riverbed Modeler. This integration potentially brought additional features and synergies with other Riverbed products.

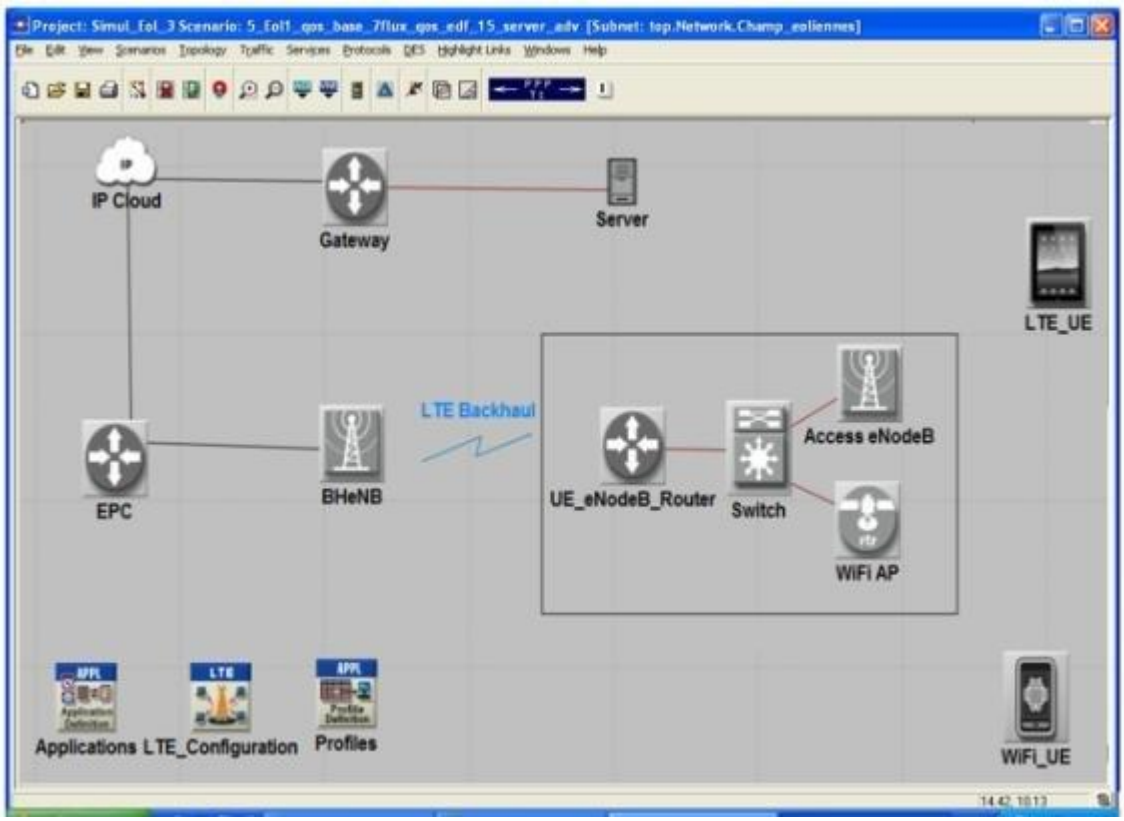


Figure 2.7. OPNET Modeler simulation interface

5. MATLAB and Simulink are powerful software tools used in various fields of engineering, particularly in control systems, signal processing, and other disciplines involving numerical computation and simulation.

   MATLAB:

   MATLAB stands for MATrix LABoratory. MATLAB is a high-level programming language and interactive environment used primarily for numerical computation, data analysis, and visualization.

   MATLAB is known for its extensive library of mathematical functions, making it a popular choice for tasks such as linear algebra, statistics, optimization, and more.

   MATLAB is widely used in academia, industry, and research for tasks ranging from algorithm development to complex simulations.

   MATLAB allows users to create scripts and functions for automating tasks, and it provides a command-line interface for immediate feedback.

   Simulink:

   Simulink is an extension of MATLAB that provides a graphical environment for modelling, simulating, and analysing multidomain dynamical systems.

   Simulink is particularly used for systems that can be represented by block diagrams, such as control systems, signal processing, and communications.

   Simulink provides a wide range of pre-built blocks representing different components of a system (e.g., integrators, transfer functions, sensors, actuators).

Simulink allows for the simulation of dynamic systems in both time and frequency domains.

Engineers use Simulink for tasks such as control system design, digital signal processing, and mechatronics.

Integration:

MATLAB and Simulink are designed to work together seamlessly. One can call MATLAB functions and scripts from Simulink models, and one can also use Simulink blocks within MATLAB scripts.

This integration is powerful for tasks that require both numerical computation and simulation capabilities.

Applications:

MATLAB and Simulink find applications in a wide range of fields, including control engineering, signal processing, image processing, communications, financial modelling, computational biology, and more.

Both systems are extensively used in industries such as aerospace, automotive, electronics, and telecommunications.

Toolboxes:

MATLAB offers various toolboxes that provide specialized functionality for specific domains. For example, the control system toolbox provides tools for designing and analysing control systems, while the image processing toolbox provides functions for working with images.

Community and Support:

MATLAB has a large and active user community. There are also numerous online forums, tutorials, and official MathWorks support resources available.

Licensing:

MATLAB and Simulink are commercial software products developed by MathWorks. They require a licence for usage.

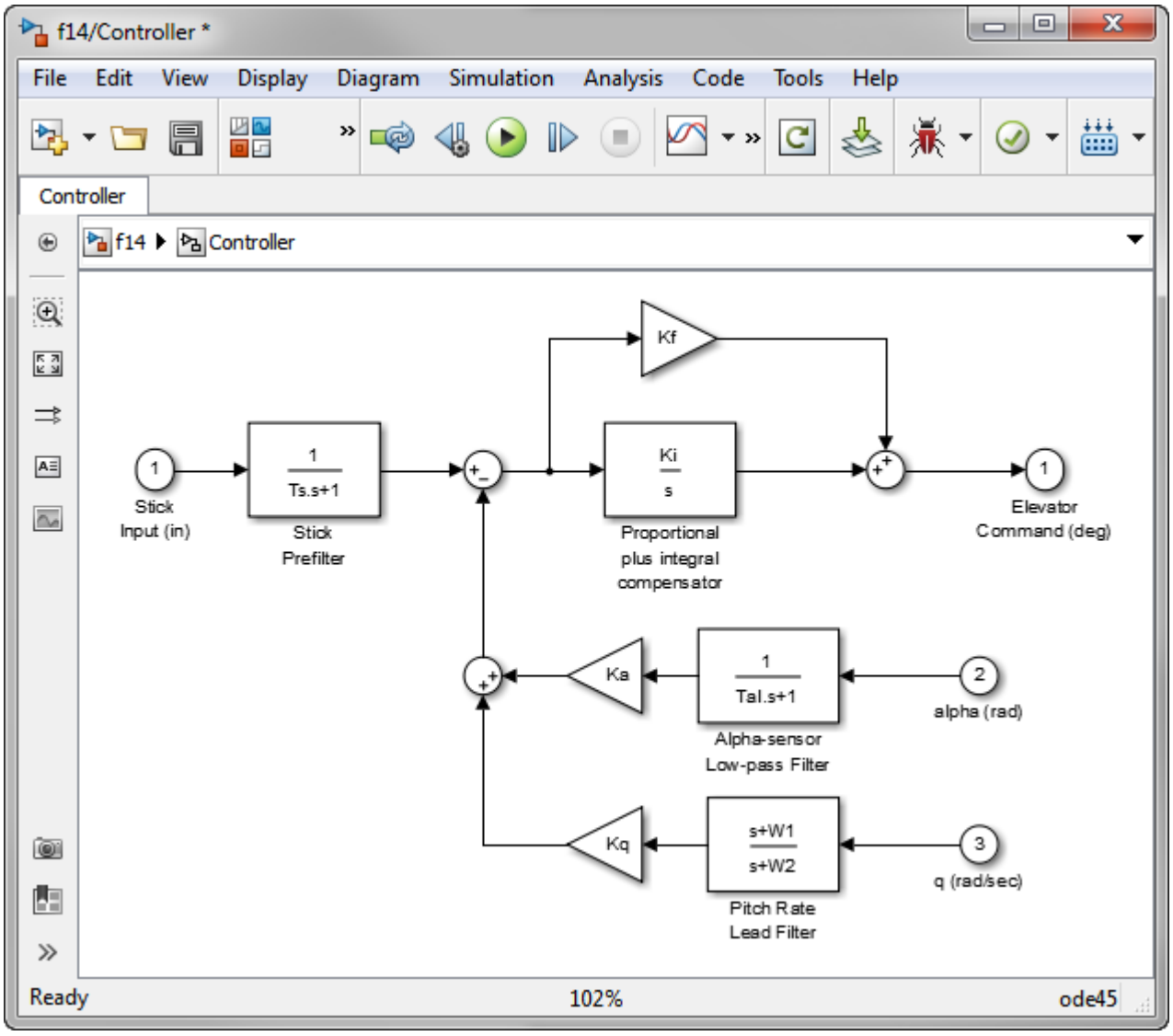


Figure 2.8. MATLAB/Simulink: Simulation interface

6. QualNet is a commercial network simulator developed by Scalable Network Technologies (SNT). QualNet is used for modelling, simulating, and analysing

the performance of computer networks, including wired, wireless, and mixed networks. The simulator provides a platform for researchers, engineers, and network designers to evaluate the behaviour of network protocols, applications, and devices in a controlled and repeatable environment.

Some key features of QualNet include:

Network Topology Modelling: QualNet allows users to create complex network topologies with various types of nodes, links, and connections.

Protocol Modelling: QualNet provides support for modelling a wide range of network protocols, including routing, transport, and application-layer protocols. This enables researchers to study the behaviour of these protocols under various conditions.

Scenario Creation: Users can define different scenarios to simulate various network conditions, such as varying traffic loads, node mobility, interference, and environmental factors.

Realistic Radio and Mobility Models: QualNet includes detailed models for wireless communication, considering factors such as signal propagation, interference, and mobility of nodes.

Visualization and Analysis Tools: QualNet offers tools for visualizing simulation results, which can include graphs, charts, and animation of network behaviour.

Parallel and Distributed Simulation: QualNet supports parallel and distributed simulation, allowing for the efficient execution of large-scale simulations.

Integration with External Tools: QualNet can be integrated with other simulation environments and tools, allowing users to extend its functionality or interface it with existing systems.

Scalability: QualNet is designed to handle large-scale network simulations, which is crucial for modelling complex networks.

Validation and Verification: QualNet undergoes rigorous testing and validation to ensure that it accurately models network behaviour.

Support and Documentation: SNT provides support for QualNet users, including documentation, tutorials, and technical assistance.

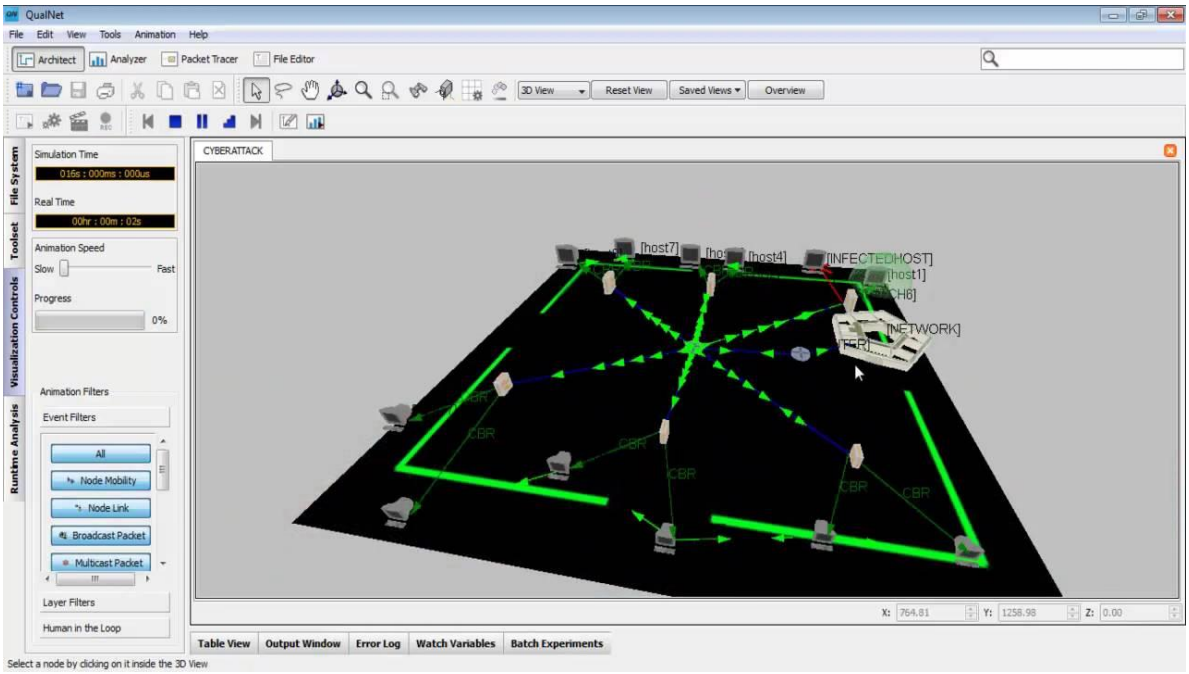


Figure 2.9. QualNet: Network simulator

7. Cooja is a network simulator specifically designed for wireless sensor networks (WSNs). Cooja is part of the Contiki operating system, which is an open-source operating system designed for the Internet of Things (IoT) and low-power wireless devices. Cooja allows developers to simulate and test the behaviour

of WSN applications and protocols in a controlled environment before deploying them on real hardware.

Key features of Cooja include:

Realistic Simulation: Cooja provides an environment where you can simulate the behaviour of sensor nodes, their radio communication, and network topologies. This helps developers understand how their applications will perform in a real-world setting.

Time-Based Simulation: Cooja operates on a discrete-event simulation model, meaning that it simulates events in a time-ordered fashion. This allows for precise control over the timing of events, which is crucial in network simulations.

Support for Contiki OS: Cooja is tightly integrated with the Contiki operating system, allowing developers to easily run and test their Contiki-based applications.

Energy Consumption Modelling: Cooja includes energy consumption models for the various components of a sensor node, which is crucial for evaluating the battery life of devices in a WSN.

Visualizations and Debugging: Cooja provides visualizations of the network topology, allowing developers to see how nodes communicate and interact. Cooja also offers debugging tools to help identify and fix issues in the simulated network.

Plugin System: Cooja has a plugin system that allows developers to extend its functionality or add custom features for specific research or development purposes.

Overall, Cooja is a valuable tool for researchers, developers, and hobbyists working on WSNs and IoT applications. Cooja provides a controlled environment for testing and refining protocols and applications before deploying them in the field, saving time and resources.

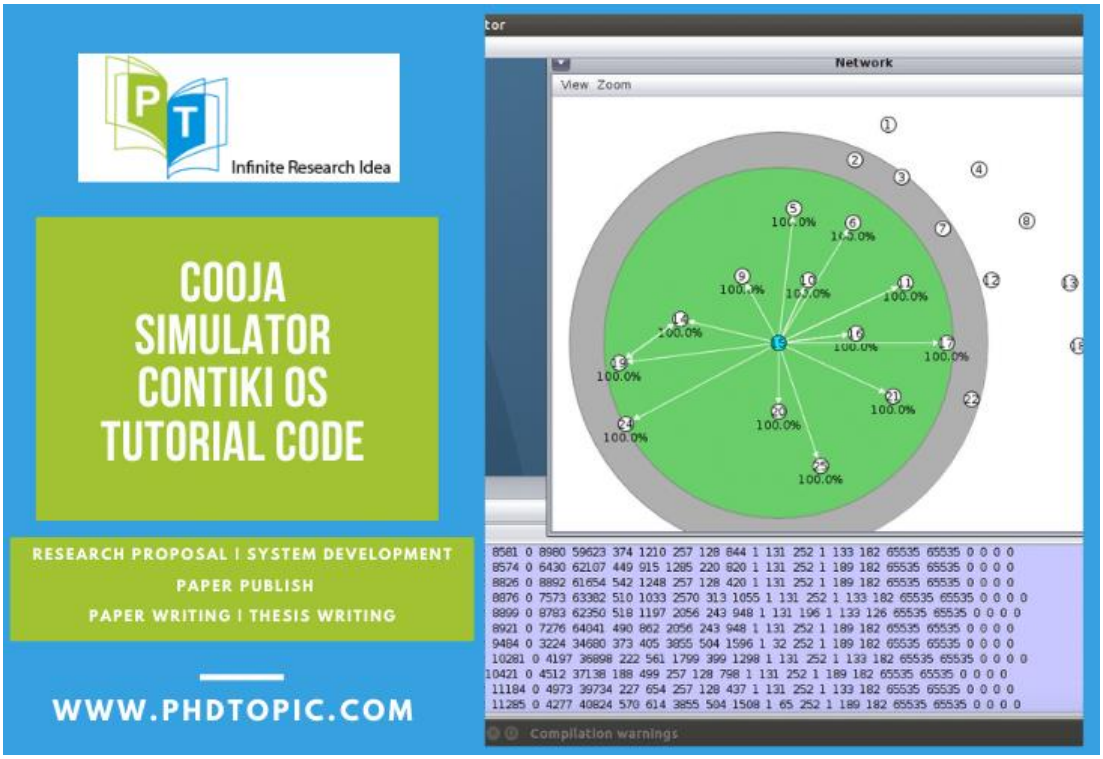


Figure 2.10. Cooja: Network simulator simulation interface

Table IV: below summarizes the advantages and disadvantages of the most commonly used network simulators

Table IV: Advantages and disadvantages of the most commonly used network simulators

Network Simulators	**Advantages**	**Disadvantages**
NS-2		• Real system is too complex to model.

	• Complex scenarios can be easily tested. • NS-2 supports protocols such as TCP, UDP, FTP, HTTP, etc. • NS-2 allows for add-ons and modification of protocols. • Online support group is available.	• Bugs are unreliable.
NS-3	• It can simulate large-scale wireless and wired networks. Ns-3 provides features not available in NS-2, such as an implementation	• The system is quite complex and time-consuming to learn.

	code-execution environment.	
GloMoSim	• It can simulate large-scale wireless and wired networks. • The system supports asymmetric and multicast paths configurations.	• Setting up of QualNet on Linux operating system is very difficult.
OMNeT ++	• This is an expendable, modular, component-based C++ simulation. • It can simulate large-scale wireless and wired networks.	• It does not support a variety of protocols.

MATLAB	• MATLAB runs on cross-platforms that include Microsoft Windows, Linux, and Mac OS X. • Uses different programming languages that include C, C++, Java, etc.	• Requires deep MATLAB knowledge to deal with all programming errors.

2.10 Chapter Summary

The real-time IoT Internet of Things (IoT) requires interconnected sensor nodes and supporting network communication. Various applications can be developed based on this infrastructure. In this chapter a number of different technologies used a wireless tracking system which is in real-time IoT system which prevents livestock theft by using real-time IoT systems that uses sensor which are nodes, RFID, and LoraWAN have been discussed.

Previously livestock tracking or monitoring systems failed because they were using base stations and they were not in real-time which couldn't prevent

livestock theft and in section 2.8 of this chapter related work is discussed and with the gaps identified.

Different types of simulations tools and their advantages and disadvantages are discussed and the best simulation which is chosen for this research which is NS-3 is discussed.

Chapter 3: System Modelling

3.1 Introduction

Most farmers in the lowveld of Mpumalanga are experiencing livestock theft. Due to this, there is a demand for a livestock theft system which can report in real-time to monitor the livestock. This has led to the implementation of the livestock theft prevention system in this study using LoRaWAN wireless communication technology. This is because it allows the farm owners to manage their livestock in real-time. LoRa is based on spread-spectrum modulation techniques derived from chirp spread spectrum (CSS) technology.

In this chapter, this study discusses the design of a proposed real-time wireless livestock theft prevention system that uses LoRaWAN wireless communication technology to help farm owners manage and monitor their cattle. The proposed conventional LoRaWAN wireless communication technology livestock theft prevention system architecture is shown in Section 3.2. In Section 3.3, this study presents the proposed LoRaWAN wireless communication design, including the system concept and all technologies used. Finally, in Section 3.4, this study presents a summary of the chapter.

3.2 System Architecture

This section describes the design and modelling of the real-time IoT wireless livestock tracking system. This is used to prevent livestock theft and to make the life of the herder easy; and also to assist the farmers by making sure that they know where their livestock is. The farmers receive notifications if something wrong is happening to their livestock, or if they cross the GEO fencing set. This system is organized in 3 tiers, as shown in Figure 3.1.

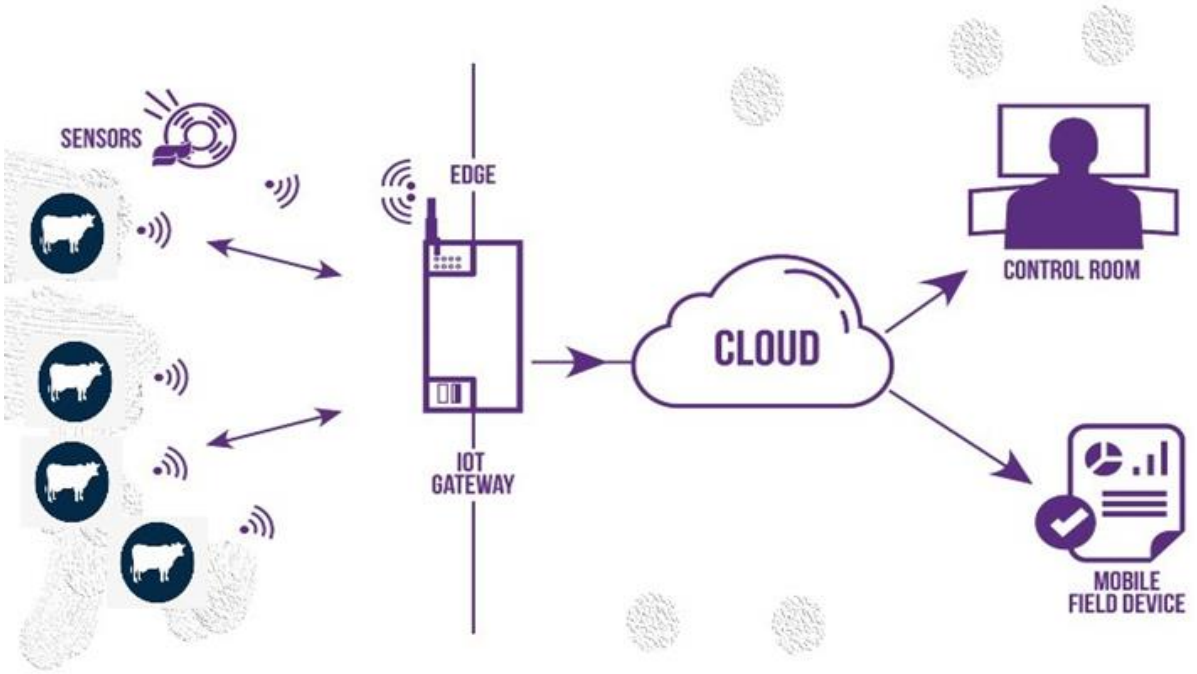


Figure 3.1. LoRaWAN IoT architecture

The first tier is the wireless sensor nodes which uses the RFID that is worn by the animals so that it is possible to track down the livestock in real-time using LoRaWAN which is a low-power wide-area network (LPWAN) technology that provides an appealing combination of long-range, high link margin, and low power consumption. Of recent years, there has been a rapid increase in the deployment of LoRaWAN networks to meet the needs of today's IoT applications.

One of the potential interferences that has drawn attention is the signal from RFID systems, notably UHF RFID devices that are being used in most counties. These dense RFID systems are commonly used in large retail stores, airports, museums, and other large facilities with inventory functionality; and this fits well to this research. However, there is significant opportunity for parallel deployment of LoRaWAN-based IoT solutions in these same regions.

Semtech and other LoRaWAN ecosystem firms conducted a collaborative study on the performance of LoRaWAN while co-located and co-existing with a densely deployed UHF RFID system. The investigation's study component assessed the influence of the RFID system on a LoRaWAN network and attempted to develop an optimized way of preventing interference. Several field trial tests validated the solution from the study component of this investigation. When a LoRaWAN network coexists with other high-power systems that cause frequency-selective interference, the certified solution serves as a reference.

The second tier is the LoRaWAN-based gateway. This gateway is used to transmit and convert the radio frequency signals from the wireless sensor nodes worn by the livestock, converting them to a format that the cloud server of mobile apps understands easily. This gateway is able to transmit signals over a distance of more than 10 km in rural areas, which makes it the best solution based in the rural areas.

3.3 Proposed LoRaWAN Wireless Communication Design

The LoRaWAN-based gateway assists in making sure that data is transmitted in real-time; and that the livestock owners are able to track and locate their livestock's live locations in real-time from their laptops or mobile phones. The LoRaWAN used in this design serves or connects multiple nodes of livestock at a time. The gateway receives the radio frequency signals when they are in the same range and then sends the packets to the cloud. To make this possible, the sensor nodes are connected to the LoRaWAN gateway wirelessly. Then the gateway sends the data from all the sensor nodes on to the cloud and also the application server; then to the farmers' laptops and smartphones. The gateway also works as the mailbox between the livestock tracking device and the cloud. The third tier is the cloud that is the central part of the system

which gathers the RF signals after they have been received and converted by the gateway. In this research study, a maximum of 50KB/s data rate can be transmitted more rapidly at a given time which is sufficient for device-to-device or device-to-gateway communication. Thus, data was transmitted more rapidly, thereby improving the performance of the proposed real-time tracking system.

A LoRaWAN network is often configured in a star-of-stars topology, with gateways relaying communications between end-devices and a central network server (ARAS, E, et al, 2017). Standard IP connections connect the gateways to the network server. These connections simply transform RF packets to IP packets and vice versa, acting as transparent bridges. The wireless communication takes advantage of the LoRa physical layer's long-range features, allowing for a single-hop link between end-devices and one or more gateways. End-devices based on LoRa are capable of bidirectional communication.

3.3.1 LoRaWAN Adaptive Capabilities

LoRaWAN offers adaptive capabilities that allow it to coexist with systems that produce frequency-selective interference, such as the UHF-RFID system.

- LoRa modulation provides excellent co- and adjacent-channel rejection: The co-channel rejection with a single carrier interference is 5-19 dB depending on the spreading factor (SF), while the adjacent-channel rejection is 60-72 dB, according to the SX1262 datasheet.
- An adaptive channel plan from the adaptive data rate (ADR) command is required, as stated in the LoRaWAN MAC protocol. This feature enables the network server to deactivate channels known to have high interference in order to improve overall packet transmission quality.

3.3.2 RFID UHF specifications

- All UHF RFID interrogators are network-controlled and have a programmable channel plan. Some high-end solutions allow one to change the RFID channel plan while still operating without losing data.
- Because the end-node (RFID tag) is a passive device, the channel plan is not stored. This means that the tags can be tailored to any channel plan employed by the interrogator.

3.3.3 LoRa range calculator and formula

This section discusses the LoRaWAN range calculator, which computes LoRa range (i.e. distance) using the Egli model. The LoRaWAN range calculator computes the link budget and LoRaWAN range between the gateway and the LoRa nodes, which are the livestock sensor nodes and the owners' application servers.

The following is an example of a LoRaWAN range calculator and a LoRaWAN link budget calculation:

INPUTS: Gateway antenna gain = 0; Node antenna gain = 0; Gateway height = 100 metres; Node height = 10; Noise margin = 5; Operating Frequency = 868 MHz; Gateway transmit power = 27 dBm; Node Receiver sensitivity = -137 dBm.

OUTPUTS: Link Budget = 159, LoRaWAN range (i.e. distance) between gateway and node = 64087 metres.

Path loss for point to point link (Egli Model) :-

$$PL\ (dB) = Gt * Gr * \left(\frac{ht*hr}{d^2} \right)^2 * \left(\frac{40}{f} \right)^2$$

Where,

Gt = Transmit Antenna Gain
Gr = Receive Antenna Gain
ht = Transmit antenna height, meters
hr = Receive antenna height, meters
d = Distance between Tx and Rx antenna, meters
f = Operating frequency in MHz

PL(dB) = Path Loss

Figure 3.2. Egli pathloss model based on LoRaWAN range

The Egli pathloss model is described above. LoRaWAN range formula is used to compute LoRa gateway distance coverage to cover many LoRa nodes. The computation of range or distance for LPWAN technologies such as NB-Fi, Sigfox, and Ingenu RPMA is conducted in the same manner as described in this LoRaWAN range calculator. Rural regions have a greater range than urban areas; and this makes it an advantage for this study and solution as the study is based on livestock theft in the rural areas.

The following are typical parameters for an NB-Fi range calculator for downlink (gateway to node).

• Gateway power is 27 dBm, and the gateway antenna gain is 0 dB

• Sensitivity of the node: -147 dBm (range: -124 dBm to -164 dBm)

• Gain of Node Antenna: 0 dB

• Node noise: 5 decibels

• Bandwidth: 500 MHz or 868/915 MHz

Typical parameters for Sigfox range calculator for downlink (gateway to node) are as follows:

• Gateway power: 27 dBm

• Gateway antenna gain: 0 dB

• Node sensitivity: -129 dBm (Range: -124 dBm to -164 dBm)

• Node Antenna gain: 0 dB

• Node noise: 5 dB

• Frequency: 868/915 MHz

Typical parameters for Ingenu RPMA range calculator for downlink (gateway to node) are as follows:

• Gateway power: 27 dBm

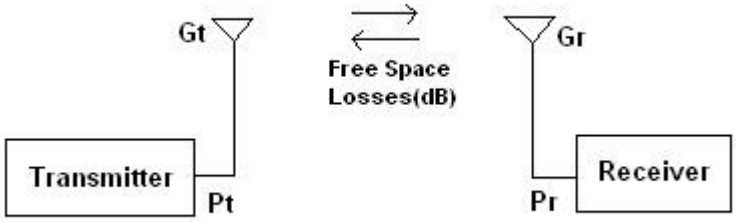
• Gateway antenna gain: 0 dB

• Node sensitivity: -133 dBm (Range: -124 dBm to -164 dBm)

• Node Antenna gain: 8 dB

• Node noise: 5 dB

• Frequency: 2.4 GHz



$$Free\ Space\ Path\ Loss\ (dB) = -20\log(x) + 20\log(d) + 21.98$$

$$where\ , x = \frac{c}{f}, c = 3\ x\ \wedge 8\frac{m}{s}$$

$$receiver\ Power, \Pr = Pt - L + Gt + Gr$$

$$where\ , Pt = Transmitter\ Power$$

$$L = Free\ scale\ path\ loss$$

$$at = Transmitting\ antenna\ gain$$

$$ar = Receiving\ antena\ gain \qquad (3.1)$$

The term “RF budget” is most commonly used in the satellite communication arena. It well known that when an RF signal goes from one end to the other, it is attenuated; and the amount of attenuation depends on the medium through which the EM wave travels. In the case of satellite communication, loss happens primarily in free space. The free space loss here is determined by the distance between the transmitter and the receiver as well as the wavelength (or frequency) of operation.

$$Free\ Space\ path\ loss = (4 * \pi * \mathrm{d}/\lambda)2 \qquad (3.2)$$

The above-mentioned equation is used for an RF budget calculator.

This RF budget calculator calculates power received at satellite receiver and free space path loss. Transmitter power and antenna gains are provided as input to the RF budget calculator.

3.4 Chapter Summary

This chapter discussed the proposed real-time wireless livestock theft prevention system, which leverages LoRaWAN wireless communication technology to assist farm owners in managing and monitoring their animals. LoRa gateways and wireless sensor nodes are also mentioned, since they enable a low-cost, low-power real-time livestock tracking system that helps to reduce cattle theft in rural regions.

LoRaWAN is defined and used as a low-power, wide-area wireless communication technology designed for the IoT and machine M2M applications. System modelling for LoRaWAN involves understanding its key components, architecture, and operation, including its advantages, as discussed in this chapter.

LoRaWAN is also a wireless communication technology that is well-suited for long-range, low-power IoT applications. It offers a flexible and secure communication solution with various classes of devices, a robust network architecture, and a growing ecosystem of supported devices and services.

The significance of determining the range of LoRaWAN devices is explained in this chapter. Range computation is critical because it assists network planners and device designers in understanding the effective coverage of their LoRaWAN devices. The chapter also described a tool or procedure known as the LoRa Range Calculator. This calculator is intended to determine the maximum communication

range possible given a set of characteristics such as transmit power, receiver sensitivity, and environmental conditions.

The section contains the mathematical formula or algorithm that the LoRa range calculator uses to estimate range. To compute the predicted range, this formula takes into account variables such as transmit power, spreading factor, bandwidth, and receiver sensitivity. It also explores how geography, barriers, interference, and environmental variables affect the range of LoRaWAN devices. Understanding these variables is critical for making accurate range predictions.

This study employed LoRaWAN when constructing the proposed system to enable real-time communication between the wireless sensor nodes worn by the animals and the farm owners via the LoRa gateway and application servers. Furthermore, in this dissertation, numerous technologies have been merged into the proposed system that enable real-time communication and long-range communication, particularly in rural areas.

Examples of how to utilize the range calculator and formula in real-world circumstances are provided in the section. Network planning, device deployment, and optimizing LoRaWAN network coverage could all fall under this category. The section also emphasizes the need for proper range estimate in LoRaWAN deployments; such will ensure that IoT devices can interact successfully with the gateway while conserving power.

This study concluded by summarising the LoRa range calculator and formula's importance in LoRaWAN deployments, encouraging users to use this tool for successful network planning.

Chapter 4: Simulation and Experiment

4.1 Introduction

In this chapter, this study presents the way in which the proposed real-time wireless tracking system was implemented to prevent cattle theft, utilizing the LoRaWAN wireless communication network. In this dissertation, this study created the proposed real-time wireless tracking system to prevent cattle theft using the LoRaWAN wireless communication network, and the IEEE 802.11ac model was established using NS-3. Simulation is a vital modern technology; this is because computer simulations can model both hypothetical and real-world objects, allowing them to be studied. Simulation can be used for a variety of purposes in science, engineering, and other fields of application. Many natural systems can benefit from computer simulation for modelling and analysis. A network simulator is a technique for simulating a network on a computer (Kumar, Rao, & Goswami, 2013).

This study used the NS3 simulator to implement the designed network architecture, which is to gather packets from wireless sensor nodes using RFID to gain the live location of livestock, thereafter sending it through the LoRa gateway to the cloud servers and application servers of the livestock farmers. In addition, the network simulator then provides an integrated, versatile, and user-friendly GUI-based network designer tool for designing and simulating a network via SNMP, TL1, TFTP, FTP, Telnet, and Cisco IOS devices (Kumar, Rao, & Goswami, 2013).

In this dissertation, this study used the open-source network simulator named NS-3. NS3 is flexible and reflects the latest changes of new technologies more rapidly than commercial network simulators. Researchers can use network simulators to test scenarios that are difficult or expensive to simulate in the real world. This is particularly useful for testing new network protocols or for modifying those existing in a controlled

and reproducible environment. Various types of node can be used to create various network topologies (hosts, hubs, bridges, routers, mobile devices, among many others). Following that, the network topology is merely a set of simulation parameters; the routing behaviour can easily be studied in various topologies. The majority of available network simulation tools are based on the discrete event-based simulation paradigm. Network simulators are classified into several types that can be compared based on the following criteria: range (from very simple to very complex), specification of nodes and links between nodes and traffic between nodes, specification of all protocols used to move traffic in a network between the wearable's sensor nodes, LoRa gateway, application servers, and livestock owners' applications (Kumar, Rao, & Goswami, 2013).

4.2 Implementation of the Proposed System

Based on open-source code-shared by the Semtech company and other contributions, a LoRa module for the NS-3 is created in this dissertation.

NS-3 offers three open source LoRaWAN implementations: i) an implementation of LoRaWAN Class A and C end devices using SX1272/76 radio drivers; ii) the library corresponding to the driver/hardware abstraction layer for building a gateway using a concentrator board based on the Semtech SX1301 multi-channel modem and SX1257/SX1255 RF transceivers; and iii) a LoRa packet forwarder running on the LoRa gateway for relaying packets to the end devices over the LoRa link.

The implementations provide a thorough understanding of how to create the NS-3 module for LoRaWAN class A end devices and gateways allowing transmission of packets from the LoRa Sensor nodes to the application servers via the gateway as shown in Figure 4.2. The difference between Figures 4.1 and 4.2 is not great − both

figures display how this proposed solution is articulated and how the packets are transferred from the sensor nodes to the farmer in real-time. Figure 4.1 shows an architecture of the LoRaWAN IoT gateway connecting up the livestock wireless sensor which is representing the livestock; and showing how the packets are collected from the livestock which is the live location and how these are sent to the farmer's device through the LoRa gateway. These packets are collected through the sensor nodes and transferred to the LoRa Gateway; this then transfers the packets directly to the application server which is running through the cloud in real-time. Figure 4.2 shows the architecture of LoRaWAN and the connectivity used which is the same as in Figure 4.1. This also shows the cloud computing, data analytics and artificial intelligence which all allow the farmers to receive data on their livestock in real-time.

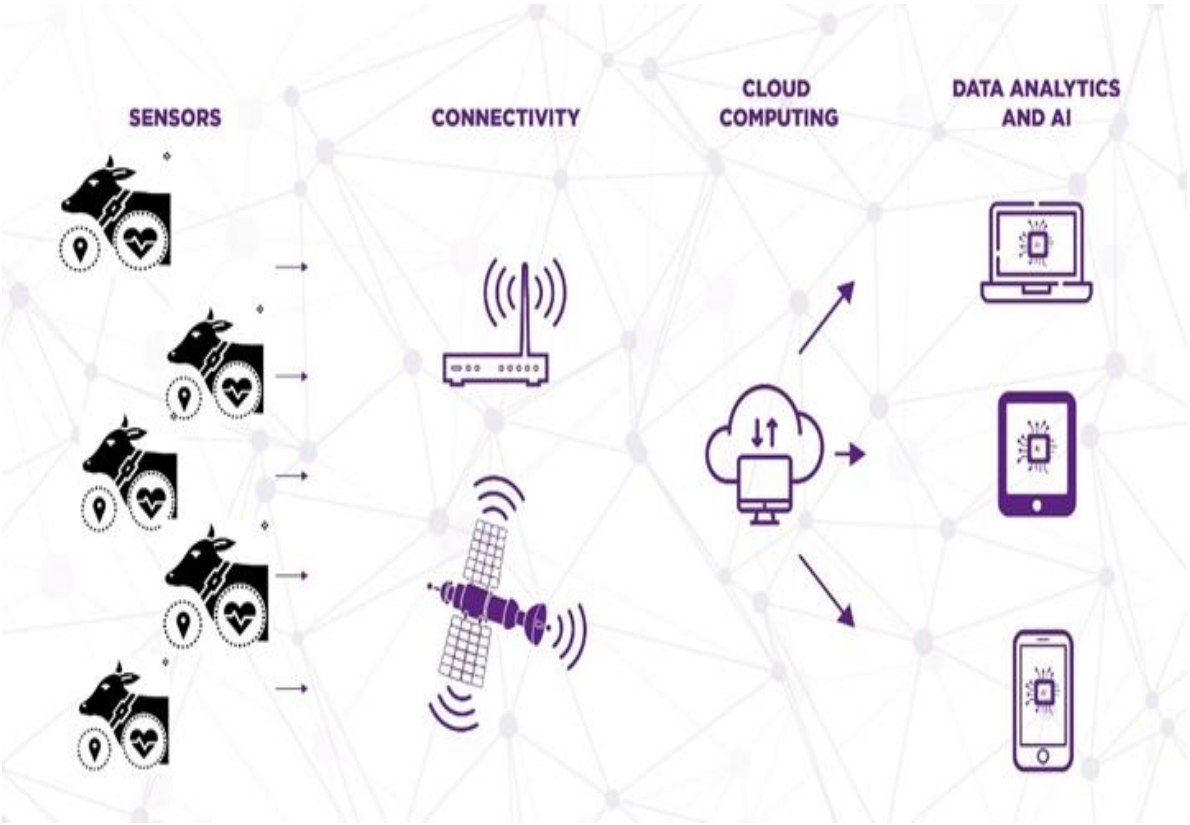


Figure 4.1. The proposed LoRaWAN connectivity architecture

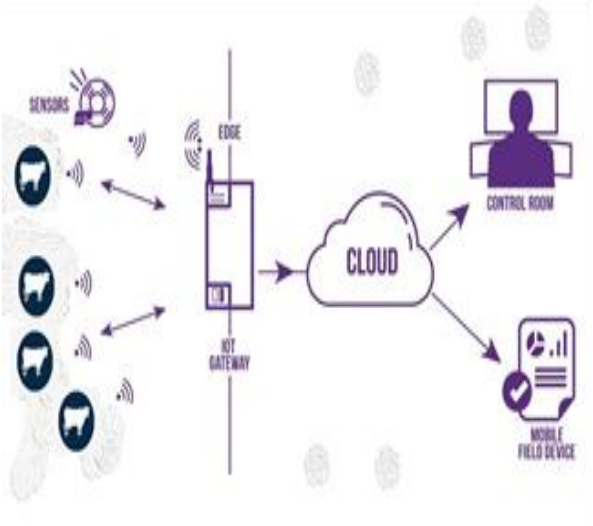


Figure 4.2 LoRaWAN IoT architecture

B. Simulation Scenario and Settings

```
#include “ns3/core-module.h”
#include “ns3/global-route-manager.h”
#include “ns3/network-module.h”
#include “ns3/internet-module.h”
#include “ns3/bridge-module.h”
#include “ns3/csma-module.h”
#include “ns3/applications-module.h”
#include “ns3/v4ping-helper.h”
#include “ns3/v4ping.h”using namespace ns3;int main(int argc, char *argv[])
{
CommandLine cmd;
cmd.Parse (argc, argv);/* Configuration. */
/* Build nodes. */
NodeContainer term_0;
term_0.Create (1);
NodeContainer term_1;
term_1.Create (1);
/* Build link. */
CsmaHelper csma_hub_0;
csma_hub_0.SetChannelAttribute (“DataRate”, DataRateValue (100000000));
csma_hub_0.SetChannelAttribute (“Delay”, TimeValue (MilliSeconds (10000)));
/* Build link net device container. */
NodeContainer all_hub_0;
all_hub_0.Add (term_0);
all_hub_0.Add (term_1);
NetDeviceContainer ndc_hub_0 = csma_hub_0.Install (all_hub_0);
/* Install the IP stack. */
InternetStackHelper internetStackH;
internetStackH.Install (term_0);
internetStackH.Install (term_1);
```

Figure 4.3. Ns-3 topology generator code

The suggested LoRaWAN communication architecture is depicted in Figures 4.1 and 4.2, which outline the network connection from the sensor nodes worn by the cattle. Connectivity is the position of the LoRa gateway, which allows data to be transported from nodes to cloud computing, in which all databases are stored; and then to data analytics, where all system users may access all data in real-time to determine the location of the animals.

Figure 4.3 depicts the NS-3 topology generator code, which shows how the NS-simulation interface is produced using C++, which is generated automatically after selecting generate -> C++ from the menu.

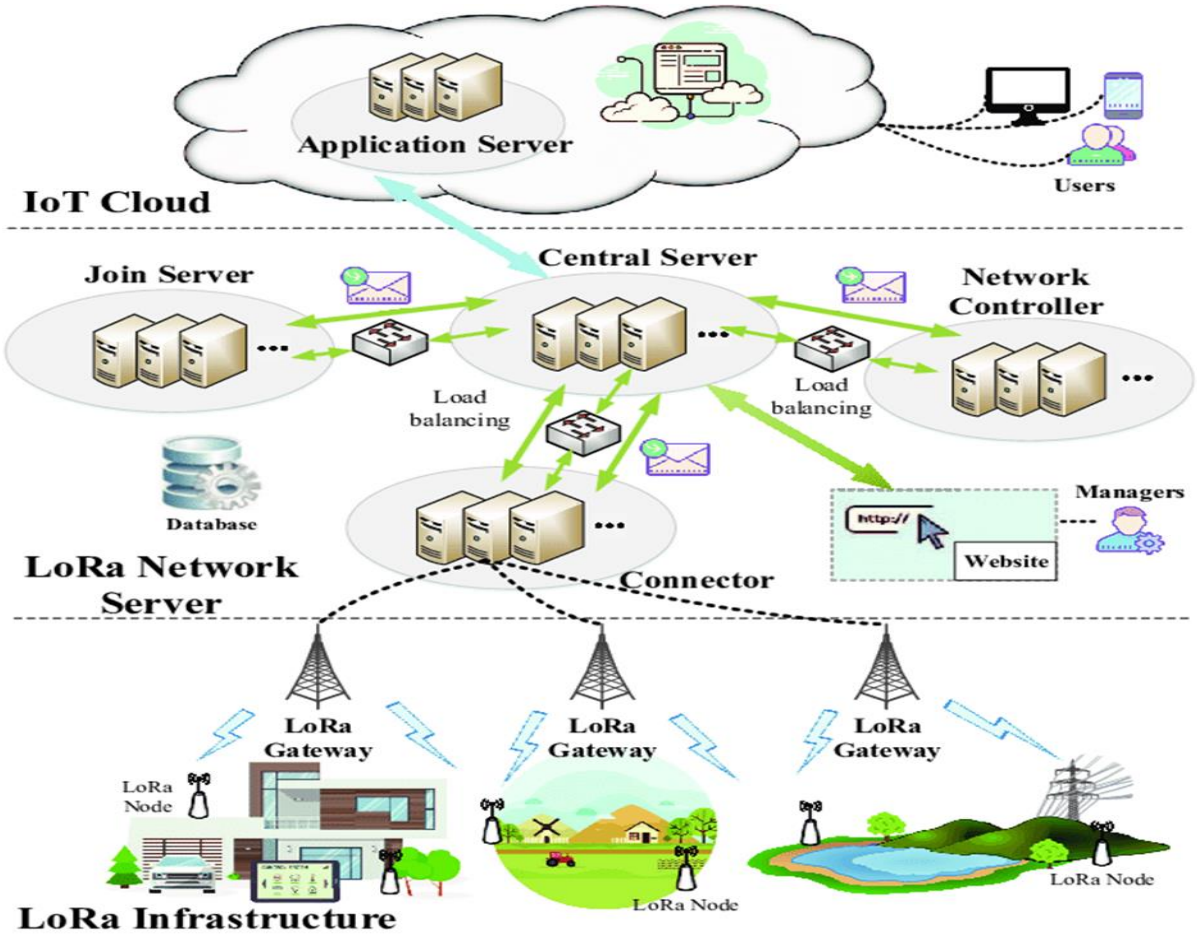


Figure 4.4. LoRa infrastructure

Figure 4.4 above illustrates LoRa (long range) infrastructure, being the network and components that enable LoRa technology to operate. LoRa is a wireless communication technology intended for long-distance, low-power IoT (Internet of Things) applications. The following are the major elements and principles of a LoRa infrastructure:

In the top and middle tiers of Figure 4.4 is the IoT Server which is the LoRaWAN network server: this study describes this LoRaWAN network server as a crucial component of a LoRa architecture. This server is in charge of managing communication between end devices (sensor nodes worn by the livestock) and application servers (places where users are accessing the system). The server is in charge of device registration, security, and message routing. This also joins to the LoRa gateway which forms part of the crucial components that operate as go-betweens for end devices and network servers. Messages from adjacent devices are received and forwarded to the network server. Gateways have LoRa wireless transceivers and can cover a large region. This then transmit the data from the sensor nodes which are end devices; these are IoT devices that collect and transmit data over LoRa. These devices are often battery-powered and engineered to consume less energy. They interact with gateways via LoRa.

This solution also uses LoRa transceivers which are used in LoRa devices such as sensor nodes and gateways. By modulating the signals in a form that is resistant to interference and capable of travelling great distances, these transceivers enable long-range and low-power communication.

The simulation above uses NS3 for WSN; and is also a collection of nodes organized into a cooperative network. The nodes worn by the animals have processing capability and several types of memory, allowing researchers easily to process or send data from the nodes to the LoRaWAN. In this simulation, an RFID RF transceiver is also used, which includes a power source, and can handle multiple sensors and actuators. This Ns3 WSN system has a gateway that offers wireless communication back to the wired world as well as dispersed nodes. In this simulation, the wireless protocol used is a star topology.

4.2.1 NS-3 Wireless Simulation

Using NS-3 wireless simulation, this study created a dynamic library for future events that is kept in a sorted event list that supports events, simulating packet transmission, receipt, and timers. In this simulation, network interfaces in NS-3 are used, which are Layer 2 protocols such as 802.11.

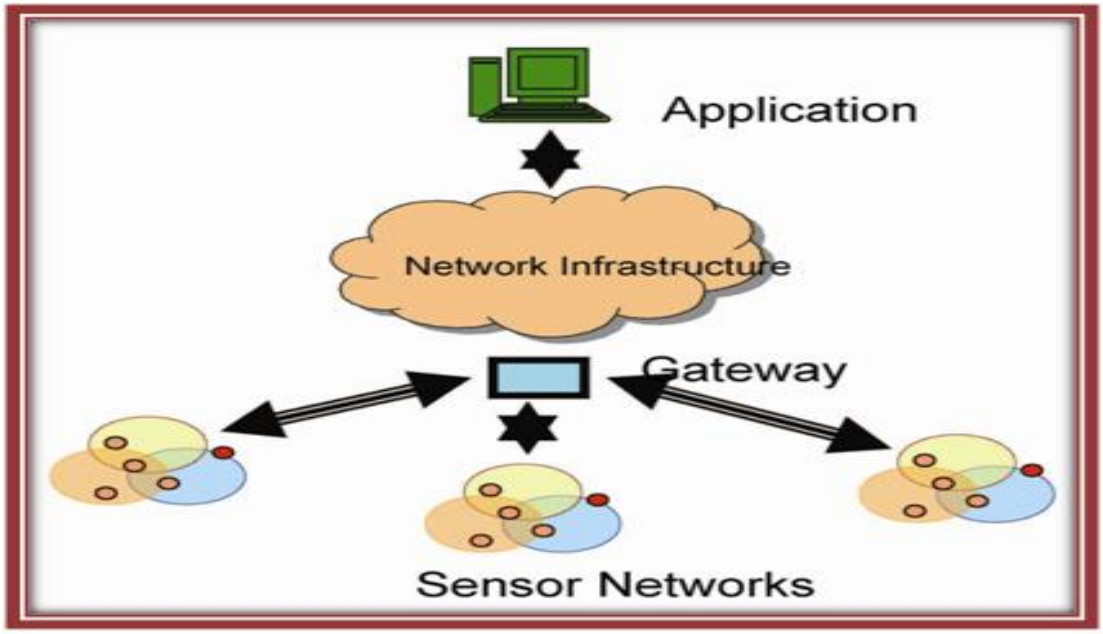


Figure 4.6. Architecture of NS-3 for WSN

```
double DegreesToRadians (double degrees)
{
return degrees * M_PI / 180.0;
}
double RadiansToDegrees (double radians)
{
return radians * 180.0 / M_PI;
}
std::ostream&amp;amp;amp;amp;amp;amp;amp;amp;amp;amp;amp; operator&amp;amp
{
os &amp;amp;amp;amp;amp;amp;amp;amp;amp;amp;amp;lt;&amp;amp;amp;amp;amp;amp;am
return os;
}
std::istream &amp;amp;amp;amp;amp;amp;amp;amp;amp;amp;amp;operator &amp;am
{
char c;
is &amp;amp;amp;amp;amp;amp;amp;amp;amp;amp;gt;&amp;amp;amp;amp;amp;amp;am
if (c != ':')
{
is.setstate (std::ios_base::failbit);
}
return is;
}
Angles::Angles ()
: phi (0),
theta (0)
{
}
Angles::Angles (double p, double t)
: phi (p),
theta (t)
{
}
Angles::Angles (Vector v)
: phi (std::atan2 (v.y, v.x)),
theta (std::acos (v.z / sqrt (v.x*v.x + v.y*v.y + v.z*v.z)))
{
}
Angles::Angles (Vector v, Vector o)
: phi (std::atan2 (v.y - o.y, v.x - o.x)),
theta (std::acos ((v.z - o.z) / CalculateDistance (v, o)))
{
```

Figure 4.7. WSN NS-3 Code 1

```
#include "ns3/core-module.h"
#include "ns3/wifi-module.h"
#include "ns3/mobility-module.h"
#include "ns3/ipv4-global-routing-helper.h"
using namespace ns3;
NS_LOG_COMPONENT_DEFINE ("Wifi-2-nodes-fixed");
void
PrintLocations (NodeContainer nodes, std::string header)
{
std::cout &amp;amp;amp;amp;amp;amp;amp;lt;&amp;amp;amp;amp;amp;amp;amp;lt; header &amp;amp;a
for(NodeContainer::Iterator iNode = nodes.Begin (); iNode != nodes.End (); ++iNode)
{
Ptr&amp;amp;amp;amp;amp;amp;amp;lt;Node&amp;amp;amp;amp;amp;amp;amp;gt; object = *iNode;
Ptr&amp;amp;amp;amp;amp;amp;amp;lt;MobilityModel&amp;amp;amp;amp;amp;amp;amp;gt; position =
&amp;amp;amp;amp;amp;amp;amp;gt;GetObject&amp;amp;amp;amp;amp;amp;amp;lt;MobilityModel&amp;a
NS_ASSERT (position != 0);
Vector pos = position-&amp;amp;amp;amp;amp;amp;amp;gt;GetPosition ();
```

```
std::cout &amp;amp;amp;amp;amp;amp;amp;amp;lt;&amp;amp;amp;amp;amp;amp;amp;amp;lt; "(" &amp;amp;amp
&amp;amp;amp;amp;amp;amp;amp;amp;lt;&amp;amp;amp;amp;amp;amp;amp;amp;lt; ", " &amp;amp;amp;amp;amp;a
&amp;amp;amp;amp;amp;amp;amp;amp;lt;&amp;amp;amp;amp;amp;amp;amp;amp;lt; ", " &amp;amp;amp;amp;amp;a
&amp;amp;amp;amp;amp;amp;amp;amp;lt;&amp;amp;amp;amp;amp;amp;amp;amp;lt; ")" &amp;amp;amp;amp;amp;ar
}
std::cout &amp;amp;amp;amp;amp;amp;amp;amp;lt;&amp;amp;amp;amp;amp;amp;amp;amp;lt; std::endl;
}
void
PrintAddresses(Ipv4InterfaceContainer container, std::string header)
{
std::cout &amp;amp;amp;amp;amp;amp;amp;amp;lt;&amp;amp;amp;amp;amp;amp;amp;amp;lt; header &amp;amp;amp;a
uint32_t nNodes = container.GetN ();
for (uint32_t i = 0; i &amp;amp;amp;amp;amp;amp;amp;lt; nNodes; ++i)
{
std::cout &amp;amp;amp;amp;amp;amp;amp;amp;lt;&amp;amp;amp;amp;amp;amp;amp;amp;lt; container.GetAddr
}
std::cout &amp;amp;amp;amp;amp;amp;amp;amp;lt;&amp;amp;amp;amp;amp;amp;amp;amp;lt; std::endl;
}
int
main (int argc, char *argv[])
{
bool verbose = true;
uint32_t nWifi = 2;
double xDistance = 10.0;
CommandLine cmd;
cmd.AddValue ("xDistance", "Distance between two nodes along x-axis", xDistance);
cmd.Parse (argc,argv);
if (verbose)
{
LogComponentEnable("UdpEchoClientApplication", LOG_LEVEL_INFO);
LogComponentEnable("UdpEchoServerApplication", LOG_LEVEL_INFO);
}
NodeContainer wifiStaNodes,
wifiApNode;
wifiStaNodes.Create (nWifi);
wifiApNode = wifiStaNodes.Get (0);
YansWifiChannelHelper channel = YansWifiChannelHelper::Default ();
YansWifiPhyHelper phy = YansWifiPhyHelper::Default ();
phy.SetChannel (channel.Create ());
WifiHelper wifi = WifiHelper::Default ();
wifi.SetRemoteStationManager ("ns3::AarfWifiManager");
NqosWifiMacHelper mac = NqosWifiMacHelper::Default ();
Ssid ssid = Ssid ("ns-3-ssid");
mac.SetType ("ns3::StaWifiMac",
"Ssid", SsidValue (ssid),
"ActiveProbing", BooleanValue (false));
NetDeviceContainer staDevices;
staDevices = wifi.Install (phy, mac, wifiStaNodes.Get (1));
mac.SetType ("ns3::ApWifiMac",
"Ssid", SsidValue (ssid),
"BeaconGeneration", BooleanValue (true),
"BeaconInterval", TimeValue (Seconds (5)));
```

```
NetDeviceContainer apDevice;
apDevice = wifi.Install (phy, mac, wifiApNode);
MobilityHelper mobility;
mobility.SetPositionAllocator ("ns3::GridPositionAllocator",
"MinX", DoubleValue (0.0),
"MinY", DoubleValue (0.0),
"DeltaX", DoubleValue (xDistance),
"DeltaY", DoubleValue (10.0),
"GridWidth", UintegerValue (3),
"LayoutType", StringValue ("RowFirst"));
mobility.SetMobilityModel ("ns3::ConstantPositionMobilityModel");
mobility.Install (wifiStaNodes);
InternetStackHelper stack;
stack.Install (wifiStaNodes);
Ipv4AddressHelper address;
Ipv4InterfaceContainer wifiInterfaces,
wifiApInterface;
address.SetBase ("10.1.1.0", "255.255.255.0");
wifiApInterface = address.Assign (apDevice);
wifiInterfaces = address.Assign (staDevices);
UdpEchoServerHelper echoServer (9); // Port # 9
ApplicationContainer serverApps = echoServer.Install (wifiApNode);
serverApps.Start (Seconds (1.0));
serverApps.Stop (Seconds (4.0));
UdpEchoClientHelper echoClient (wifiApInterface.GetAddress (0), 9);
echoClient.SetAttribute ("MaxPackets", UintegerValue (1));
echoClient.SetAttribute ("Interval", TimeValue (Seconds (1.)));
echoClient.SetAttribute ("PacketSize", UintegerValue (1024));
ApplicationContainer clientApps = echoClient.Install (wifiStaNodes.Get (1));
clientApps.Start (Seconds (2.0));
clientApps.Stop (Seconds (3.0));
Ipv4GlobalRoutingHelper::PopulateRoutingTables ();
Simulator::Stop (Seconds (4.0));
PrintAddresses(wifiInterfaces, "IP addresses of base stations");
PrintAddresses(wifiApInterface, "IP address of AP");
PrintLocations(wifiStaNodes, "Location of all nodes");
Simulator::Run ();
Simulator::Destroy ();
return 0;
}
```

Figure 4.8 WSN NS-3 Code 2

The NS-3 wireless simulation solution shown above is a significant network connection that allows data to be transmitted from livestock nodes to the LoRa gateway; thereafter to all application servers using wireless nodes. This study also provides several simulation tools for wireless-based network. Because of its open-source nature, NS-3 is now widely used in research for implementation of the solution. This proposed solution uses diverse technologies such as WPAN, WLAN, and cellular networks. NS-3 wireless simulation was implemented using the following networks:

WPAN Network: This study utilizes wireless personal area network (WPAN) to send data over short distances between livestock sensor nodes and network devices. WPAN connections require low (or no) infrastructure in comparison with outside linkages. This study also uses WPAN to ensure that network devices are power efficient, compact, and inexpensive.

IEEE 802.15.1: This study employs a popular WPAN device known as Bluetooth. The study also defines the architecture and operation of the physical and media access control layers.

NS3 Zigbee PROJECTS: This study builds ZigBee networks, which are a type of WPAN network. ZigBee ensures dependable data transport over short distances.

TABLE V: Simulation Parameters

Voltage	3.3 V
Frequency Band	868 MHz
Code Rate	4/5
Bandwidth	125 kHz

Duty Cycle	1%
Output Power	20 dBm
Payload Length	10 bytes
Preamble Length	12 symbols
Number of Channels	3
Spreading Factor	SF7-SF12

This dissertation considers a scenario with one gateway and up to 10,000 end devices. The simulation timer runs out after 20,000 seconds. End-device positions are distributed at random around the gateway in a 10000 m x 10000 m area. 50KB/s data frames are sent by end devices. This study simulates LoRaWAN, CSMA, and CSMA-10 (CSMA-x with a 10 ms interval). This result provides live locations for the livestock by means of low power, and low bit rate, while also covering long ranges up to 10km.

4.3 Chapter Summary

This study presented a full explanation of the implementation and simulation of the proposed real-time IoT livestock theft prevention system utilizing NS-3 in this Chapter. In addition, this study covered how we captured the data and which shows all the technologies used to graphically depict the simulation results. The simulation results obtained during the many simulations undertaken to test the performance of the proposed LoRaWAN solution are presented in the next chapter.

CHAPTER 5: Results and Discussion

5.1. Introduction

Many researchers use network simulators to test protocols and applications in a variety of network setups. Simulators enable researchers to model the network in order to mimic the behaviour of real communication networks, while setting up a genuine network is costly and time-consuming. In this Chapter, we discuss the performance of the proposed LoRaWAN real-time wireless livestock prevention system based on simulation results. The rest of this chapter is organized as follows: We offer the computer simulation evaluation in Section 5.2. The simulation results and discussions are presented in Section 5.2. Finally, in Section 5.3, we recapitulate the contents of this chapter.

5.2 Computer Simulation Evaluation, Results, and Discussion

For the long-range and low-power requirements of this dissertation, we evaluated CSMA and CSMA-10, and their performance compared with LoRaWAN, using NS-3. The packet delivery ratio, collision ratio, and energy consumption are considered in the comparison. A network with nodes ranging from one to ten thousand nodes is simulated. The packet delivery ratio is defined as PDR = Ri / Si, where Ri denotes the number of nodes received by the receiver; and Si is the number of nodes actually transmitted through the senders.

It should be noted that when a receiver receives a packet while also receiving the preamble of another packet, the capture effect occurs. Under this situation, if the signal-to-interference ratio (SIR) of the new packet is higher than a certain threshold, the current packet is dropped; and the new incoming packet will be fully received. In Figure 5.1, the packet delivery rate for the used protocols which is LoRaWAN, CSMA,

and CSMA-10 (the ratio of the number of received packets by the gateway to the number of all packets transmitted by end devices) is presented. It is observed that a much better rate for CSMA compared with LoRa is gained. Figure 5.1 also shows better scalability of CSMA, which obtains the packet delivery rate of over 90% in a range of some 4000 devices or more. The CSMA-10 rate is higher than that of CSMA in which the number of devices goes beyond 1500.

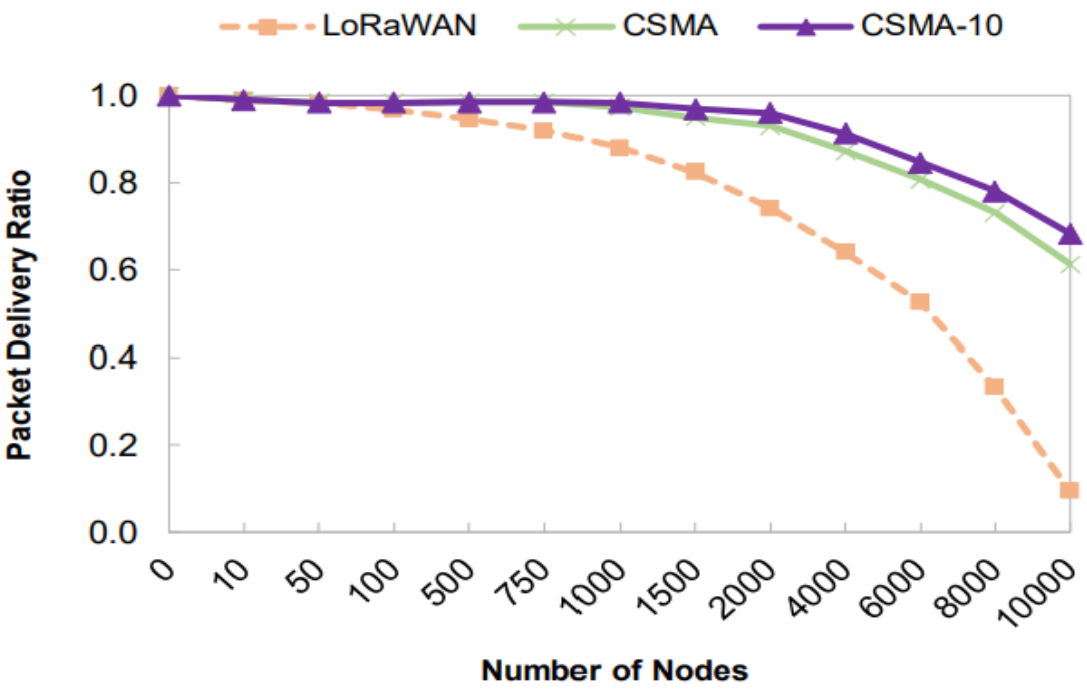


Figure 5.1. Packet delivery ratio in the whole network under LoRaWAN, CSMA, and CSMA-10

Figure 5.1 depicts the packet delivery rate for all protocols employed, including LoRaWAN, CSMA, and CSMA-10, i.e., the percentage of packets received by the gateway to total packets delivered by the LoRa sensing nodes. According to Figure 5.1, CSMA has a substantially greater packet delivery rate than LoRaWAN. Because it delivers a packet delivery rate of greater than 90% for over 4000 nodes, CSMA also increases scalability.

In terms of packet delivery ratio, collision ratio, and energy consumption, we compared the performance of previously deployed livestock monitoring systems that used MAC and transport layer models, with LoRaWAN employing NS-3. We simulated a network with one to ten thousand nodes. The capture effect occurs when a packet is received by the receiver while also receiving the preamble of another packet: if the new packet's signal-to-interference ratio (SIR) is greater than a certain threshold, the current packet is dropped and the receiver locks on the new incoming packet. Figure 5.1 depicts the LoRaWAN, MAC, and the transport layer model packet delivery rates (the ratio of the number of packets received by the gateway to the total number of packets transmitted by sensor nodes).

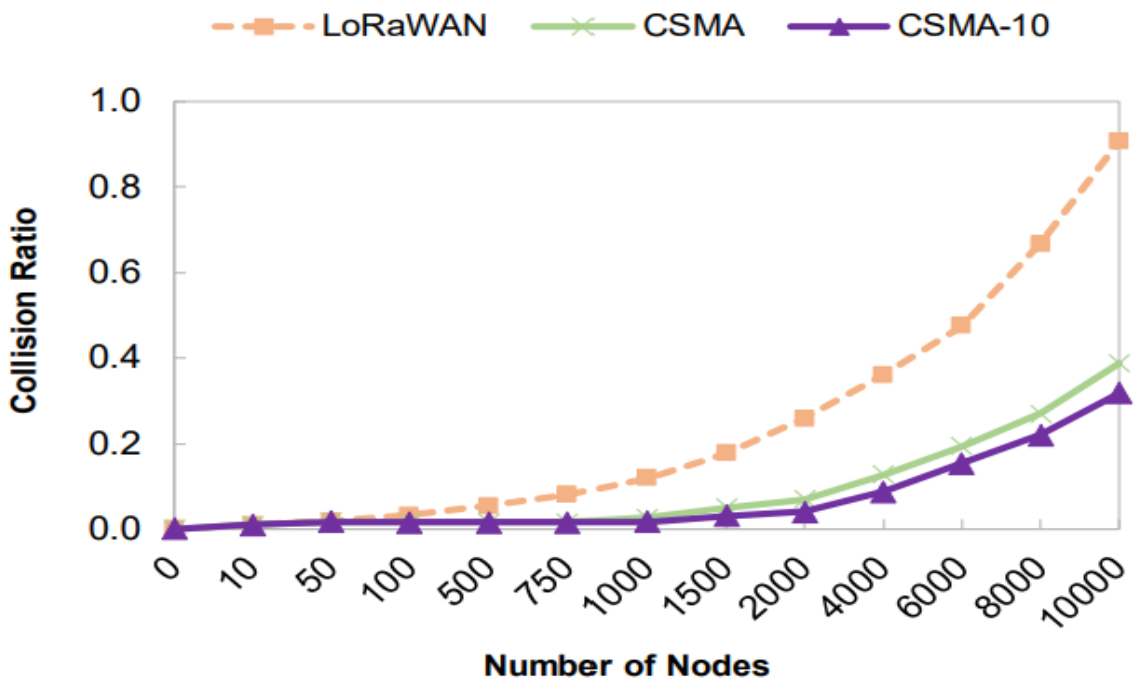


Figure 5.2. Collision ratio in the whole network under LoRaWAN, CSMA, and CSMA-10

Figure 5.2 illustrates the collision ratio for LoRaWAN, CSMA and CSMA-10, which is defined as the number of released packets due to collisions alienated by the total number of transmitted packets. The collision ratio for LoRaWAN knowingly increases

with the number of competing sensor nodes. Because sensor nodes send far fewer packets involved in collisions, the increase in CSMA is moderate. CSMA-10 grew the lowest collision rate.

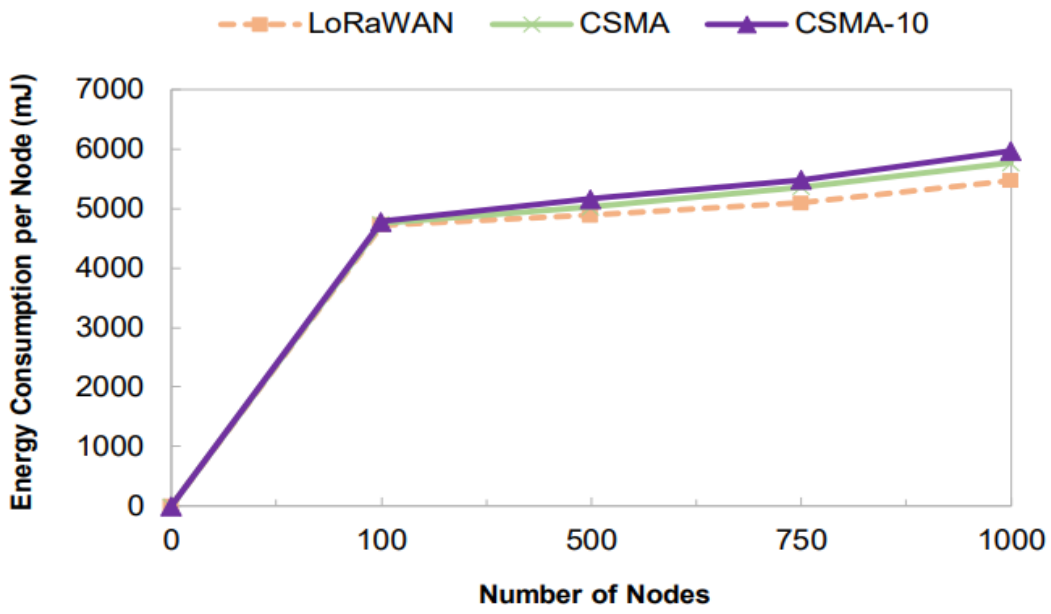


Figure 5.3 Energy consumption per node under LoRaWAN, CSMA, and CSMA-10 for 0 – 1000 nodes

Figure 5.3 shows the energy that is consumed by use of LoRaWAN, CSMA, and CSMA-10 in a network, with the number of sensor nodes ranging from 0 to 1000. Because of the interval before transmission during which a device is awake, the total consumed energy for CSMA with 0 – 1000 sensor nodes is greater than that of LoRaWAN. making LoRaWAN the best solution for the problem at hand.

5.3 Summary

We reviewed computer simulation evaluation and outcome discussions in this chapter based on the simulation scenarios presented in Section 5.2. We reviewed the findings in relation to the wireless technologies employed in this study, including LoRaWAN

wireless communication network, radio frequency identification, wireless sensor nodes, CCMA, and real-time packet transmission. We will end this study and discuss future work in the following chapter. In addition, we explore aspects that are not included in this study.

Chapter 6: Conclusion and Future Work

6.1. Introduction

In this dissertation, we created and deployed a LoRaWAN communication network architecture to aid in the prevention of livestock theft in rural Mpumalanga, namely, the Nkomazi Local Municipality, which is near to the Mozambique and eSwatini borders. We developed a wireless livestock tracking system based on real-time Internet of Things for theft prevention using LoRaWAN communication to help ensure that animals are tracked and kept within a geographic fence; and this information will be transmitted in real-time via sensor nodes that employ LoRaWAN and LoRa gateways.

This dissertation incorporated WSN into the proposed LoRaWAN network architecture in order to allow real-time tracking of livestock via data transmission from sensor nodes to gateways and subsequently to application servers operated by livestock owners.

The rest of this chapter is organized as follows: Section 6.2 goes in depth on how we met our goals and objectives. We present an overview of this study in Section 6.3. In Section 6.4, we explain the difficulties we experienced during the study. Section 6.5 then discusses future work. Finally, in Section 6.6, we summarize this chapter.

6.2 Aim and Objectives Achievements

This section discusses how we met the goals and objectives indicated in Section 1.5 of Chapter 1.

1. **To investigate underlying factors influencing livestock theft in this era; and to investigate types of real-time IoT networks considered useful for tracking livestock wirelessly:**

   In Chapter 2 we investigated and identified underlying factors which influence livestock theft in South Africa. Later we discussed all the types in an overview of the existing livestock tracking systems using LoRaWAN technologies. While conducting the research it was evident that livestock theft is a significant problem in South Africa; and several underlying factors contribute to its prevalence. These factors are complex and interrelated, making it essential to address them comprehensively in effectively combatting livestock theft. The are many factors which were identified as the main factors such as high levels of

poverty in many rural areas of South Africa that drive individuals to engage in livestock theft as a means of survival.
Unemployment: Limited employment opportunities in rural areas can lead people to resort to illegal activities such as theft to make a living. Many more factors obtain (Masuku, S.C. and Motlalekgosi, H.P., 2021).

Addressing livestock theft in South Africa requires a multifaceted approach that combines law-enforcement efforts, community engagement, improved economic opportunities, and better livestock traceability systems. Measures such as increased police presence in rural areas, public-awareness campaigns, and community-based initiatives can help reduce the prevalence of livestock theft and protect the livelihoods of farmers. Additionally, economic development and poverty alleviation programmes in rural areas can help address some of the root causes of livestock theft (Masuku, S.C. and Motlalekgosi, H.P., 2021). Livestock traceability systems are the main systems which will be used to prevent this problem. We discovered that previously proposed livestock tracking systems have failed to solve the problem because they are mostly not in real-time. As a result, these livestock-theft-prevention systems have experienced some challenges with regard to tracking the livestock in real-time.

In this chapter we also discussed the real-time IoT (Internet of Things) networks which are highly valuable for tracking livestock wirelessly, in that they provide real-time data, and they enable remote monitoring and management of animals. Some types of IoT networks and technologies that are considered useful for tracking livestock are:

- LPWAN and LoRaWAN, which are low-power, long-range wireless communication technologies well suited for tracking livestock in rural areas. This study is more on rural areas than urban; therefore these technologies offer extended coverage and low power consumption, making them cost-effective for large outdoor deployment.
- Cellular Networks: 2G, 3G, 4G, and 5G: Cellular networks provide broad coverage and high data rates for real-time tracking of livestock. Cellular-based IoT devices can transmit location and sensor data to a central

server, enabling real-time monitoring (Liang, R., Zhao, L. and Wang, P., 2020).

- GPS Tracking: Global Positioning System (GPS): GPS technology is widely used for tracking the location of livestock. GPS trackers can provide precise location data, allowing farmers to monitor the movement of animals and receive alerts in case of unauthorized movement.
- RFID (radio-frequency identification): RFID tags: RFID tags are attached to individual animals and can be read wirelessly. These tags are often used for identification and tracking of livestock within a limited range. RFID readers at key points on the farm can monitor the movement of animals.
- NB-IoT (narrowband IoT): NB-IoT is a cellular-based technology designed for low-power, wide-area IoT applications. NB-IoT is suitable for tracking livestock due to its energy efficiency and long-range capabilities.
- Sigfox: Sigfox is a global low-power, wide-area network technology designed for IoT applications. Sigfox provides long-range coverage and can be used to track and monitor livestock.
- Wi-Fi and Bluetooth: Wi-Fi and Bluetooth technologies can be employed for short-range tracking and monitoring of livestock. These technologies are useful for tracking animals within confined areas such as barns or feedlots.
- Satellite Communication: Satellite-based tracking devices can be used to monitor livestock in remote or geographically challenging areas where other network options may not be available.
- Edge Computing: Edge computing devices can be deployed in the field to process data locally and send only relevant information to the central server. This can help reduce the amount of data transmitted and extend lower power consumption.
- Cloud-Based Platforms: Cloud-based IoT platforms are essential for collecting and analysing data from tracking devices. These platforms enable farmers to access real-time information and historical data about the location, health, and behaviour of their livestock.

When implementing an IoT network for livestock tracking, it is important to consider factors such as the specific requirements of the farm, the range and coverage needed, power consumption, and the type of data to be collected. The choice of technology will depend on the farm's location, size, and budget. In this study we examined all the above technologies and selected the best for sending data in real-time therefore the best to implement the proposed solution.

2. **To design a real-time wireless tracking system using low-power wireless communication technology that will be used to prevent livestock theft:**

In order to prevent livestock theft by using real-time wireless LoRa communication we designed a real-time wireless tracking system which involves combining various technologies and components to ensure accuracy, reliability, and low power consumption. Below is a high-level overview of the key components and steps involved in designing such a proposed system. In Section 3.2 of Chapter 3 we described the design and modelling of the real-time IoT wireless livestock tracking system. This is used to prevent livestock theft and make the life of the herder easy; also of the farmers, by making sure that they know where to find their livestock. The farmers receive notifications if there is something wrong happening to the livestock or if animals cross the GEO fencing set. Using Figure 3.1 we presented a LoRaWAN IoT architecture which had various components making it possible to implement the solution. In addition, we discussed the hardware components used to implement the architecture: the GPS module used to determine the livestock's location with high accuracy, the low-power microcontroller which assists in processing and managing data efficiently, for instance Arduino or Raspberry Pi. We further discussed wireless communication modules such as LoRa and NB-IoT or Sigfox to transmit data to the central server, sensors which incorporate environmental sensors which temper detection sensors to monitor the livestock's surroundings and thereafter to detect theft attempts.

Furthermore, we used data processing and analysis which is the microcontroller that preprocesses and compresses the GPS data before transmitting it wirelessly. We implemented onboard algorithms to detect unusual behaviour

(e.g., sudden movement or tampering); and the use of data encryption to secure information. Wireless communication was used to set up a low-power, long-range wireless network to transmit data from the tracking devices to a central server, ensuring bidirectional communication for remote device management and firmware updates.
We also implemented error-checking and retransmission mechanisms to guarantee data reliability.

In Section 3.3 of Chapter 3 we discussed the central server and cloud platform which is used to collect and analyse the data from tracking devices worn by the livestock. These systems also store and process data, and provide real-time monitoring and reporting to farmers or authorities, implementing geofencing to trigger alerts when livestock leaves predefined boundaries. User interface is also discussed as it is used to create a user-friendly interface, such as a web or mobile application, to allow farmers and authorities to track livestock in real-time; and also to provide alerts and notifications for suspicious activities.

3. **To evaluate the effectiveness of the designed IoT Livestock wireless tracking system:**
To evaluate the effectiveness of the designed IoT Livestock wireless tracking system, we have applied the following structured evaluation process. Here are steps we have taken to assess its performance:

Setting of Clear Objectives
In Section 1.5 of Chapter 1 we defined the specific objectives and goals for the tracking system, such as reducing theft incidents, improving livestock management, or increasing the safety of the livestock by using the LoRaWAN communication technologies which assist to track the livestock in real-time.

Data Collection and Analysis
We further discussed the gathering of data from the livestock through the sensor nodes worn by the animals over an extended period, ideally encompassing various seasons and conditions, before analysing the collected

data to assess various aspects of the system's performance. Consider the following metrics and aspects:

Theft prevention in which we compared theft incidents before and after the system's implementation.

Location accuracy evaluated the accuracy of the location data by comparing the system's reported positions with actual livestock locations.

Communication reliability analysed the reliability of wireless communication. The success rate of data transmission and any data loss were measured.

Geofencing and alerting examined the effectiveness of geofencing by monitoring whether alerts are triggered when livestock breach predefined boundaries.

Scalability

We also tested the system's performance with a larger number of tracking devices and livestock to ensure that it can handle increased data traffic and device management.

Documentation and Reporting

Through this dissertation we are providing a detailed documentation of all evaluation results, including data analysis and user feedback, giving regular reports to stakeholders, including recommendations for improvements.

By conducting a comprehensive evaluation using these steps, we managed to determine whether the IoT Livestock wireless tracking system effectively meets our objectives and made informed decisions about potential enhancements or adjustments to the system.

6.3 Research Summary

Livestock theft has a long history, reaching back to the days when livestock raiding was frequent. Many livestock owners in South Africa have faced this difficulty; and we discovered during our investigation that many people are affected. To avoid livestock theft, livestock owners utilized branding, which involves burning a distinctive mark or symbol onto the animal's hide. This practice is still used today, frequently alongside current theft prevention strategies. This study provided a solution to help reduce this

type of theft in the community. Livestock theft prevention has developed as technology has advanced. Electronic tracking and surveillance devices have enhanced or replaced traditional approaches such as branding. Throughout this investigation, we discovered that livestock theft prevention technologies have changed throughout time in response to the persistent problem of livestock theft, which can result in large financial losses for farmers and ranchers. To secure animals and deter theft, these systems incorporate a variety of technologies and tactics. In this study, we reviewed various technologies used to prevent livestock theft that are now in use, such as GPS, LoRaWAN, NB-IoT, or other wireless technologies to track the position of cattle in real-time.

These systems provide precise positional data and can provide alerts when animals cross predefined boundaries. Tracking devices that are tamper-resistant and generally disguised within robust, waterproof casings are used in the aforementioned technologies. Tampering sets off alarms that inhibit stealing. We also talked about how to use geofencing to ensure that the livestock's location is logged and notices or alarms are given to the owners in real time. Virtual boundaries, also known as geofences, were established together with alarms to notify owners when cattle leave these preset zones. We expanded on remote monitoring by collecting and analysing data from tracking devices, using central servers or cloud platforms. Farmers may now remotely monitor their cattle, receive real-time warnings, and access historical data.

Livestock theft prevention systems are constantly evolving, with efforts to improve their capabilities ongoing. Improved geolocation accuracy, energy harvesting solutions, machine learning for predictive analytics, and integration with other IoT technologies such as drones and blockchain for greater security and traceability may be areas of future research. Furthermore, the systems must comply with changing rules and certification criteria.

To summarize, livestock theft prevention systems have a long history of evolving from conventional approaches such as branding to modern, technology-driven alternatives. Modern devices are critical in protecting cattle and in minimizing financial losses for producers. Their evolution will most likely continue to satisfy the changing needs of the agriculture business while also ensuring cattle security and well-being.

6.4 Challenges Encountered

Conducting research takes much time; therefore I had to work late/early hours, weekends, and I had to take leave at some point to attempt to push the research forward. Because establishing a real network is both costly and time-consuming, I used an open-source programme called NS-3 to construct the suggested livestock wireless tracking system using real-time LoRaWAN communication network architecture. With the advice and feedback on my work from my supervisor, my work improved as I dealt with all of the issues I was encountering, together with a heavy workload from my employer.

6.5 Future Work

In this section, we provide future work that can be considered to improve the performance of the proposed LoRaWAN IoT livestock tracking system LoRa communication network architect.

In this dissertation we have worked to gain a successful proposed solution. Continued research and development in LoRaWAN IoT livestock wireless tracking systems will lead to improvements in various aspects, including performance, efficiency, and functionality. Below we discuss some potential areas for future work and enhancements which will be looked at going forward.

Improved Geolocation Accuracy: This study will continue to develop and integrate more advanced geolocation techniques, such as hybrid positioning combining GPS, Wi-Fi, and cellular positioning, to achieve even higher location accuracy, especially in challenging environments such as rural areas in which this system will be deployed. In addition, machine learning and predictive analytics will be used to integrate machine-learning algorithms that can analyse historical data and predict livestock behaviour, health issues, and potential theft risks, providing proactive alerts and recommendations to farmers in real-time. In future this will be made possible by using mesh networking. We will investigate the use of LoRaWAN mesh networking to create a more resilient and robust network, enabling devices to act as relays and to extend network coverage, especially in remote or large-scale livestock operations. With regard to the wireless sensor nodes, a multi-sensor integration will be used to enhance the tracking devices; with additional sensors to monitor livestock health, environmental

conditions (e.g., temperature, humidity, air quality), and even behaviour patterns (e.g., feeding, resting), providing a more comprehensive view of livestock well-being.

The use of enhanced data security will help us to implement stronger data encryption and security measures to protect sensitive livestock and farm data, especially if the system collects and stores personally identifiable information. For data analytics and insights, we looking forward to developing advanced data-analytics tools to provide farmers with actionable insights, such as optimal feeding schedules, disease detection, and resource utilization improvements.

We will enforce the cross-compatibility work on standardization efforts to ensure cross-compatibility between different LoRaWAN tracking devices and networks, promoting interoperability and easy scalability for farmers. We will implement this function to make sure that cross-compatibility between the different LoRaWAN tracking devices and networks promotes interoperability and easy scalability for the livestock owners.

Below are other issues which we are looking into considering in the future with this research. There is the environmental monitoring in which we will expand the system's capability to monitor environmental factors that can affect livestock health, such as soil moisture levels, pasture quality, and water quality, providing a holistic view of the farm's ecosystem. Integration with other IoT Technologies such as drones for aerial surveillance, smart feeding systems, and automated health monitoring systems, will help create a more comprehensive and interconnected livestock management ecosystem. Creating a friendly user interface and user experience will continuously improve the user interface and user experience of the tracking system's applications to make them more intuitive, informative, and user-friendly. We will further Investigate the use of blockchain technology to ensure the integrity and immutability of data, especially in cases where data traceability and auditability are critical, such as organic farming or food supply chains. This research will also look into staying updated with evolving regulations and certification requirements in the field of livestock tracking, ensuring that the system adheres to the latest standards. Global expansion is part of the plan which we will adapt for the system for use in different regions and under varying regulatory frameworks, thus making it accessible and valuable for livestock farmers worldwide. We will promote the enforcing of community and collaboration to 109address common challenges.

The future research work on LoRaWAN IoT livestock wireless tracking systems focuses more on enhancing the technology's capabilities, ensuring sustainability, and addressing the evolving needs of livestock farmers while maintaining data security and privacy.

6.6 Summary

In this chapter, we explored how we met our goals and objectives. We offered a synopsis of this study. Based on the simulation results reported in Chapters 4 and 5, we believe that we have met the study's objectives. We also mentioned the difficulties we experienced while performing the research, and how we overcame them. Furthermore, we addressed future work, which includes focusing on testing the real-time LoRaWAN wireless tracking system in real-world scenarios; and looking into all of the additions described in the future work section of this research.

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