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**DESIGNING A SYSTEM FOR MONITORING
AND DETECTING FAULTS IN THE WATER
PUMPING SYSTEM USING LORA NETWORK**

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Master's Thesis

Supervisor
Prof. Dr. Galip CANSEVER

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Signature

DEDICATION

This thesis is dedicated to my parents, who have been my rock and support system throughout my academic journey. Your unwavering love, encouragement, and belief in me have been invaluable, and I am forever grateful.

I would also like to dedicate this work to my advisor, Dr. X, for his/her guidance, expertise, and patience throughout this process. Your mentorship has helped me grow both academically and personally.

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ABSTRACT

DESIGNING A SYSTEM FOR MONITORING AND DETECTING FAULTS IN THE WATER PUMPING SYSTEM USING LORA NETWORK

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The purpose of this system is to monitor and detect faults in a water pumping system using LoRa network technology. The LoRa network is a low-power, long-range wireless communication technology that can be used to transmit data over long distances. The system consists of a LoRa gateway, LoRa nodes, and sensors. The sensors are placed on various parts of the water pumping system, such as the pump, motor, and pipes, to measure parameters such as flow rate, pressure, temperature, and vibration. The LoRa nodes collect the sensor data and transmit it to the LoRa gateway using the LoRa network. The LoRa gateway receives the data and sends it to a central server or cloud-based application for analysis. The analysis can be done in real-time, and the system can detect anomalies in the data, such as sudden drops in flow rate or pressure, abnormal temperature or vibration levels, or other faults in the system. The system can also send alerts to maintenance personnel or operators if it detects a fault or anomaly in the system. The alerts can be sent via email, SMS, or through a mobile app. The system can also generate reports on the performance of the water pumping system, which can be used to optimize the system and improve its efficiency. In summary, the system for monitoring and detecting faults in the water pumping system using LoRa network technology includes sensors placed on various parts of the system, LoRa nodes to collect the sensor data and transmit it to the LoRa gateway, and a central server or cloud-based application for data analysis and fault detection. The system can send alerts to maintenance personnel or operators and generate reports on the performance of the water pumping system.

Keywords: LORA, Gateway, Node, Water System, Maintenance Personnel.



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ABBREVIATION

ABP	:	Activation By Personalization
AC	:	Alternative current
ADR	:	Adaptive Data Rate
AWGN	:	Adaptive Wide Gaussian Noise
BER	:	Bit Error Rate
CSS	:	Safe Twitter Spread range
ECC	:	Error Correction Codes
FEC	:	Forward Error Correction
FPAV	:	Fire Plug Air Valves
IIoT	:	Industrial Internet of Things
LCC	:	Life-Cycle Cost
LoRa	:	Long Range Low Power
LPWAN	:	Organization
LTE	:	Long Term Evolution
MARS	:	Multivariate Regression Bands
MCMC	:	Markov chain Monte Carlo
MDG	:	Millennium Improvement
ML	:	Machine Learning
MSCL	:	Mechanosensitive Ion Channel
NHPP	:	Non-Homogeneous Poisson Process
OTAA	:	Over-The-Air Activation
PCCP	:	Placer County Conservation Program

PHY	:	Physical Layer
PVC	:	Polyvinyl Chloride
RF	:	Radio Frequency
ROC	:	Receiver Operating Characteristic
RSSI	:	Received Signal Strength Indicator
SDR	:	Software-defined Radio
SF	:	Spread Factor
SNR	:	Signal to Noise Ratio
SQL	:	Structured Question Language
SSE	:	Sum of Squares Error
TTN	:	Transient tachypnea of the Newborn
WAN	:	Wide Area Network
WDN	:	Wage Dynamics Network
WSS	:	Water Supply Systems

1. INTRODUCTION

Life on Earth would exceed the capabilities of humans, creatures and plants in the absence of his existence. Water is the basic need of every living organism, including humans, creatures, and plants. The most basic asset for living on Earth after air is water [1].

Each individual requires an adaptable plan with adequate and safe drinking water [2]. Moreover, accurate assessment of the water supply consumed is an essential part of urban management that greatly influences both the social and monetary development of a city or towns. Water is the source of all life-supporting assets [3]. Hence, regardless of the countries monetary or social status, all groups of people depend on having access to sufficient drinking water supplies to meet their basic needs for daily activities.

An increasing number of individuals are realizing the importance of water in social progress, financial development, and the eradication of destitution [4]. Today, it is seen as a commodity. The Millennium Improvement Goal (MDG), which focused on water supply, immediate and posterior commitment to the entire target plus a larger portion of the targets, has assessed the relevance of water supply to reaching the target in checks that have been conducted by a few organizations. On the contrary, the function of water is more focused on other formative activities than its primary function in achieving the goal of environmental management and on how best to reach the goal related to water supply, sterilization and hygiene [5].

The most significant public assistance in the whole globe is water. It is second just to oxygen in significance forever [6]. Accordingly, whatever disturbs the accessibility of water will in general mischief human endurance and day to day existence. The most major fundamental for human endurance is water. Through financial and social variables, having an adequate private water supply is a beginning stage for feasible turn of events. Be that as it may, most of emerging countries have low water supplies, restricted admittance to water, and unfortunate disinfection, all of which add to expanded destitution [6].

More than a century has passed since the development and improvement of the main water supply framework in some countries. Water utilities are currently facing another problem due to the maturing framework: how to keep up and reshape the framework in the best way. The rapid development of urban enterprises in various fields (communication, transport,

etc.) in the field of water comes to improve the activity of water supply frameworks by supporting their credibility, accessibility, well-being and efficiency. It is necessary to constantly develop the functional methodology. Thus, the water sector is obliged to look for new and modern ways to deal with the resource [7].

Transmission and appropriation frameworks make up the two principal parts of the water conveyance framework. A transmission framework is comprised of parts that are planned to move gigantic volumes of water across significant distances, normally between the framework's essential offices. Water circulation frameworks are utilized to move the water conveyed by transmission pipelines to neighborhoods. Fluctuated pipe sizes and materials, as well as various water driven profiles, recognize transmission from dispersion frameworks. A careful comprehension of the disappointment component, the board cycle, and related costs should be framed to assess and discuss different line disappointment the executives and condition evaluation frameworks [8].

There are several ways to identify problems that occur in water pumping systems in terms of calcifications and fractures that may affect pipes. This research attempted to employ the Internet known as Long Range Low Power Network (LoRa) to track pipe failure.

Because of the fast progression of data innovation, a reindustrialization through the possibility of Industry 4.0 is growing internationally [9][10]. Modern hardware as of now requires complex correspondence and information handling utilizing brilliant and low power organizations, in addition to other things, in frameworks like transportation and assembling [11]. As a matter of fact, some low power wide regions organization (LPWAN) innovations really do meet basic prerequisites like long-range inclusion, low information rates, energy proficiency, and savvy end-gadgets.

The Industrial Internet of Things (IIoT), which is still in its beginning phases and is characterized as a powerful organization framework with self-designing capacities, interoperable correspondence conventions, and virtual "Things" personalities, should have the option to offer adaptability and versatility in future modern organizations for use in regions like transportation, medical care natural observing, and creation the board, among others [12].

In 2020, there will be 212 billion Web associated gadgets, and by 2022, machine-to-machine correspondence will represent 45% of all Web traffic, predicts [13]. These social affairs force states, organizations, and scholastics to go to conversations on subjects including financial development, business, and logical exploration, separately, to animate the execution of Web of Things (IoT) innovation [14]. As per gauges by Al-Fuqaha et al. (2015), the IoT market esteem by 2025 will be somewhere in the range of \$2.7 and \$6.2 trillion [15].

Despite very low recipient responsiveness and transmission recognition with negative Signal to Noise Ratio (SNRs), Long-Reach (LoRa) is a remote narrowband innovation that utilizations minimal expense and low power gadgets for low information rate transmission in ranges longer than customary cell networks [16]. It ordinarily researches a kind of impedance safe, multipath blurring, Doppler impact safe twitter spread range (CSS) balance plot [17]. Thusly, LoRaWan is an actual layer (PHY) convention that utilizes LoRa as its media access regulator (Macintosh) layer [18][19]. Building both public and confidential remote organizations is reachable with various LoRaWan entryways that connect to a solitary server through the Web [12].

1.1 PROBLEM STATEMENT

Urban water supply is a huge and multifaceted framework that has been developed and worked on over the past 100 years. Water supply resources, especially pipes, are prone to disintegration and pipe failure with age. Water utilities currently need to investigate viable proactive and receptive line disappointment regarding executive arrangements due to the rise in pipe failure.

In urban water supply systems (WSS), where pipe failures (halfway or complete) are part of the degradation cycle, the lack of a rapid framework that detects line resource disappointments and vulnerabilities is the primary issue in this study.

1.2 OBJECTIVES

Following up on failures in the urban water supply using existing tools and assets has been the primary and widely useful task. According to the water sector's point of view, the various issues that were found during the core stage were very worrying. Then, the follow

By coordinating the LoRa network in the management of urban water supply, it will be possible to make progress using the estimation, information examination, clarification, and reinforcement procedures that have been used so far, and in this way reduce failures, eliminate related misfortunes, and improve reliability, accessibility, security, and effectiveness primary goal was created:

1.3 TARGET GROUPES

This study targets the Directorate of Water and Sewage in Nineveh Governorate, where it generalizes the development of water pumping systems and seeks to develop them.

1.4 CONTRIBUTIONS

This study contributes to coverage of both preemptive and response failures of operational lines along with examination of the intubation and occlusion process. The techniques used in the area of receptive disappointment are surveyed and proactive case detection and evaluation, also it also employs the Internet of things and its sensors and long-range networks with low capacity to monitor the failure of water pumping systems and damage to pipes. Recreated results are utilized to introduce and approve a programmed strategy for network disappointment observing, discovery, and area.

1.5 THESIS OUTLINE

Chapter One: Introduction and Objectives.

Chapter Two: Literature Review

Chapter Three: Theoretical background.

Chapter Four: System Implementation and Results.

Chapter Five: Conclusion and Future Works

2. LITERATURE REVIEW

2.1 INTRODUCTION

Many studies dealt with the issue of predicting the failure of water pumping systems using several methods, some of them resorted to machine learning and some of them took other methods. The previous studies in this work were divided into two parts, the first part included the issue of failure of water pumping systems, while the second part included studies related to the topic of LoRa network.

2.2 LITERATURE REVIEW

2.2.1 Pipe Failure Prediction

In 2017, Wang & Chen Create a business procedure to organize practical problems as an AI framework. In order to demonstrate practical problem avoidance initiatives at different stages of the ML pipeline, water pipe failure prediction was used as a contextual query. The workflow has demonstrated that using ML to solve a practical problem, such as predicting water pipe hiccups, can be broken down into different steps: collecting area information, consulting with local experts, cleaning/pretreatment and displaying area specific information, removing Machine Learning (ML) features, planning ML models, and providing feedback. on the results. ML and direction are discussed, and the framework is criticized in light of navigation. To increase productivity, machine learning developers and space experts must work closely together [20].

In 2019, Shirzad & Safari gives association findings between failure prediction techniques using irregular backwoods (RF) and multivariate regression bands (MARS) in two water dispersal regulators. In these specific circumstances, the information factors are pipe width, pipe length, pipe construction depth, pipe age, and normal water pressure. The results reveal that RF performs better compared to MARS, which is a reliable indicator of line disappointment rate. By dividing the information into three pools with low, intermediate, and most prominent disappointment rate estimates, the proposed models are then further evaluated. Three factors—tube breadth, tube age, and normal water-driven pressure—are the most valuable factors in measuring the tube disappointment rate in the main contextual analysis, under the conditions produced by the MARS approach. In the subsequent

contextual analysis, the four factors pipe width, pipe length, pipe age, and water-driven normal pressure are seen as the most beneficial [21].

In 2019, Abdel Aleem et. al., Make a philosophy that might be applied to pick the best line material for a specific utilization of water networks while considering plan measures, local skill, natural variables, development, activity, support, and monetary evaluation. Development, activity, upkeep, ecological elements, and primary attributes are completely considered during specialized assessment. Contingent upon the venture seriousness factor, the effect of these attributes changes from one task to another. Monetary investigation considers the picked lines' all's supply and establishment costs [22].

In 2020, Almheiri et. al., recommended a framework for estimating water mains faults in obvious locations that would enable one-step failure predictions as well as accurate disappointment guidance nine months ahead of time. The recommended model also includes arrangements for additional factors to find central piping failures in the specified areas. A vector autoregressive model was performed using external factors, including the influence of climatic changes, to achieve this goal. For this review, Quebec and Ontario, Canada, provided spatial and transient information for central pipe disappointment events in addition to climatic data. A Monte Carlo approach was used to scan the consistency of the model. As such, Monte Carlo transcripts have been used to predict critical water line failures. The findings show that understanding environmental change can help estimate plumbing failures. The results show that the proposed model is able to accurately predict the transient failures of water pipes in two simultaneous water circulation frameworks [23].

In 2020, Dawood et. al., established their system regarding the use of presentation strategies obtained from 3D graphical imaging and a measurable relapse scan. The compelling factors that added to the destruction of informal societies are first noted. Secondly, the failure rate is scanned and proven with the RA method using iterative recreations and 3D surface evidence. Finally, a residual screening technique was used to validate the feasibility of the model using a variety of implementation measures. The agreement of the model with R2 and the sum of squares error (SSE) gave later effects of 0.9767 and 0.0008, individually. Civil designers can use the generated model as a scientific device to take a preventive step against pipeline explosions or punctures from now on [24].

In 2020, Alhumoud et. al., used the corresponding risk model to assess and prove failure and failure in Kuwait. There are some boundaries (communicating with disappointments and breaks) that can help with maintenance and repair decisions. The proportional hazard model has been shown to be suitable for depicting partial failure rates. The size of the example and the small portion of the controlled information affects the ability to take risks. While reaching conclusions, one should consider the possibility of changing the information. It has the interesting property of having the option to recognize other stressors, which are usually explicitly site-specific, and the effect of time-related maturity. Another advantage is that the information from the dataset can be used successfully because it is suitable for examining the information that has been stifled. Another benefit is product availability and convenience. Moreover, its ability to identify heterogeneous information and highlight key explanatory factors makes it suitable for disappointments seen in other frameworks, such as sewers and gas lines, as it can provide intelligent data about those frameworks [25].

In 2020, Barr et. al., considered establishing guidelines for enforcing safe dead-end distances close to high - take a chance with pipelines is important because of the chance of injury to personnel and damage to property in the event of failure. Despite the fact that there is no widely distributed data on drilling optimization during the arrival of core tension from line outages, it is possible to perform an examination with covered explosive rings, about which there is an abundance of data. The limits affecting pit distance are evaluated in this work using a finite component width of the underground line disappointments, where the tube measurement, pressure, air content, and depth of the tomb show to be massive. A power dump is changed from a completely tripped line to an identical block of gravity to make an unstable drilling tool that can be used with water pipes. The better device accurately predicts the bore size presented in novel disappointment situations and reliably recreates the bore size from the explanatory results ($r = 0.95$), demonstrating the true ability of the tool to be used in making arrangements with respect to safe inertia distances [26].

In 2020, Hekmati et. al., Characterizes common causes of water mains failure in a water supply organization and presents a proof-of-concept information-gathering approach that uses freely accessible (open) sources of information. This strategy may be computerized using man-made awareness (simulated intelligence) innovation. Using Adelaide, South Australia, as the subject of our contextual investigation, areas of pipe disappointment were

identified using open source datasets, eg SA Water pipe disappointments (Twitter channels), information from the Department of Met, Adelaide Metropolitan Soil Information Reports, and so on. These regions were then linked to environmental variables, for example, soil type, month-to-month precipitation design, and so on. The methodology generated through this exploration was validated by comparing results and the SA water revival engine. The findings showed how effectively SA Water's framework handles its direct resources, focusing on areas for the central canal replacement program that match intently with the sites of line disappointments. This contact government and public offices abroad by means of their open access information, which may enhance their center administrations, confirmed the strategy recognized by the ability of this exploration with recognition of high-risk disillusionment destinations [27].

In 2020, Gorenstein et. al., make a strong expectation model that can accurately gauge waterline shortcomings before they happen. We likewise give three information driven models and one rule-based expectation model, as well as a particular division procedure for extended transmission mains. We use three standard measures to evaluate a certifiable waterline network in Israel run by the Mekorot organization. The discoveries exhibit that the information driven calculations beat the standard based model in every measurement by no less than 5%. Also, as they are prepared with new information, their expectation turns out to be more precise, however adding geologically related factors to the information doesn't expand the exactness any further [28].

In 2020, Auma et. al., used the verifiable information to make two strategic relapse models, which were then surveyed for their insight power, responsible complex receiver operating characteristic (ROC) characteristics, and area under flexion (AUC). At WDN, pipe sizes from 150mm to 350mm were sufficient to prevent pipe disappointment. In any case, the chance of frustration was less for tubes measuring 250mm. In contrast to newer lines, more established tubes are less likely to disappoint. Steel pipe had a lower probability of disappointment than uPVC at a similar depth of dirt surface, regardless of plasticized polyvinyl chloride (uPVC) replacing steel in water pipe construction plans. Wider tubes encased in boulders were less likely to be frustrated than tubes of greater width laid in clay. The binomial calculated regression model performed better (accuracy – 96.9%, AUC – 0.996) than the multinomial strategic model (accuracy – 90.9%, AUC – 0.992), showing

accurate model predictions, with a median line age of 8 years in WDN and More weight of the ground layer on the pipe failure. For a more accurate identification of incoming water pipes that need repair or replacement, information collection methods can be modified using the form guide [29].

In 2020, Barton et. al., Use partial dependence diagrams to substantiate climate, soil, and hydrogeological factors in an additive material model summarized for each of the five most commonly known marine pipe materials. We show the relationship between high disappointment and outrageous temperatures. Primary drivers of failure in mineral lines throughout the colder time of the year include low temperatures, air icing, and their associations with the soil. Disappointments in an asbestos-concrete line are expanded in late spring due to warm temperatures, severe lack of soil moisture, and soil development. PVC pipe failures in the middle of the year are mostly caused by warm temperatures, land development and soil waste of time and attention to water. Ice is an essential component of winter affecting polyethylene pipelines. Understanding the actual parameters and disappointments in the baselines can help model designers make more accurate recreations, which can therefore help with systems management [30].

In 2022, Dimas et. al., Present a novel way to deal with coupling ML expectation models for pipe barges in WDNs with substitution systems, assessing their viability with Monte Carlo water driven reproductions to manage vulnerability. Since a pressure driven reenactment is unthinkable without information on request, supply, and control, we use information from a genuine framework to prepare the ML models and assess substitution choices in a manufactured WDN. It's conceivable that the substitution planning for this present reality situation will vary from this example case. Nonetheless, it fills in as a fundamental reasonable model of an uplifting system that assists water utilities with being proactive and strong as to their resource the board methods and grows their tool stash for long haul key preparation and hazard mindfulness [31].

In 2022, Nugroho et. al., seeks to predict pipe breakdown. The most suitable parameters for forecasting pipe failure in the optimization are investigated by this research methodology. As a comparison method, maximum likelihood (ML) is used for frequentist inference while the non-homogeneous Poisson process (NHPP) and Markov chain Monte Carlo (MCMC) approaches are offered for Bayesian inference. The two estimates are, it may be inferred,

fairly accurate at forecasting failures, although the MCMC guess is more in line with the overall amount of observed data. According to a life-cycle cost (LCC) analysis, the MCMC estimation produces flatter LCC curves and lower LCC values than the ML estimation, which has an impact on the choice of the best pipe replacement strategy in water distribution networks [32].

In 2022, Tafsirojjaman et. al., Focus on evaluating the baseline exposure of PIP frameworks under various load activities, such as impact, axis stresses, warm distortion, horizontal distortion, cross-area whitening, vibration/fatigue due to traffic loads, and internal stress. Screening findings showed that thickness and the versatility modulus significantly affect the disappointment tooling of PIP frameworks. According to the Performed Order Pecking (AHP) piercing interaction, when the plan pressure is 200 psi, the internal tension is the main disappointment mode, lags the lateral deformation in view of the universal need and the two standards (thickness and elastic modulus), with the whitening process longer Across the region is most important. The findings of this study provide useful presentation approaches and master plan tools for PIP frameworks for advancing new physical frameworks as well as assessing the plausibility of currently accessible PIP frameworks for pipeline reform [33].

2.2.2 LORA Network

In 2020, Yusri & Nashiruddin proposed, a coordinated IoT design in light of LoRa for Cutting edge Metering Foundation for power, water, and gas can apply in metropolitan, rural, and country regions. they relies upon scope quantification and inclusion wanting to decide the quantity of passages required, the quantity of clients, the LoRa limit framework, and the geological region. The asserted that the passage necessities from every locale were fourteen doors for Medan (Metropolitan Situation), five entryways for Pematang Siantar (Sub Metropolitan Situation), and two passages for Padang Sidempuan (Country Situation). Fourth, from the reproductions completed, it can likewise infer that for the Medan City that is determined can be served at an OK level with a worth > -132 dBm, Pematang Siantar with a sufficient level > -129 dBm, while for the Padang Sidempuan City it is > -129 dBm. The best sign levels on normal are $-76,28$ dBm, $-75,7$ dBm, and $-81,67$ dBm for the Medan, Pematang Siantar, and Padang Sidempuan. The quantity of entryways that determined in this paper needs to change with the genuine climate to track down an exact absolute passage to

ideally serve clients. For additional examination, it is important to utilize BTS existing to plan LoRa entryways laying to diminish speculation costs [34].

In 2022, Kuntke et. al., presents the reach and information speed of reasonable low power LoRa radios. It likewise (after a few bombed endeavors) attempted to comprehend and disentangle signals from an authority handset utilizing a reasonable SDR dongle and GNU Radio. The actual layer assault surface is truly developing - it is vital to comprehend and get it. This examination paper starts by performing a range trial of a shopper module physical (PHY) layer. Contingent upon the settings, up to 5 Km was accomplished to communicate an edge - to the detriment of speed. 1 Km was accomplished at a more sensible rate. En route, how reasonable RTL-SDR (programming characterized radio) was utilized to record crude transmissions from the authority PHY module. These transmissions were then endeavored (and effectively) demodulated and decoded utilizing GNU Radio and the exploratory gr-Lora out-of-tree module from Bastille Exploration. A few normal radio weaknesses are likewise examined in relationship with LORA [35].

2.3 CONCLUSION

City water transmission frameworks are important public utilities, and their failure can lead to serious physical, environmental, and social damage, including road flooding and shortages of treated drinking water. A modest technique for determining initial dissolution of water dispersion frameworks is to distinguish between examples of central channel disappointment in the long term and in more favorable conditions. It is an alternative way of dealing with direct valuation as well, and it requires huge assets. Time-related factors such as changes in temperature and precipitation can influence land development and ice depth, causing strains to exceed formation values and increasing the risk of disappointments in the central channel. The researchers used several methods to predict the failure of water pumping systems from physical methods, including through machine learning.

3. THEORETICAL BACKGROUND

3.1 WATER SUPPLY SYSTEM

Despite the fact that drinking water transportation systems can vary widely in size and complexity, they all have a similar central structure: the transportation of water to the customer from the source (or treatment plant) [36]. The goals of urban water systems include providing potable water for domestic use, sufficient water at a stress strong enough to extinguish fires, and water for modern use. Urban supplies could be obtained from wells, streams, lakes, and warehouses. Across the planet, surface water sources provide about 66% of the water used for general use [37]. On a regular basis the nature of the ground water is high enough to keep away from non-chlorinated and fluoride-treated drugs. Figure (3.1) gives a schematic depiction of the evolution of water carriers. The transmission system and the transmission frame are the two basic parts that make up the whole frame.

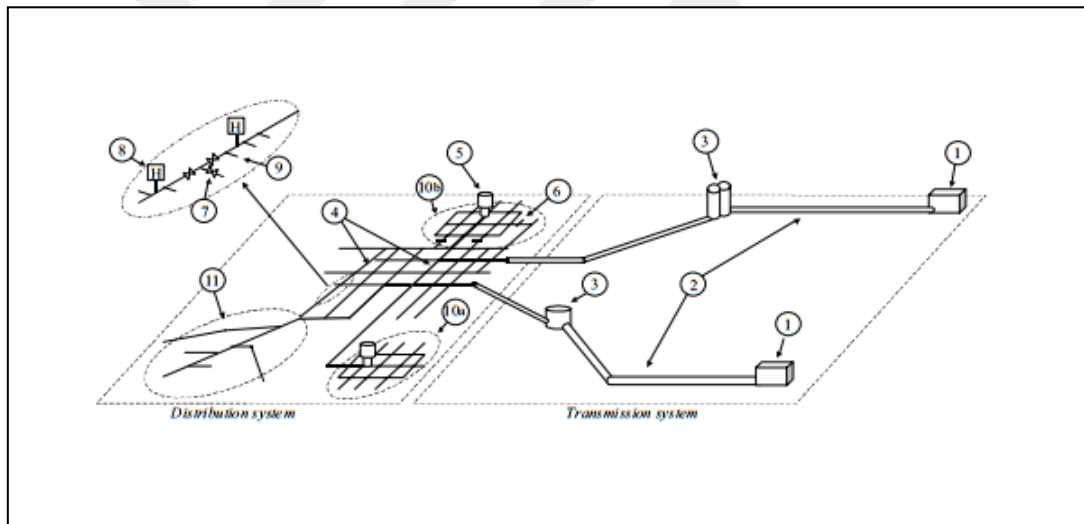


Figure 3.1:Water Supply System [37].

A transmission framework is comprised of parts that are planned to ship tremendous volumes of water across significant distances, ordinarily between the framework's essential offices. The arrangement of a treatment office and capacity supplies as portrayed in Figure (3.1) is an ordinary illustration of a transmission framework. Water transmission pipelines can be built over the ground or underground and regularly have widths more noteworthy than 300 mm. Pipelines can run long enormously. In certain spots, conveying water over distances of a few hundred kilometers is vital [38].

Inline stop valves, fire plug air valves (FPAV), scour valves, and sewer vents are normal pieces of transmission pipes. Water can be moved between offices with the assistance of siphons (treatment plant to supply or repository to repository). Siphoning is finished during off-top power use hours to save working costs [39]. Off-top hours are when energy costs are most minimal. During siphoning, the transmission pipeline's stream rate is very high, and the water there is regularly still the remainder of the time. Normally, transmission mains don't support explicit clients straightforwardly. Conveyance mains may sometimes be connected at specific areas along the transmission pipeline's length. The water allocation framework disperses the water transported by transmission pipelines to neighborhoods [40]. The transport frame regularly contains complex geometry and many parts. The deployment framework contains administrative associations and deployment networks, which are two unique types of fonts. Transmission lines are larger in width than transmission pipes, which act as an intermediate stage in transporting water to select buyers. The turning tubes adjust frequently and follow the general example of city roads. Circuits can be made by connecting pipes at crossing points [41].

3.1.1 Pipe Assets

A water supply resource is comprised of the relative multitude of lines, valves, siphons, repositories, and different pieces of a water conveyance framework. One of the principal resources is pipes. Transmission mains, dissemination mains, and administrations are the three essential line types in the water supply framework, as was referenced in the part above [42].

Water supply pipes have generally been made utilizing a scope of materials and procedures. The width and establishment year influence the line's particular material. Restressed substantial chamber pipes (PCCP) or gentle steel concrete lined (MSCL) pipes are much of the time utilized for enormous transmission pipelines (with distances across more than 300 mm). Project iron or asbestos concrete are usually used to build more established water dispersion mains, while pliable iron and polyvinyl chloride (PVC) are fundamentally used to develop fresher mains. Various countries and even urban communities have various appropriations of line materials in their ongoing frameworks.

3.1.2 Pipe Deterioration Process

As shown in Figure (3.2), failure in piping can be considered as a multi-step process. One can predict it through the following steps [43]:

- a. Installation: The new flawless line is introduced.
- b. Erosion process starting: After the line has been in need for some time, consumption processes start on the line's inward or outside (or both) surfaces.
- c. Crack before leak: The normal results of the consumption cycle are breaks, erosion pits, and graphitization. Mechanical pressure can some of the time make breaks structure.
- d. Partial failure: Over the long haul, consumption pits and breaks diminish the line wall's leftover strength underneath interior or outer powers, prompting pipe wall disappointment. Thusly, contingent upon how much the break, the hole or burst will start. Some of the time the size of the disappointment is excessively little to be promptly seen.
- e. Complete Failure: The line may totally bomb because of a break, consumption pit, currently present hole or burst, or outside obstruction. Water regularly shows up on the ground after such a breakdown, or the pressure driven harmony of the framework changes essentially.

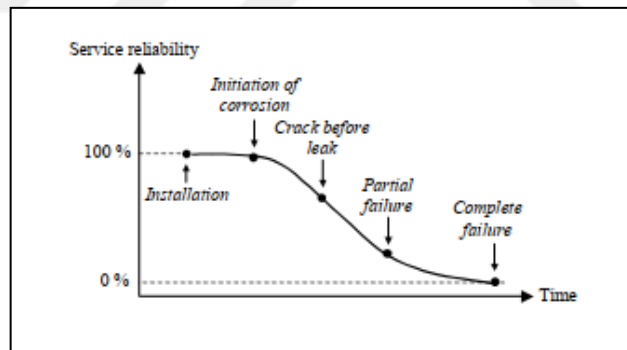


Figure 3.2: Pipe Failure Development [44].

3.1.3 Pipe Failure

If the line strength is not enough (due to wrong material selection, weakness, pressure erosion, etc.) Pipe failure. Pipe failures can often be separated into types and sizes [45].

- a. Corrosion: When gray cast iron is damaged by corrosion, graphitization, which is the result of iron being leached away by corrosion, is frequently seen. Any type of metal loss indicates a corrosion pit, which will enlarge over time and finally result in a pipe break. The pipe's physical surroundings have a big impact on how quickly it deteriorates.

Deterioration of pipe structure may also be impacted by severe interior corrosion. Chemical deterioration may also affect plastic pipe materials. Chemical reactions that either dissolve the asbestos cement or penetrate the concrete to produce compounds that degrade the cement matrix can cause asbestos cement and concrete pipes to deteriorate [46].

- b. Excessive forces: Cross over and longitudinal mechanical burdens are the two primary sorts that could cause pipe disappointment. The accompanying elements can add to longitudinal pressure [45]:
 - i. Warm shrinkage from low water temperatures in the cylinder and nearby cylinders.
 - ii. Flexural stress from differential soil development or huge voids in the sheet material near the cylinder (because of releases).
 - iii. Ill-advised digging methods and bedding.
 - iv. Outside obstruction. Cross over pressure might result from any of the accompanying:
 - a. annulus stress from interior cylinder pressure.
 - b. annulus stress from soil stacking.
 - c. annulus stress from other outer stacking, like traffic.
 - d. annulus loads from freezing dampness extension in the encompassing soil.
- c. Production flaws: One of the most common creation imperfections in cast iron lines is porosity. Considerations cause an irregularity in the line's organization and can make breaks happen. A part of the line wall may never again have an adequate wall thickness to endure expected greatest tensions because of a variety in the line wall thickness. The presence of iron phosphide structures all through the line metal is one more creation shortcoming. To bring down creation costs, phosphorus is added. Iron phosphide compound, then again, is fragile and debilitates the line [47].
- d. Human error: Various technologies used during and after development, starting with an unfortunate plan, can make a dividing line. Unfortunate development, consolidation and transfer technologies can stimulate consumption and lead to pipe failure. An unexpectedly removed cover opens the line to overconsumption. External damage is another expected excuse that fails. The most common case occurs during discovery [48].

3.1.4 Failure Management Cycle

Disappointment the board is a component of the normal support of pipelines and line networks since pipe disappointment has transformed into a genuinely continuous event in metropolitan water conveyance frameworks. In any case, the water area presently utilizes a generally modest number of line disappointment control techniques. The writing, then again, has introduced many methodologies, exhibiting the undeniable interest in such devices. Two classifications of line disappointment the board systems can be recognized in light of the planning of disappointment the executives activities as for the actual disappointment: proactive disappointment the executives, where line fix or substitution choices are made ahead of the disappointment occasion to stay away from the disappointment, and receptive disappointment the executives, where the maintenance or substitution is just done after the disappointment has happened [45].

3.1.5 Pipe Rehabilitation Planning

Pipe restoration arranging is getting increasingly more consideration from the water business and established researchers as water conveyance frameworks progress in years. The significant objective of restoration arranging is to augment the activity's financial proficiency while guaranteeing the framework proceeds as required [49]. Three primary execution measurements should be considered:

- a. Hydraulic performance.
- b. Water quality.
- c. Reliability of the service.

3.2 INTERNET OF THINGS (IOT)

The term "IoTs" describes the utilization of smart gadgets that are online. The connectivity, sensing, scalability, intelligence, and integration are the main components of cloud-based IoTs application architecture [50]. IoT devices can be linked together using a variety of network connections, including radio waves, Bluetooth, and Wi-Fi [51]. According to the needs of the business and the application, IoT devices must be designed and executed to be minimized or scaled [52]. The study indicated that 38.6 billion devices and appliances will be connected to the Internet by 2025. The total economic impact is expected to range

between \$3.9 trillion and \$11.1 trillion. IoT solutions are profitable in the fields of construction, energy, transportation and health [53].

Notwithstanding, due to its fast extension and remote, distributed computing has needed to conquer various difficulties. With regards to supporting QoS measures like low inertness, distributed computing can't deal with the rising number of IoT gadgets and the created information they produce. Customary distributed computing models experience slow reaction times, deficient security and protection, and weighty data transmission use as additional savvy gadgets interface with the Web [54]. Since customary distributed computing can never again fulfill the different information handling necessities of the present smart society, high level edge processing arrangements have advanced.

Although there is no consensus on a precise and defined architecture for the IoTs, a well-known architecture with Four layers the Perception Layer, the Network Layer, and the Application Layer is widely recognized [55].

3.2.1 Details for Each Layer

- a. Perception Layer: This layer focuses on detecting physical phenomena like speed, location, and temperature using a variety of sensing devices and then turning this data into digital signals that are simple to store and communicate via digital communication networks. Endpoints, actuators, and sensors make up this layer [56].
- b. Network Layer: This layer's primary responsibility is to transmit data collected from the perception layer to a server, processing facility, or database. This layer is mostly implemented using ZigBee, Bluetooth, Wi-Fi, and cellular technologies 2G/3G/LTE. Although there are many different radio access methods today, IPv6 at the transport layer allows for the interconnection of all of these as well as addressing the many predicted objects that will connect in the future, according to [57].
- c. Middle-ware Layer: This layer includes information processing systems that carry out automated activities based on the outcomes of the processed data, connecting the database and the system through the ability to store acquired data. [58].
- d. The application layer is where the data provided by the middle layer is processed, stored, and evaluated. These enable the end-user applications to connect with the IoT devices, including building automation, safety, identity, and location-based services [58]. Applications addressing various technological difficulties, such as managing end device

values, processing, and monitoring, are offered in this layer. These apps encourage the development of the IoTs.

3.3 ARCHITECTURE OF AIOT SYSTEM

The IoT standards already in place will be improved by IoT to create autonomous future communication architectures that will facilitate the intelligent data flow between millions of devices. The structure The IoT system has four layers: IoT hardware, cloud computing, communication layers, and data analytics [59][60]. Figure (2.3) shows the IoT device structure.

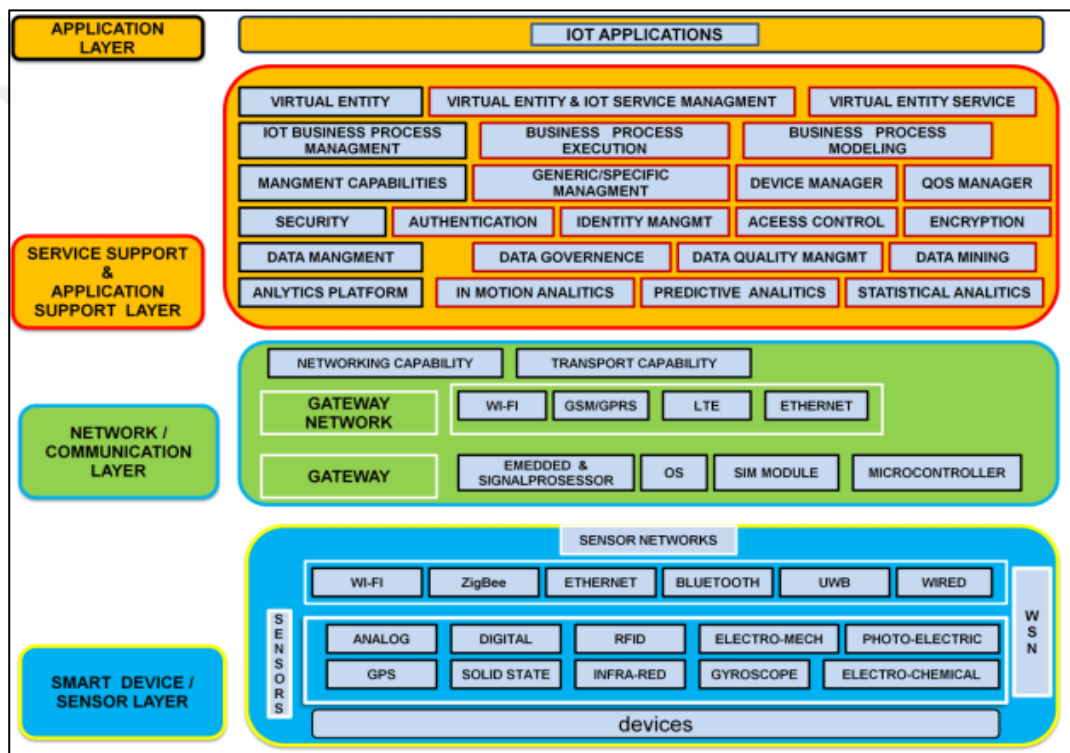


Figure 3.3: IOT System Architecture [62].

Equipment for (IoT) associations is required in light of the fact that energy resources have their own information sources. It is likewise conceivable to add cheap IoT sensors to accumulate resource status information, for example, power, stream rate, pressure, and so on. Transducers, for example, sensors and actuators are a piece of IoT gadgets. The conventional power gear, for example, savvy lights, associated valves and siphons, brilliant meters, connected power plants, shrewd structure parts, and so on, become associated with the minimal expense and low power IoT equipment. Fundamentally, IoT gadgets are gathering information, which fills in as the stage for IoT engineering.

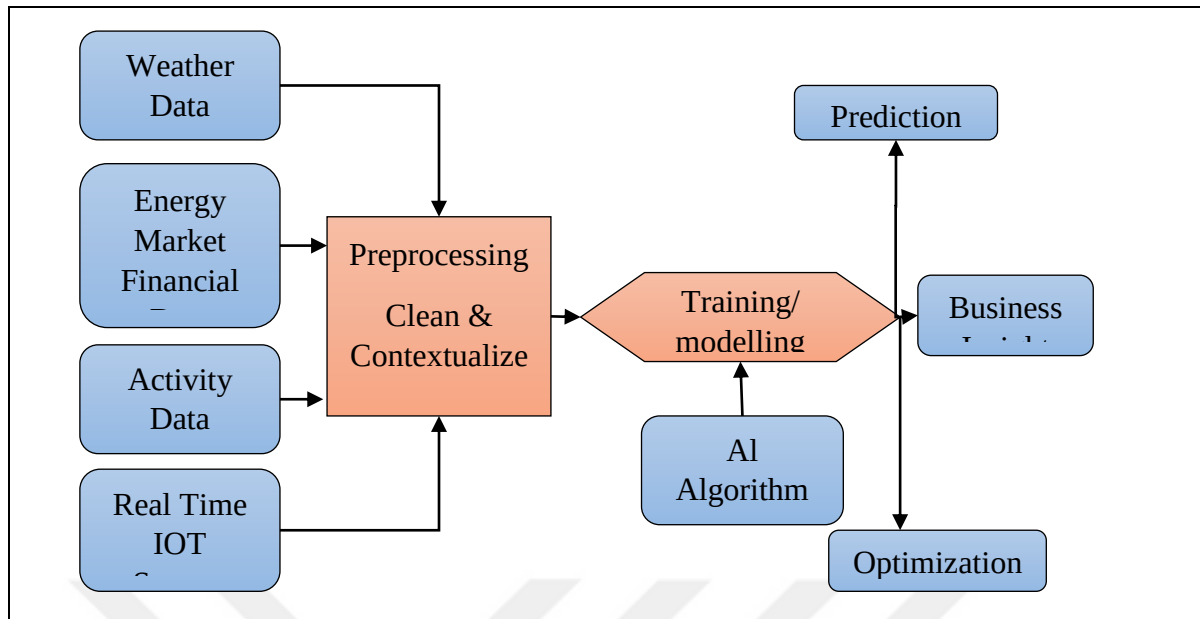


Figure 3.4: AI Data Process Flow for IoT Applications [65].

The role of the connectivity layer is to collect and transmit data over a network. Sensors and devices are the essential elements that complete the

- a. connectivity layer: Information is gathered by sensors, which then transmit it to the next layer for processing. Technology advancements have led to the usage of semiconductor technology, which enables the manufacturing of small, versatile sensors [63]. Additionally, the network layer offers the framework for large information handling and stockpiling. Appropriated Dataset administration is one of the most pivotal components of the IoT cloud. The cloud basically coordinates various gadgets, doors, conventions, gadgets, and an effectively analyzable Dataset. To convey powerful information investigation that can help work on the administrations and products, these frameworks are essential to the IoT engineering [64].
- b. Data Analytics Layer: The ongoing examination that IoT innovation gives to find inconsistencies and make upgrades is its most essential component. This layer utilizes different information science and investigation techniques, like ML calculations, to figure out the information, can utilize the information to track down patterns and gain significant bits of knowledge, can evaluate the exhibition of gadgets, can assist with recognizing failures, and can deliver more powerful models for control applications. The mind of the whole AIoT framework, as portrayed in Figure (2.4), is information

examination, which can assist with expanding energy activities, productivity, or even foresee future occasions like hardware disappointment [66].

3.4 LONG RANGE LOW POWER NETWORK (LORA)

LoRa introduces itself as a solid competitor for transmission over a significant distance while being energy proficient because of its protection from commotion impedance, multipath blurring, and Doppler impact presented by the regulation configuration [67]. Along these lines, minimal expense gadgets are utilized with this narrowband remote innovation [16] to send information at lower rates over longer distances than average cell organizations. The LoRa adjustment method is utilized in the actual layer of the twitter proliferation range, which is much of the time worked in unlicensed channels [16]. The LoRa actual layer model's basics are made sense of in this segment. Numerical portrayals are given of the CSS regulation organization's exhibition in added substance GSN white channels as well as metropolitan and rural channel models.

3.4.1 The CSS Modulation Format

CSS, also called frequency shift chirp, makes chirps at variable frequencies directly increase or decrease within a predetermined time frame, essentially moving from a basic frequency (f_{min}) to a larger frequency (f_{max}), or vice versa [68]. CSS uses the recurrence offset of each trail, which is the beginning of the tweet's recurrence, to modify an image (different parts somewhere in the range of 7 and 12) in Twitter. By further estimating the image through the image rate (R_s), which is obtained as $R_s = BW/2^{SF}$, where BW is the data transmission signal and SF is the spread factor, shift recording is possible. The fin frequency rises to the upper (f_{min}), where it then shifts continuously to the lower (f_{min}). Again, the iteration goes up until the image finishes one cycle, so, in general, it goes back to (f_{off}). The period $s Ts = 2SF \times T$, for $SF \in 7, 8, \dots 12$ $f = 1 / \text{sample time}$, is another term for the amount of time it takes to finish a cycle. This term is similarly referred to as chip[12].

With a peep made out of 2^{SF} examples, a discrete-time LoRa image can be communicated as:

$$s_k(nT) = \sqrt{E_s} \times z_k(nT) = \sqrt{\frac{E_s}{2^{SF}}} \exp \left(j2\pi(k+n) \bmod 2^{SF} \cdot \frac{n}{2^{SF}} \right) \quad (3.1)$$

for $k \in 0, 1, 2, \dots, 2^{SF} - 1$, E_s the trill energy, $sk(nT)$ the orthonormal premise elements of the flagging space and mod the modulo administrator [69].

Expecting amazing time and recurrence synchronizations and considering the semi symmetry of the tweet flags, the accompanying connection procedure can be utilized to perform LoRa demodulation.

$$\sum_{m=0}^{2^{SF}-1} r_k(nT) \cdot s_i^*(nT) = \begin{cases} \sqrt{E_s} + \eta_i & i = k \\ \eta_i & i \neq k \end{cases} \quad (3.2)$$

where $rk(nT) = s(nT) + \eta(nT)$ is the gotten waveform corrupted by the zero mean white Gaussian commotion $\eta(nT)$ of an AWGN channel and $s^* i(nT)$ the mind boggling form of $sk(nT)$. As per [69], [70] and [71], the got image with most noteworthy connection (got in the recurrence space with a quick Fourier change) with the compared sent waveform can be recognized as:

$$Y_k = \arg_i \max(|\delta_{k,i} \sqrt{E_s} + \eta_i|) \quad (3.3)$$

in which $\delta_{k,i} = 1$ for $i = k$ and 0 otherwise.

3.4.2 Common LORA Signal Bandwidths

The only available signal bandwidths in the older LoRa integrated circuits are 125, 250, and 500 KHz [72]. In the new versions of LoRa, it is possible to adopt one of 11 different signal bandwidths, with the lowest value being 7.8 kHz and the highest 500 kHz.

By the by, on account of LoRaWan, the conceivable selectable sign transmission capacities are restricted to the accompanying three, 125, 250, and 500 kHz.

3.4.3 LoRa Spreading Factor

An essential component in LoRa frameworks is the spreading factor (SF), which can be set to a number somewhere in the range of 7 and 12. It is accountable for what amount of time it requires for one LoRa image or trill to be finished in the CSS design. The recipe for this image period is $T_s = 2^{SF}/BW$ [71]. The LoRa framework's piece rate and the responsiveness of the LoRa collector are essentially affected by the image period. This presents a compromise that ought to be thought about while planning a LoRa framework.

Table (3.1) shows a correlation between bit rate (R_b), image period (T_s) and beneficiary responsiveness 1. The piece rate can be communicated as $R_b = SF \cdot \left(\frac{Bw}{2^{SF}}\right) \cdot \left(\frac{4}{4+CR}\right)$, for CR the code rate.

Table 3.1: Spreading Factor Trade-Off [71].

SF	Rb in Kb/s	Ts in ms	Sensitivity in dBm
7	6.836	1.0	-123
8	3.906	2.0	-126
9	2.197	4.1	-129
10	1.221	8.2	-132
11	0.672	16.4	-134.5
12	0.366	32.8	-137

Table (3.1) shows that the collector responsiveness increments by 3 dB for each step of SF, with a complete improvement of 14 dB for SF = 12 over SF = 7. Be that as it may, each SF increment copies the image time frame, which decreases the framework bit rate considerably. At the point when SF = 7, the framework communicates one tweet in 1 ms at a piece pace of 6.836 kb/s, and when SF = 12, it does as such in 32.8 ms at a pace of 0.366 kb/s. It is vital to recall that SF decides the number of pieces a peep that addresses. For instance, a trill in a LoRa transmission with SF = 7 comprises of 7 pieces, however a twitter in a sign with SF = 12 comprises of 12 pieces.

3.4.4 LoRa Forward Error Correction

Through packet loss, the degree of noise in LoRa can reduce the reliability of the correspondence. Transform coding becomes essential in this present circumstance to check the effect of channel perturbation. Existing messaging frameworks often use FEC methods to add overt censorship redundancy to the information flow to recognize any transmission blaming that could be occurring and, to some extent, fix it. Block codes and convolutional codes are two classes of this, more commonly known as Error Correction Codes (ECC). In the event that the result of two cipher words is similarly a cipher word, then the block code is straight ($\bar{c}l$). Moreover, ECC is defined as a double code revision error assuming that the transmitted block of images consists of characters of the order $M = \{0 \text{ and } 1\}$ [12].

As a paired ECC, the Hamming codes have a place with the group of single mistakes remedying codes, with a block length $L = 2^m - 1$, for $m \geq 3$ (least distance). Hence, the

information source is coordinated in blocks of $k = 2^m - m - 1$ pieces as $\bar{b} = (b_0, b_1, \dots, b_{k-1})$ (message words), before codification in code words $\bar{c} = (c_0, c_1, \dots, c_{L-1})$ of length L . Subsequently, at a rate $(2^{m-m-1}/2^{m-1})$, the encoder adds $CR = m$ repetitive pieces in each block. The code words are gotten with the paired information succession and an age framework G that is connected with an equality really look at network H of a specific code. Further insights concerning the connection among G and H in deliberate structures, as likewise about the disorder table used to translate the pieces can be found in [73], a Hamming code at a rate $4/7$ ($CR = 3$) can be utilized in LoRa, which can recognize two blunders or to address a solitary mistake.

3.4.5 System Performance in AWGN Channels

To affirm the precision of mathematical models, it is critical to embrace a logical articulation for the BER execution of the mimicked LoRa framework in AWGN channels. The approximations introduced in [19] are two significant BER exhibitions of LoRa balance tracked down in the writing. Notwithstanding, the two articulations [74] don't consider the effect of the code rate boundary in the previously mentioned execution. Subsequently, one of the fundamental commitments of this work result from a change proposed in the accompanying BER articulation.

$$BER = Q\left(\frac{\log_{12}(SF)}{\sqrt{2}} \cdot \frac{E_b}{N_0}\right) \quad (3.4)$$

where E_b/N_0 is the energy per spot to clamor power ghashly thickness [Reynders, Meert ePollin 2016] determined as following.

$$\frac{E_b}{N_0} [dB] = SNR[dB] + 10 \log_{10}\left(\frac{Bw}{R_b}\right) [dB] \quad (3.5)$$

The got signal strength pointer is a significant estimation boundary that mirrors the nature of LoRaWan joins [74]. For NF the beneficiary commotion figure and PT_X the sent power, it is feasible to appraise the SNR from estimated upsides of $RSSI$ as following:

$$SNR[dB] = RSSI - R_{TX} + 174 - 10 \log_{10}(Bw) - NF \quad (3.6)$$

3.4.6 Urban, Suburban and Open Area Channel Models

The remote channel climate to a great extent decides how well LoRa proceeds as a remote correspondence framework. Way misfortune (PL) and shadowing by huge items are critical drivers of sign crumbling for the huge scope blurring channel [75]. The Aloha channel is a random access protocol primarily used in traditional wireless networks, while LoRa employs a different modulation scheme and access method [75]. Aloha channel, which allows devices to transmit data at any time, LoRa employs a more controlled and coordinated approach to minimize interference and optimize transmission efficiency. It uses different channels and spreading factors to enable multiple devices to communicate simultaneously within a LoRaWAN network.

The Aloha protocol, also known as the Aloha channel, is an early random access protocol used in computer networking. It was developed at the University of Hawaii in the 1970s for radio communication and later extended for use in wired networks as well. The original Aloha protocol had the following specifications:

- a. Simplex Communication: The Aloha protocol allows devices to transmit data in one direction only, from the sender to the receiver.
- b. Random Access: Devices can transmit data at any time without prior coordination or synchronization with other devices on the network. This leads to the possibility of collisions if two or more devices transmit simultaneously.
- c. Collision Detection: After transmitting a frame, a device listens for an acknowledgment (ACK) from the receiver. If no ACK is received, it assumes a collision has occurred and retransmits the frame after a random waiting period.
- d. Slot Time: The network is divided into discrete time slots, and each device waits for a free slot before transmitting its data. The slot time is typically set to be larger than the maximum round-trip time between devices in the network.
- e. Continuous Operation: The Aloha protocol operates continuously, allowing devices to transmit data whenever they have it to send. There is no centralized control or scheduling mechanism.
- f. Efficiency: The Aloha protocol achieves a maximum efficiency of approximately 18.4% due to the possibility of collisions and subsequent retransmissions.

These specifications formed the basis for later versions of the Aloha protocol, including slotted Aloha, which improved efficiency by dividing time into slots and reducing the chances of collisions.

It's important to note that while the Aloha protocol has influenced the development of various access control methods and protocols, it is less commonly used in modern wireless networks, which employ more sophisticated protocols such as Carrier Sense Multiple Access (CSMA) and its variants.

3.4.7 Determination of the Noise Floor

At the point when set up with a transmission capacity of 125 kHz and a SF of 12, a LoRa collector can get a sign beneath the commotion floor down to 20 dBm [75]. In any case, it relies upon components like climate, environment, front end circuit, and then some. The commotion floor NoF should be perceived to work out the recipient responsiveness precisely. It tends to be determined as:

$$N_0F = 10 \log_{10}(k \times T \times Bw) + NF[dBm] \quad (3.7)$$

where k is the Boltzmann constant, T the temperature in Kelvin, NF is the noise figure of the front end circuit [75].

3.5 LORAWAN BASIC CONCEPTS

A LoRaWan network ordinarily comprises of four parts, as found in Figure (3.5). The end-gadgets or end-hubs, which are in many cases conveyed in the field and furnished with sensors or actuators, are found in the primary segment [76].

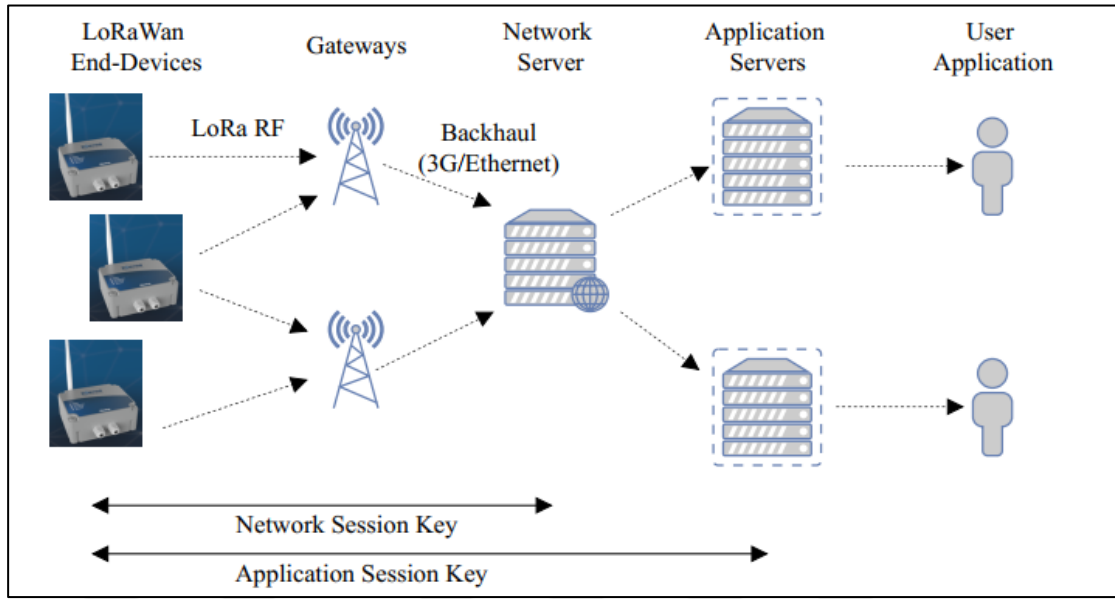


Figure 3.5: LORA Wan End-To-End Network Architecture [76].

As displayed in Figure (3.6), the subsequent part is comprised of passages or concentrators that take part in bidirectional correspondence with the end gadgets utilizing a star network geography and LoRa remote associations. On the off chance that there are a few entryways nearby, they all get the sent signals and forward the data to the LoRaWan server. LoRaWan's rationale is all constrained by the organization server. Also, it deals with all excess messages sent by various doors, does security investigation, completes versatile rate control, and plans the ideal entryway for downlink association with an end gadget [77].

The application server, where clients survey the information sent toward the end gadgets, finishes the LoRaWan framework. Regularly, passages speak with the organization server over a backhaul that normally utilizes client datagram or transmission control conventions [77].

Since end gadgets can enter profound rest in a star engineering for LoRaWan organizations, the LoRa Union picked this plan, which fundamentally diminishes how much energy consumed. Nonetheless, a cross section design can be utilized, as shown in Figure (3.6). By differentiating the structures of Figures (3.6-a) and (3.6-b), it is feasible to affirm that the star design gets rid of between gadget correspondence, saving batteries all the while.

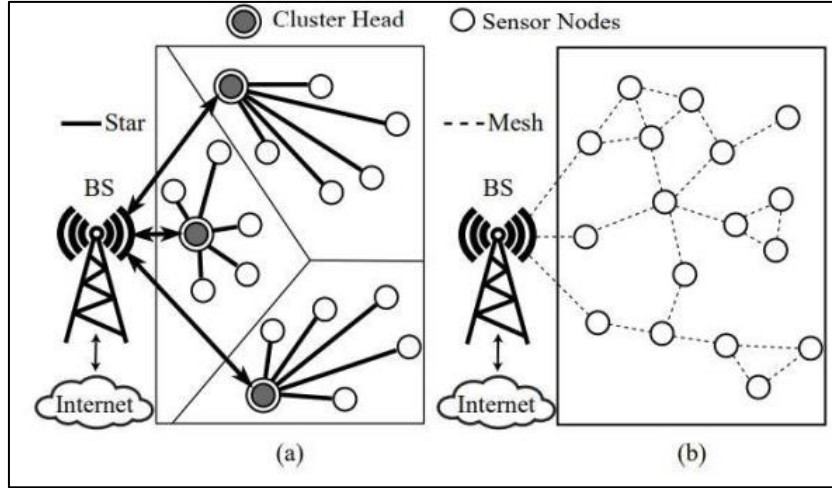


Figure 3.6: (a) Star and (b) Mesh Architectures [77].

Notwithstanding the way that LoRa signs can be distinguished in conditions with low SNR on account of the strength of the regulation against impedance, view blocks keep on influencing the exact location of LoRa information [12]. A mixture star and cross section LoRaWan was proposed in [12] to resolve issues with the absence of LOS and where introducing additional passages, for example, in country areas is testing.

3.5.1 LoRaWan Classes and Energy Efficiency

Contingent upon the LoRaWan application, a compromise among unwavering quality and energy saving should be considered. Low power utilization ought to be viewed as in the applications running on batteries, which stands out from the cases wherein more dependable uplink and downlink transmissions are requested. Along these lines, LoRaWan gives three unique kinds of classes, that primarily separate as indicated by the way the end-gadgets get the information bundles [78]. Figure (3.7) shows that in class A, the organization consumes the rented measure of energy, while still ready to convey in a bi-directional manner, in light of a Salud correspondence convention.

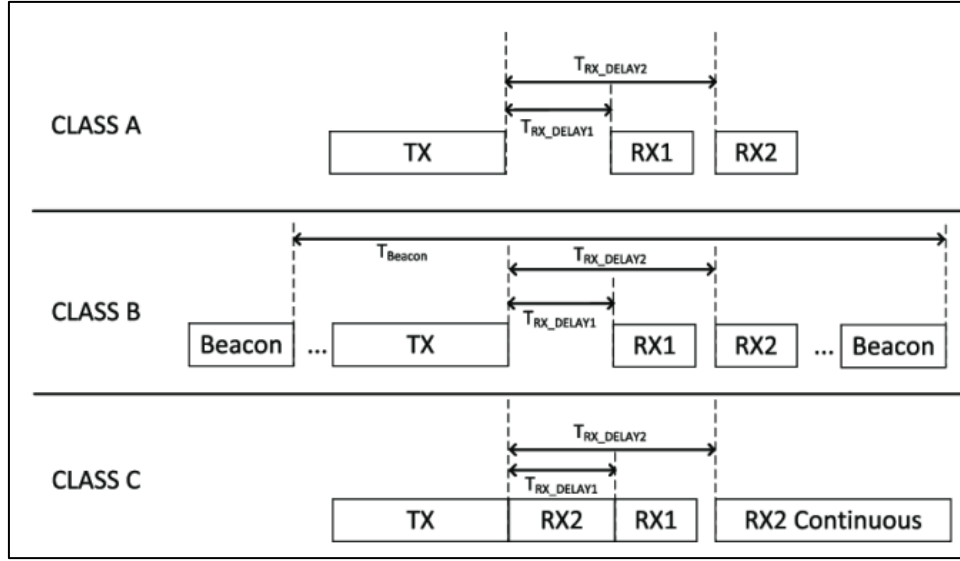


Figure 3.7: LORA Wan Classes [78].

The Salud framework permits end gadgets to awaken whenever and convey uplink messages without considering the probability of transmission impacts. Two gathering windows RX1 and RX2 are quickly opened by the LoRaWan radio after an uplink transmission at Tx postpone 1. These are the two possibilities the entryway needs to communicate a downlink sign to the end gadget. The end gadget will continue its rest state assuming the entryway neglected to get both of these messages. Solely after the ensuing uplink transmission can the passage send a downlink transmission [78].

Class B is really like class A, as it likewise has the bi-directional correspondence between end-gadget and door. In any case, while in class A the gathering windows rely just upon the uplink, in class B more windows are opened at planned stretches. For the doorway to send a downlink transmission, it necessities to synchronize with the end-gadget, which happens before in a period synchronized guide sent by the entryway. In class C, the end-gadgets keeps a nonstop tuning in of downlink transmissions. The main second, they are not listening is the point at which they are sending uplink messages. This outcomes in low-idleness among door and end-gadget. Notwithstanding, in light of the fact that the recipient is continually tuning in (dynamic) it involves considerably more energy than the end-gadgets in class A or B. To this end the utilization of this class is more proper in Alternative current (AC) provided applications [78].

3.5.2 Scalability and Security

Regardless of the heartiness against obstruction and the capacity to get signals at SNR values as low as -20 dB, LoRaWan is impacted by crashes from signs of other LoRaWan's [71]. As a result of this restriction, LoRaWan carries out different strategies and guidelines that permit versatility. LoRaWan entryways can get signals with $SF = 7$ to 12, without aforesaid knowing what SF the end-gadget is utilizing. Besides, the entryways can tune in up to 8 channels simultaneously. The best beneficiary responsiveness is gotten by utilizing $SF = 12$, however the time live (ToA) is likewise multiple times greater than the one gave $SF = 7$, which essentially builds the likelihood of an impact. For end-gadgets that have adequately stable RF conditions, a lower SF ought to be utilized. This should be possible physically or by empowering versatile Data rate (ADR) systems. On the off chance that ADR is empowered, the doors naturally change the information rate utilized in the correspondences with the end-gadgets [79].

When a package is transmitted over LoRaWan, it initially passes through two-layered AES-128 encryption using an Application Meeting Key (AppSKey) and an Enterprise Meeting Key (NwkSKey). The entire package is encrypted until it reaches the organization's server, where it is decrypted using NwkSKey, as shown in Figure (3.5). This protects the data if a hacker finds out how to block a LoRaWan package during transmission by way of a backbone approach to the organization's server. will be sent to the application server, where the AppSKey will unscramble it. If the organization server is hacked, this shields the information [71].

LoRaWan support actuation by personalization (ABP) and over-the-air initiation (OTAA) techniques to join an end-gadget to the organization [Han e Wang 2018]. ABP is a static type of enactment, where the end-gadget has to know in advance the NwkSKey and AppSKey, as well as the gadget address (DevAddr). The straightforwardness of this type of initiation is differentiated to its less security and versatility on the grounds that the NwkSKey and AppSKey never show signs of change, and this could give a rebel substance additional opportunity to utilize savage power assaults. The OTAA technique progressively arranges the NwkSKey and AppSKey with the organization and application servers. For this situation,

the end-gadget doesn't have to know in advance the NwkSKey and AppSKey. All things being equal, it has to realize the gadgets broadened special identifier (DevEUI), the application expanded interesting identifier (AppEUI), and the application key (AppKey). At the point when an end-gadget needs to join an organization, it will send a join demand that incorporates the DevEUI and the AppEUI. This join demand is then scrambled by the AppKey as displayed in Figure (3.8). At the point when a join demand is acknowledged, the application server produces an AppSKey and the organization server makes a NwkSKey. Both will be returned through a downlink bundle to the end-gadget. Starting there, the end-gadget utilize the NwkSKey and the AppSKey similarly as in ABP [71].

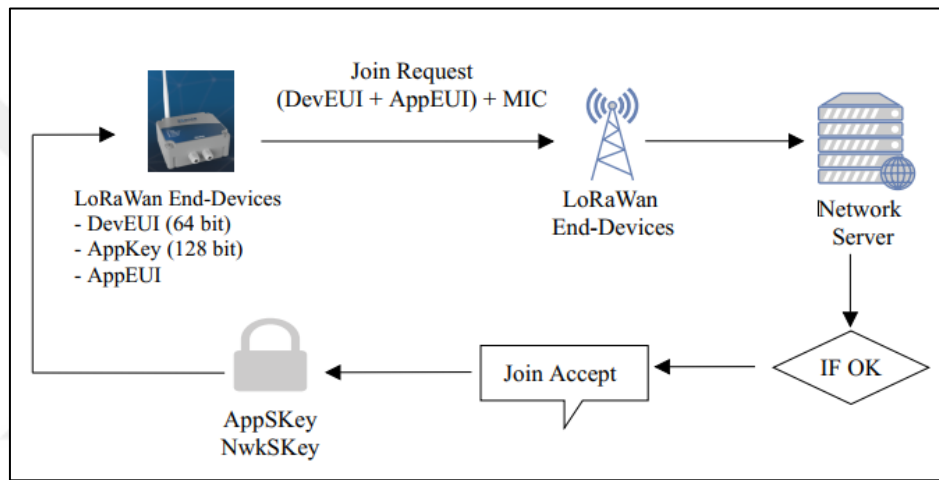


Figure 3.8: LORA Wan OTAA Join Sequence [71].

Without the NwkSKey and AppSKey, a noxious entertainer can't get to the information on the grounds that the LoRaWan parcel in both ABP and OTAA is scrambled. The message respectability code (MIC), which is produced and sent in every transmission bundle, forestalls altering. A replay assault isn't, be that as it may, safeguarded from by the MIC and encryption. A casing counter (FC) is incorporated by LoRaWan in every parcel to accomplish this objective. Each time information is communicated or gotten, the 32-cycle esteem saved for uplink (FCntUp) and downlink (FCntDown) is expanded.

3.5.3 Basic Specifications for LORAWan Ratification in Brazil

Before the goals 14448 and 705, which administer LoRa innovation in Brazil, were endorsed, the Brazilian organization Anatel (Agencia Nacional de Telecomunica coes) worked with hardware makers and held formal conferences. The goals determined that the recurrence plan for Latin America be the Australian norm of 923MHz (915MHz to 928MHz)

[80], [Ato no 14448, de The recurrence plan for LoRaWan used by the Things Organization network waiter in Brazil is shown in Table (3.2) under the heading, "The Things Organization, LoRaWan recurrence plans."

Table 3.2: LORA Wan Frequency Plan in Brazil [80].

	Frequency MHz	Value
Uplink	916.8	SF7BW125; ...; SF10BW125
	917.0	SF7BW125; ...; SF10BW125
	917.2	SF7BW125; ...; SF10BW125
	917.4	SF7BW125; ...; SF10BW125
	917.6	SF7BW125; ...; SF10BW125
	917.8	SF7BW125; ...; SF10BW125
	918.0	SF7BW125; ...; SF10BW125
	918.2	SF7BW125; ...; SF10BW125
	917.5	SF8BW500
Downlink	923.3	SF7BW500; ...; SF12BW500
	923.9	SF7BW500; ...; SF12BW500
	924.5	SF7BW500; ...; SF12BW500
	925.1	SF7BW500; ...; SF12BW500
	925.7	SF7BW500; ...; SF12BW500
	926.3	SF7BW500; ...; SF12BW500
	926.9	SF7BW500; ...; SF12BW500
	927.5	SF7BW500; ...; SF12BW500

There are a couple of undertakings and organizations in Brazil that advance LoRa and LoRaWan. The Things Organization TTN is an allowed to-utilize LoRaWan server situated in the Netherlands. Their goal is to broaden a local area kept up with, free LoRaWan network all over the planet. The Things Organization (TTN) has the biggest LoRaWan people group on the planet, which remembers a branch for Brazil. Their discussion is an incredible asset for information and highlights, in addition to other things, instructional exercises, entryways, end-gadget modules, and guidelines.

A business company called American Tower has real radio pinnacles spread out across Brazil. They generally rent tower space to critical media communications suppliers like vivo.

In the previous year, they started laying out a LoRaWan network all through Brazil, including Espirito Santo, in a joint effort with territorial telecoms suppliers. The American Pinnacle LoRaWan ought to as of now give complete inclusion to Grande Vitoria. A Curitiba-based firm named Radioenge makes LoRaWan and LoRaMesh modules that have been ensured by Anatel.

3.6 LORA NETWORK ARCHITECTURE

A three-level progressive LoRa network design is recommended, as displayed in Figure (3.9) This segment portrays the elements of every part.

3.6.1 LORA Node and Gateway

The LoRa Node and Gateway are fundamental pieces of the entire LoRa network since they can speak with the rest of the world and give information to the LoRa network server for investigation. Sensors, actuators, batteries, and different parts are the principal parts of a LoRa hub, which can do at least one positions relying upon the requests of the application. All uplink radio parcels are sent to the LoRa network server utilizing the LoRa Passage, which additionally adds data such the Signal-Noise-Ratio (SNR) and Got Signal Strength-Pointer (RSSI). Then again, the LoRa Door handles transmission demands showing up from the LoRa network server on the downlink. By and large, it simply goes about as a transfer for get uplink/downlink bundles; the payloads are not decoded. The subtleties of the equipment execution are talked about in the accompanying segment [81].

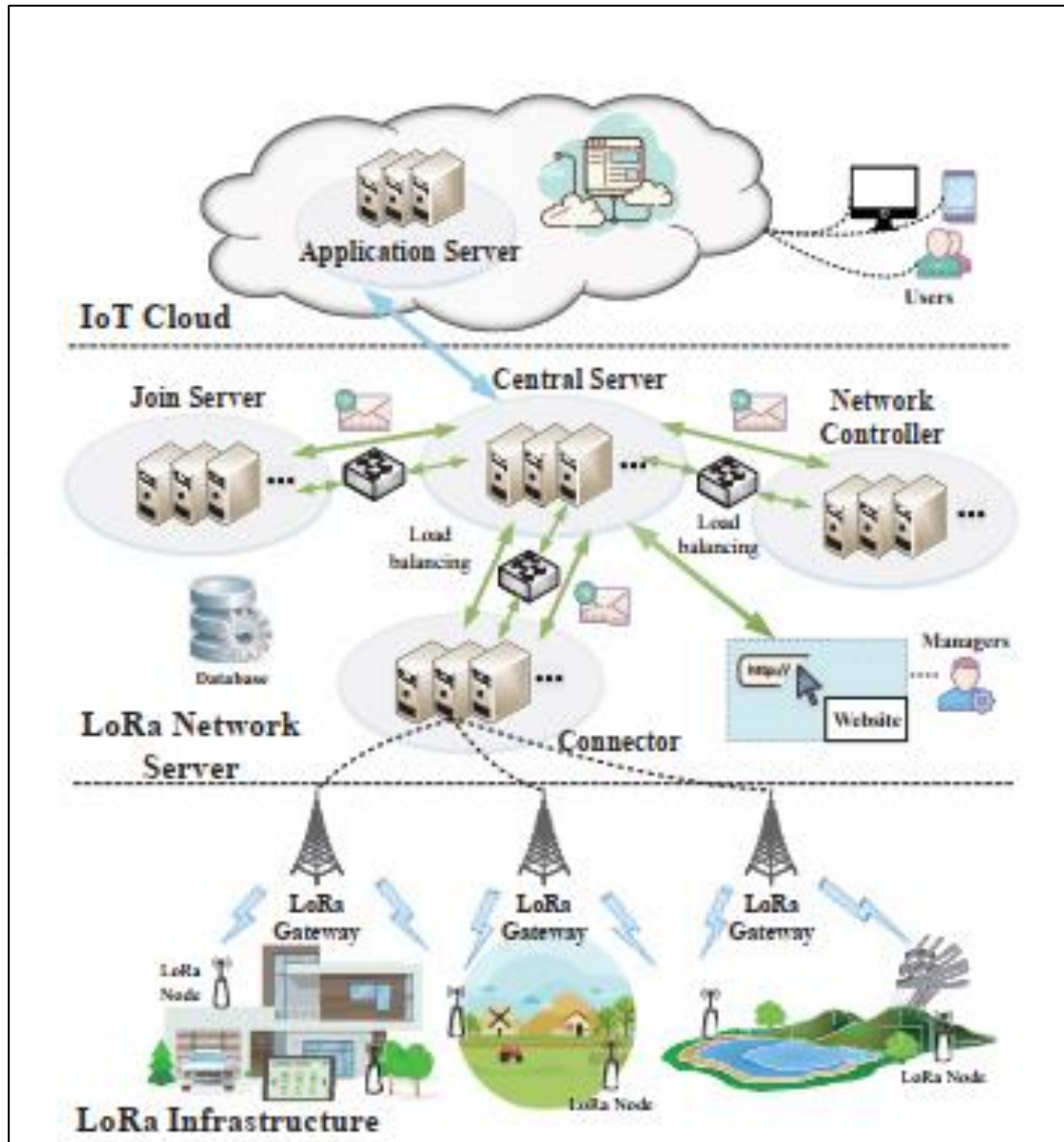


Figure 3.9: LORA network Architecture [81].

3.6.2 LORA Network Server

The LoRa network server is responsible for bundle handling and convention examination in the wake of getting parcels sent from the LoRa Passage. The LoRa network server should carry out an immense number of highlights. To give some examples, network the executive's techniques, booking affirmations, sifting copy uplink bundles, guaranteeing end-gadget legitimacy, sending application layer information to the application server, and so forth. The LoRa network server's very much planned engineering is significant for powerful handling and functional administration. Specifically, the versatility can oblige the requests

of supporting huge LoRa Hubs and the adaptability empowers clients to make different applications on current LoRa equipment gadgets. An administration structure is likewise expected to help clients in enlisting, making due, and monitoring their LoRa gadgets, including doors and hubs[82] (See Figure 3.10).

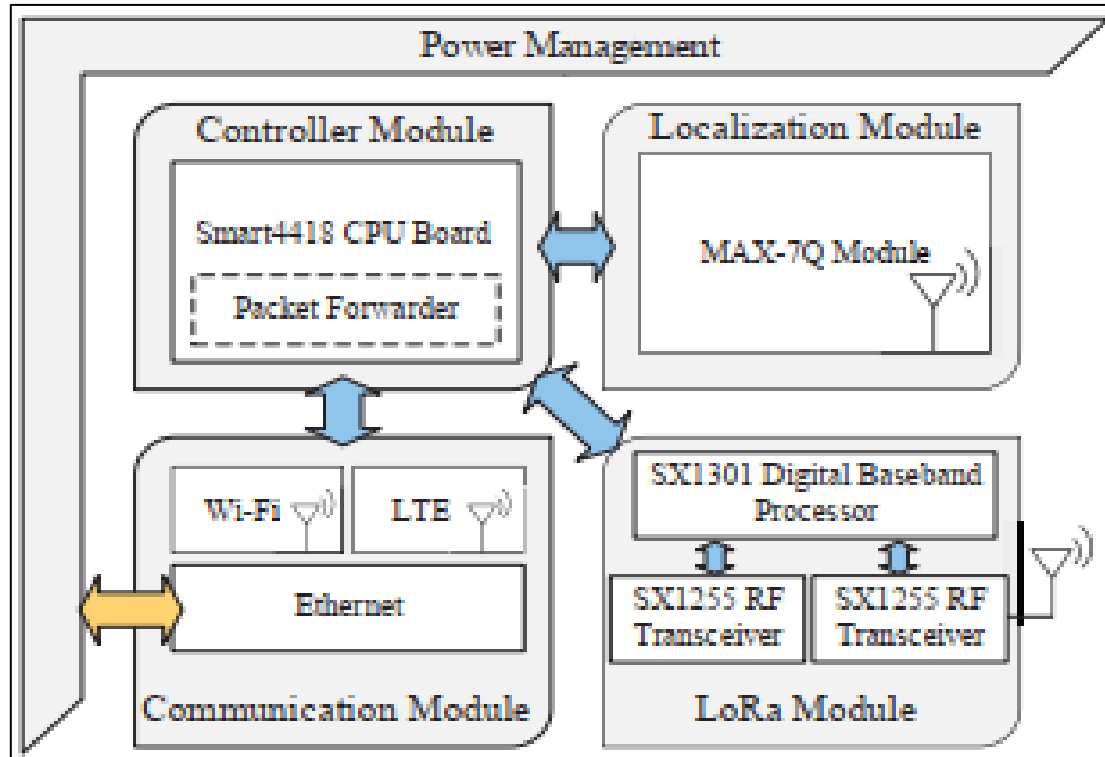


Figure 3.10: LORA Gateway [82].

3.6.3 Application Server in IOT Cloud

The handling of application layer payloads, including encryption and decoding, is under the domain of the LoRa Application Server. To safeguard information and increment transmission viability, it can uphold different applications with different encoding or encryption methods, for example, Convention Support. Applications are thusly made accessible to clients by the IoT cloud through Application Program Points of interaction (APIs). The LoRa Application Server fills in as a connection between the IoT cloud and the LoRa network server, empowering clients to control LoRa Hubs and use LoRa network applications from any area utilizing internet browsers or cell phones [82]. gives an intensive portrayal of IoT mists.

4. SYSTEM IMPLEMENTATION AND RESULTS

4.1 INTRODUCTION

This chapter includes the practical side of the project, starting with the tools used, then the system work plan, as well as the LoRa design method, then the design process, and review and discussion of the results.

4.2 OMNET ++ TOOL

An adaptable structure for network recreation is OMNeT++. It offers a development set for different situations. Reusable modules are at the core of OMNeT++, which is the reason it's alluded to as a part engineering. The development is practically identical to LEGO blocks [11], which fills in as a reasonable correlation. At the point when modules are appropriately executed, they can be reused in different reproductions similarly as LEGO blocks can. The usefulness of OMNeT++'s inward and outer design is portrayed in the parts that follow [83].

The design of OMNeT++ is made out of modules that convey by means of messages. The dynamic modules, otherwise called basic modules and compound modules, come in two unique assortments. Compound modules, the second type of module, can be comprised of straightforward modules. Compound modules consolidate numerous modules into a solitary unit and can be considered inactively exclusively addressing inward functionalities. Since there could be no maximum breaking point to the quantity of progressive layers, OMNeT++'s construction is viewed as various leveled [84]. Consequently, a compound module is the recreation model's entire portrayal by an organization. In C++, straightforward modules are made. Messages are utilized by modules to speak with each other. Basic modules incorporate info and result doors for sending and getting messages. Despite the fact that it is regularly done by means of utilizing entryways, it is additionally achievable to communicate messages straightforwardly to their expected beneficiary.

During a reproduction, messages could sub for bundles on an organization or clients in a line. By utilizing purported associations, info and result entryways can be associated. Such associations and entryways are additionally present in compound modules for connecting with outside modules. Sub modules can interface with the compound module door or to other sub modules inside a compound module, however not to the outside, as associations must be

made at one level of the module progressive system. To keep modules reusable, that is vital. Concerning factors like piece mistake rate or deferral, these connections can be considered separate elements. Reusing associations that have predefined boundaries is likewise conceivable [85].

4.3 METHODOLOGY SYSTEM FLOW CHART

The idea of this work is to read the speed of water flow in the water pipes in cities, districts and villages and then send it through the LoRa network to the maintenance unit to be constantly monitored and maintained while maintenance is required without waiting for a notification from the people. The system block diagram shown in Figure (4.1).

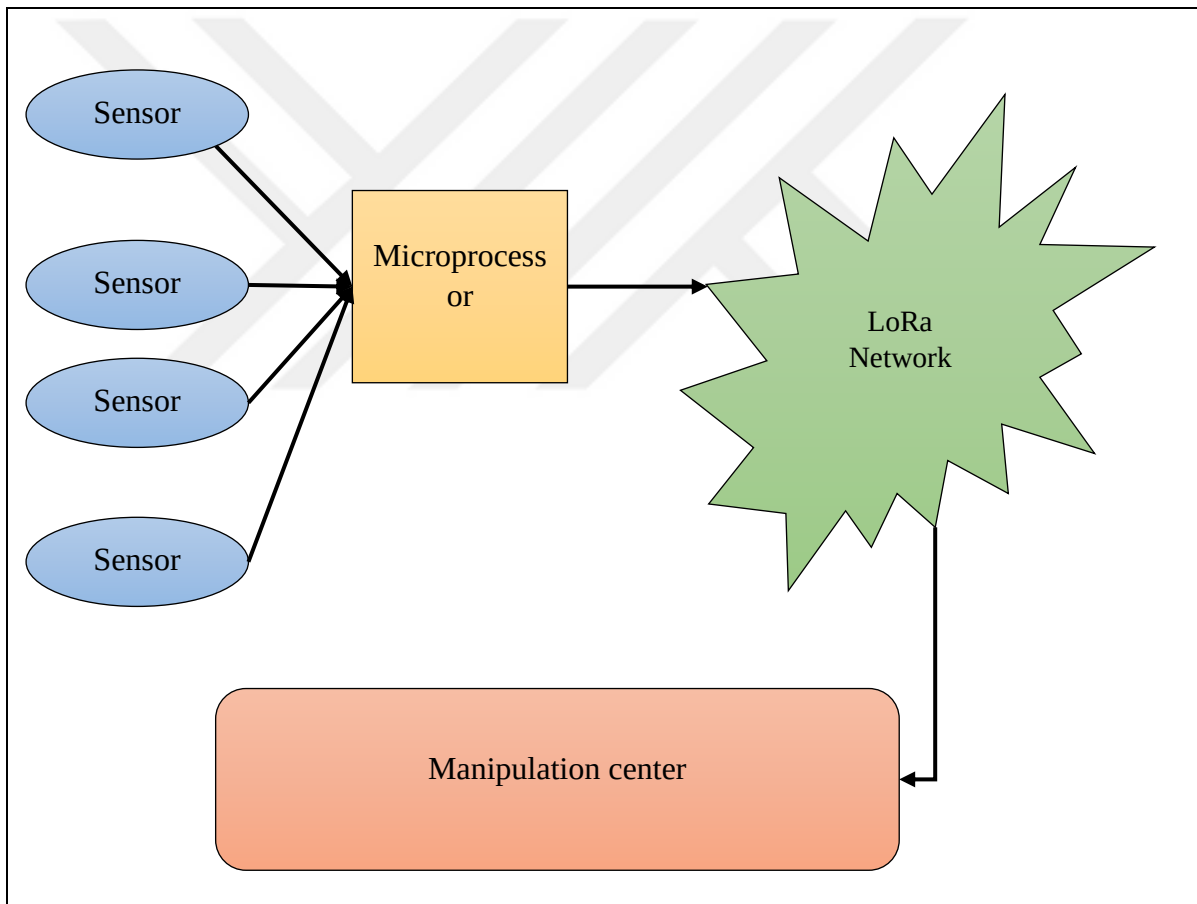


Figure 4.1: Proposed System Block Diagram.

4.4 LORA IMPLEMENTATION

The usefulness of every module is given alongside the LoRa network server execution. Various classifications of material are allotted to various modules for handling fully intent on handling colossal measures of parcels successfully. These modules were created

involving micro services design to decouple their capabilities and execute dispersed sending. A site project is additionally made as an administration system that empowers administrators to enroll gadgets, screen gadgets, access verifiable information, and so on.

4.4.1 Connector

Between the LoRa Passage and the Focal Server, the Connector goes about as a scaffold and offers the administrations for parsing and bundling the payload as per the LoRaWAN determination. Utilizing an IP spine, the LoRa Passage lays out an association with a particular Connector and communicates parcels utilizing UDP. To forestall unapproved access, Connector performs lawfulness mind LoRa Hubs and Door. For example, assuming that the LoRa Passage has been properly enlisted, Connector will quickly recognize the bundle's receipt. In the event that not, the parcel is basically discarded. Besides, handling and pressing a bundle require various fundamental data set activities. It is ideal to isolate the capability from standard organization servers to disperse the handling load and expand the utilization, everything being equal.

4.4.2 Central Server

The booking of administrations and information organization are dealt with by the focal server. The Focal Server plans a few modules as per the requests of information handling. The data in the parcel is separated into the fitting organizations as per the kind of uplink bundle to work on future handling. From that point forward, the join bundles are communicated to the join server, the Macintosh orders are shipped off the organization regulator, and the first application information is taken care of into the application server. Also, Focal Server assembles and stores the communicated information. Directors can investigate the uplink/downlink parcels and consistently screen the LoRa hub and door's functional circumstances utilizing internet browsers.

A solitary parcel might be gotten by numerous doors immediately since LoRa Hubs are not connected to a specific LoRa Passage. The Focal Server is important for screening excess parcels to forestall the misuse of radio assets brought about by overt repetitiveness. Copy bundles are just taken care of into the following handling module once. In addition, the Focal Waiter is responsible for downlink bundle booking. One ideal passage is decided to send the downlink bundle by using the transmission data, for example, RSSI and SNR associated in

the copy parcels, which isn't erased. Also, Focal Server peruses the downlink payload from two information lines that are accountable for application information and Macintosh orders prior to deciding the downlink boundaries as per significant arrangements.

4.4.3 Join Server

Join Server offers various administrations, including handling initiation demands and making meeting keys. Both Over-The-Air Enactment (OTAA) and Initiation By Customization are ways of activate LoRa nodes (ABP). For the OTAA strategy, the LoRa Hub should stick to a join convention that involves a trade of join demands and join acknowledges. The join demand bundle is just deciphered by Join Server, and the meeting keys are then created utilizing the pre-shared key and the sent arbitrary number to defend the initiation system. The pertinent key in Join Server is then used to typify and encode the join acknowledge bundle. Also, LoRa Hubs utilizing the ABP method should enroll on the site utilizing specific organization interfaces.

4.4.4 Network Controller

Handling and directing Macintosh orders are the essential obligations of Organization Regulator. To change related arrangements or alter transmission boundaries, Macintosh orders are sent to and from between Organization Regulator and LoRa Hubs [22]. The customary LoRa network server's Organization Regulator has been eliminated, passing on it to deftly complete Macintosh orders and creative organization the executives' procedures. Since they can expand the reliability and usefulness of LoRa organizations, very much planned techniques like Adaptive Data Rate (ADR) are utilized [23]. The Organization Regulator's work process is displayed in Figure (4.2). Think about the ADR execution for instance. The Focal Server sends the transmission boundaries for the uplink bundles. The Organization Regulator then carries out the ADR framework and chooses whether to change the transmission power or information rate. The Macintosh orders are then sent by the downlink parcel subsequent to being put to the downlink line. The effective solicitation orders are removed from the line subsequent to getting the affirmation bundle. On the off chance that not, the ineffective orders are put something aside for the ensuing transmission.

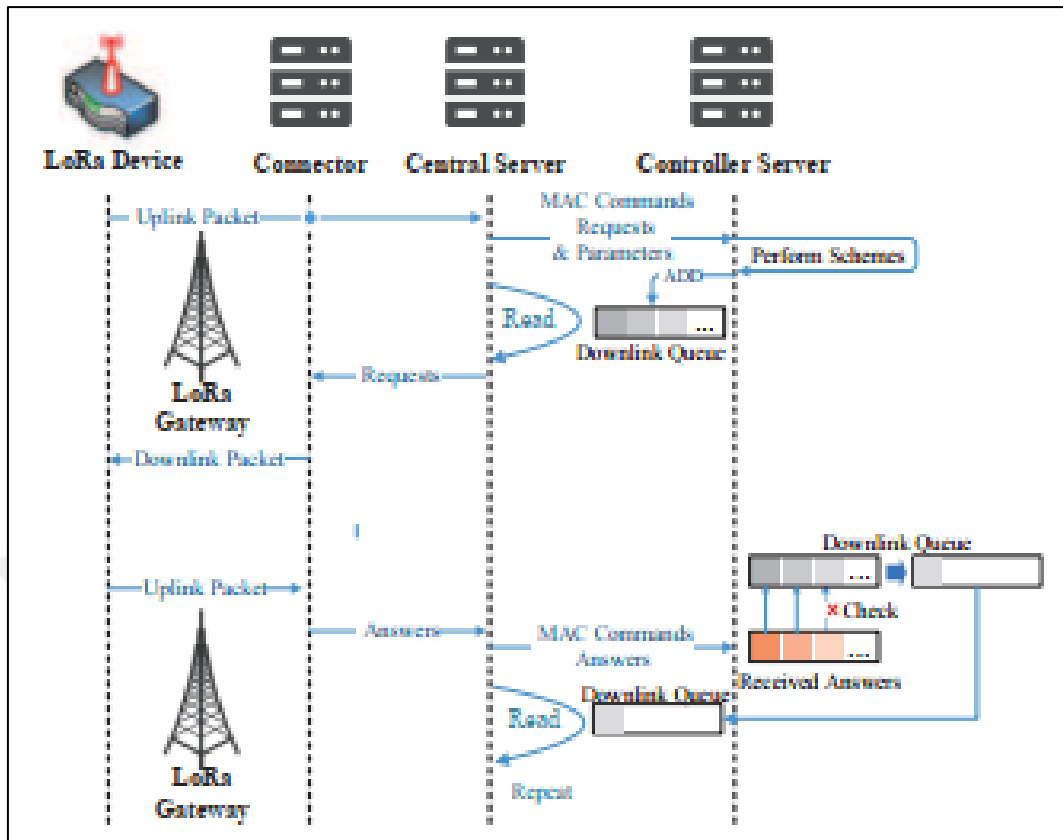


Figure 4.2: Workflow of Network Controller.

4.5 SYSTEM RESULTS

A model LoRa network has been put up and sent in normal metropolitan settings together to survey the presentation of the proposed LoRa organization. In this part, the LoRa framework's inclusion and organization server execution are both surveyed.

4.5.1 Implement 100 Node with ADR

To implement a 100 node LoRa network with ADR (Adaptive Data Rate), we will need to follow the below steps:

Step a: Choose a suitable LoRa gateway.

Choosing a suitable LoRa gateway depends on several factors such as the number of nodes in the network, the range required, and the features required. In this work we choose (5) Gateway for transmission.

Step b: Configure the gateway.

The gateway must be configured with the correct settings to enable ADR. This includes adjusting the range of spread factor (SF) and maximum transmission power to use nodes, where selected SF between (7-12) according to the distance from the center.

Step c: Configure the nodes.

Each node needs to be configured with a unique device ID, and the gateway's ID needs to be added to each node's configuration. The nodes also need to be configured with the right SF range and maximum transmission power, so they can communicate with the gateway.

Step d: Enable ADR.

To enable ADR, the gateway needs to be configured to monitor the signal strength of each node and adjust the SF and transmission power accordingly. This can be done using software tools provided by the gateway manufacturer.

Step e: Test the network.

Once the nodes and gateway are configured, we need to test the network to ensure that all nodes are communicating with the gateway correctly. We can use network monitoring tools to check the performance of the network and identify any issues.

The LoRa network specification is shown in Table (4.1) and the LoRa structure is shown in Figure (4.3).

Table 4.1: 100 Node LoRa With ADR Network Specification.

BW	125 KHz
Number of Gateway	1-4
Number of Nodes	100
Network Size	2500*1100
Code Rate	4
packet Time of next	Exp (800)
Total packet received	10,368-41,818

When the SF is increased, the symbol rate decreases, which means that fewer symbols can be transmitted per second. This reduces the overall data rate of the system. Additionally, higher SFs increase the time on air for each transmission, which can lead to increased collision rates in high traffic networks.

However, increasing the SF can also increase the range and reliability of the network, which may be desirable in some cases. The choice of SF ultimately depends on the specific requirements of the application and the trade-off between data rate and range/reliability.

The server in a LoRa network typically receives more data than the NS (Network Server) router and the Gateway router because it performs additional processing and data management tasks that are not performed by the NS and Gateway routers. When a node transmits data over a LoRa network, the Gateway router receives the signal and forwards it to the NS router. The NS router then performs basic processing tasks such as filtering and routing the data to the appropriate application server. However, the NS router typically does not store or manage large amounts of data.

On the other hand, the application server or network server is responsible for managing the entire network, including the data transmitted by the nodes. The server stores data from all the nodes, processes it, and makes it available to the appropriate applications or databases. It may also perform additional tasks such as device management, data analytics, and security enforcement.

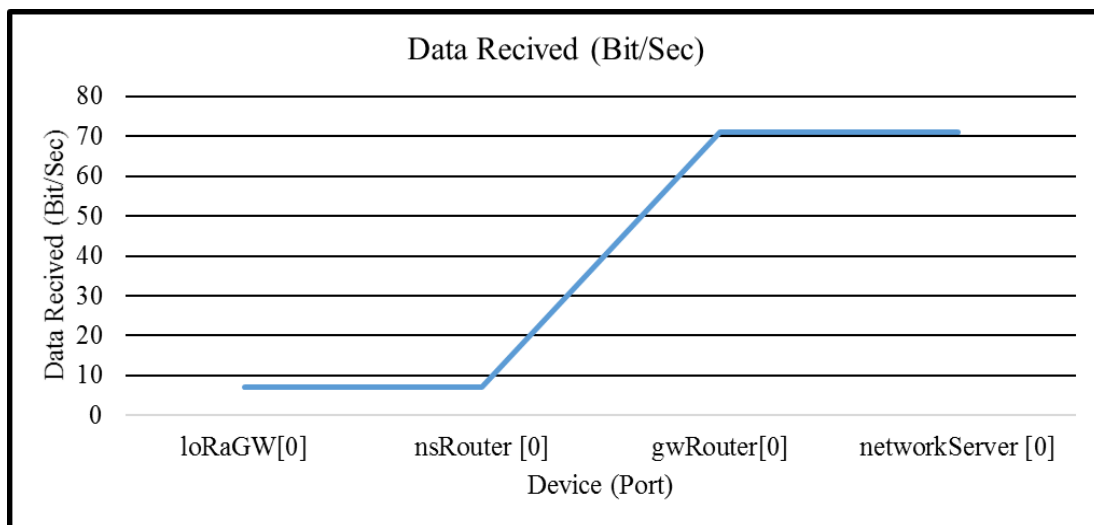


Figure 4.5: Data Received (Bit/ Sec) for 100 Node LORA With ADR.

Therefore, the server in a LoRa network typically receives more data than the NS and Gateway routers (Figure 4.5, 4.6) because it performs more advanced processing and data management tasks. Additionally, the server may receive data from multiple NS routers and Gateway routers, further increasing the amount of data it receives.

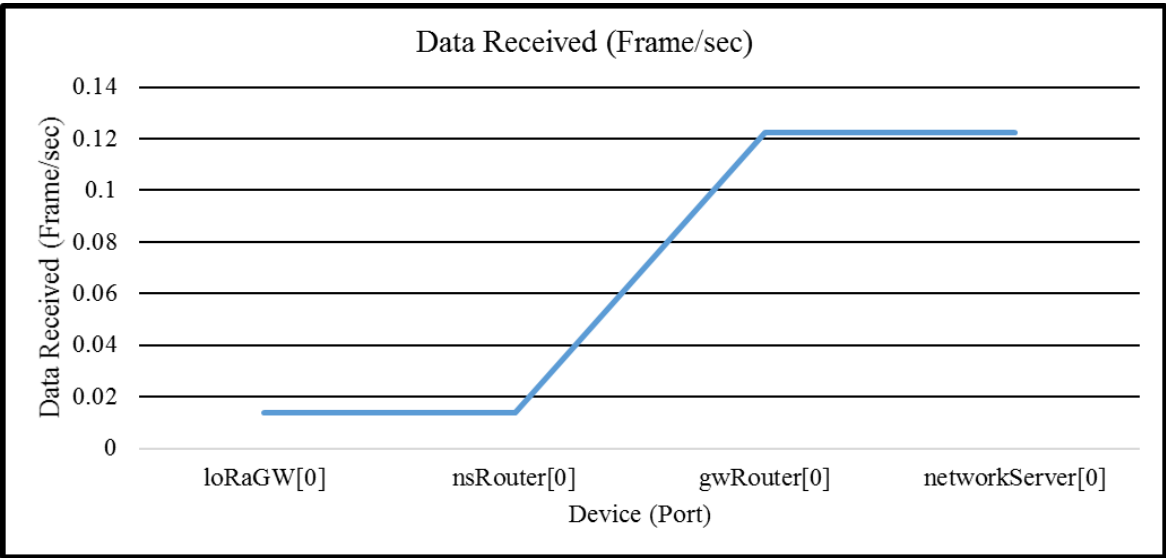


Figure 4.6: Data Received (Frame/ Sec) for 100 Node LORA With ADR.

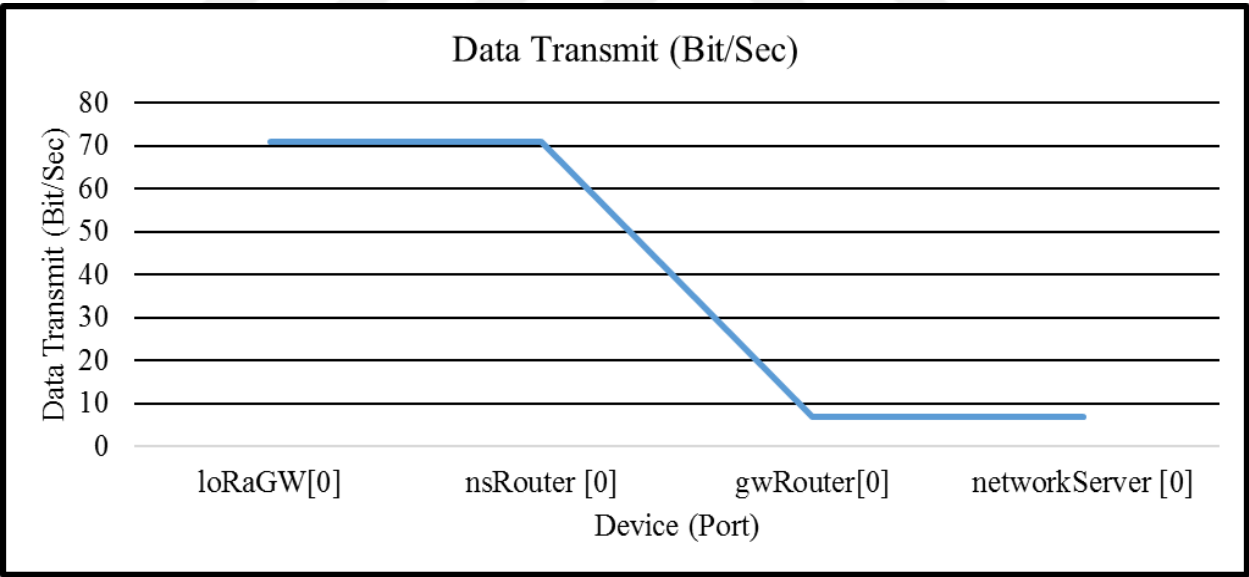


Figure 4.7: Data Transmitted (Bit/ Sec) for 100 Node LORA With ADR.

In a LoRa network, the amount of data transmitted by the gateway, NS (Network Server), and server can vary depending on the specific configuration and usage of the network. However, in general, it is possible for the gateway to transmit more data than the NS and server in certain scenarios. One reason for this is that the gateway is responsible for receiving and forwarding data from multiple nodes to the NS or server. If there are many nodes in the

network, each transmitting data at regular intervals, the amount of data received by the gateway can be significant. This is particularly true if the nodes are transmitting at a high data rate or using a low spreading factor, which increases the amount of data transmitted per packet.

Additionally, the gateway may perform some data processing tasks, such as filtering or aggregation, which can further increase the amount of data transmitted. For example, the gateway may aggregate data from multiple nodes before forwarding it to the NS or server, which can reduce the amount of traffic on the network but increase the size of the packets.

However, it is also possible for the NS or server to receive more data than the gateway in certain scenarios. For example, if the network is designed with many gateways but only one NS or server, the NS or server may receive more data as it is responsible for processing and managing all the data from the different gateways. Ultimately, the amount of data transmitted by the gateway, NS, and server in a LoRa network depends on various factors such as the number of nodes, data rate, spreading factor, and network configuration (See Figures 4.6, 4.7).

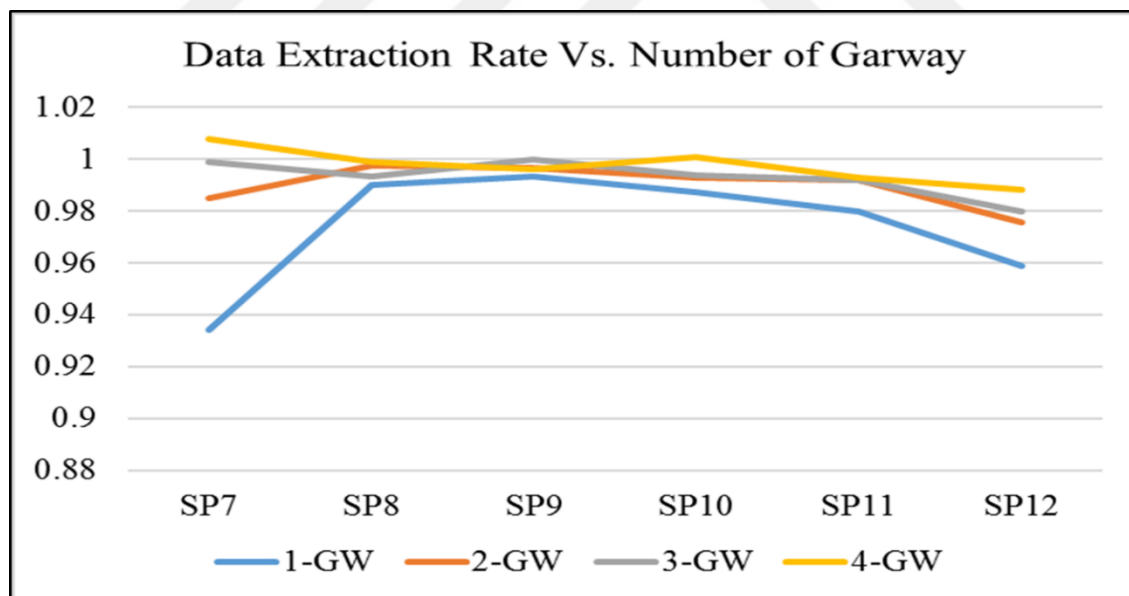


Figure 4.8: Data Transmitted (Frame/ Sec) for 100 Node LORA With ADR

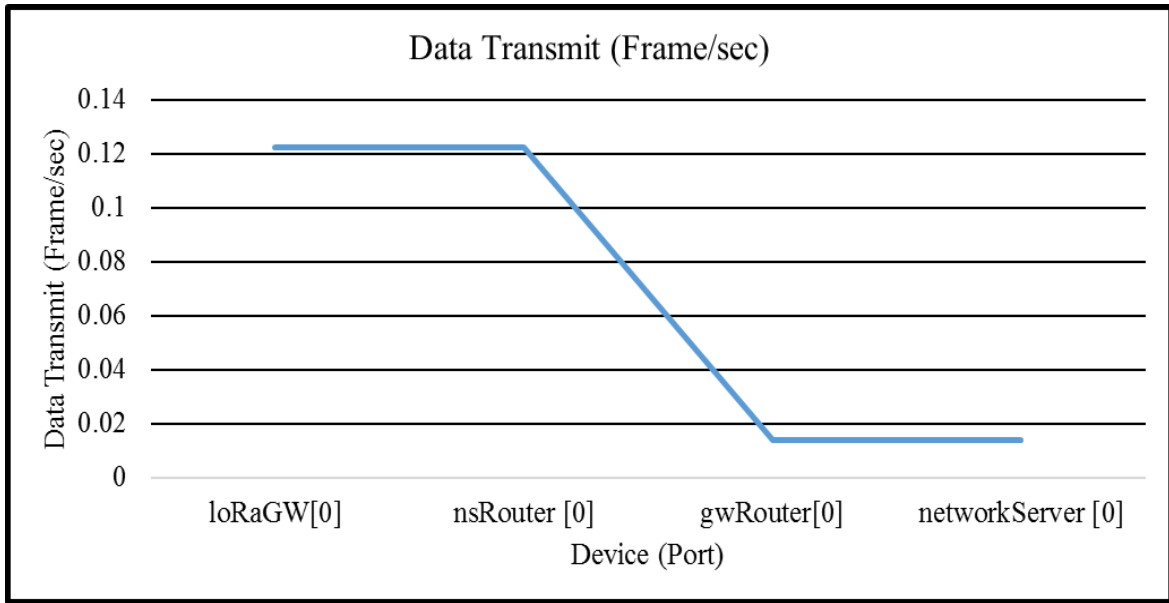


Figure 4.9: Data Extraction Rate vs Number of Gateway.

Figure (4.9) shows the percentage of successful transmissions for different spread factors (SP) and the number of gateways ranging from 1 to 5. Similar to the previous table, we can see that the success rate increases with the number of gateways for each spread factor. However, there are some differences worth noting.

For SP7, we see that the success rate is highest with 4 gateways (100.07%) but drops slightly to 99.34% with 5 gateways. This may suggest that adding more gateways beyond a certain point may not provide much additional benefit and could even lead to a slight decrease in performance. For SP8, the success rate remains consistently high across all numbers of gateways. This suggests that SP8 is well-suited for use in a network with a few or many gateways.

For SP9, the success rate is already very high with 1 or 2 gateways and remains high with 3, 4, or 5 gateways. This suggests that SP9 is very reliable and can be used in a network with a range of gateway configurations.

For SP10, the success rate is highest with 4 gateways (100%) but drops to 98.7% with 5 gateways. This suggests that, similar to SP7, adding more gateways beyond a certain point may not provide much additional benefit and could even lead to a slight decrease in performance.

For SP11 and SP12, the success rate increases somewhat as the number of gateways increases, but the increase is not as large as for some of the other spread factors. This suggests that these spread factors may benefit somewhat from having multiple gateways, but not as much as other spread factors like SP7 and SP9.

Overall, the choice of spread factor and the number of gateways to use will depend on the specific requirements of the network, including the desired level of reliability and the availability of gateway infrastructure. It's important to note that the addition of more gateways beyond a certain point may not always provide additional benefits and could even decrease performance.

4.5.2 Implement 100 Node Without ADR

ADR (Adaptive Data Rate) is a feature in LoRaWAN that automatically adjusts the data rate based on the signal quality between the end device (node) and the gateway. ADR helps to optimize network capacity and battery life by reducing unnecessary transmissions and maximizing the use of available bandwidth. Table (4.2) shows the LoRa network specifications of 100 Node without ADR.

Table 4.2: The LORA Network Specifications of 100 Node Without ADR.

BW	125 KHz
Number of Gateway	1-4
Number of Nodes	100
Network Size	2500*1100m
Code Rate	4
packet Time of next	Exp (800)
Total packet received	8,442-39,212

When comparing LoRa with ADR and without ADR for data extraction rate as a function of spread factor, there are several key differences to consider:

- Data rate: LoRa with ADR typically achieves a higher data extraction rate than LoRa without ADR, particularly at higher spreading factors. This is because ADR adjusts the data rate based on the signal quality, allowing for higher data rates in areas with strong signals and lower data rates in areas with weak signals.
- Range: LoRa without ADR can achieve longer range than LoRa with ADR, particularly at higher spreading factors. This is because LoRa with ADR reduces the data rate in areas with weak signals, which can limit the range of the signal.

- c. Network capacity: LoRa with ADR typically achieves higher network capacity than LoRa without ADR, particularly for networks with many nodes. This is because ADR reduces the amount of unnecessary traffic on the network, which can help to optimize network capacity.

Overall, the choice between LoRa with ADR and without ADR depends on the specific requirements of the application and the trade-off between data rate, range, battery life, and network capacity. In general, LoRa with ADR is better suited for applications that require frequent and reliable data transmission, while LoRa without ADR is better suited for applications that require long-range communication. Figures (4.10) to (4.15) shows the results of 100 Node LoRa without ADR.

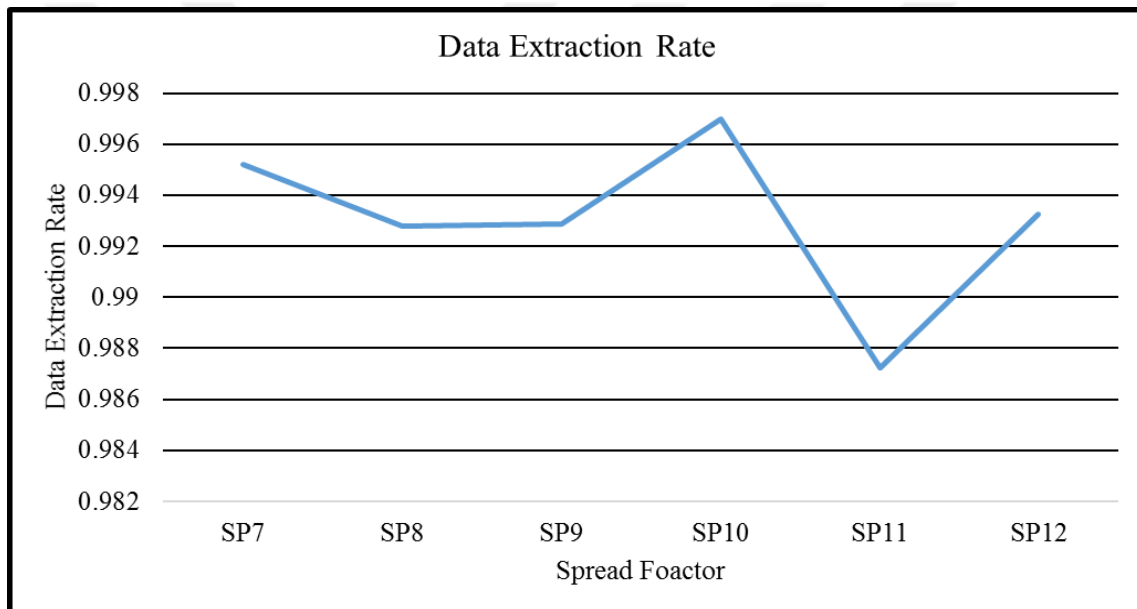


Figure 4.10: Data Extraction Rate as a Function of SF for 100 Node LORA Without ADR.

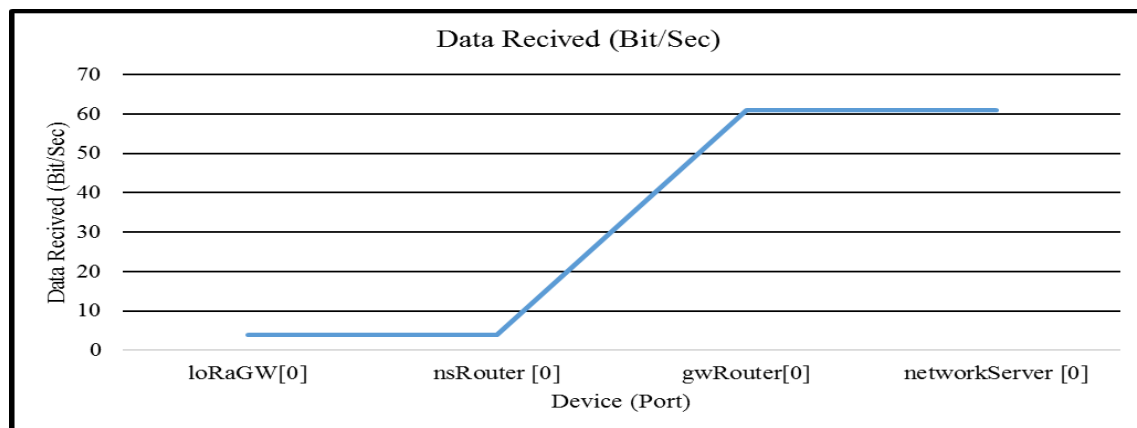


Figure 4.11: Data Received (Bit/ Sec) for 100 Node LoRa Without ADR

As shown in Figure (4.10), LoRa without ADR (Adaptive Data Rate), the data extraction rate can fluctuate as a function of spreading factor (SF). This is because SF affects the sensitivity and range of the LoRa transmission, and therefore the reliability of data transmission. At lower spreading factors, such as SF7 or SF8, the data extraction rate may be relatively high because these spreading factors have higher data rates and are more robust to noise and interference. However, as the spreading factor increases, such as to SF10 or SF12, the data extraction rate may decrease because these spreading factors have lower data rates and are more sensitive to noise and interference.

In addition, at higher spreading factors, the range of the transmission may decrease, which can further affect the reliability of data extraction. This is because the higher spreading factor results in a narrower bandwidth and a longer transmission time, which makes the signal more susceptible to fading and other types of interference. It is important to note that the fluctuation in data extraction rate as a function of SF in LoRa without ADR depends on various factors such as the signal strength, noise level, and interference in the specific environment. Therefore, it is important to optimize the network configuration and SF selection based on the specific requirements of the application and the characteristics of the environment.

The Data transmission and receiving is same as the data for LoRa Network With ADR as shown Below.

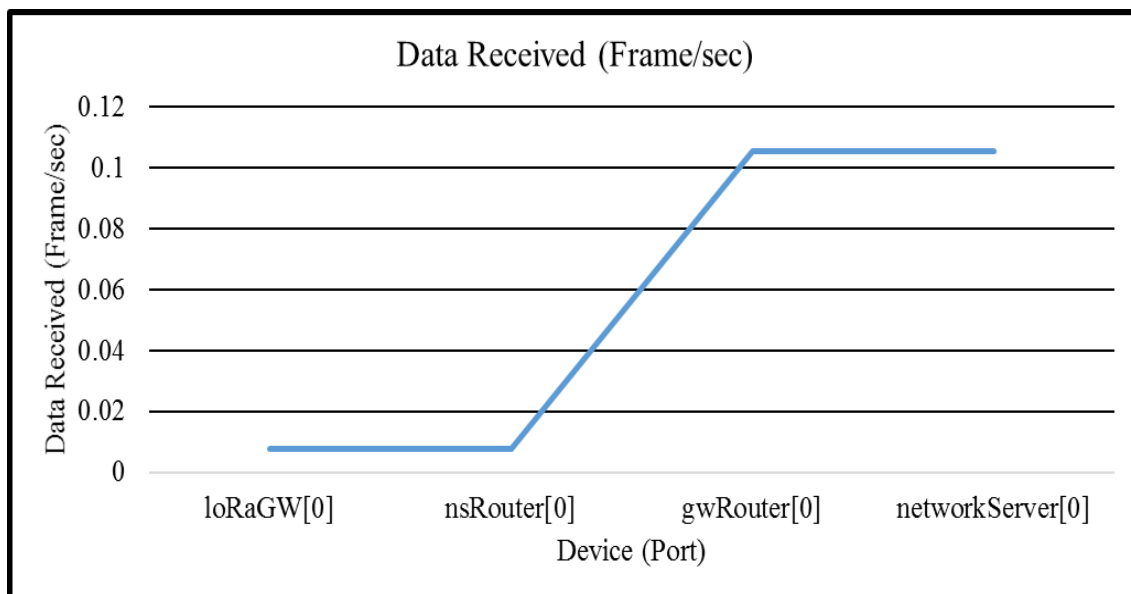


Figure 4.12: Data Received (Frame/ Sec) for 100 Node LORA Without ADR

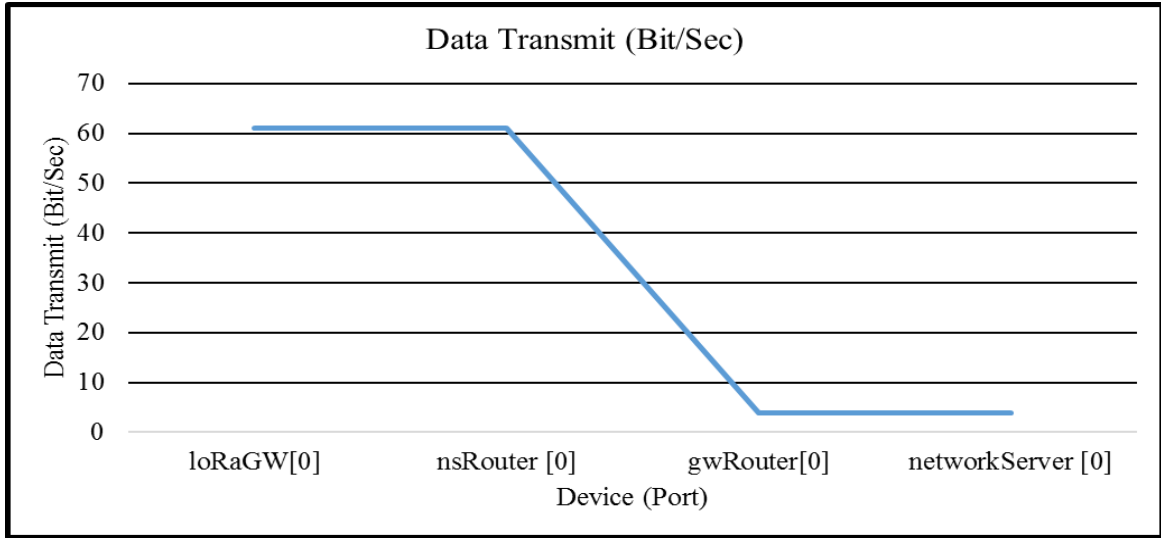


Figure 4.13: Data Transmit (Bit/ Sec) for 100 Node LORA Without ADR

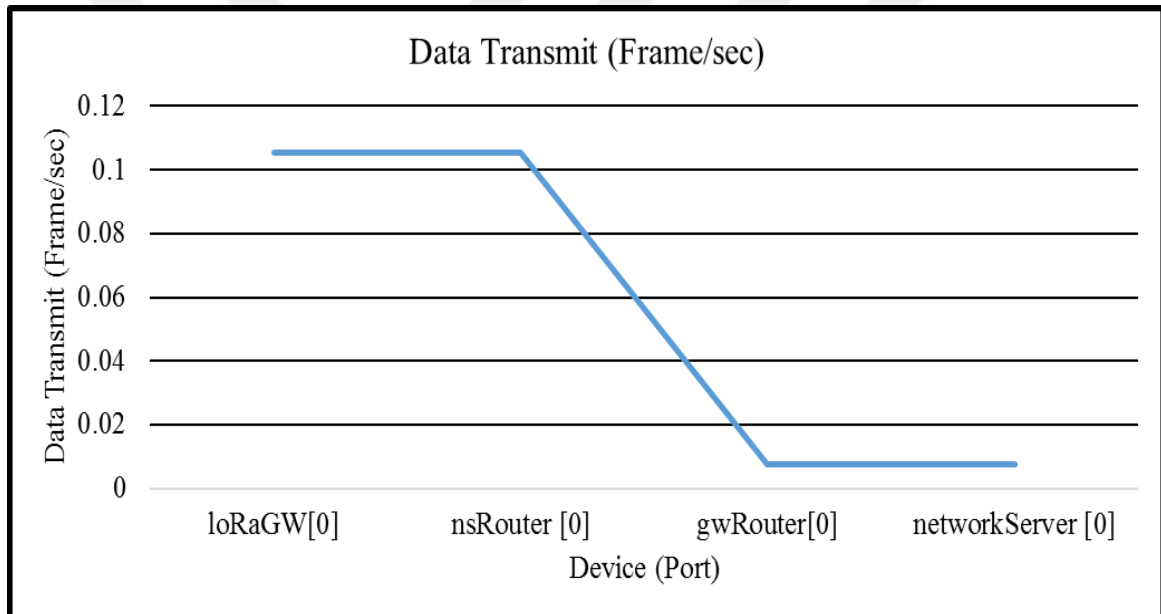


Figure 4.14: Data Transmit (Bit/ Sec) for 100 Node LORA Without ADR.

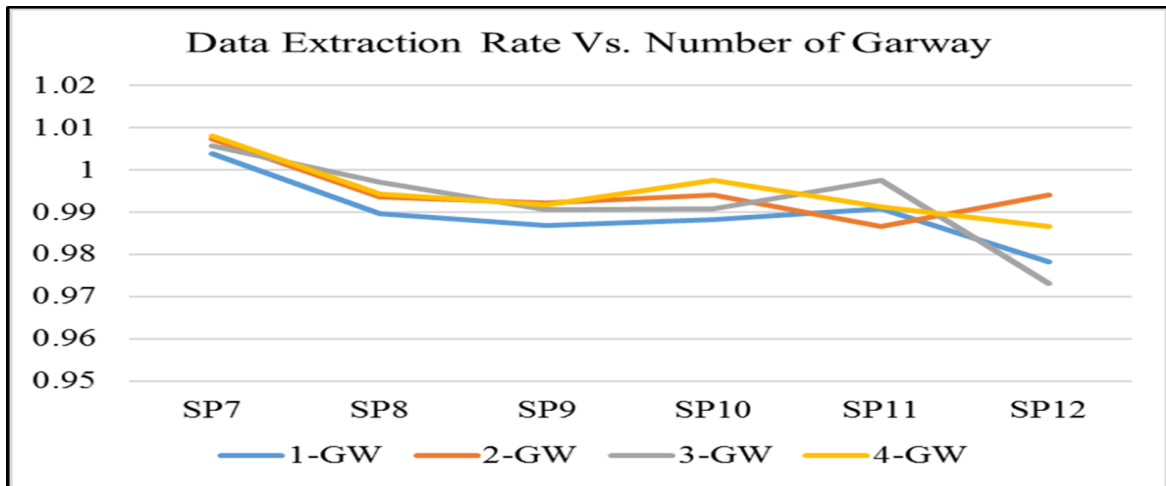


Figure 4.15: Data Extraction Rate vs Number of Gateways for 100 Node LORA Without ADR

Figure (4.15) shows the percentage of successful transmissions for different spread factors (SP) and the number of gateways ranging from 1 to 5. Compared to the previous tables, we see some variation in the success rate across different numbers of gateways for each spread factor.

For SP7, the success rate is highest with 2 gateways (100.72%) and remains above 100% up to 4 gateways. However, the success rate drops significantly to 99.5187% with 5 gateways, which suggests that adding more gateways beyond a certain point could lead to decreased performance.

For SP8, the success rate is consistently high across all numbers of gateways. However, we see a slight decrease in success rate with 4 and 5 gateways, indicating that there may be an optimal number of gateways for SP8. For SP9, the success rate is highest with 2 gateways (99.21%) and remains above 99% up to 4 gateways. However, we see a slight decrease in success rate with 5 gateways. For SP10, the success rate is highest with 4 gateways (99.76%) and remains consistently high up to 5 gateways. For SP11, we see some variation in the success rate across different numbers of gateways. The success rate is highest with 3 gateways (99.75%) and drops significantly with 2 and 5 gateways. This suggests that there may be an optimal number of gateways for SP11. For SP12, the success rate is highest with 2 gateways (99.4%) and drops significantly with 3 and 5 gateways.

Overall, the results suggest that the choice of spread factor and the number of gateways to use can significantly impact the success rate of transmissions in a LoRa network. There may be an optimal number of gateways for each spread factor, beyond which adding more

gateways could lead to decreased performance. Thus, it's important to carefully consider the network requirements and available gateway infrastructure when designing a LoRa network.

4.5.3 Implement 600 Node With ADR

When designing a LoRaWAN network with ADR (Adaptive Data Rate), the network size can have a significant impact on the design considerations and performance. Here are some key differences between a 600-node network with ADR and a 100-node network with ADR:

- a. Gateway requirements: In a 600-node network, multiple gateways may be needed to cover the entire network area and ensure reliable connectivity. This requires careful planning and deployment of gateways to ensure adequate coverage and capacity. In contrast, a 100-node network may require fewer gateways or even just one, depending on the network area and density of nodes.
- b. Network architecture: With a larger network, the network architecture becomes more complex and requires more careful design to ensure reliable and efficient communication. This may involve using multiple sub-networks or gateways, optimizing data routing and redundancy, and implementing load balancing and failover mechanisms. A smaller network may have a simpler network architecture that is easier to manage.
- c. Battery life: In a larger network, maximizing the battery life of the nodes becomes even more critical to minimize maintenance and replacement costs. ADR can help to optimize battery life by reducing unnecessary transmissions and maximizing the use of available bandwidth. However, in a larger network, it may be more challenging to ensure that all nodes are using ADR effectively and not causing unnecessary network congestion.
- d. Data rate and latency: With a larger network, the data rate and latency may be lower due to increased network congestion and limited available bandwidth. This can affect the overall performance of the network and the user experience. Careful selection of the spreading factor and other network parameters can help to mitigate this issue and optimize the performance of the network.

Overall, designing a LoRaWAN network with ADR for 600 nodes requires more careful planning and management than a 100-node network. However, with careful design and optimization, a large-scale LoRaWAN network can provide reliable and efficient communication for IoT devices in a variety of applications. Table (4.3) shows the

specifications of 600 Node LoRa network with ADR, and Figure (4.16) shows the network structure.

Table 4.3: 600 Node LORA Network With ADR Specifications.

BW	125 KHz
Number of Gateway	5-1
Number of Nodes	600
Network Size	5000*5000m
Code Rate	4
packet Time of next	Exp (800)
Total packet received	215,419

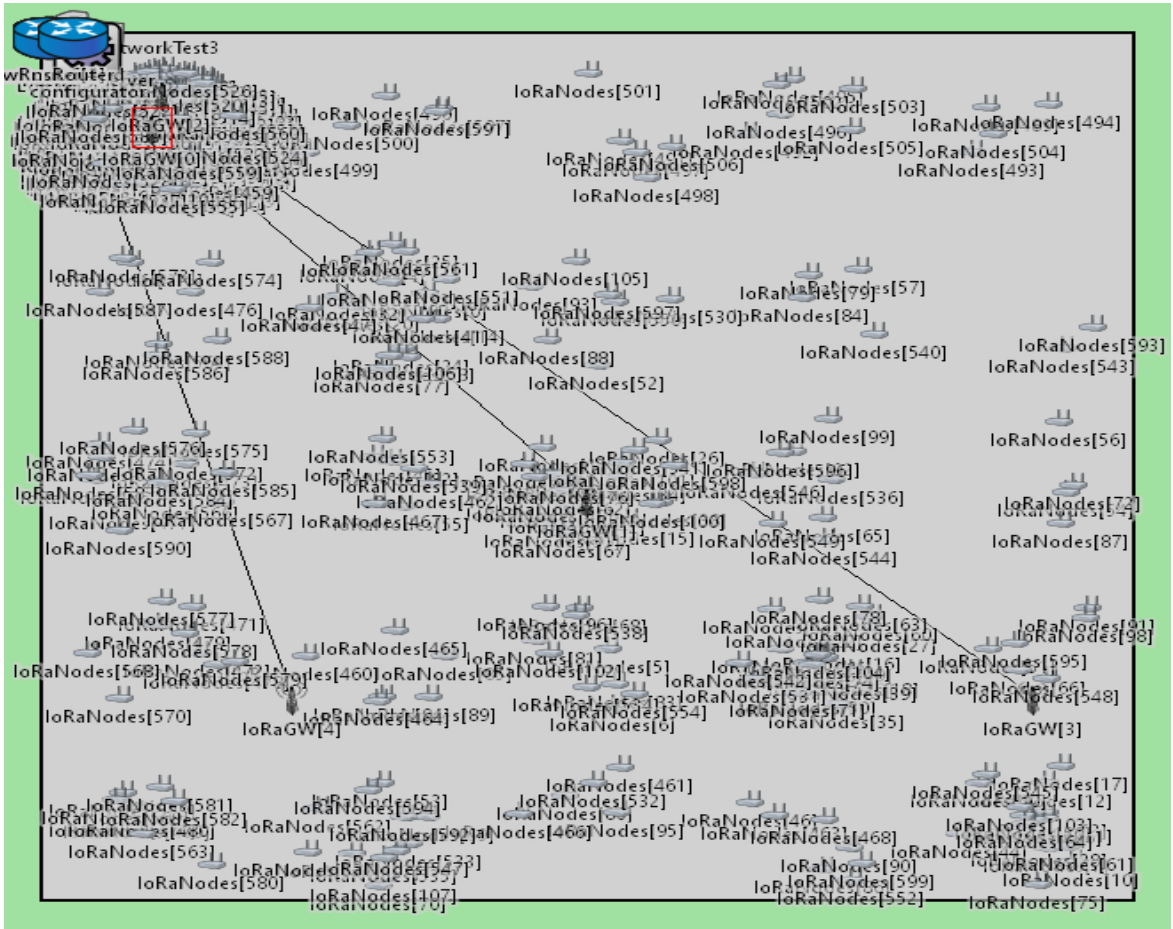


Figure 4.16: 600 Node LORA With ADR Network Structure.

In LoRa communication, the spreading factor (SF) is a key parameter that determines the data rate, range, and reliability of the transmission. The data extraction rate refers to the percentage of successfully received packets, and it can vary depending on the SF used. As the SF increases, the data rate decreases, but the range and reliability of the transmission improve. This is because a higher SF means that the transmission is spread over a wider

frequency band and a longer time period, which makes it less susceptible to interference and noise. However, the increased spreading also means that the transmission takes longer and requires more energy, which can reduce the overall data extraction rate.

Looking at the data in Figure (4.17), we can see that the data extraction rate varies as a function of the SF used. Specifically, the data extraction rate is highest for SF9, which is the optimal SF for most LoRa applications. This is because SF9 provides a good balance between data rate and range/reliability. At SF7, the data extraction rate is slightly lower than at SF8 and SF9, which is likely due to the higher spreading and longer transmission time required at SF7. At SF12, the data extraction rate is significantly lower than at the other SFs, which is expected due to the very high spreading and long transmission time required at SF12.

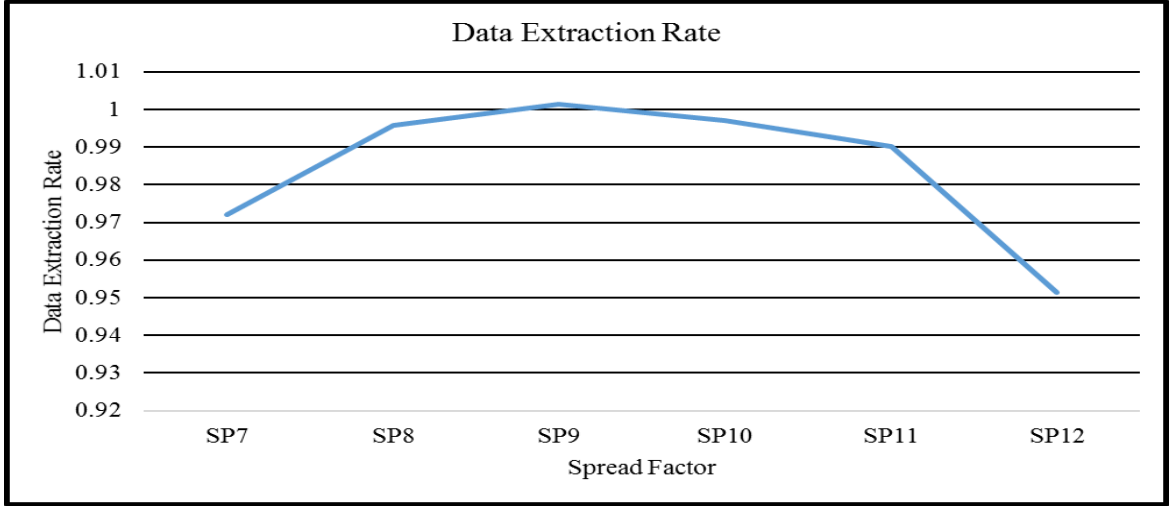


Figure 4.17: Data Extraction Rate as a Function of SF for 600 Node LORA With ADR.

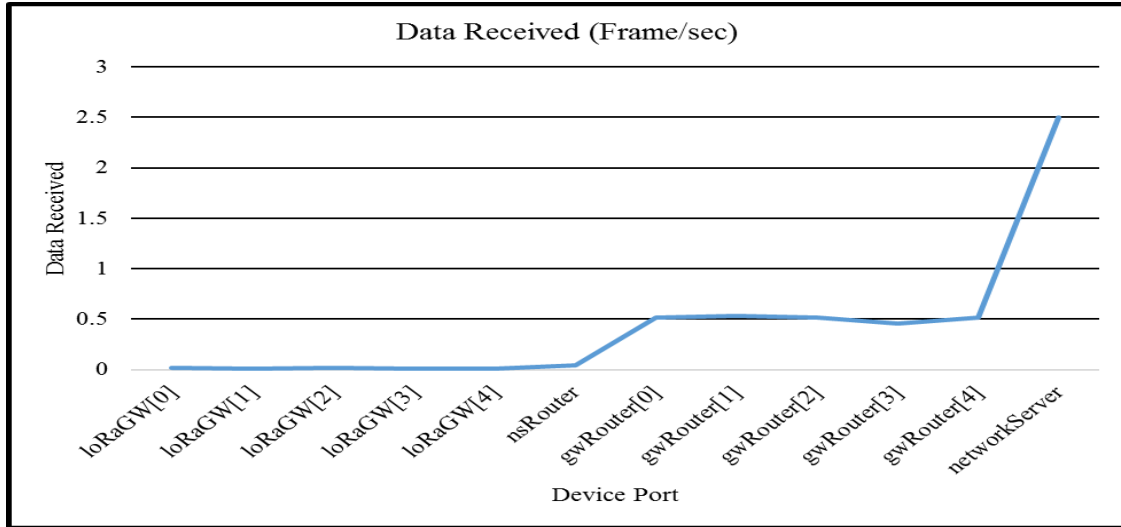


Figure 4.18: Data Received (Frame/ Sec) for 600 Node LORA With ADR.

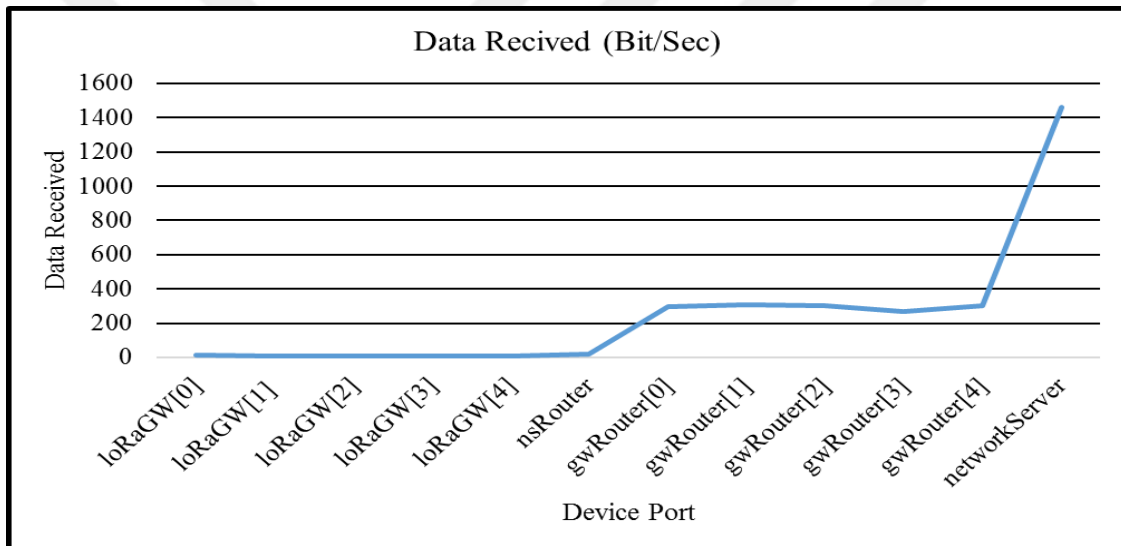


Figure 4.19: Data Received (Bit/ Sec) for 100 Node LORA With ADR.

Overall, these results demonstrate the trade-offs between data rate, range, and reliability in LoRa communication and highlight the importance of selecting the optimal SF for each application based on its specific requirements and constraints.

The results provided show the data shown in Figure (4.18) and (4.19) received in bit/sec and frame/sec for various LoRa devices in a network. Here's a brief discussion of each device's data received:

- a. LoRaGW [0]-4: These are the five LoRa gateways in the network. The data received ranges from 5.8 to 11.4 bit/sec, which is relatively low compared to other devices in the network. However, it's important to note that gateways typically handle a large volume

of data from multiple nodes, so the data received by each gateway may be lower than other devices.

- b. NSRouter: The network server router receives the highest data in the network at 22.05 bit/sec. This is expected since the network server router typically receives and processes data from multiple gateways and nodes.
- c. GWRouter [0]-4: These are the four gateway routers in the network. They receive a relatively high amount of data, ranging from 268 to 309 bit/sec. This is likely because gateway routers are responsible for forwarding data from the gateway to the network server router.
- d. networkServer: The network server receives the highest amount of data in the network at 1,460.29 bit/sec, which is expected since it processes data from all devices in the network.

In terms of frame/sec, the data received is much lower for all devices. This is likely because each frame contains more data than a single bit, so fewer frames are received compared to bits.

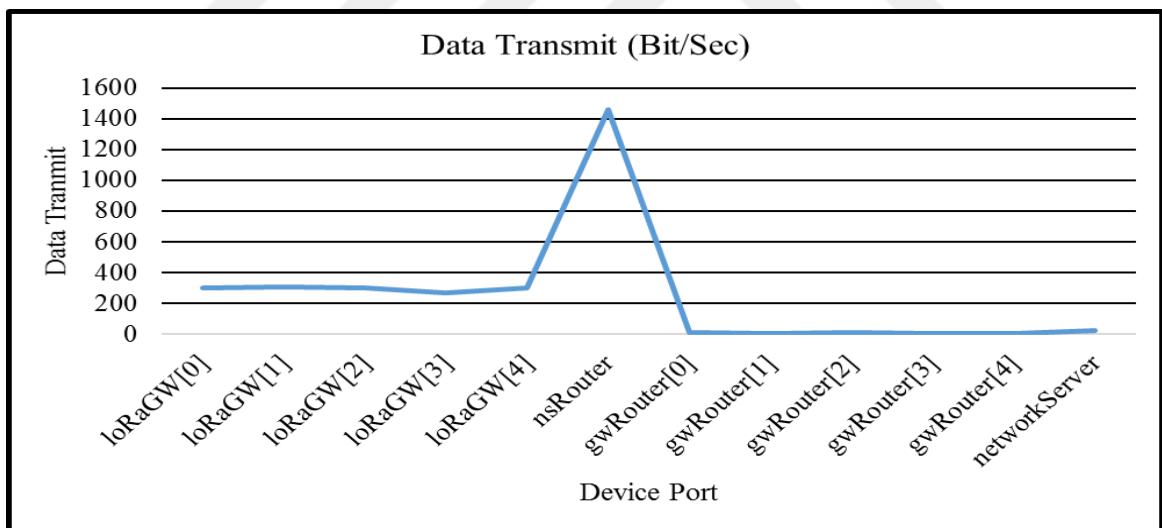


Figure 4.20: Data Transmit (Bit/ Sec) for 600 Node LORA With ADR.

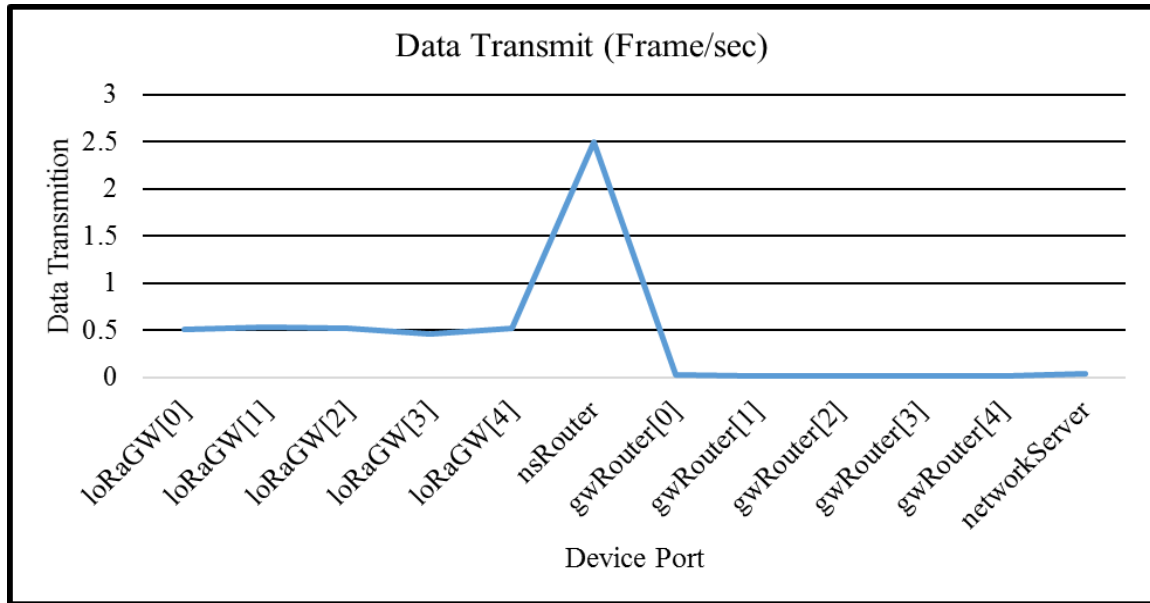


Figure 4.21: Data Transmit (Frame/ Sec) for 600 Node LORA With ADR.

The results in Figure (4.20) and (4.21) related to data transmission rates for different devices and ports within a network. Specifically, the data includes the data transmit rate in bits/sec and frames/sec for various devices including loRaGWs, nsRouter, gwRouters, and networkServer. Looking at the results for data transmit rate in bits/sec, it appears that the loRaGW devices have relatively consistent data transmit rates, ranging from 268.16 to 309.21 bit/sec. The nsRouter has a much higher data transmit rate at 1460.29 bit/sec, likely due to its role in managing the network. The gwRouters have much lower data transmit rates, ranging from 5.80 to 11.37 bit/sec. Finally, the networkServer has a data transmit rate of 22.05 bit/sec.

In terms of data transmit rate in frames/sec, the results are consistent with the bit/sec results. The loRaGW devices have relatively consistent frame transmit rates, ranging from 0.46 to 0.53 frame/sec. The nsRouter has a much higher frame transmit rate at 2.50 frame/sec, likely due to its role in managing the network. The gwRouters have much lower frame transmit rates, ranging from 0.01 to 0.02 frame/sec. Finally, the networkServer has a frame transmit rate of 0.04 frame/sec.

Overall, these results provide some insight into the data transmission rates of various devices and ports within a network. However, it is difficult to draw any concrete conclusions without additional context regarding the network setup and the specific role of each device and port. Additionally, it is important to note that data transmission rates are only one aspect of

network performance and do not necessarily indicate overall network efficiency or reliability.

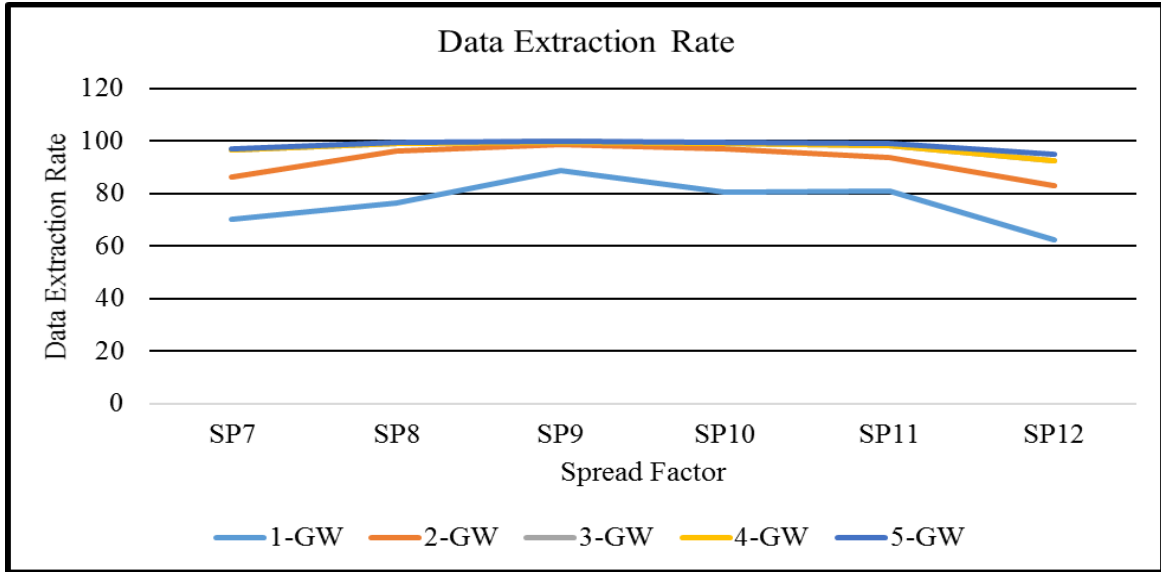


Figure 4.22: DER for 600 Node LORA With ADR.

Figure (4.22) shows These values seem to represent the performance of different spread factors (SP) in a LoRaWAN network with varying numbers of gateways. The percentages indicate the packet delivery ratio, which is the percentage of packets transmitted by a device that are successfully received by at least one gateway.

Looking at the results, we can see that generally, the packet delivery ratio increases as the number of gateways increases. However, this improvement in performance is not uniform across all spread factors. For example, at SP7, the packet delivery ratio only increases slightly from 70.13% with one gateway to 97.19% with five gateways, indicating that SP7 may not be the best choice for this network. In contrast, at SP9, the packet delivery ratio increases significantly from 88.68% with one gateway to 100.01% with five gateways, indicating that SP9 is a good choice for this network.

Overall, the choice of spread factor depends on the specific requirements of the application and the network environment, such as the distance between devices and gateways, the amount of interference, and the desired battery life of the devices. It is important to evaluate the performance of different spread factors and gateway configurations in order to choose the optimal settings for a given network.

4.5.4 Implement 1000 Node LoRa With ADR

When comparing a 1000 node LoRa network with a 600 node LoRa network, there are several differences that should be taken into consideration. The Network coverage with 1000 nodes, the LoRa network will require greater coverage area than the 600-node network. This means that more LoRa gateways may be required to provide adequate coverage for all of the nodes. Table (4.4) shows the network specification with 1000 Node.

Table 4.4: LoRa Network Specification With 1000 Node.

BW	125 KHz
Number of Gateway	1-4
Number of Nodes	1000
Network Size	1100*2500 m
Code Rate	4
packet Time of next	Exp (800)
Total packet received	289,437

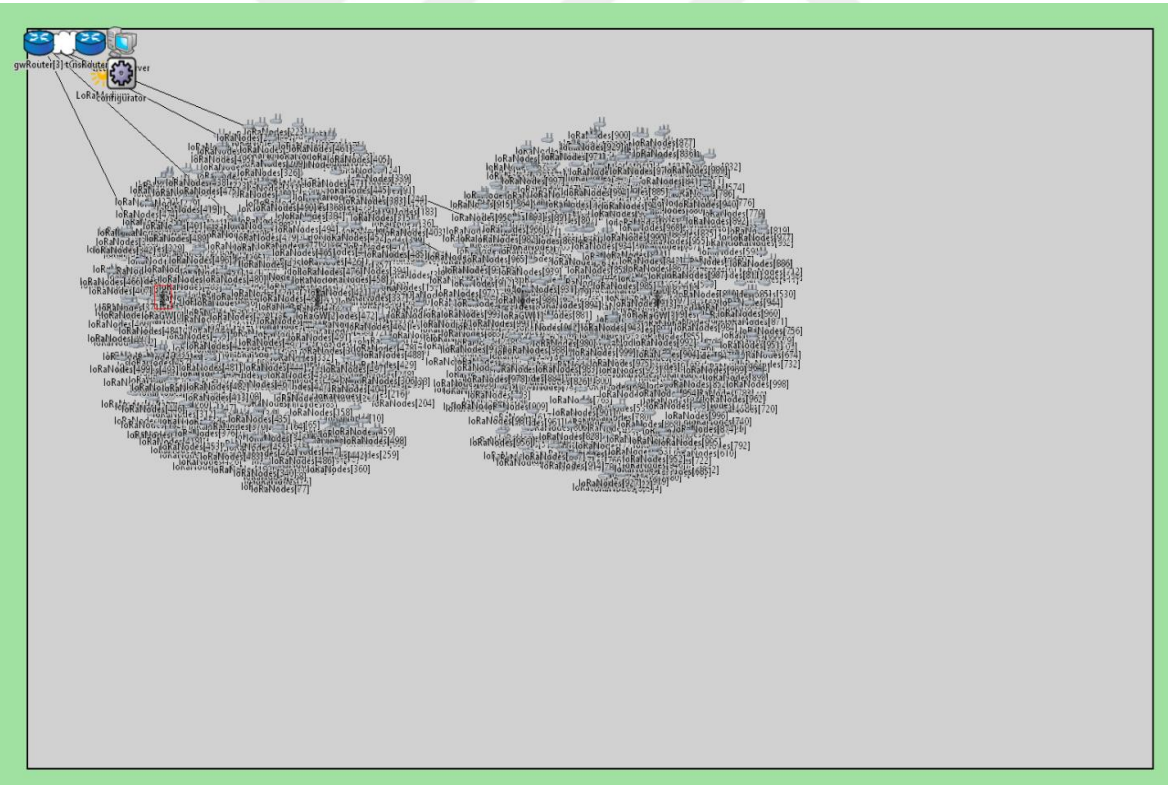


Figure 4.23: 1000 Node LORA With ADR Network Structure.

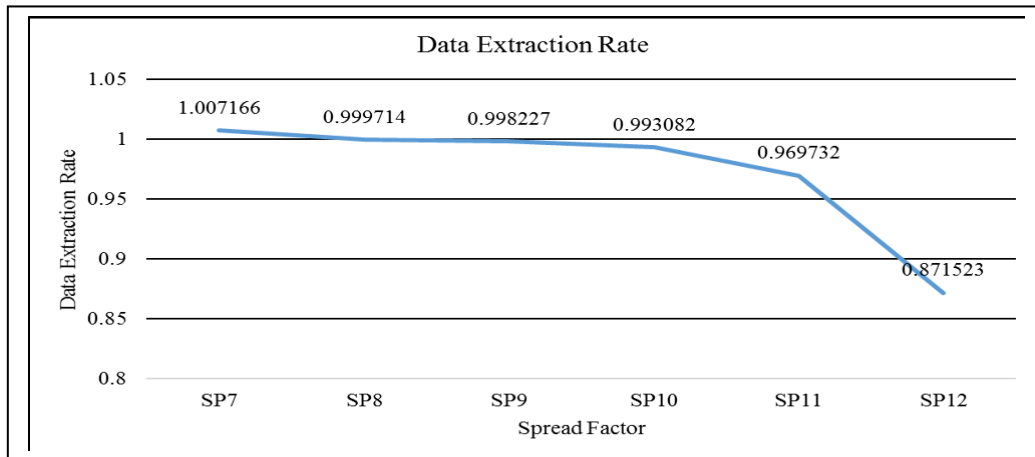


Figure 4.24: Data Extraction Rate as a Function of SF for 1000 Node LORA With ADR. The given results in Figure (4.24) show the relationship between the spread factor and the data extraction rate for a LoRa network. The spread factor refers to the modulation technique used in the network, with a higher spread factor resulting in lower data rates but longer range, and a lower spread factor resulting in higher data rates but shorter range. The data extraction rate refers to the percentage of data that can be extracted from the network.

Looking at the results, it can be observed that as the spread factor increases from SP7 to SP12, the data extraction rate decreases. This is expected, as higher spread factors result in lower data rates, and therefore, fewer packets can be transmitted within a given time period. At SP7, the data extraction rate is the highest, indicating that the network is able to transmit and receive the highest amount of data. However, as the spread factor increases, the data extraction rate decreases, with the lowest rate of 0.871523 being observed at SP12.

Overall, these results show that the choice of spread factor in a LoRa network is a trade-off between data rate and range. While a higher spread factor may provide longer range, it results in lower data rates and lower data extraction rates. Therefore, the choice of spread factor must be made based on the specific requirements of the network, balancing the need for range and data rate.

For The given results show the data received by different devices in a LoRa network. The data received is measured in bits per second and is an indication of the amount of data that each device is processing.

Looking at the results, it can be observed that the highest data received is by the network server, with a rate of 1960.62 bits per second. This is expected as the network server is responsible for processing and analyzing all the data transmitted within the network.

The next highest data received is by the gateway routers, with rates ranging from 487.733611 bits per second to 499.306296 bits per second. These devices are responsible for forwarding the data from the end devices to the network server and vice versa.

The end devices, represented by the LoRaGWs and the nsRouter, have comparatively lower data received rates. This is because the end devices typically have lower processing capabilities and are responsible for sending data to the gateway routers, which handle the majority of the network processing.

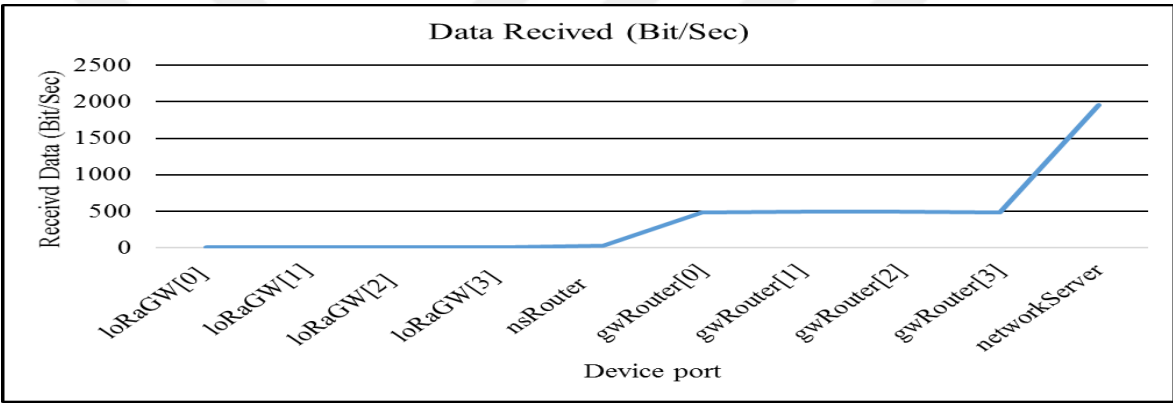


Figure 4.25: Data received (Bit/ Sec) for 1000 Node LORA With ADR.

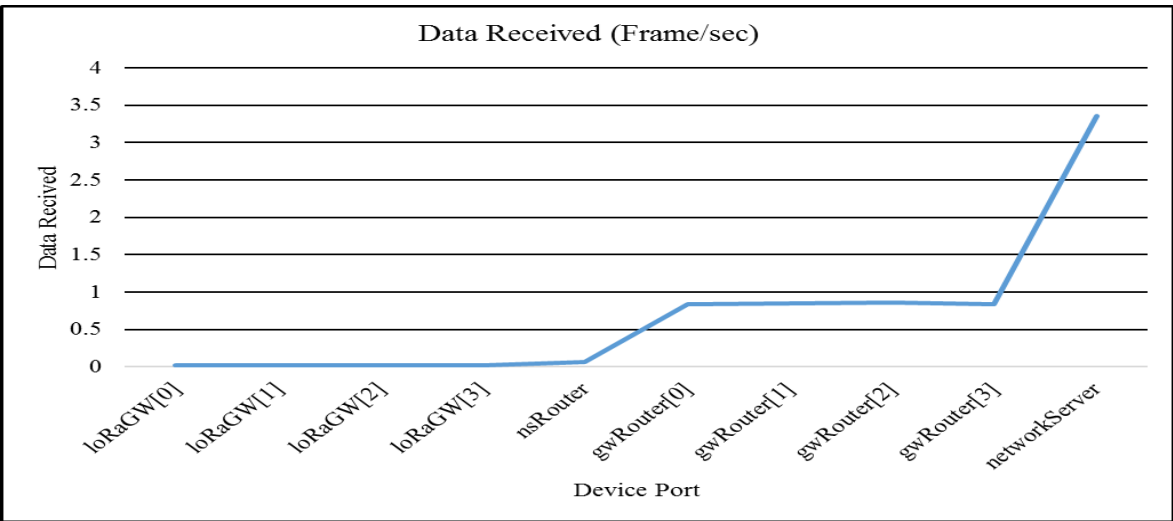


Figure 4.26: Data Received (Frame/ Sec) for 1000 Node LORA With ADR.

The given results show the number of frames received by different devices in a LoRa network. The frames received are measured in frames per second and provide an indication of the amount of data that each device is processing. Looking at the results, it can be observed that the highest number of frames received is by the network server, with a rate of 3.358241 frames per second. This is expected as the network server is responsible for processing and analyzing all the data transmitted within the network.

The next highest number of frames received is by the gateway routers, with rates ranging from 0.836181 frames per second to 0.855995 frames per second. These devices are responsible for forwarding the data from the end devices to the network server and vice versa.

The end devices, represented by the LoRaGWs and the nsRouter, have comparatively lower frame received rates. This is because the end devices typically have lower processing capabilities and are responsible for sending data to the gateway routers, which handle the majority of the network processing.

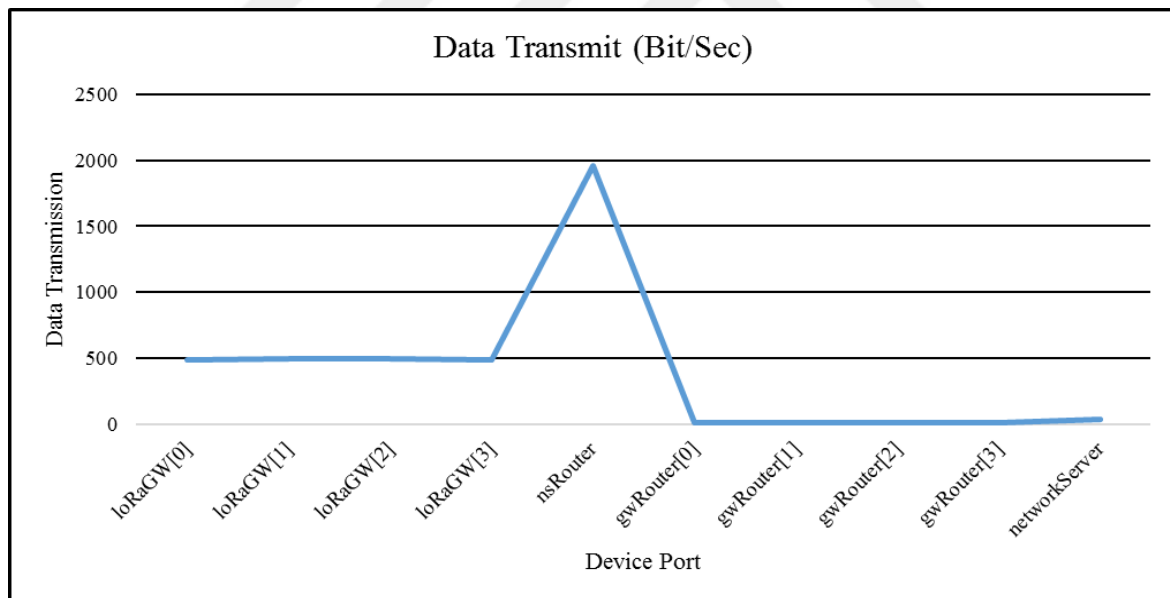


Figure 4.27: Data Transmit (Frame/ Sec) for 1000 Node LORA With ADR.

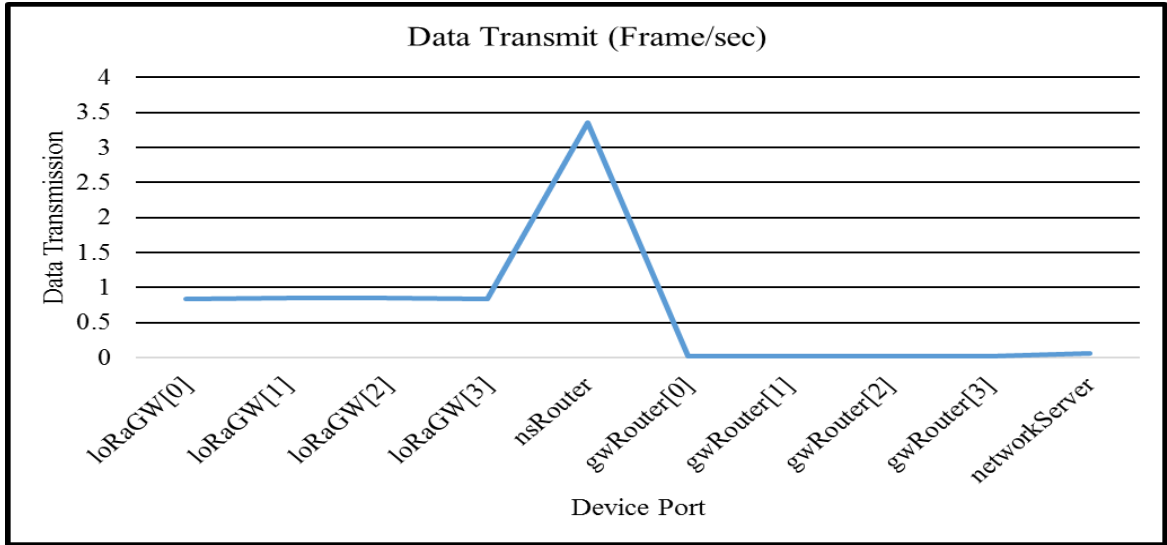


Figure 4.28: Data Transmit (Bit/ Sec) for 1000 Node LORA With ADR.

These results of data transmission and frame rate for different devices shown in Figures (4.27) and (4.28). From the results, it can be observed that the LoRa gateways (loRaGW) and the network server have higher data transmission rates and frame rates compared to the gateway routers (gwRouter) and the network server has a lower frame rate compared to other devices. This is because the network server is responsible for receiving and processing data from multiple gateways and routers, which results in a higher data transmission rate.

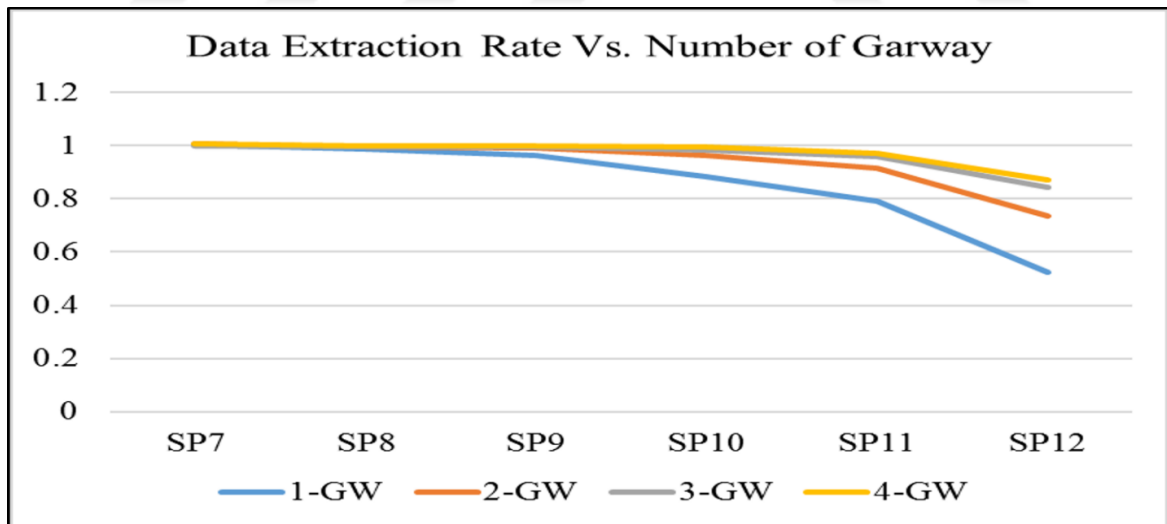


Figure 4.29: Data Extraction Rate vs Number of Gateways.

In terms of frame rates, the network server has the highest frame rate, followed by the gateway routers and LoRa gateways. This is because the LoRa gateways and gateway routers have to forward data from multiple devices, which results in a lower frame rate.

Figure (4.29) appears to be showing the Spread Factor values for different numbers of gateways (1-Gateway, 2-Gateway, 3-Gateway, 4-Gateway) for six different transmission system operators (SP7, SP8, SP9, SP10, SP11, and SP12).

Spread Factor is a measure of the ability of a power system to withstand disturbances, and higher values indicate greater stability. Looking at the table, we can see that the Spread Factor generally increases as the number of gateways increases. This is because having more gateways allows for greater redundancy and flexibility in the power system, which can improve stability.

However, there are some variations in the Spread Factor values between different transmission system operators. For example, SP7 has the highest Spread Factor at 2-Gateway, but its value drops significantly at 3-Gateway. In contrast, SP10 has a relatively low Spread Factor at 1-Gateway, but its value increases significantly as the number of gateways increases.

Overall, the table highlights the importance of considering the specific characteristics of each transmission system operator when assessing the stability of a power system, as well as the importance of having a sufficient number of gateways to improve the stability of the system.

4.5.6 Analyze SNR vs Spread Factor

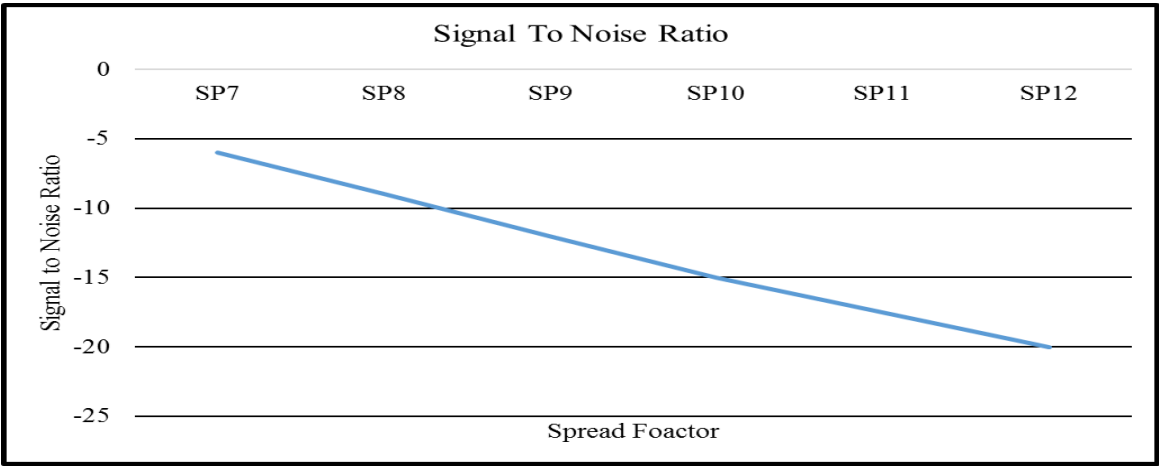


Figure 4.30: Signal to Noise Ratio vs Spread Factor.

Figure (4.30) appears to be showing the relationship between Spread Factor and SNR (Signal-to-Noise Ratio) for a communication system. The Spread Factor is a measure of the

ability of the system to withstand interference and maintain a reliable connection, while the SNR is a measure of the ratio of the signal power to the noise power present in the system.

Looking at the Figure the Spread Factor increases, the required SNR decreases. This is because a higher Spread Factor can help to reduce the effects of interference and improve the stability of the communication system, which means that a lower SNR is needed to maintain a reliable connection.

For example, at a Spread Factor of 7, a minimum SNR of -6 dB is required, while at a Spread Factor of 12, a minimum SNR of -20 dB is required. This means that as the Spread Factor increases, the system becomes more resilient to interference and can maintain a reliable connection with a lower quality signal.

However, it's important to note that the values in the table are specific to the particular communication system and application, and may not apply universally. The optimal values for both Spread Factor and SNR will depend on a variety of factors, including the frequency band, modulation scheme, and channel characteristics of the communication system.

5. CONCLUSION AND FUTURE WORKS

5.1 CONCLUSION

In conclusion, a system for monitoring and detecting faults in the water pumping system using LoRa network technology can help improve the efficiency and reliability of the water pumping system. By using sensors to collect data on parameters such as flow rate, pressure, temperature, and vibration, the system can detect anomalies and faults in the system in real-time. The use of LoRa network technology provides the advantage of long-range wireless communication with low power consumption, making it ideal for remote monitoring of the water pumping system. The system can send alerts to maintenance personnel or operators if it detects a fault, allowing for prompt action to be taken to prevent further damage to the system.

LoRa has carried various applications to the IoT market thanks to its wide inclusion and low power utilization. In this review, the plan and execution of a LoRa network enveloping equipment and programming is proposed fully intent on offering an adaptable and far reaching answer for fostering a confidential LoRa organization. The open source project is moreover available on GitHub. Concurring on field tracks, the best transmission range for our gadget in metropolitan settings is generally 7.5 kilometers. Besides, we exhibit that the upgraded engineering of the LoRa framework permits it to oblige in excess of 10,000 LoRa hubs with equitably disseminated PC assets.

Increasing the number of LoRa nodes in a network has both benefits and drawbacks. On the one hand, a larger number of nodes can provide more extensive coverage, allowing for more data to be transmitted and received. However, this also leads to increased congestion, which can result in slower data rates and longer transmission times. Additionally, as the number of nodes increases, so does the likelihood of collisions and packet loss, which can degrade the overall performance of the network.

Also, Adaptive Data Rate (ADR) can significantly improve the performance of a LoRa network by optimizing the transmission parameters based on the current network conditions. ADR can help reduce energy consumption, increase network capacity, and improve overall reliability. Our analysis of a 600 node and a 1000 node LoRa network with and without ADR showed that ADR can increase the data extraction rate and reduce the packet loss rate.

However, it should be noted that the optimal ADR parameters depend on the specific use case and network conditions, and they should be carefully tuned to achieve the best performance. Overall, the use of ADR can be a beneficial approach for optimizing the performance of LoRa networks, especially for large-scale deployments.

Increasing the number of gateways in a LoRaWAN network can have a positive effect on the data extraction rate, as it can increase the overall network coverage and reduce the probability of packet loss due to interference or other factors.

When a device transmits a packet, it is received by one or more gateways in the network, which then forward the packet to the network server for processing. If the packet is not received by any gateway or is lost during transmission, it cannot be processed by the server, resulting in a lower data extraction rate.

By adding more gateways to the network, the chances of a device's transmission being received by at least one gateway increases, as the coverage area of the network expands. This, in turn, can increase the data extraction rate by reducing the number of lost packets and ensuring that more data is available for processing.

However, the effect of increasing the number of gateways on the data extraction rate is not linear, and there may be diminishing returns as the number of gateways increases. Additionally, other factors such as the network topology, interference, and packet collision may also affect the data extraction rate, so it is important to carefully evaluate and optimize the network configuration to achieve the best possible performance.

5.2 FUTURE WORKS

There are several future works that can be done to enhance the system for monitoring and detecting faults in the water pumping system using LoRa network technology. Some of these future works include:

- a. **Implementing predictive maintenance:** In addition to detecting faults in the water pumping system, the system can be enhanced by implementing predictive maintenance. This involves using machine learning algorithms to analyze the data collected by the sensors and predict when maintenance is required before a fault occurs.
- b. **Integrating with other systems:** The system can be integrated with other systems such as billing and customer management systems to provide a more comprehensive view of the

water pumping system's performance. This can help to identify trends and patterns that can be used to optimize the system further.

- c. Improving sensor technology: Advances in sensor technology can be utilized to improve the accuracy and reliability of the system. For example, the use of smart sensors with self-diagnostic capabilities can provide more accurate data and reduce the likelihood of false alarms.
- d. Exploring alternative communication technologies: Although LoRa network technology is suitable for long-range wireless communication with low power consumption, exploring other communication technologies such as 5G and NB-IoT can provide additional benefits such as higher data transfer rates and lower latency.
- e. Incorporating remote control: The system can be enhanced by incorporating remote control capabilities, allowing maintenance personnel or operators to control the water pumping system remotely. This can be particularly useful in cases where access to the system is difficult or dangerous.

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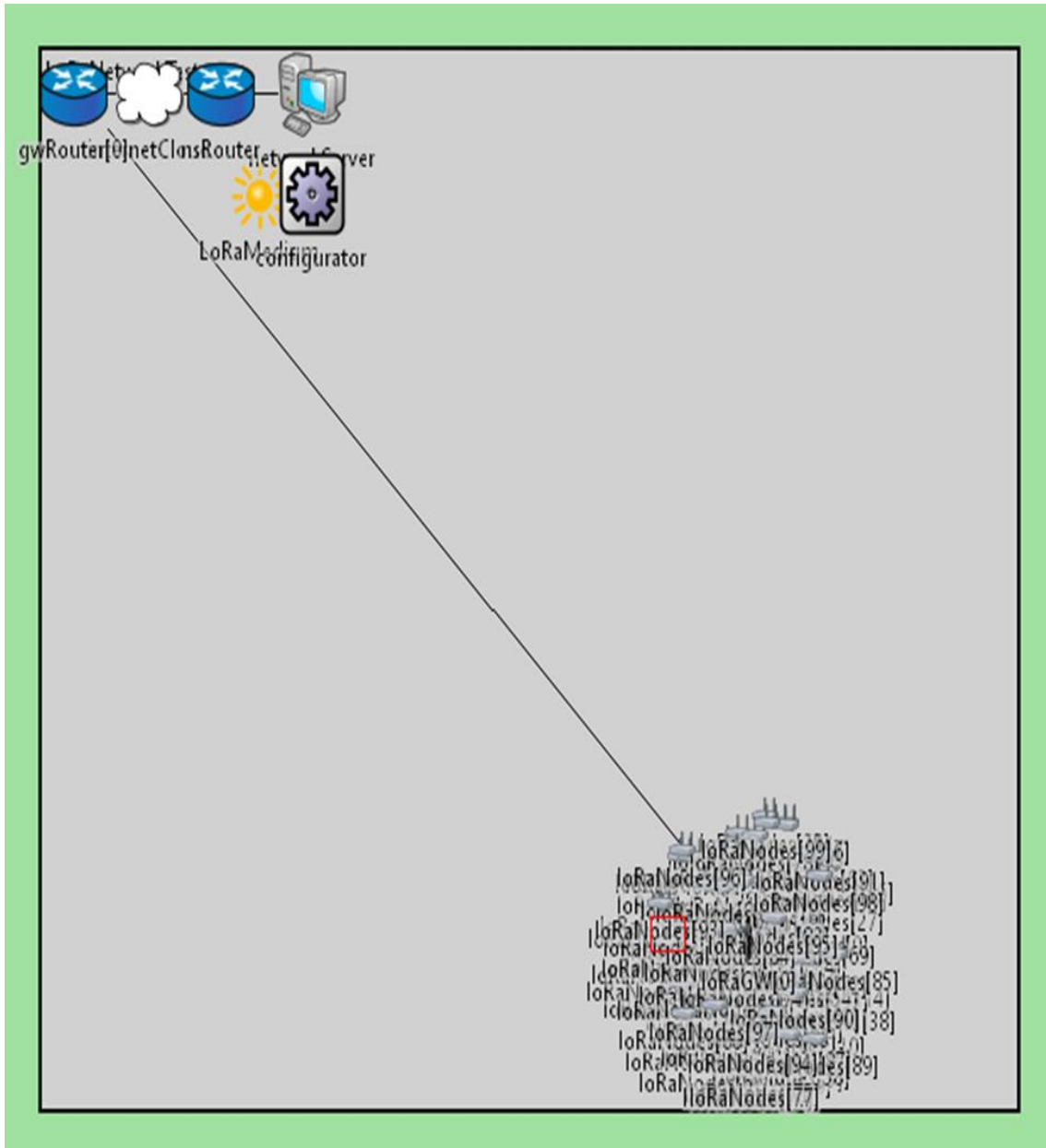
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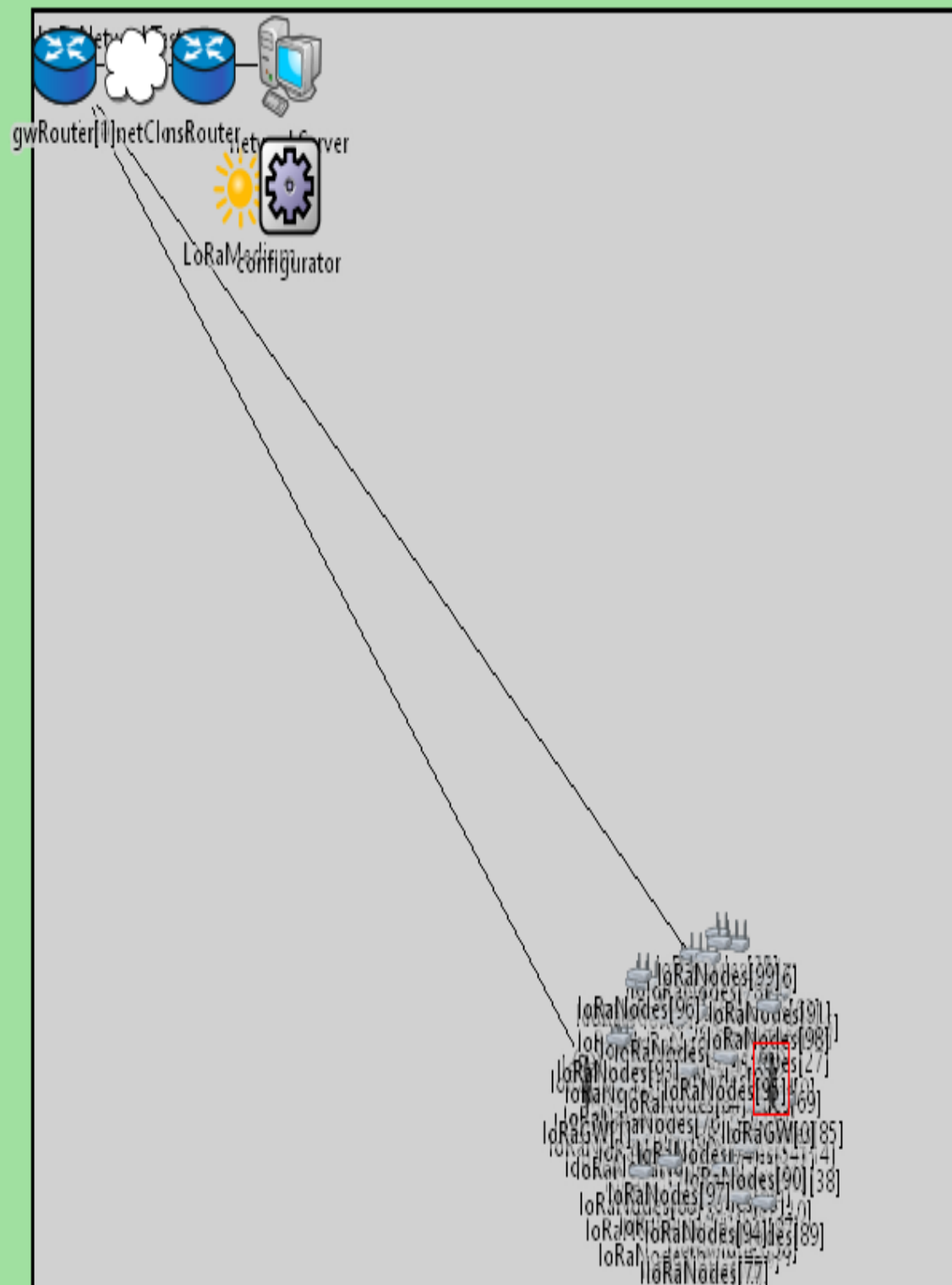
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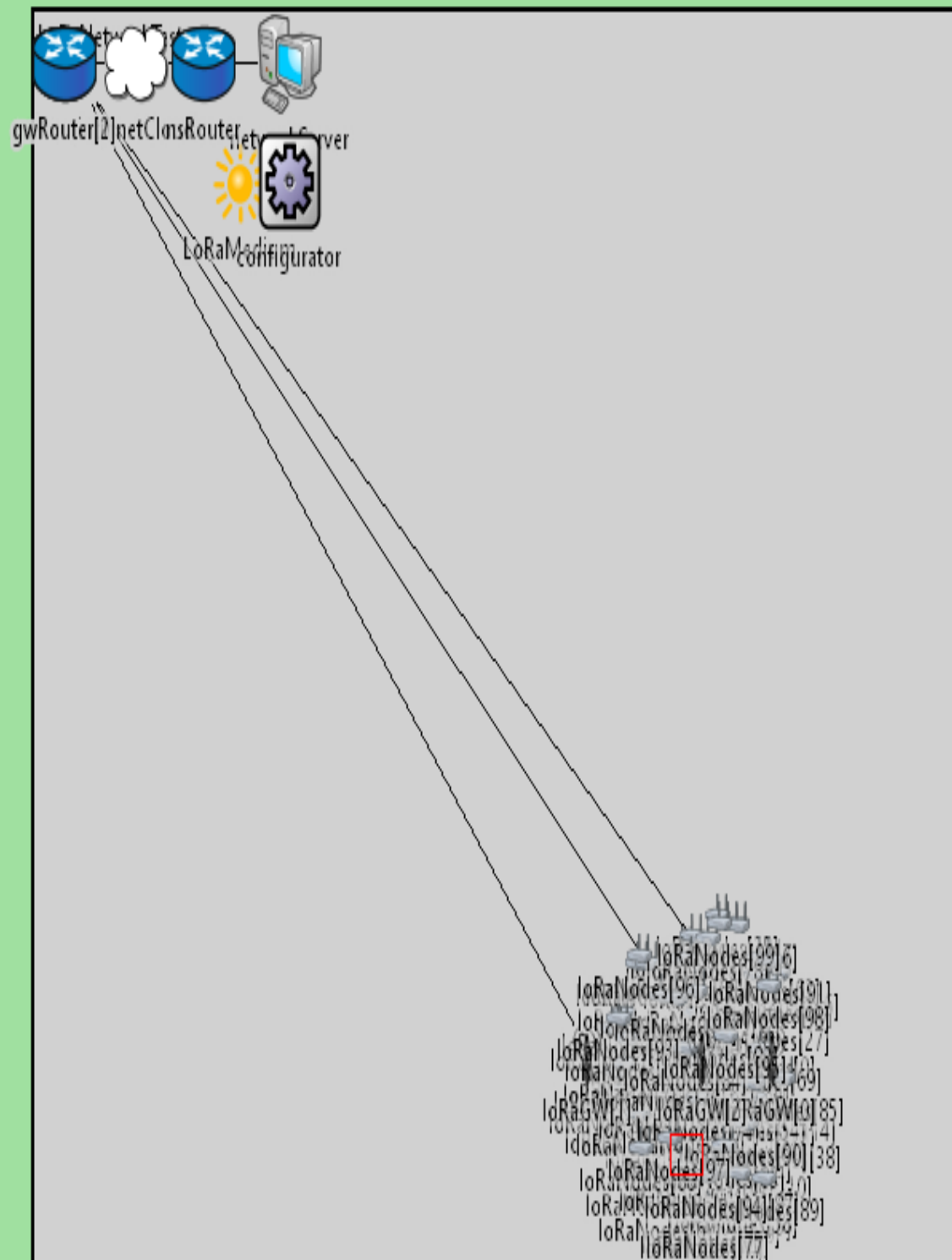
APPENDIX

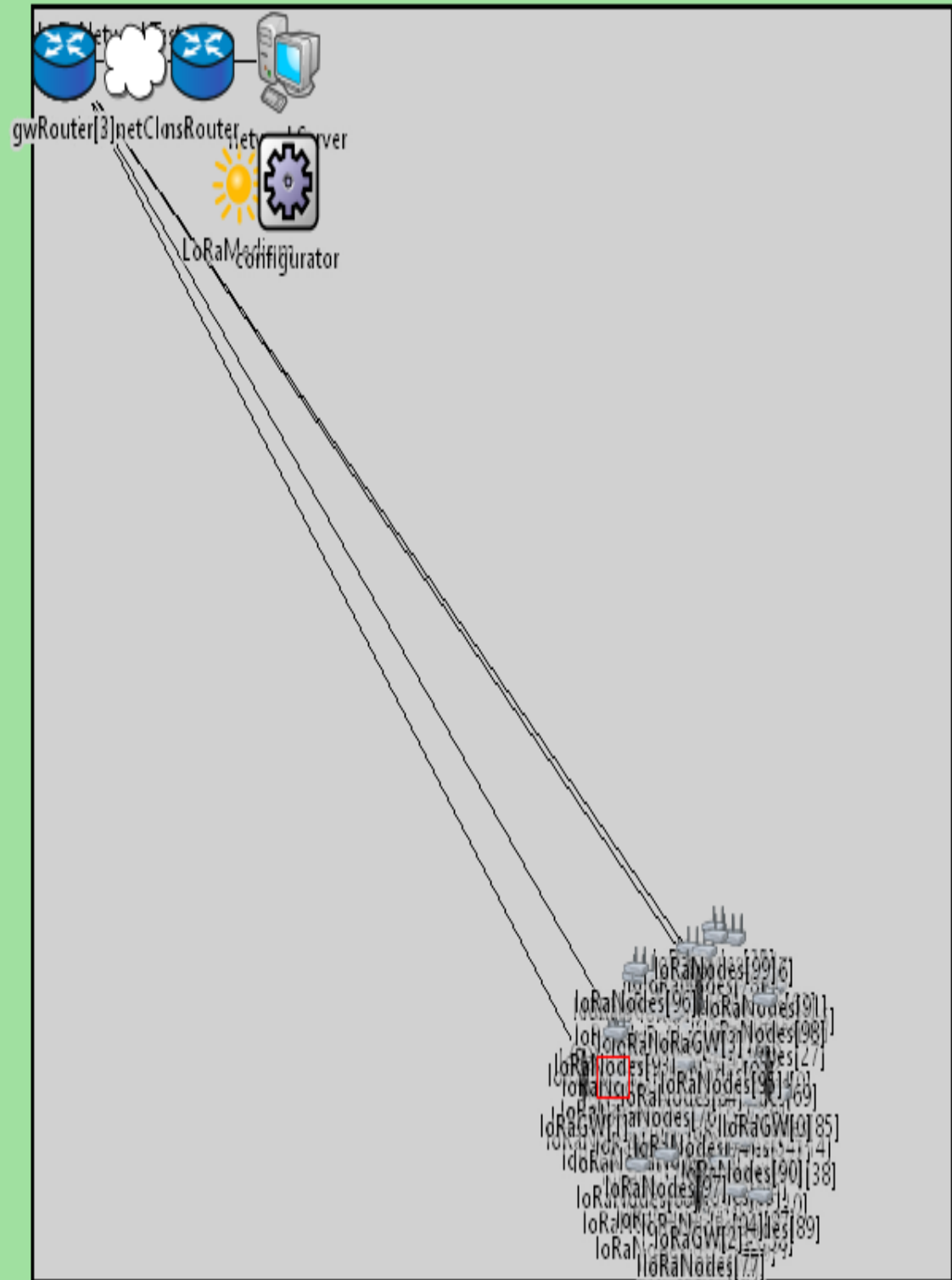
LORA NETWORKS ARCHITECTURE

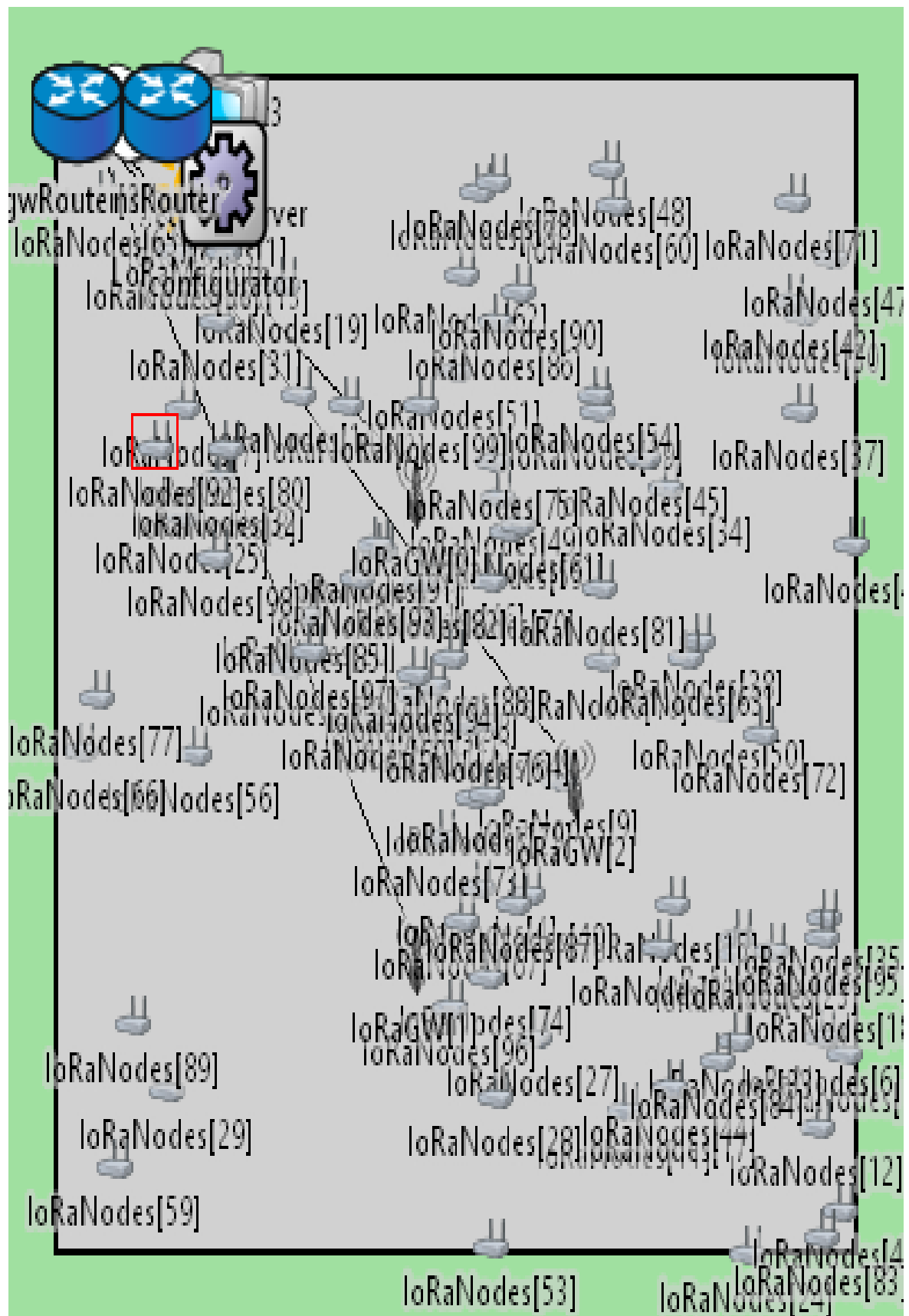
a. 100 Node Without ADR

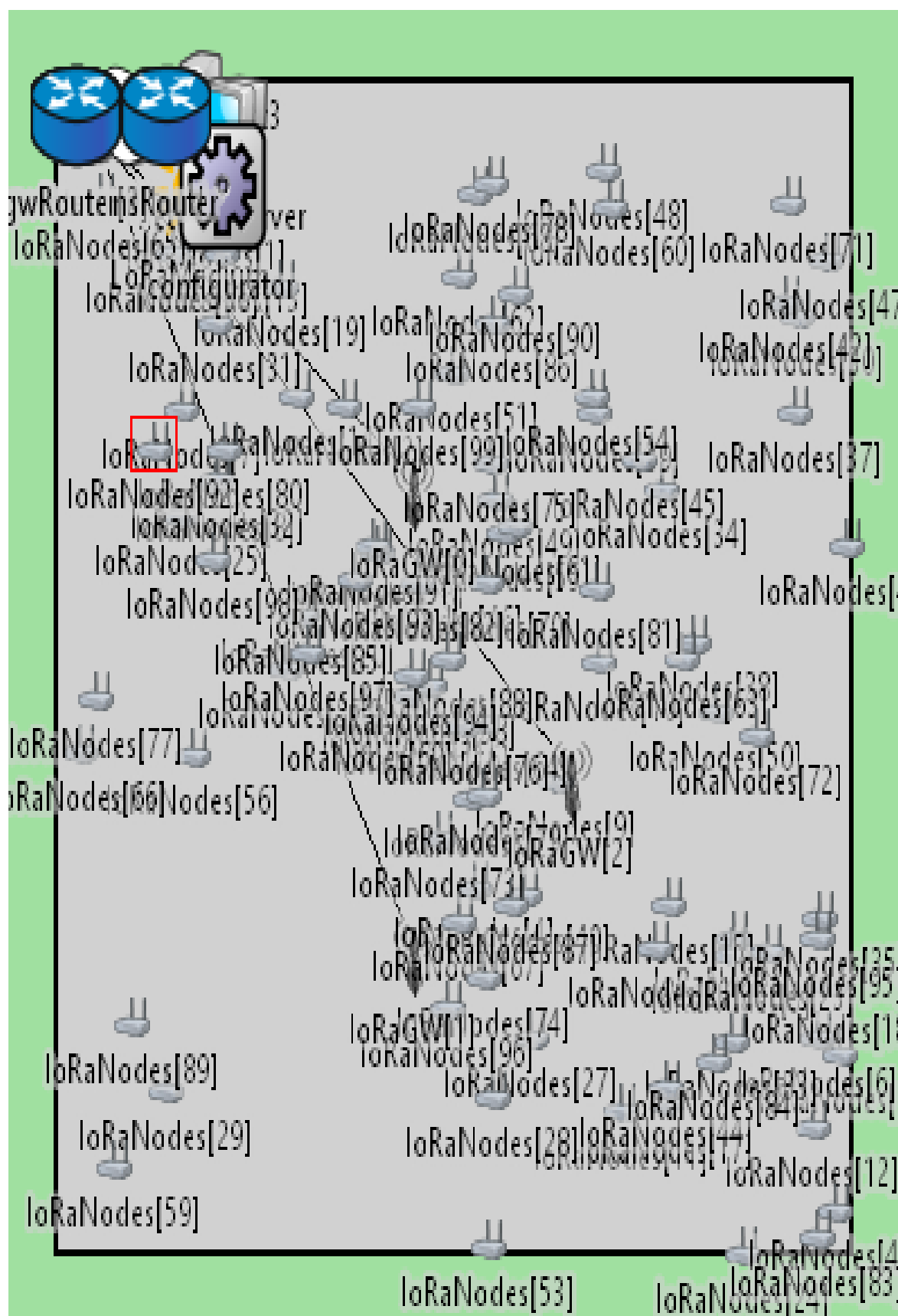


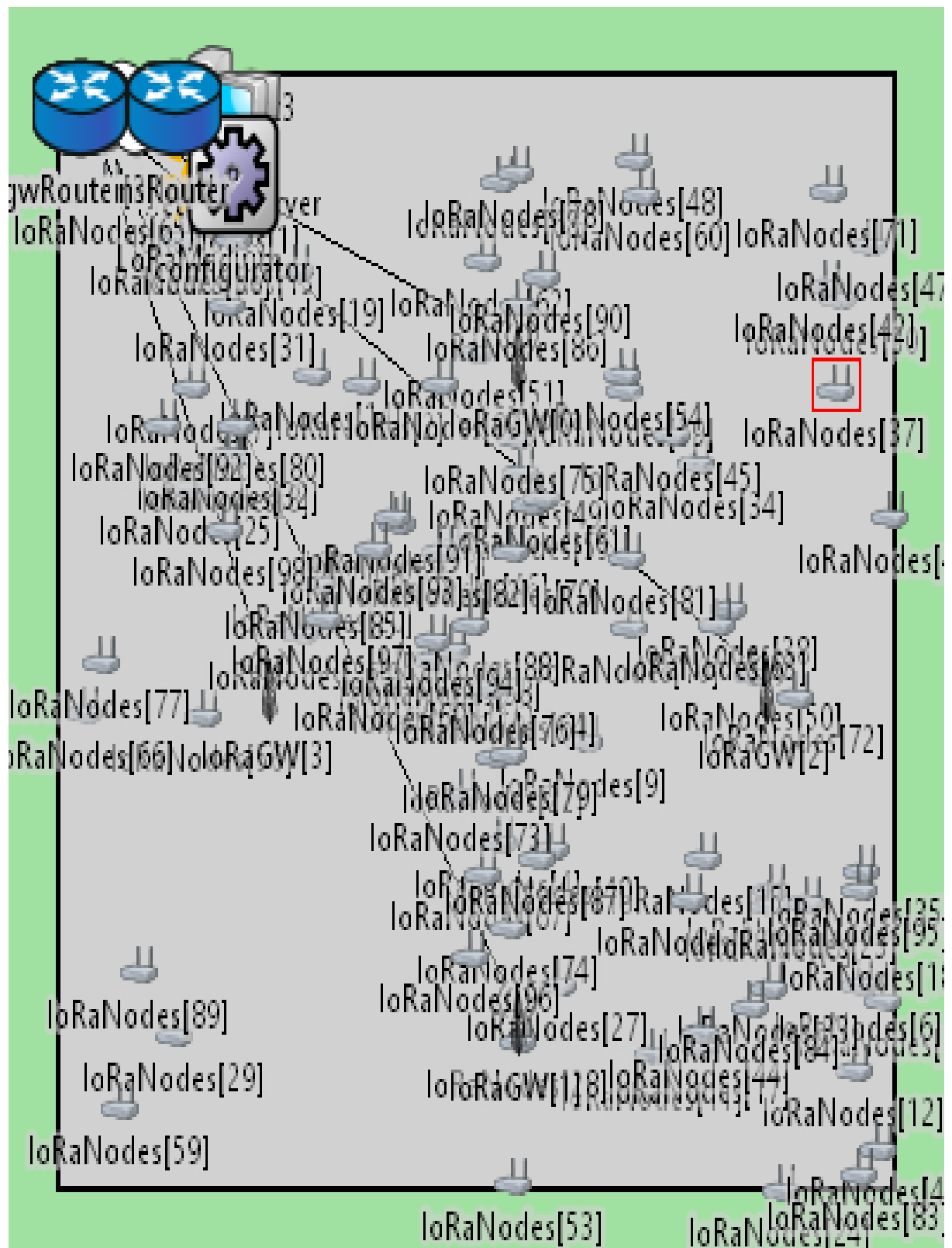




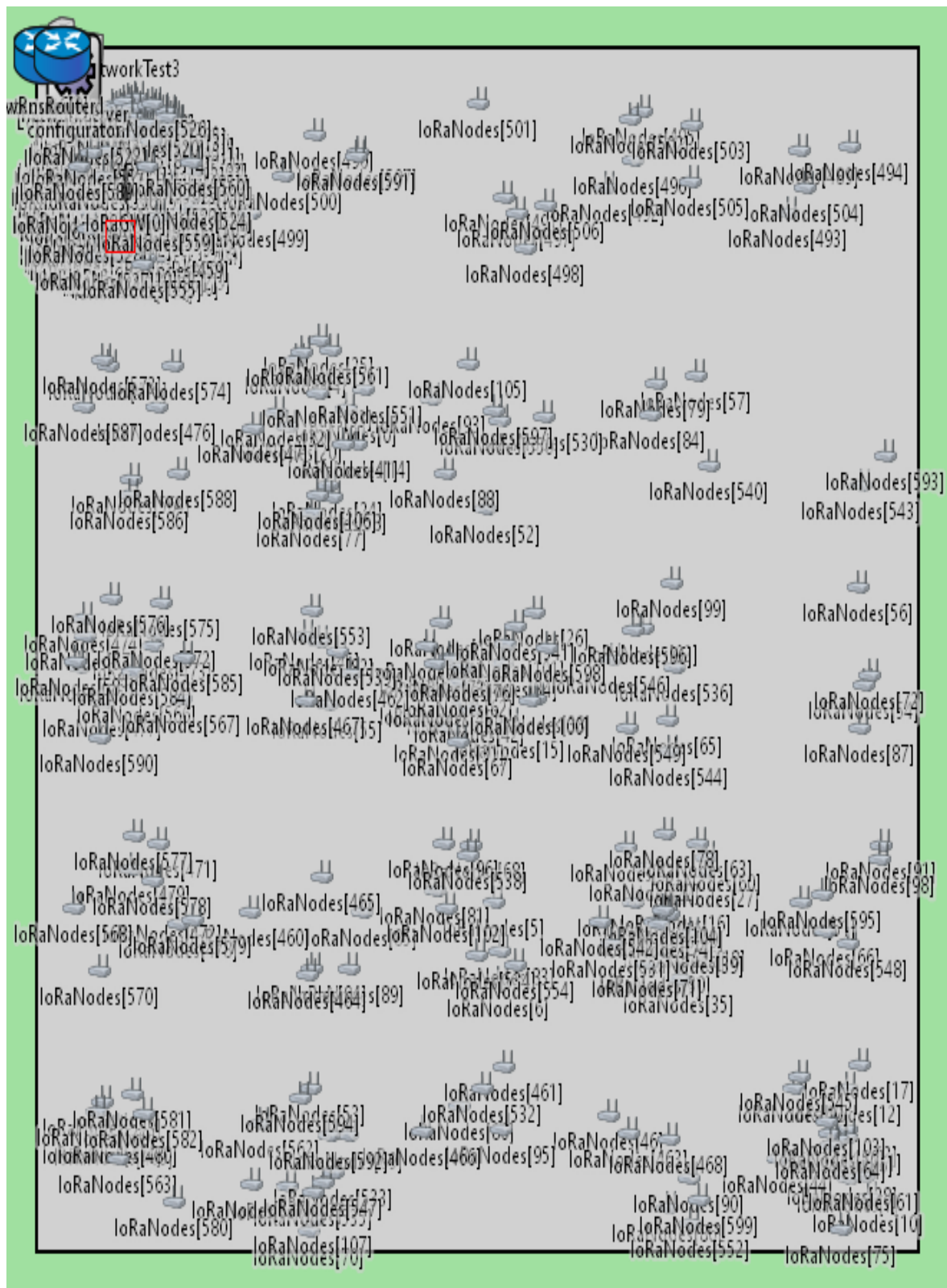


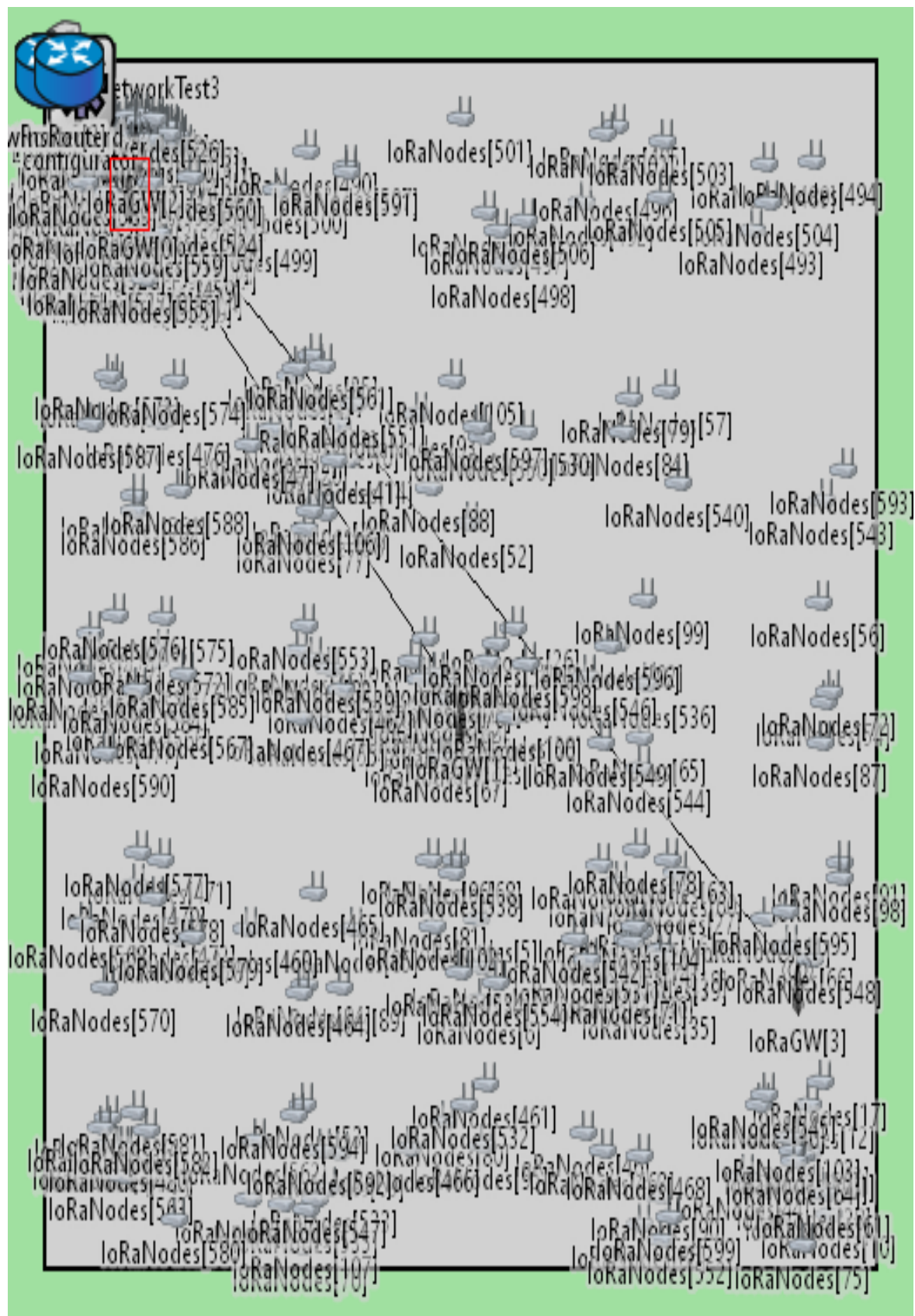






a. 600 Node With ADR





b. 1000 Node Without ADR

