



**USING THE WIRELESS SENSER NETWORK TO MONITOR
THE ENVIRONMENT OF THE TRANSMISSION LINE
IN THE ELECTRICAL GRID**

by

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DECLARATION

I, Lu Han, declare that I am the sole author of this Project; that all references cited have been consulted; that I have conducted all work of which this is a record, and that the finished work lies within the prescribed word limits.

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Abstract

The pressure on global power resources has increased rapidly in recent years. The reliability requirements of power supply are gradually increasing, which causes tremendous pressure on the operation of the power grid. Since transmission lines are often distributed in complex and variable areas of the environment which will have a certain degree of impact on the normal operation of transmission lines, such as excessive wire temperature, voltage and current failure, wire tension and ice covered wires. After a failure, the traditional manual inspection and fibre transmission methods are costly, and the staff cannot find the fault point and solve the corresponding problem as quickly as possible.

Based on the above problems, this thesis designs a transmission line monitoring system based on actual conditions. The function requirements and components of the monitoring system are analyzed. Through the online detection of the transmission line, the operating state of the transmission line can be grasped in real time, and the voltage, current, wire temperature, wire tension and wire icing can be detected in the transmission line. And The operation information of the transmission line is displayed on the webpage of the monitoring center. Staff can timely grasp the information of transmission lines and improve work efficiency.

Based on the NetSim simulation platform, ZigBee technology was tested in the smart grid online monitoring application. And the availability of wireless sensing technology was further verified. In the experiment, three network sizes and five traffic types were selected for simulation. In order to verify and evaluate the effectiveness, advantages and disadvantages of the research on the intelligent grid online monitoring system based on the IOT(Internet of things) technology, the routing protocol in the network layer of the IOT three-layer technology network structure is deeply studied. In the simulation process, four parameters of throughput, delay, packet transceiving rate and energy consumption are selected for comparison. The optimal parameters are selected based on the simulation results.

Through the implementation of the intelligent grid online monitoring system of the IOT technology, the purpose of reducing the workload of the inspection personnel is achieved, and real-time data can be provided for the staff to make decisions. Finally, the transmission line status score and further operations are automatically given by establishing a transmission line evaluation table. It can reduced human resource waste and human error.

The transmission line online monitoring system can improve the reliability and safety of the power grid operation and play a role in remote monitoring and fault warning for the special environment of the transmission line.

1. Introduction

1.1 Background

As global demand for electricity continues to increase, power supply reliability needs to increase gradually. The operation of the grid is under tremendous pressure. There are many factors affecting the stability and safety of the power system. Among them, the power generation, transmission, substation, power distribution, electricity and power resources of the power system are rationally dispatched [1]. Transmission lines are typically distributed in complex areas with variable environments, which have a significant impact on grid security. The use of the internet of thing (IOT) and wireless sensor network (WSN) technologies can effectively monitor the grid environment[2].

The characteristics of transmission lines are: wide distribution, large scope, and easy to be affected by natural environment, meteorological and industrial and agricultural pollution [3]. In order to minimize the impact of the above factors on the grid, it is necessary to apply emerging IOT technologies. The use of advanced IOT technology can promote the intelligent management of power systems. The grid monitoring system provides real-time and comprehensive data for grid management.

1.2 Problem Statement

Most of the transmission lines are distributed in the wild, and the coverage of the lines is wide where the geographical environment and climatic conditions are poor. The traditional manual inspection method is difficult to ensure the accuracy of the results, and it will consume a lot of human and financial resources. At the same time, real-time online measurement is not possible, and the efficiency is very low. It is impossible to find the safety hazard on the high-voltage transmission line in time. Moreover, the scope of power grid monitoring is huge, the service life is long, and subsequent maintenance is also difficult[4]. For grid workers, it is difficult to understand the real-time status of the actual grid and quickly detect faults.

1.3 Aims & Objectives

Based on the application of WSN in transmission line monitoring system, this thesis combines the topology of long-chain WSN to study the WSN suitable for transmission line monitoring. According to the requirements of reliability and real-time in the wireless transmission process, the real-time status monitoring of the power grid is achieved.

The following objectives are used to study how to use WSN technology to monitor the transmission line environment in real time:

- According to the characteristics of the transmission line itself, through a wide read of

literature. How the wireless sensor technology overcomes the shortcomings of the prior art is studied.

- Design a grid monitoring system based on WSN technology and select the technology that is appropriate for the system (eg ZigBee or Wi-Fi). The system should have the advantages of low power consumption, low cost, safety and reliability.
- Establish a network transmission model for real-time monitoring of the grid. The applicability of the wireless transmission mode is tested corresponding to different evaluation parameters (such as packet transmission rate, average end-to-end delay, network throughput, etc.).
- Establish a transmission line monitoring system evaluation system to enable staff to understand the real-time status of the grid and to detect faults.

1.4 Thesis outline

The rest of the thesis is organized as follows:

- Chapter 2 will introduce the need for grid monitoring and the application of WSN in transmission line monitoring systems. The focus is on the applicability of ZigBee and Wi-Fi technology in such field.
- Chapter 3 will introduce the methodology used to implement this project. The research philosophy and research methods have been established, especially the application of the control variable method. The advantages and disadvantages of serial port debugging and software simulation are discussed in detail.
- Chapter 4 will show experimental methods and data collection. Firstly, the system requirements were analyzed and the transmission line monitoring system was designed. Then the performance of the simulation experimental test system was designed.
- Chapter 5 will discuss experimental results and assessments. The impact of different node numbers, traffic types and routing protocols on network performance is tested by simulation. A transmission line evaluation mechanism has been established, and the data is transmitted to the monitoring center for processing. Discuss how the system evaluates the safety of transmission lines.
- Chapter 6 summarizes the contributions made by this thesis and the possible directions for further research.

2. Literature Review

2.1 Power grid

The substation of various voltages in the power system and the whole of the transmission and distribution lines are called power grids. It consists of three units: generation, transmission and distribution[5]. The typical structure of power grid is shown at Figure 1.

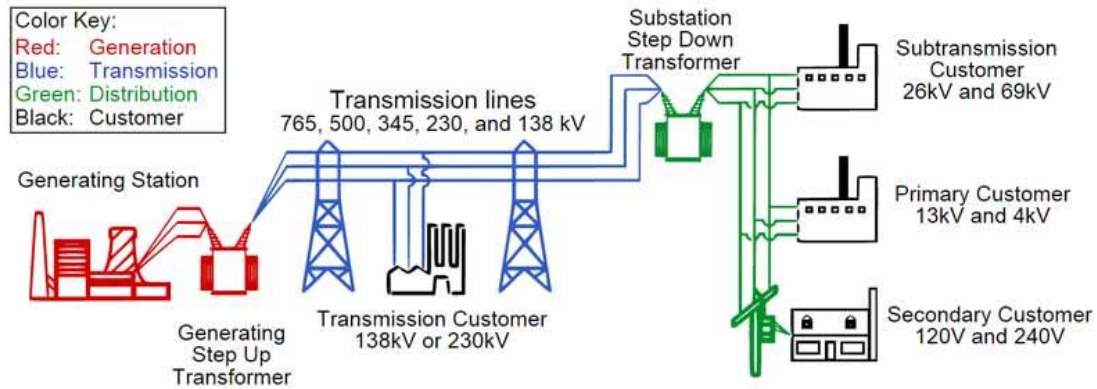


Figure 1 The typical power grid structure[6]

The task of the power grid is to transport and distribute electrical energy and change the voltage. In recent years, with the development of social economy, the national electricity consumption has increased sharply, and the construction and scale of ultra-high voltage power grids have expanded rapidly [7]. As shown in Figure 2, world electricity consumption in various regions has increased rapidly from 1980 to 2030.

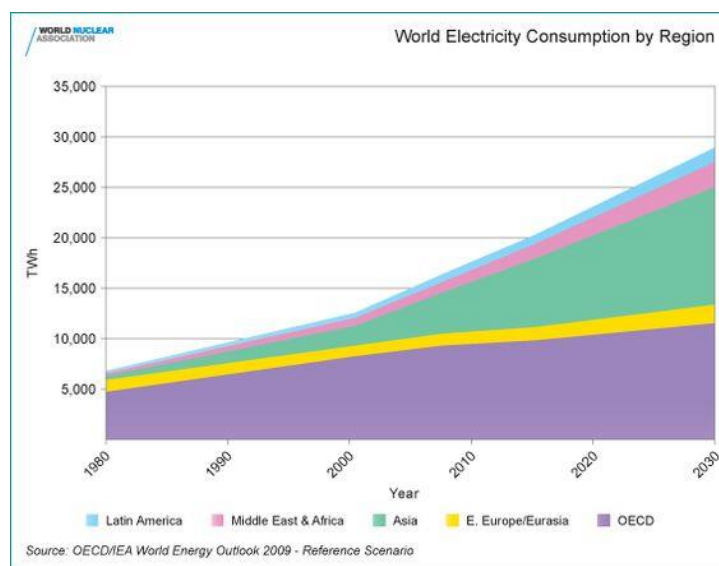


Figure 2 World Electricity Consumption by Region[8]

2.1.1.1 Consequences of grid failure

The grid environment is complex and variable, and the grid is closely related to our daily lives and work. Once the grid fails, the consequences are very serious. Every country has suffered tremendous damage to varying degrees due to the failure of modern power systems.[9]

2.1.1.1.1 Blackouts

In the United States, the most famous grid accident was the 2003 Northeast Power Outage. Power outages affected 10 million people in Ontario and 45 million in 8 US states[10]. In India, existing power systems face many problems, such as intermittent power and power theft. These problems have caused huge losses to the local power grid [11].

According to the load loss, the severity of the power outage is divided. A power outage accident with a load loss of ≥ 8 million kilowatts per time is called a major power outage. So far, the world has reached 25 times. Of the 25 accidents, the most serious was the “8.14 US gold blackout” with a load loss of 70 million kilowatts. Some major power outages are listed in Table 1.

Article	Millions of people affected	Location	Date
July 2012 India blackout	620	India	30 July 2012
January 2001 India blackout	230	India	2 January 2001
November 2014 Bangladesh blackout	150	Bangladesh	1 November 2014
2015 Pakistan Blackout	140	Pakistan	26 January 2015
2005 Java-Bali blackout	100	Indonesia	18 august 2005

Table 1 Major blackouts [12]

On August 14, 2003, at 16:11 EST, power outages occurred in the north-eastern United States and south-eastern Canada (1.790, 0.00, 0.00%). A three-circuit line hits the tree and the load is transferred. The power outage affected eight states and 50 million people. Ten million people in the two provinces of Canada are also affected. In addition, at least 8 people were killed in the power outage [13].

On March 7, 2019, Venezuela began to lose power. In the following days, the continuous blackout and water cuts caused many parts of the country to fall into paralysis. Some of Venezuela’s power facilities are outdated, and failures occur frequently in the context of social unrest [14], [15].

In fact, a blackout is a small probability event, but it is always possible. The daily work of many power systems is to further reduce this small probability. As the transmission distance of the transmission line becomes longer and longer, the power system becomes a "small neck of the big head", which is represented by the oscillation between the two areas. It has attracted the attention of power engineers. The most effective way is to reduce the transmission distance, build more lines, and strengthen the monitoring of transmission lines.

Critical infrastructure security efforts must be guided from the overall national security perspective. Critical infrastructure is the target of various threat actors, and their attacks are often cross-domain combinations. Therefore, infrastructure defence cannot simply be regarded as a technical confrontation, but as a comprehensive confrontation. A capacity-oriented construction model that enhances the security protection capabilities of critical information infrastructure [16].

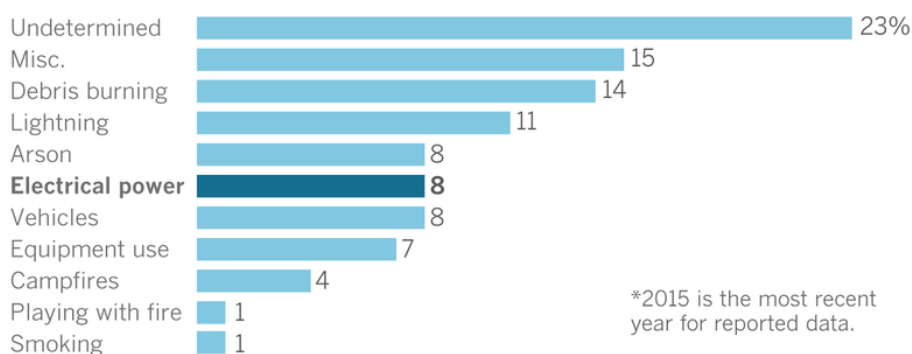
2.1.1.2 Wildfires

On a global scale, most of the grid infrastructure we rely on every day has been more than 35 years old. Aging infrastructure may lead to forest fires. The cause of the 19-year-old Beijing Da Xing fire was due to electrical fires caused by wire failures buried in polyurethane moisturizing materials [17]–[19].

Explosive failures in power lines and other electrical equipment have often been listed as one of the three singular sources of wildfires in California in the past few years. In 2015, the last year of reporting data, the power problem triggered 149,241 acres of burning - more than twice as many other reasons. The wildfire caused by grid equipment is shown in Figure 3:

Sources of wildfires

Power lines and electrical gear problems have regularly ranked among the top identified causes of California wildfires. Shown below are data for 2015.*



*2015 is the most recent year for reported data.

Source: California Department of Forestry and Fire Protection

@latimesgraphics

Figure 3 Fire causes[20]

2.1.2 Reasons for the grid to be monitored

From the August 2003 North American blackout to the California wildfire accident, monitoring of transmission lines is critical. The main problems in the operation and maintenance of the power grid include damage to the power grid itself and external damage.

2.1.2.1 Damage to the power grid equipment

The most common and dangerous fault in the entire process of circuit delivery is a short circuit fault. Most of the short-circuit faults are caused by insulation degradation or mechanical damage to electrical equipment. In addition to this, there is an overvoltage caused by lightning, which leads to damage to the tower, short circuit caused by bird contact, and operator misoperation. Therefore, it is difficult for power grid equipment to operate safely and reliably. [21].

2.1.2.2 External force damage

External forces can be divided into natural forces and artificial forces. The external damage caused by nature mainly includes lightning strikes, snow and ice disasters, hurricanes, forest fires, etc., causing pole collapse, transmission line disconnection, and transmission line damage. Such external damage is unpredictable and sudden. The external damage caused by man-made mainly includes the construction of the transmission line corridor and the destruction of the transmission line caused by the theft [7], [22].

As an important part of the power industry, power transmission will lead to power supply failures, which will cause large economic losses and adverse social impacts. There are two basic steps in the realization of the function of the smart grid: one is the efficient and accurate conversion of electrical energy; the other is the effective control of electrical energy. To achieve these two functions, the smart grid needs to focus on the basic characteristics of strong, self-healing, compatible, economic, integrated, and optimized. Therefore, a perfect monitoring system has become an effective guarantee for the realization of the basic characteristics of the smart grid [23].

2.1.3 Traditional methods of power line monitoring— manual patrol

In order to ensure the safe and reliable transmission of electrical energy to the transmission line, manual inspection is the conventional way of patrol the transmission line.

This method seems to be very simple, but the actual efficiency is low, it takes a long time, and it needs to be equipped with some optical equipment, as well as the need to train some high-quality and experienced line-patents, which have more manpower and financial resources for the inspection department. If the tower is high and the surrounding geographical environment is complex, manual inspection is more difficult. The use of helicopters for high-altitude inspections makes it easier to miss faults, resulting in incomplete inspection lines.

This makes it difficult for the manual inspection method to meet the operation and maintenance requirements of the high-voltage power grid. With the in-depth development of state maintenance work and the construction of a strong smart grid, the application of transmission line condition monitoring technology is more and more extensive. With the continuous development and advancement of computer technology, sensor technology and network technology, it is easier to realize intelligent monitoring and real-time inspection of transmission lines [24].

2.1.4 Transmission line online monitoring system---optical fibre

In the field of transmission line online monitoring technology, the online monitoring technology of transmission lines has been studied since the 1980s. Many related companies have studied many products used in the power grid. Early equipment was mainly used for monitoring the temperature, vibration, inclination, tension and sag of the wire, using contact, non-contact sensor measurement [25].

Various sensor nodes, such as RFID (radio-frequency identification), temperature sensors, voltage acquisition devices, etc., are applied in the power grid. These terminal sensing devices collect various parameters in the grid and transmit them to the grid company. Most data transmission uses wired transmission methods such as fibre optic cable [19], [26]. Remote video transmission has been limited until the popularity of wireless transmission technology. Many products require video to be relayed to the fibre breakpoint of the power private network.

Among various communication methods, optical fibre has fast communication speed, low cost and strong anti-interference ability, and has become the main choice for line monitoring. However, since the transmission line is long and there is a lot of data to be monitored and there are many miscellaneous items, a large number of sensors are required on the entire line. At the same time, the position and communication specifications of various sensors vary depending on different objects. Therefore, even considering the cost of the fibre access port, it is impossible to connect all the sensors through the fibre.[27]

In summary, the method of optical fibre transmission is costly and the transmission is unreliable. The power transmission line has wider coverage of the area, a longer transmission distance, and the geographical conditions of the transmission line passing through the region are complex and the climate is variable. These features have brought great challenges to the daily operation, maintenance and overhaul of the power supply inspection department line.

2.1.5 Smart Grid

Since the 21st century, the world has entered an era of rapid development of science and technology, all thanks to the construction of power grids. This is because energy services to human society are through the grid. Whether it is the people's life, industrial production, agricultural production and the realization of urban functions, it is inseparable from the

construction of the power grid. Electricity is the foundation and an important pillar industry of the national economy. Power transmission is an important part of the power industry. For any country, the power industry is an extremely important basic industry [4], [28].

Smart grids add intelligence to traditional grids by using advanced transmission technologies, allowing two-way communication between utility companies and customers. Smart grid usage includes control technology, automation technology, and new equipment that works in tandem with the grid to digitally respond to our rapidly changing power needs [29]. Smart grids can affect many aspects of our lives, as shown in Figure 4.

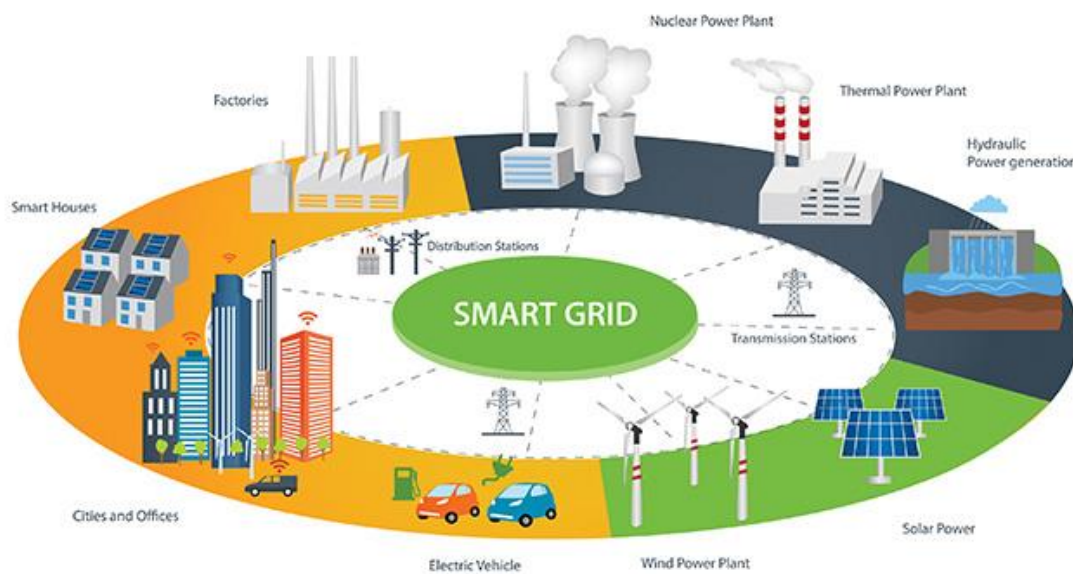


Figure 4 The Application of Smart Grid [30]

In recent years, many high-tech technologies have been fully utilized in the power grid. The smart grid is bound to become the future of the grid.

2.2 WSN

A wireless sensor network (WSN) is a self-organizing network system consisting of a large number of sensor nodes deployed in the monitoring area and composed of wireless transmission technologies. It can be said that WSN is the technical support of the IOT.

A typical WSN system is shown in Figure 5. It contains a variety of connected sensors, gateways, wireless communication technologies and client computers.

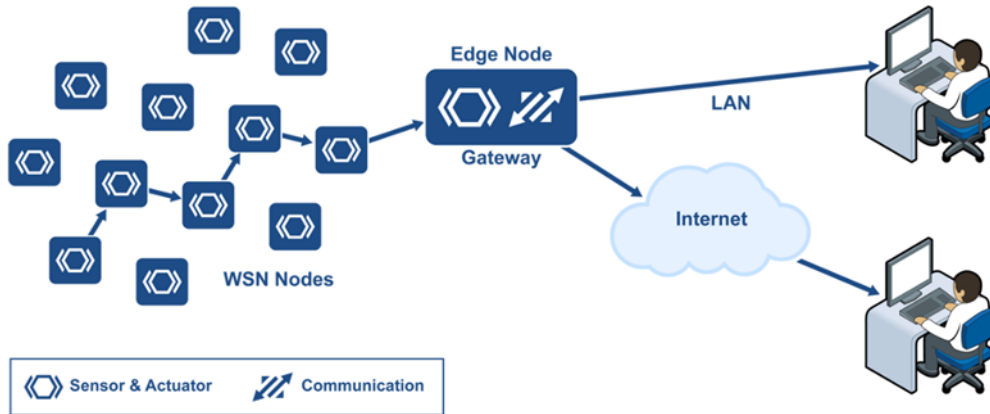


Figure 5 A typical WSN [31]

WSN were originally designed to promote military operations and extend to the health, transportation, and industrial sectors [30].

2.2.1 IOT

The Internet of thing (IOT) is considered to be the most important part of the new generation of information technology. As an emerging technology, the main purpose of the IOT is to achieve intelligent identification, location, tracking, monitoring and management of objects.

With IOT technology, people can exchange a lot of information with anyone and anyone, anytime, anywhere. Cisco expects to build about 50 billion new connections for the IOT in the next decade[31].

From the perspective of technical architecture, the IOT has three layers: the perception layer, the network layer and the application layer, as shown in Figure 6.

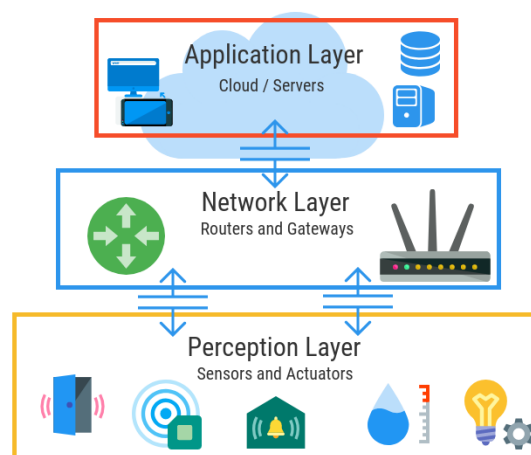


Figure 6 Three Layer (Tier) IOT Architecture[34]

- The sensing layer consists of sensors, actuators, and edge devices that interact with the environment. These numerous sensors are an important source for identifying objects and collecting information.
- The network layer consists of various networks and cloud computing platforms. The information collected and processed by the sensing layer is the primary function of the network layer.
- The application layer is the interface between the IOT and the application. It provides users with data processing and storage as well as professional services.

2.2.2 WSN applied to real-time monitoring system of power grid

At present, the application of WSN in the smart grid is mainly reflected in the power supply side and the transmission side. Among them, the power supply side is mainly used for smart meter networks and advanced measurement systems, while the transmission side is mainly used for transmission line monitoring.

The application of the WSN on the transmission side mainly monitors the state of the transmission line. Considering the need for smart grids for grid security and self-recovery, it is necessary to monitor line temperatures, circuit breakers, wires, etc., so that the transmission network itself can predict accidents based on environmental changes. These sensors are then connected to a secure communication network to monitor various parameters of the entire line in real time.[35]

Sensing acquisition module could include temperature and humidity, infrared camera, wind speed, leakage current, ice coating condition, wire stress, dip angle, lightning current, wind bias, vibration and other sensors.

In order to eliminate the hidden dangers in the transmission process, the traditional power grid equipment maintenance method is periodic maintenance, which originated in the 20th century and is still in use today. For existing electrical equipment, this type of maintenance is flawed[7].

First of all, it is necessary to overhaul the well-functioning electrical equipment, wasting financial resources and manpower, which is a major overhaul and has little impact. Second, if a sudden electrical failure occurs, it needs to be repaired in time. If regular maintenance is still performed, it will seriously damage the equipment and manpower.

Real-time monitoring, diagnosis and protection of the power system can prevent, mitigate or avoid the impact of power equipment failures and natural disasters on the system. Therefore, the use of online real-time sensing technology to monitor grid operation is the key to ensuring safe, reliable and efficient operation of the smart grid.

2.2.3 Advantages of WSN

When IOT technology is added to the grid, the network layer can be changed from the original fibre-optic cable transmission to wireless transmission. This information transmission saves a lot of cost and the equipment is easy to install. The data collected by the terminal sensing device is uploaded to the server, which makes data query and call more convenient. Installing multiple sensors in a certain area facilitates timely detection of problems and reduces accidents. Through the application of WSN technology, real-time monitoring of the transmission line can be realized. Data is transmitted to remote clients via wireless transmission technology and displayed on the computer for increased productivity.

WSN has the following advantages[11], [36]:

- 1) The data acquisition, data processing and data communication functions of the nodes in the WSN are highly integrated.
- 2) Using the wireless communication mode can eliminate complicated communication line wiring, and WSN is undoubtedly cheaper than the traditional wired network.
- 3) WSN is a self-organizing large-scale network that processes wireless sensors in a distributed manner.
- 4) WSN is more suitable for use in remote areas or harsh environments. For example, in the pasture, some animals may damage the wiring.

WSN have low-cost, self-organizing networks and application-related features. It is ideal for wireless monitoring and diagnostic systems in the power grid. Transmission line status and environmental monitoring use WSN technology to distribute a certain number of sensors to the grid. Each sensor node is aggregated into a routing node in the ad hoc network to send data to the monitor via wireless communication technology.

2.3. Comparison of ZigBee and Wi-Fi

As the basis of smart grid implementation, with the construction and development of smart grid, communication technology will have huge potential development space. Wireless communication technologies include ZigBee, Wi-Fi, Bluetooth, and ultra-wideband. Because ZigBee and Wi-Fi are more widely used in surveillance systems. This section will analyze these two wireless sensing technologies from the following aspects.

A. Power consumption

Compared to WiFi, ZigBee can support the device for six months to two years under the same

power (two AA batteries), WiFi can only work for a few hours. [37]

B. Operating frequency

The frequency bands of 2.4 GHz, 868 MHz and 915 MHz are all ZigBee license-free bands. Wi-Fi also works at 2.4 GHz and shares the same frequency band with many wireless devices, such as cordless phones and Bluetooth, that do not require a frequency license. [38]

C. Channel Bandwidth

Communication based on the ZigBee protocol has a channel bandwidth of 1 MHz, while Wi-Fi channels have a bandwidth of 0.3, 0.6 or 2 MHz. [39]

D Transmission distance:

ZigBee is limited to wireless personal area networks (WPAN), reaching 10-30 meters in normal applications. Recently, some applications have tended to reach 100 meters in terms of scope. Wi-Fi is available for PAN and WLAN area networks, with an average range of 30 to 100 meters.[40]

E. Data transmission speed

Although the Wi-Fi network is faster than ZigBee in data transmission, it shows a change in speed. The maximum data transmission speed of the Wi-Fi network defined under the 802.11b standard is 11 mbps, while the maximum data transmission speed of the a and c versions is 54 mbps. The ZigBee network's top speed is only 250kbps, which is equivalent to the lowest WiFi network. [40]

F. Network elements

In a standard peer-to-peer network, two stations can be connected to each other. Wi-Fi routers are also needed in places where multiple devices need to be connected to each other and/or want to connect to the Internet. [40]

In ZigBee, network elements can be broadly classified into three types: ZigBee Coordinator, ZigBee End Router, and ZigBee End Device. [40]

G. Network Size

A single Wi-Fi based network can have a network size up to 2007 nodes, while a ZigBee based network can have more than 65,000 nodes in one such network.[40]

H. Network Security

The ZigBee protocol uses the Advanced Encryption Security (AES) method for encryption and uses the CCB-CCM method for network security. On the other hand, Wi-Fi-based networks use WEP, WPA, and WPA2 protocols for network encryption and security, respectively. [40]

I. Applications

Wi-Fi is the preferred choice for Internet-based networks and now encourages wireless connectivity to a variety of media/entertainment devices. People can find Wi-Fi in the data exchange between computers and modems, playing streaming music and video on TV through Wi-Fi-enabled computers or media devices.[40]

The ZigBee protocol has been precisely designed to exchange data, and it is more prevalent in wireless sensor-based networks, such as networks in home automation systems or industrial machinery coordination systems.

A comparison of ZigBee and Wi-Fi is shown in Table 2.

Aspects	ZigBee	Wi-Fi
Standard	802.15.4	802.11a,b,g
Application	Automation, control	Web , e-email, video
Data rate	50-60kbyte	>1Mbyte
Battery lifetime(d)	>1000	1-5
Network size	65535	32
Bandwidth(kb/s)	20-250	11000
Transmission distance(m)	10-30	10-30
Advantages	Reliability, low cost	High data rate, flexibility

Table 2 Comparison of ZigBee and Wi-Fi [40]

Through the above comparison, short-distance communication that meets one of the following conditions can be considered for ZigBee [38]:

- 1) There are many outlets that need data collection or monitoring;
- 2) The amount of data required to be transmitted is not large, but the equipment cost is low;
- 3) Requires high reliability and high security of data transmission;
- 4) The equipment is required to be small in size, and it is inconvenient to place a large rechargeable battery or power module;
- 5) Can be powered by battery;
- 6) The terrain is complex, there are many monitoring points, and a large network coverage is required;
- 7) Covering blind areas of existing mobile networks;
- 8) A telemetry remote control system that has used an existing mobile network for low data transmission.

The transmission line monitoring of the grid is in line with the conditions of using ZigBee technology, so the fourth chapter of this thesis will analyze and experiment with ZigBee technology.

3. Methodology

3.1 Introduction

This chapter will detail the concepts, methods, strategies, and time scales applied in the project. First, the research flow chart is drawn by reading the literature and combining the projects. The methods used in each chapter are then detailed in the table, including the source of the literature and the method of data collection. Finally, the experimental methods and data evaluation methods used in this study are introduced.

3.2 Research methods

3.2.1 Research overview

When deciding on a methodology it will need to select

1. A philosophy
2. An approach
3. Three strategies

The specific philosophy, approach, and strategies are shown in Figure 7.

Philosophy	Positivism			Phenomenology	
Approach	Deductive			Inductive	
Strategies	Experiment	Software Development	Document Review	Case Study	Survey

Figure 7 Research method[41]

But just knowing these in research methods is not enough. In order to know the schedule of research, data collection and data analysis methods, the concept of "research onion" was introduced. "Research onion" [42] as shown in Figure 8.

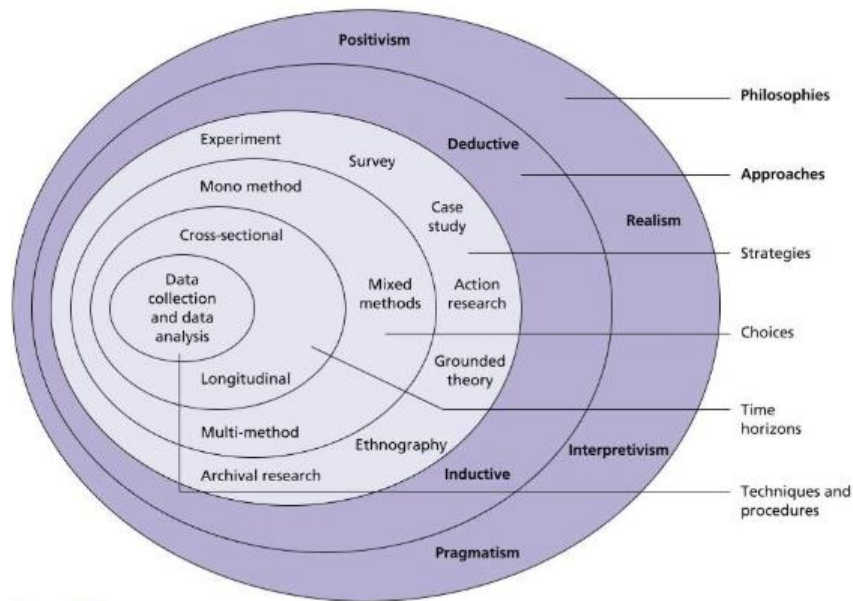


Figure 8 The research onion

Combined with the above research methods, the flow chart of the research project is drawn, as shown in Figure 9.

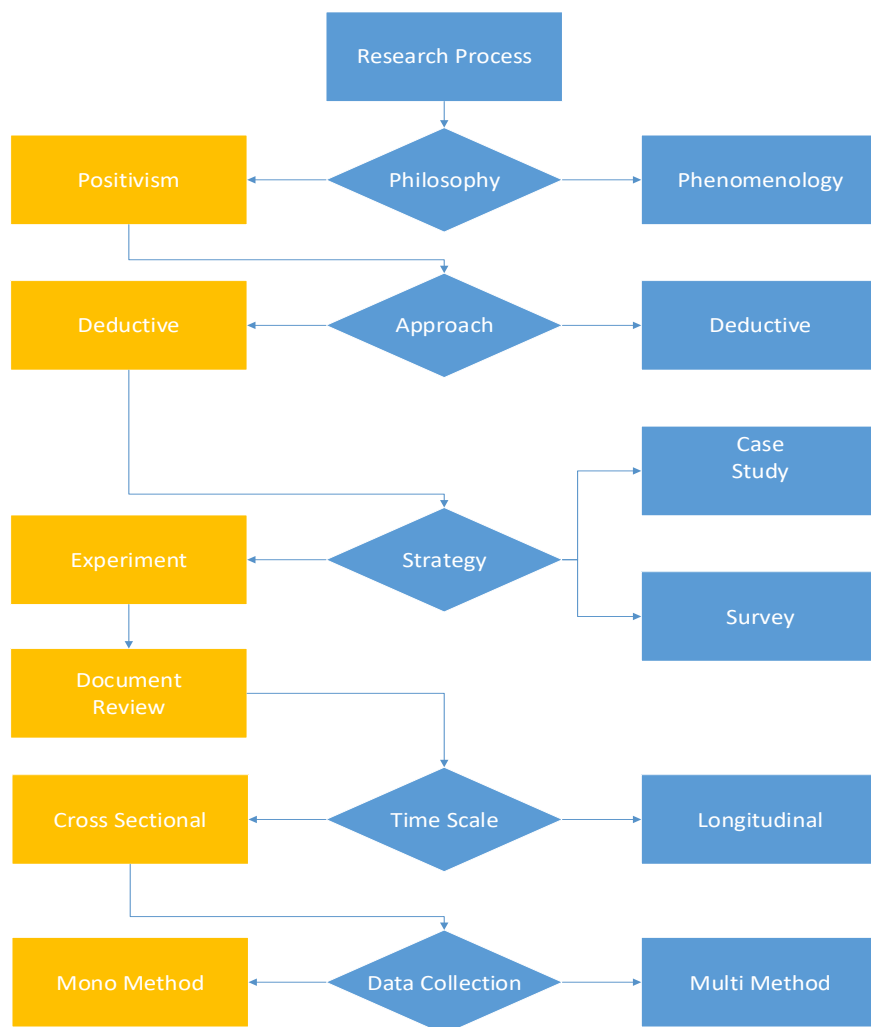


Figure 9 Research progress

The flow chart shows all the components of the research method, and the research method selected in this project is shown on the left, and the discarded method is shown on the right.

3.2.2 Research philosophy

It is known that this knowledge is based on around the principle of observation and the real-world experience. As the project is adopting an experimental same around a topic that is supposed highly researched and has existing theories an experiment and that are well documented. It is viewed that this would be correct path to work with as this links onto the deductive approach.

3.2.3 Research approach

The deductive approach were list linked to the above philosophy is thing as test theory .leading the author to develop hypothesis to test the project Theory and objectives .it is important to acknowledge at this stage that this approach allows for the collection of quantitative data .being very rigid in structure it is ideal to provide a simple yes or no to experiment .testing the theory outlined in the design chapter it is far to say this method where allowed for a definitive outcome in the experiment against the objectives .

3.2.4 Research strategy

The project is a quantitative study. The philosophical assumptions of the project are positivism and objectivism, emphasizing quantification in data collection and analysis. The deductive method is mainly used to study the relationship between theory and experiment. The project strategy is based on literature reading and experimentation.

The control variable method will be used in the experiment. The control variable method refers to the problem of turning a multi-factor problem into multiple single factors, and only changes one of the factors, so as to study the influence of this factor on things, separately study them, and finally comprehensively solve the problems. In this experiment, the independent variables are the number of nodes, traffic type and transmission protocol.

The change of a certain physical quantity to be studied will be affected by several factors. In order to explore the influence of one of the factors on the physical quantity change, it is necessary to control several other factors. The advantage of this is that the interference can be eliminated directly. Reveal the influence of a single factor on the changes of the subject.

3.2.5 Research time scale

The project Gantt chart is shown in Figure 10.

	i	Task Mode ▾	Task Name ▾	Duration ▾	Start ▾	Finish ▾	Predecessors ▾
1		📁	STAGE 1 :Proposal	67 days	04 Mar '19	04 Jun '19	
2		📌	Literature Review	40 days	04 Mar '19	26 Apr '19	
3		📌	Identify Research Area	5 days	01 Apr '19	05 Apr '19	
4		📌	Formulate Research Question	5 days	15 Apr '19	19 Apr '19	3
5		📌	Formulate Research Aim&Project	5 days	29 Apr '19	03 May '19	4
6		📌	Formulate Research Methodology	5 days	27 May '19	31 May '19	2
7		📌	Write Project Proposal	25 days	01 May '19	04 Jun '19	6
8		📌	Create PowerPoint & Poster	0 days	01 May '19	01 May '19	7
9		📁	Stage 2: Implementation	40 days	13 Jun '19	07 Aug '19	
10		📌	Design	10 days	13 Jun '19	26 Jun '19	8
11		📌	Build Model	5 days	27 Jun '19	03 Jul '19	10
12		📌	Experiment	20 days	04 Jul '19	31 Jul '19	11
13		📌	Evaluate	5 days	01 Aug '19	07 Aug '19	12
14		📁	Stage 3: Report	59 days	01 Jun '19	22 Aug '19	
15		📌	Write First Draft	20 days	01 Jun '19	27 Jun '19	
16		📌	Write Second Draft	10 days	28 Jul '19	08 Aug '19	15
17		📌	Write Final Draft	10 days	09 Aug '19	22 Aug '19	16
18		📌?	Project Submission	0 days			

Figure 10 Project Gantt Chart

The indecision has been driven by the purchase of the equipment required to complete the live experiments. It is seen that the cross-sectional approach will provide a sufficient snapshot of data to perform a could analyse. It is felt by the author that this element could be fluid and potentially moveable.

3.2.6 Research literature and data collection

Table 3 below shows all the research methods and data sources for each chapter of the experiment.

Component	Research approach
Introduction	Journals, books and manufacturer sites Secondary-multiple sources
Literature review	Journals, books and manufacturer sites Secondary-multiple sources
Research methodology	Journals and books from UWTSD library Secondary-multiple sources
Design and implementation	Project proposal and manufacturer sites Primary -multiple sources
Testing and evaluation	Collation of results quantitative data Primary -quantitative data

Table 3 Literature and data collection methods

3.3 Implementation approach

3.3.1 Serial port debugging

The serial port debugging returns the status information of the node to the PC through the serial port program, and can observe the internal execution logic of the node connected to the PC; but the internal execution of the node not connected to the PC in the network is unknown, if the node is in the node if the program Deadlock or crash, the serial port will lose its response in an unknown way. Flash debugging and serial debugging require a large number of nodes to be deployed in practice, which requires a lot of manpower, material resources and time.[43]

3.3.2 Simulation

Existing WSN simulators can be roughly divided into two types:

- 1) Program code simulators, such as TOSSIM and Avrora; the advantage of the program code simulator is to provide high-precision simulation for the operation of a single node, which can accurately simulate the behaviour of the application on the node; the disadvantage is the comparison of communication models between nodes. Simple, the implementation of the simulator depends on the specific hardware platform and requires the user to write the code first.[44]
- 2) Protocol simulation software such as NS-2 and NetSim. The advantage of protocol emulation software is that it provides a highly reliable model for communication between nodes that accurately simulates the interaction between nodes. The cost of simulation is lower than the cost of the program code simulator, and it does not depend on a specific hardware platform. The shortcoming of the protocol simulation software is that it cannot simulate the behaviour of the application, and the simulation accuracy of the internal operation of the node is relatively low.[45]

3.3.3 Conclusion

Experiment with simulation software instead of the actual deployment node. It can observe the internal execution logic of all nodes and can easily observe the overall behavior of the program. Compared with serial debugging, it has unparalleled advantages. Through the above analysis, the project uses protocol simulation software to conduct research on WSN.

Using computer simulation, it is possible to simulate the communication environment under various types of situations, with low cost and high precision. Therefore, computer simulations have been widely adopted by domestic and foreign scholars and research institutions.

So far, the most widely used simulation software in network simulation is NetSim, NS2, GlomoSim, OPNET and Qualnet. Both NS2 and GlomoSim are free software that is open source code. NetSim, OPNET, and Qualnet are widely used in developing real-world engineering applications, and their use is payable compared to GlomoSim and NS2. [46][47] Boson is currently the most popular simulation tool that operates closest to the real world.

In order to prove whether the application of WSN technology can realize real-time monitoring

of the power grid, a transmission line monitoring model is established. This thesis uses NetSim software to verify the validity of the model. In the experiment, the control variable method is mainly used, different parameters are selected for testing, and the obtained experimental data is analyzed to reach a conclusion.

4. Development

4.1 Transmission line monitoring system design

4.1.1 Monitoring system overall design

The whole system is mainly composed of three parts: monitoring center, monitoring substation and terminal. Figure 11 is a brief illustration of the installation location of each tower, transformer substation and monitoring terminal.

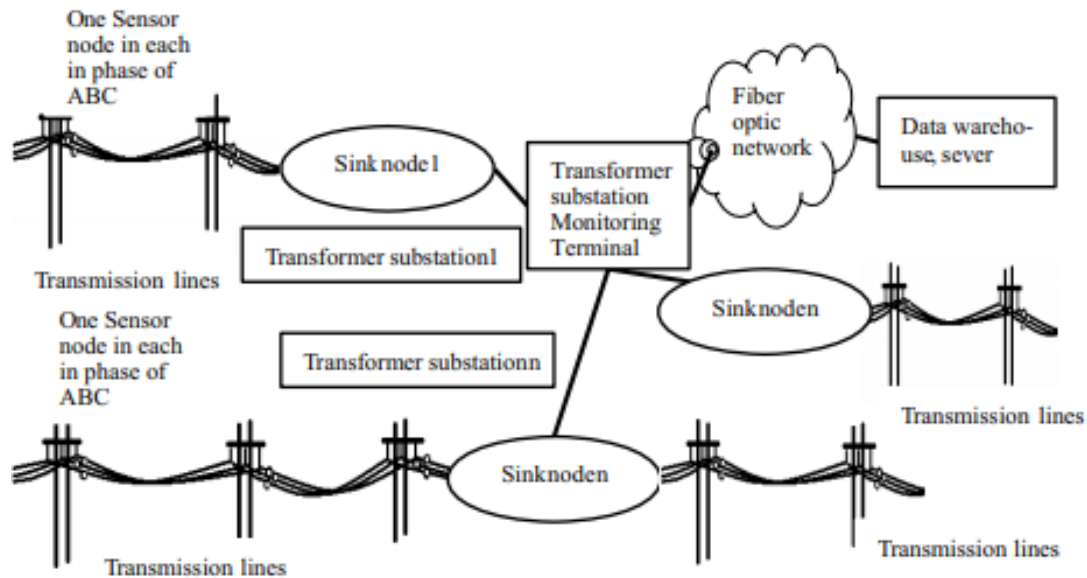


Figure 11 Overall layout of transmission line monitoring system [48]

- 1) Monitoring terminal(sensor nodes): Install a sensor node on each phase of the transmission line tower. These nodes form a long-chain tree-like network, collect and send information, and upload it to the sink node in multiple hops.
- 2) Monitoring substation(transformer substation): Install a sink node on each set of transmission lines.
- 3) Monitoring Centre (and data warehouse) : responsible for data storage and task distribution.

4.1.2 Monitoring system component

A simplified diagram of the overall structure of the system is shown in Figure 12.

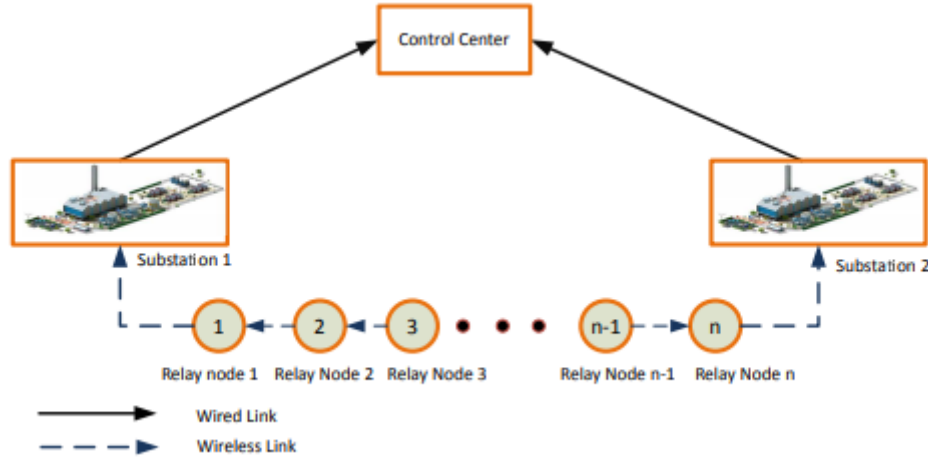


Figure 12 Monitoring system design simplified diagram[35]

For this design, the system follows the simple and applicable principle to establish a tree network. A base station is established on an electric tower, and a monitoring network and a surrounding router on the electric tower form a tree network. The tree network is considered to have a blind zone in some areas or the coordinator cannot work normally. At this time, the node data can be forwarded through the router, that is, the multi-hop transmission mode, to increase the coverage of the network, jump out of the blind zone, and join the nearest one. Network, communicate. This article does not consider building complex mesh networks.

The main modules of the collection terminal are a temperature information sensor module, a power amplification module, a sensing energy acquisition module and a wireless communication module, and the wireless communication module selects a module that supports the ZigBee standard. The monitoring substation mainly includes a collection sub-board, a power module, and a ZigBee communication module. The main control module selects a low-power chip, and the constant-temperature crystal circuit ensures the accuracy of sampling.

The monitoring center is responsible for storing, processing and analyzing the collected monitoring data. It can provide historical data query, emergency alarm, fault location, data visualization and other functions.

The following describes each part of the function:

End Equipment

It is directly installed on the electric tower bracket and the wire to complete the collection of various data, receive the command of the base station through short-range wireless communication, and send the data to the base station, which can complete data collection of multiple monitoring points.

Monitoring substation

Installed on the tower tower, the ZigBee communication method transmits the temperature

acquisition, sampling interval, data summoning and other control commands to the temperature measuring terminal; the base station receives the connector temperature data sent from the temperature measuring terminal and then packs the data to ZigBee. The communication method is transmitted to the monitoring center.

Monitoring center

It can be set in the power supply company or each substation, and send relevant control commands to the monitoring substation through wireless communication according to actual needs, including setting the system clock, sampling time, monitoring range, working mode, and so on. The received data is stored in the upper computer database, the storage time can be set by itself, and the real-time curve can be drawn according to the data parameters. When the temperature exceeds the limit, the alarm information is automatically sent out. According to the received data information, combined with the analysis of other operating parameters in other transmission lines, the reliable operation of the transmission line can be realized.

4.1.3 ZigBee node type

A complete WSN should include three parts: sensor node, aggregation node and management node. Many sensor nodes are deployed in the surveillance area, and they are particularly self-organizing and will soon form a network. The sensor node collects the data, and then sends it to the aggregation node through deep multi-hop, and finally transmits it to the management node by using ZigBee. The main task of the management node is to collect the monitored data and configure and manage the monitoring tasks.[49]

End Device - Sensor node

A sensor node can essentially be defined as a tiny embedded system. The sensor node is mainly responsible for collecting data and sending it to the aggregation node, and also storing, managing, and merging the data.

Coordinator – Convergence node

The aggregation node can be used not only as a sensor node with enhanced functionality, but also as a special device with a wireless communication interface to communicate with the external network. Its main task is to receive data sent by other nodes and forward it to the monitoring centre.

Router - Management node

The main responsibility of the management node is to facilitate the management of the network by the user. Under the role of the management node, the user can not only manage and configure the network, but also perform the following monitoring tasks.

4.1.4 Monitoring system function requirements

According to the system business requirements, the following functions need to be implemented.

- Transmission line video/image monitoring [50]
- Transmission line conductor temperature monitoring [51]
- Transmission line ice monitoring [48][52]
- Wire dancing monitoring [11][53]
- Tower tilt monitoring [54]
- Insulator condition monitoring [28]
- Anti-theft monitoring [22]

In the smart grid, overhead transmission lines are connected to two substations by wires, and a large number of sensor nodes (such as wind speed sensors, temperature and humidity sensors, tension sensors, tilt sensors, etc.) are deployed along the transmission lines to collect data information. For ease of deployment, these nodes are typically placed near the pole and a relay node must be installed on each pole to collect and process information about the surrounding nodes. These nodes on the transmission line send the collected data information to the relay node of the pole.

Example: Wire dancing monitoring system

The transmission line within a certain distance of the transmission line is used as the monitoring object. According to the length of the transmission line, different numbers of acceleration sensors are installed thereon, and the wire galloping acceleration data is monitored in real time or at a time, and sent to the monitoring center to call data processing. The program processes the acceleration data of multiple monitoring points, fits the wire dancing trajectory and calculates the relative amplitude of the dancing amplitude and frequency of the wire. As long as the number of collected nodes and the frequency of data transmission are increased, enough points can be obtained to fit the wire galloping waveform, so that accurate fitting of the wire galloping waveform is guaranteed.

As shown in Figure 13, assuming that the heights of the suspension points at both ends of the line are equal, starting from the lowest point of the arc, a measurement point is set at a distance of d meters, for a total of N measurement points.

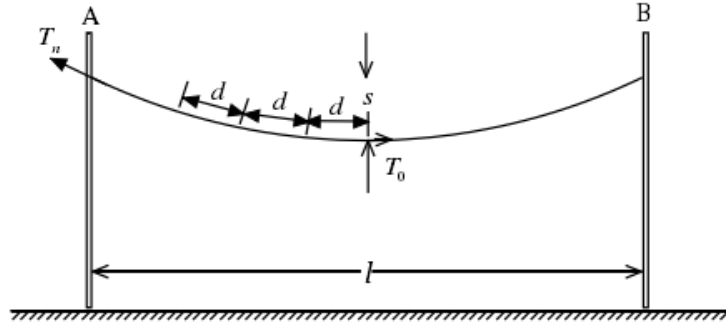


Figure 13 Wire dancing monitoring system with suspension point contour[55]

According to the above design idea, the difficulty in the installation of the wire galloping monitoring system lies in the selection of the installation position and quantity of the sensor node, and the cost must not be too high, and the system must be operated for a long time. The more sensors installed, the higher the accuracy of the data obtained, the smaller the power consumed by each node in the system, and the longer the life cycle; but the system cost is too high, and the installation of too many sensors may damage the transmission wires. A mathematical model of dancing. On the contrary, the cost is reduced, but due to the limited monitoring nodes, the power consumption of each node is too large, which shortens the system life cycle.

Therefore, in practical applications, we must weigh the pros and cons, and consider the actual situation of the transmission line.

4.2 NetSim

4.2.1 NetSim system architecture

Boson NetSim is a network simulator from Boson. There are two main components: the experimental topology design software (Boson Network Designer) and the experimental environment simulator (Boson NetSim).

The underlying NetSim is an emulator, and the upper layer visually and vividly displays the operation of the underlying network in the form of a GUI. Users can edit the network topology themselves, set up and run their own experimental network, and conduct a series of experiments. Users can view the protocol stack output, packet content, routing table, etc. to get the network running.[56]

The NetSim system uses a two-tier architecture: a graphical user interface layer and an emulator layer. The graphical user interface layer accepts the user's input upwards and displays the simulated process and state in real time, transforming the user's interaction down into a program primitive, i.e a call to an object in the emulator. The emulator is the core of the simulation and demonstration implementation, and the NetSim system simulator uses an event-driven approach to emulation. Event scheduling, simulation objects, and protocol stacks are implemented, and information such as state changes and data flow of simulation objects and

simulation protocols are notified to its customers (here, the graphical user interface layer) through a series of event interfaces. The system architecture diagram is as Figure 14:

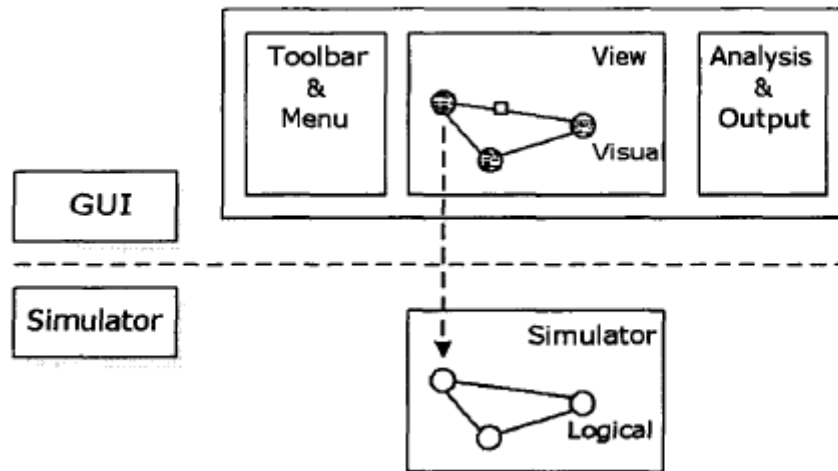


Figure 14 NetSim architecture[57]

4.2.2 802.15.4 protocol in NetSim

In NetSim, 802.15.4 has the following features:

- The data rate is 250 kbps
- Addressing mode: 16-bit IEEE addressing
- 16 channels in the 2.45 GHz ISM band
- Support for carrier sense multiple access CSMA-CA with collision avoidance
- Power management to ensure low power consumption
- GTS
- Support for contention-free and contention-based time periods.
- The MAC protocol supports two modes of operation that the coordinator can choose:
- Non-beacon enable mode: In non-beacon enable mode, the device can simply send data using Unslotted CSMA / CA. The superframe structure is not used in this mode.
- Beacon-enabled mode: The coordinator periodically generates beacons to synchronize connected devices and identify PANs. The beacon frame is the first part of the superframe, which also embeds all data frames exchanged between the node and the PAN coordinator.[58]

4.3 Scenario design

4.3.1 Number of ZigBee network topology nodes

In theory, a ZigBee network can have 65,535 nodes, that is, a coordinator hangs so many terminal nodes. But in practical applications it is almost impossible to achieve. In general, a ZigBee network has a lot of 100~200 nodes[7].

There are several reasons for limiting the number of ZigBee nodes:

- 1) There are many network nodes, which means that the routing path becomes longer, resulting in a greatly reduced transmission success rate of network data;
- 2) Each device will report the data. For example, some packets will be reported at the time of heartbeat packets and linkstatus. The number of nodes will cause the entire channel to be very crowded, communication efficiency is low, and nodes are lost.
- 3) The PRO protocol will periodically send linkstatus broadcasts. Nodes are more likely to cause broadcast storms and network congestion.

4.3.2 Scenario set up

In order to verify the advantages and disadvantages of ZigBee's transmission line monitoring, three simulation scenarios were designed. Since the transmission line monitoring system is a long-chain network, all nodes are arranged in the range of 1000*100m.

In the experiment, the number of nodes was set to 10, 30 and 100 respectively, and the node positions were randomly generated and fixed. Select one node as the sink node, and the rest of the nodes send data to the node. The simulation time is 100 seconds. The data of end-to-end average delay, data transmission rate and throughput are taken as the research object in the simulation output. The scenario is shown in Figure 15-17.

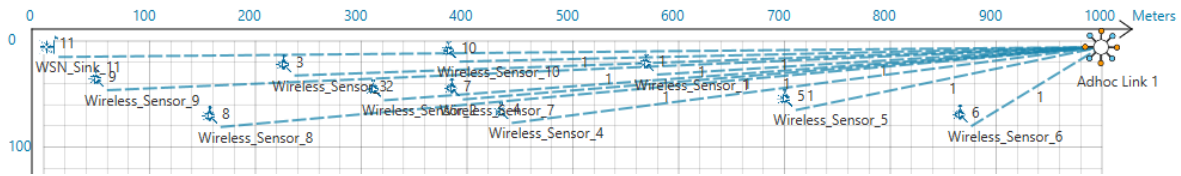


Figure 15 Scenario 1

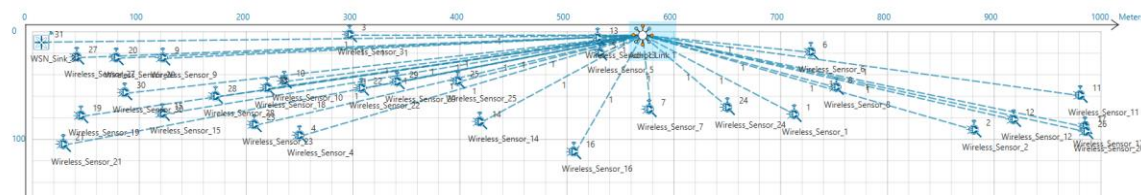


Figure 16 Scenario 2

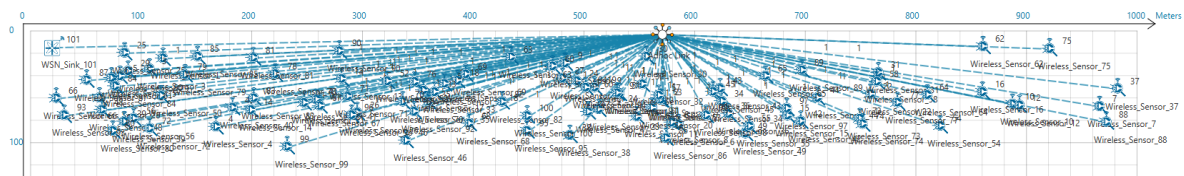


Figure 17 Scenario 3

4.3.3 Simulation time description

In the NetSim lab manual[58], the simulation time is set to 10s, 50s, 100s and 200s respectively. The throughput of the theoretical analysis is compared to the results of the simulator run. As shown in Figure 18 below.

Simulation Time (sec)	Throughput (kbps)
10	99.6
50	100.5
100	100.4
200	100.4

Figure 18 Simulation time result[58]

The small difference in throughput is due to the fact that the average of the random numbers generated for backoff does not need to be accurate to 3.5, because the simulation runs for a short time and the network layer DSR protocol is also running, so the route setup process will take some time. As we continue to increase the simulation time, the throughput value obtained from the simulation is close to the theoretical value. Therefore, all simulation time in this experiment is 100s.[58]

4.3.4 Output parameter selection

The evaluation parameters commonly used in wireless communication technology are as follows[51], [56]:

(1) Packet transfer rate

The packet transfer ratio is the ratio of the sum of the packets received by the destination to the sum of the packets sent by the source node (usually expressed as a percentage) over a period of time. The higher the packet transmission rate, the better the communication quality of the network and the more complete the information.

(2) Average end-to-end delay

The average delay is the ratio of the time the packet sent by the source successfully arrived at the destination to the total number of packets successfully received within a certain period of time. The average delay reflects the effectiveness and speed of the routing protocol. The smaller the average delay, the faster the response of the routing protocol and the shorter the time it takes for information to be transmitted.

(3) Network throughput

Network throughput represents the total number of packets sent by a node or unit during

continuous operation from the time the data message is sent to the state of the data at the time the message arrived.

- $\text{Throughput} = \text{Number of delivered packets} \times \text{packet size} \times 8 / \text{Total Duration of Simulation}.$

There are many parameters of NetSim simulation output. This experiment will focus on the above three parameters.

4.4 NetSim Simulation experiment design

First, it is necessary to determine the network scale of the transmission line monitoring system. Using NetSim default parameters, three experimental scenarios with different node counts will run for 100s to obtain throughput, latency, data transfer rate and power consumption data. Select the optimal number of nodes by analyzing the data. The next experiment uses a scenario with the optimal number of nodes. There are many different types of data in a transmission line monitoring system. Test CBR, CUSTOM, FTP, VIDEO and DATABASE for differences in throughput, latency and data transfer rates.

The core part of the ZigBee protocol stack network architecture is at the network layer, which mainly implements functions such as nodes joining or leaving the network, receiving or discarding other nodes, routing and transmitting data. The tree structure adopted by the transmission line monitoring system based on the WSN is a topology structure developed by the network coordinator to generate a tree network, which belongs to a static route and is suitable for occasions where the node is stationary or moving less.

- Network layer functions: network establishment and network address assignment
- Network topology: star, tree, mesh
- Network route management: ZigBee uses AODV (Ad hoc On-demand Distance Vector Routing) routing algorithm to implement network routing. When the network size is large, the ZigBee node needs to maintain a routing table.
- Test transmission protocol DSR, AODV, OLSR, and ZRP for differences in throughput, latency, and data transfer rates.

5. Experiment results and Transmission line status evaluation

5.1 Experiment 1: Number of nodes

The experimental results are shown in table 4.

Scenario	Throughput (Kbps)	Packet received/ Packet sent	Delay (s)	Power consumption (mj)
Scenario 1 (node=10)	0.0308	0.077	0.677	1178
Scenario 2 (node=30)	0.0513	0.012	0.499	1189
Scenario 3 (node=100)	0.038	0.095	1.086	1180

Table 4 Observations of Performance Metrics(number of node)

Draw the data into a histogram as shown in Figure 19-21.

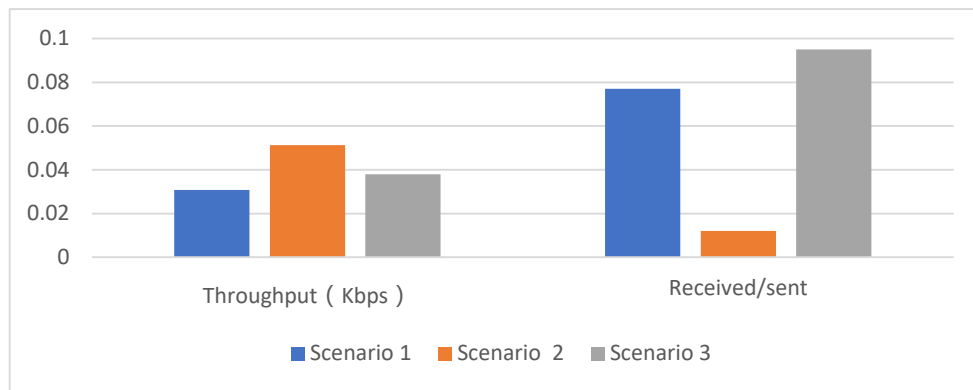


Figure 19 Under Scenario 1, Scenario 2, Scenario 3, Throughput (Mbps) ,Delay (s) ,Packet received/packet sent and Power consumption performance (a)

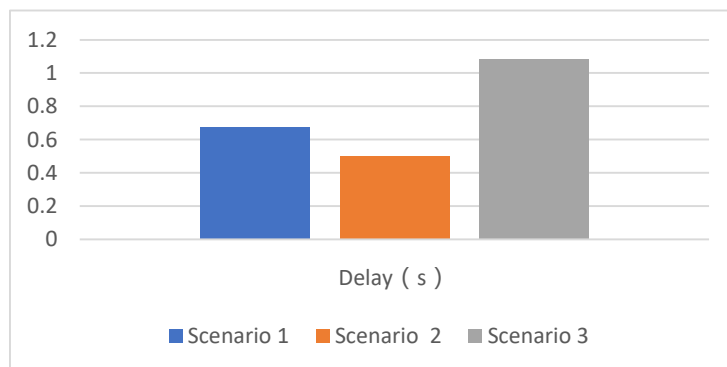


Figure 20 Under Scenario 1, Scenario 2, Scenario 3, Throughput (Mbps) ,Delay (s) ,Packet received/packet sent and Power consumption performance(b)

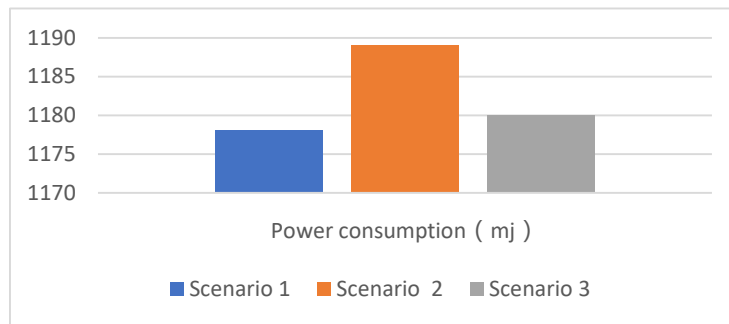


Figure 21 Under Scenario 1, Scenario 2, Scenario 3, Throughput (Mbps) ,Delay (s) ,Packet received/packet sent and Power consumption performance(c)

As can be seen from the Figures, scene 2 with 30 nodes is quite different from the other two scenes. Scenario 2 performs better in terms of latency and throughput, but is poor in packet transceiving. Among them, the packet transmission and reception rate is only 1.2%, which is obviously not suitable for transmission line monitoring systems. Scenario 3 performs best in terms of packet transceiving rate, and the other aspects are not much different from scenario 1. Therefore, the overall score is the best when the number of nodes is 100. The next experiment will be done using scenario 3. Since the difference in energy consumption is too small, energy consumption will no longer be considered in subsequent experiments.

5.2 Experiment 2: Comparison of different traffic type

Common traffic types are: CBR, CUSTOM, FTP, VIDEO, and DATABASE. These data types can be found in the NetSim user manual. See the appendix for details.

CBR

Constants Bit Rate (CBR) is a fixed-sampling compression method that often simulates dedicated lines in a time-division multiplexed mode.

Regardless of audio coding or video coding, CBR mode coding has the advantage of fast compression and can be supported by most software and devices; CBR is very useful when performing multimedia communication on a bandwidth-limited channel because the time limit is the highest bit. Rate, CBR can better use such a channel. However, the disadvantage is that the occupied space is relatively large and unsuitable for storage, because CBR will result in insufficient coding rate for encoding complex content portions, resulting in degradation of quality, while some bit rates are wasted in the simple content portion.[59]

CBR is a compression method with a fixed sampling rate. The effect is not very satisfactory and has gradually been replaced by the VBR (Variable Bit Rate) method.[60]

FTP

FTP (File Transfer Protocol) It is a standard Internet protocol and the easiest way to exchange files between computers on the Internet. FTP is the oldest network tool on the Internet. From the first FTP RFC (RFC114) proposed by A KBHUSHAN in 1971. For nearly half a century,

FTP has been the most popular on the Internet for its unique advantages. One of the most important and extensive services. [61]

The goal of FTP is to increase the sharing of files and to provide non-direct use of remote computers to enable storage media to transparently and efficiently transfer data to users. It can manipulate any type of file without further processing, just like MIME or Unicode. However, FTP has a very high latency, which means that the time between the start of the request and the first receipt of the demand data can be very long; and from time to time some lengthy login process must be performed.

IEEE 802.15.4 Media Access Control (MAC) is a complement to the IEEE 802.11 Wireless Local Area Network (WLAN) standard that supports Quality of Service (QoS). High-priority traffic is more likely to be sent than low-priority traffic: Applications with high-priority traffic wait a little longer before processing their packets. The various application traffic generated in Netsim has the priority, QoS values and other default parameters shown in table 5 below:

Traffic Type	Priority Value	QoS Class	Packet Size (Bytes)	Inter Arrival Time(ms)
CBR	8	RTPS	1460	20,000
CUSTOM	2	BE	1460	20,000
FTP	2	BE	100,000	5,000,000
VIDEO	6	nRTPS		
Database	2	BE	10,000	1,000,000

Table 5 Default parameters in NetSim

The following is an experimental analysis of the performance parameters of these three traffic type in the ZigBee wireless transmission network, and then select a higher performance stream mode. Table 6 is a simulation comparison of throughput, delay and transceiver rate under different traffic types.

Traffic type	Throughput (Kbps)	Delay(s)	Packet received/ Packet sent
CBR	116	46.139	0.754
CUSTOM	116	46.139	0.754
FTP	117.776	40.20	0.817
VIDEO	112.336	10.383	0.951
DATABASE	117.640	23.548	0.760

Table 6 Observations of Performance Metrics(Traffic type)

Draw the data into a histogram as shown in Figures 22 and 23.

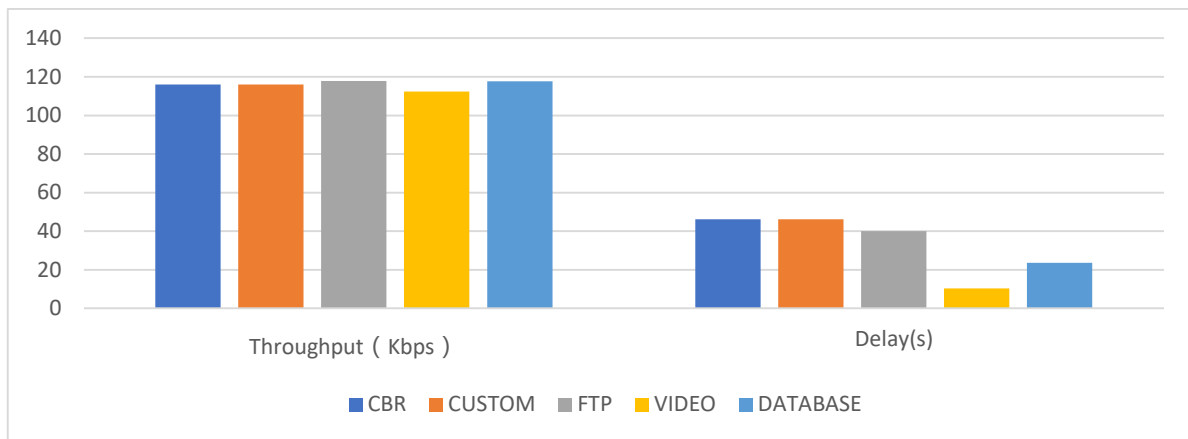


Figure 22 Under CBR, CUSTOM,FTP,VIDEO and DATABASE Throughput (Mbps) ,Delay (s) and Packet received/packet sent performance(a)

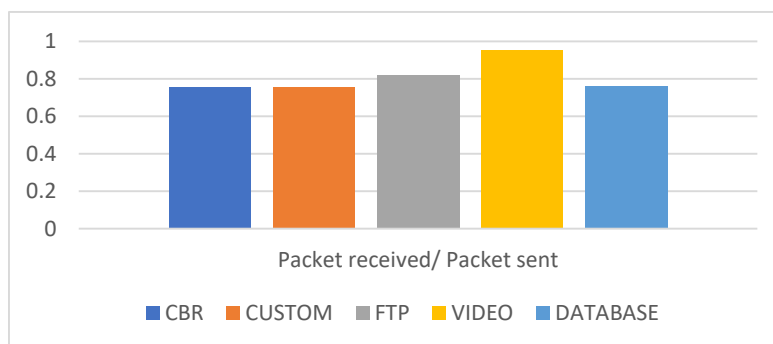


Figure 23 Under CBR, CUSTOM,FTP,VIDEO and DATABASE Throughput (Mbps) ,Delay (s) and Packet received/packet sent are used performance(b)

As can be seen from the Figures, the video type data delay is significantly lower than other types of data, and the packet transmission rate is slightly higher than other types of data. Other types of data performed similarly in all aspects.

5.3 Experiment 1: Comparison of transport protocols DSR, AODV, OLSR and ZRP

5.3.1 Set up of different transport protocols

In the network layer, users can see various protocols such as DSR, AODV, OLSR, and ZRP. Depending on the protocol enabled, users can observe their own metrics.[62]

A. DSR

The Dynamic Source Routing Protocol (DSR) is a simple and efficient routing protocol designed for multi-hop wireless Ad Hoc networks. All routes are dynamically and automatically determined and maintained by the DSR routing protocol, which provides fast reactive services to help ensure successful delivery of data packets, even when node movement or other network conditions change[63]. This routing protocol fully optimizes network traffic. DSR protocol parameter settings as shown in Table 7.

Routing protocol	Ack_Type
DSR	LINK_LAYER_ACK

Table 7 Simulation Parameters(DSR) in NetSim

B. AODV

Ad hoc On-Demand Distance Vector Routing (AODV) is a reactive routing protocol. That is to say, when sending a packet to the destination node, the source node initiates a route search process in the network to find a corresponding route. Conversely, many common Internet routing protocols are a priori, meaning that they look for routes that do not depend on whether the nodes on the path are to be sent, but each node maintains a routing message that contains the arrival of other nodes. The nodes continuously update their routing tables by periodically exchanging routing information, so that the network topology and changes can be reflected in time to maintain consistent, timely, and accurate routing information.[64]

C. ZRP

The Zone Routing Protocol (ZRP) consists of three parts: IARI, IRI, and BRP. The part of performing intra-area active routing is called intra-domain routing protocol (IARP); the external area performing on-demand routing protocol is called domain interrogation protocol (IERI). IERP and IARP do not specify a specific routing protocol.[65][56]

ZPR protocol parameter settings as shown in Table 8.

Routing protocol	IARP Protocol	Hello interval(s)	Refresh interval(s)	TC interval(s)	Zone radius
ZRP	OLSR	2	2	5	2

Table 8 Simulation Parameters(ZRP) in NetSim

D. OLSR

Optimized Link State Routing (OLSR) continuously collects data that nodes can communicate with each other and maintains an optimized routing table for each node. So the connection can be established very quickly. But OLSR is a relatively large and complex one that requires large, complex computers, large amounts of memory, and computation. At the same time, frequent discovery of other nodes on the network is a huge burden. [56] OLSR protocol parameter settings as shown in Table 9.

Routing protocol	Hello interval(s)	Refresh interval(s)	TC interval(s)
OLSR	2	2	5

Table 9 Simulation Parameters(OLSR) in NetSim

The types of these four protocols are as shown in Figure 22 below.

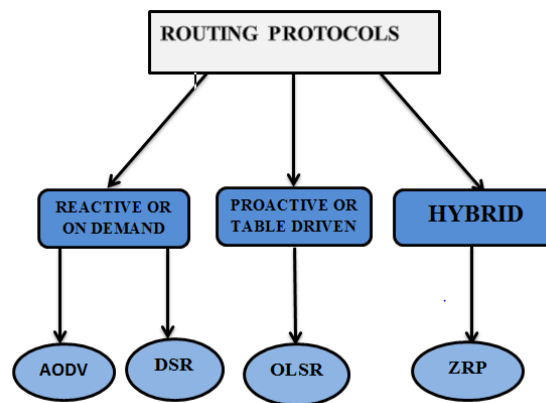


Figure 24 Types of routing protocols[56]

5.3.2 Result of using different transport protocols

The experimental results are shown in Table 10.

ROUTING PROTOCOL:	Throughput (Kbps)	Delay(s)	Packet received /packet sent
DSR	1.2	0.266	0.75
ADOV	0.364	0.027	0.45
ZRP	0.368	0.065	0.15
ORSL	0.368	0.068	0.16

Table 10 Observations of Performance Metrics(Routing protocol)

Draw the data into a histogram as shown in Figure 25.

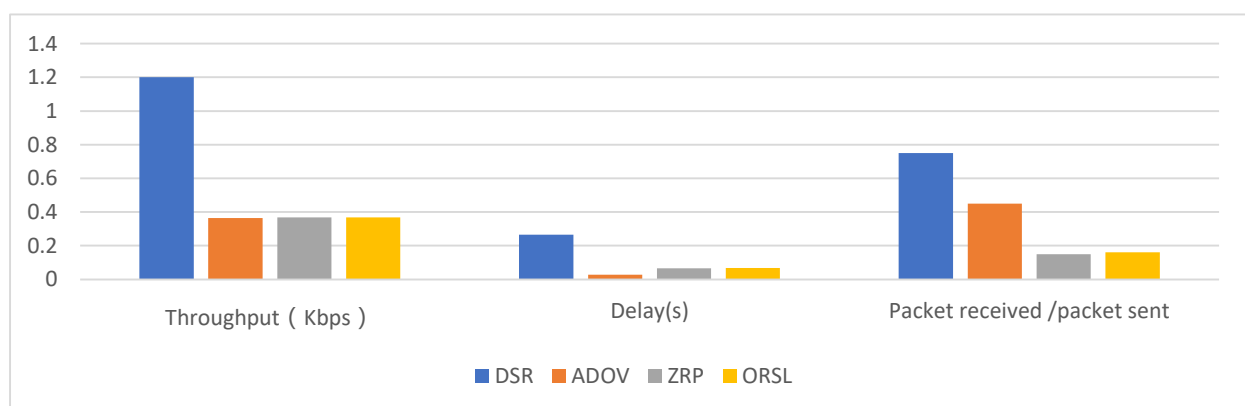


Figure 25 Under DSR, AODV, ZRP and OLSR protocols, Throughput (Mbps) ,Delay (s) and Packet received/packet sent performance

As can be seen from the Figure, DSR performs very well in terms of throughput and packet transfer rate, far higher than other protocols. But its delay is much higher than other protocols. In the transmission line monitoring system, since the routine monitoring and accidents are not particularly urgent, the delay requirements are not high. Under normal circumstances, the data transmission should choose the DSP protocol. ZRP and ORSL have little difference in all aspects. The AODV delay is very small, and the packet transfer rate is also high, which can be used for some key monitoring objects. For example, areas that are prone to problems.

5.3.2 The difference between DSR and AODV

Routing search of DSR and AODV protocols is a round trip process of query and reply. The routing information is stored on all intermediate nodes of the routing according to a certain format. But there is a difference in the dynamics between the two.

1. DSR protocol uses source routing access protocol more than AODV protocol. DSR protocol in China, the source node uses a routing request and routing response process. In addition to getting the destination node's routing, it can also get the route to each intermediate node on the route.
2. DSR protocol responds to RREQ packets of all routing requests that arrive at the destination node in a single routing request during the routing reply process. So the source node knows many routes to the destination node. In AODV protocol, the destination node only responds to the first arrival routing request packet RREQ, ignoring and discarding the subsequent arrival RREQ.
3. There is no mechanism in the current version of DSR protocol to delete out-of-date routes from routing memory. There is no mechanism to determine which route I have limited choice for multi-hop routing. AODV is more conservative than DSR protocol.[63]
4. Fourthly, the routing deletion operation using RERR packet in AODV protocol is a cursor stream. Routing error RERR packet transmission arrives at all nodes using interrupt chains to reach any destination node.

5.4 Transmission line status evaluation

5.4.1 Data transmission process

After the overhead line sensor collects the original value, it transmits it to the server database via the ZigBee module. General data processing is done on the server side. The flow chart from the sensor terminal to the web page display is shown in Figure 26.

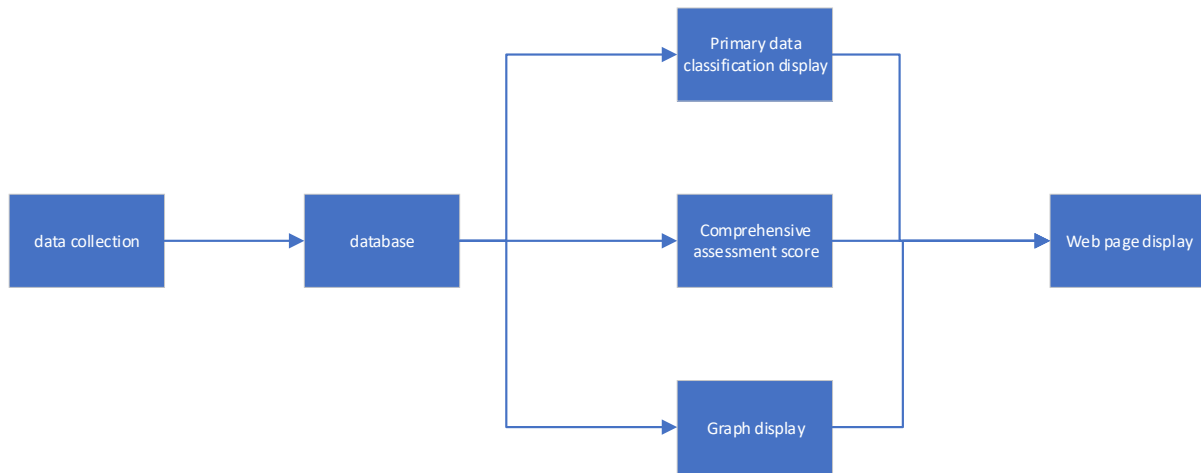


Figure 26 Monitoring and fault assessment process

The data displayed on the web page mainly includes:

- 1) The primary data classification display includes parameters such as voltage, current, power, ice thickness, and sag size that can directly assess the condition of the system.
- 2) Comprehensive evaluation scores, the overall system safety assessment is achieved through a comprehensive evaluation algorithm.

5.5.2 Transmission line outage prediction

The overhead line itself causes the fault factors to be very complicated. In the many monitoring object schemes integrated in this thesis, different fault judgment mechanisms should be established to deal with. Among them, tower tilt, lightning strike, fault location, human fault, and fault equal fault are quantifiable fault indicators. Such faults can be classified into a kind of fault judgment mechanism. By establishing a step-by-step early warning mechanism, system faults can be effectively prevented. However, for natural disasters such as wind vibration, ice coating and other factors, due to its ambiguity and uncertainty, fuzzy modeling methods can be used, and the use of operational experience to compensate for the lack of sample data can be established to suit natural disasters. The overhead line outage model is used to monitor the reference.

The natural disaster prediction and monitoring objects of transmission lines mainly include wire dancing and ice-covered disasters caused by wind vibration. Such disasters are extremely harmful. In severe cases, faults such as inverted towers and line breaks will occur, and the overhead lines will be accurately stopped under the influence of disasters. The transportation rate is extremely critical, which not only provides important reference for line dispatchers, improves the safety and stability of the power system, but also provides an effective solution for disaster maintenance and next prevention.

5.5.3 Comprehensive evaluation of transmission line stability

The stability of overhead lines is affected by many factors, and many factors are ambiguous and uncertain. This thesis proposes a transmission line evaluation method based on comprehensive evaluation, which provides multiple aspects of the evaluation of the whole system, calculates the system stability comprehensive score, and determines the security level. The establishment of this set of evaluation system requires the corresponding indicators of the line to be maintained by the maintenance personnel or experts of the line. Firstly, an evaluation index system is established.

The various indicator systems of the transmission line can be represented by a number of indicators. These indicators describe the line characteristics of the system from different directions. When designing or selecting these line indicators, attention should be paid to In line with the multi-level and all aspects, we should also pay attention to avoid duplication and complexity, and avoid adding personal subjective judgment. To be fair and objective, such a choice can best reflect the characteristics of the system. The evaluation indicators are mainly divided into: overall, tower, wire condition, insulator string, ice coating, surrounding environment, wire dancing and other equipment. The details are as Table 11:

Transmission line overall	Line damage, corrosion, etc.
Tower	Pole rail tilt
	Pole main frame bending
	Tower life
wire	wire Corrosion, fracture and burns
	wire Sag
	Out of service, jumper
Insulator string	Insulator string Corrosion
	Insulator string end connection
	Insulator string dirt, loss
	Insulator string tilt
Transmission line icing	Ice thickness
	Line ice coverage area
Wire dancing	Wire swing amplitude
	Affected line
	Wind type ·
Surrounding situation	Tower distance
	Forest cover
	Tower number plate, climbing ladder status
	Lightning strikes, bird monitoring

Table 11 Transmission line evaluation indicator

In the actual assessment, the degree of influence of different factors on the line is different, so the weight of each indicator needs to be specified. This thesis builds an evaluation matrix based on indicators to assess the state of interaction between indicators. Then build a comprehensive

review of the tiered metrics and the range of scores. Depending on the actual project situation, Table 12 below is an example of a five-level evaluation criteria.

Score	grade	status description
90-100	A	The line runs normally and all monitoring indicators are within the safe value. The line can perform the maximum maintenance plan and can be repaired on a monthly basis.
80-90	B	The normal operation of the line, all the monitoring indicators are within the warning value, there is a tendency to approach the warning value, strengthen maintenance, and carry out maintenance on a weekly basis.
70-80	C	Some of the monitoring parameters have reached the yellow warning value. The manual state analysis should be carried out and repaired on a daily basis to avoid deterioration.
60-70	D	The important monitoring parameters of the line and the over-alarm value require immediate maintenance.
<60	F	Most of the important monitoring parameters of the line cross the warning value and have a deteriorating trend. Need to stop immediately for maintenance.

Table 12 Evaluation score comparison table

The line security status assessment process is shown in Figure 27 below.

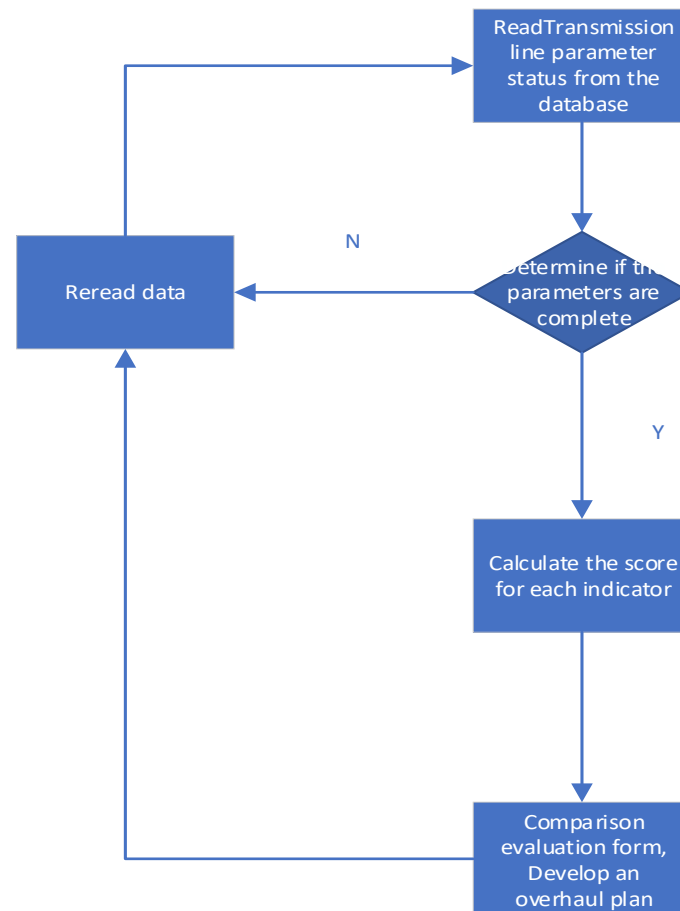


Figure 27 Evaluation process

The comprehensive evaluation of the line status is carried out dynamically. The current database read frequency is 10s, that is, the status value in the database is read every 10 seconds, and then comprehensive evaluation is performed. There are multiple lines in the actual monitoring, and each line has multiple towers. The above algorithm is for a specific tower. In the upper configuration and mobile monitoring screen, the monitoring screen at the top level mainly shows all The overall status monitoring of the line, click on a line will jump into the detailed monitoring interface of the line, click on a tower monitoring point to display all monitoring parameters of the monitoring point, including all the above monitoring indicators.

6. Conclusions & Future Work

6.1 Conclusions

Through the research and analysis of the intelligent grid online monitoring system of the IOT technology, the thesis has achieved the following results:

1. Based on ZigBee wireless communication technology, this thesis studies the monitoring system of transmission line wire temperature, wire icing and wire dancing. Through the real-time data collection of the conductor temperature, working voltage, wire icing and video in the transmission line, the transmission line monitoring system enables the monitoring center to fully understand the operation status of the transmission line and master the instantaneous information. Thereby preventing the occurrence of major safety accidents and reducing unnecessary losses.
2. Based on the NetSim simulation platform, the application of ZigBee technology in the transmission line monitoring system was tested, and the availability of wireless sensing technology was further verified. Simulations were performed in the 1000*100m area, changing the number of nodes, traffic types and routing protocols, and drawing conclusions by comparing throughput, latency, and packet transceiving rates. The number of nodes is 100, and the network performs best when the traffic type is VIDEO.
3. In the Ad hoc network, the movement of nodes is irregular, and the path changes, so it is accompanied by path changes and lookups. Path changes and lookups will reduce the quality of service of the network, such as increased packet loss rate and increased latency. Based on the NetSim simulation platform, it is concluded that DSR is most suitable for routine monitoring of transmission lines. And ADOV is suitable for monitoring areas with higher frequencies.
4. Through the designed online monitoring system, the parameters such as ambient temperature and humidity, light intensity, and tower tilt angle of the transmission line are monitored. The transmission line evaluation mechanism is designed to process and judge the data transmitted by the terminal to the monitoring center. So that the staff can judge whether there is a problem with the transmission line, whether it needs to be repaired or even stopped.

6.2 Future Work

6.2.1 Node Deployment——WSN Transmission Bottleneck Solution in Transmission Line Monitoring

Based on WSN's system architecture for transmission line monitoring, the system has a high cost performance in communication, and because it uses wireless communication, it does not

require wiring, so the construction is relatively simple. The sensor nodes are deployed in a long-chain radial manner. The closer the network is to the Sink node, the larger the amount of data, the heavier the forwarding task undertaken by the sensor nodes. The Sink and its nearby hop nodes become the bottleneck restricting the network capacity. Congestion and hot zone problems will inevitably occur.

Line-distributed WSN node deployment The problem of node deployment in a linear distribution network can be described as: how the number of working nodes is determined and how the nodes are placed in a linear distribution network with a node-aware distance and length. The following goals:

- The distance between any two working nodes is less than that, ensuring that any area in the network is covered;
- Equilibrium energy consumption across all nodes, i.e avoiding “energy holes”;
- Achieve the highest network efficiency.

6.2.2 Experiment

In practical applications, more sensors are installed at the terminal nodes to perform multi-channel data acquisition, and corresponding software programs need to be designed. In the case of more sensors, the data acquisition program is difficult to write, and the protocol stack task scheduling will be more complicated. These are new challenges.

In this thesis, simulation experiments are carried out only in the simulation software environment to verify the feasibility and effectiveness of the environmental monitoring system. However, there are some differences between the laboratory simulation experiments and the actual field experiments. The transmission line monitoring system designed in this thesis also needs to do more field tests and follow-up research on the nodes in the system and the overall operating conditions of the system.

6.2.3 Data Mining

In this thesis, the data collected by the sensor is simply analyzed and utilized. The analysis and processing of the operating state of the transmission line is not deep enough. In the subsequent research process, the elimination and correction of the erroneous data can be considered, and then Establish a scientific and effective expert decision-making system.

6.2.4 Band interference between different Wireless Sensor Technology

The 2.4G frequency band is a global free frequency band. The equipment using the 2.4G frequency band is growing rapidly and the actual use quantity is too large. The 16 communication channels in the 2.4G frequency band have become too crowded in the past 20 years, and the network interference between devices. The situation that causes it to work is often the case. Because the interference in the 2.4G band is so serious that all the new generation

wireless routers have been fully considered from the beginning of design, they must be compatible with the old 2.4G band and the newly adopted 5G band.

ZigBee technology in the IOT space will face enormous challenges. As a ZigBee technology accumulated in the field of traditional automation and industrial control for more than 10 years, if this challenge cannot be solved in this wave of IOT, it will inevitably slow down the pace of further development and miss the opportunity of the tide of IOT. The WSN monitors the transmission line not only to reduce human and material resources, but also has low system maintenance cost, strong real-time performance, good flexibility, high scalability, and can remotely monitor the data parameters of the tested environment.

Appendix-- Traffic generator (Application models)

CBR

Packet Size

Distribution: The options available for distribution is

- Constant

Packet Size (Bytes): Sets the size of the packets being generated by the chosen distribution. By default 1460 bytes is entered.

Inter Arrival Time

This indicates the time gap between packets.

Distribution: The options available for distribution is

- Constant

Inter Arrival Time: Enter the average inter-arrival time between packets. A lower inter-arrival time would lead to a higher generation rate and vice versa. By default 20000 Micro Sec is entered.

Custom

Packet Size

Distribution: The options available for distribution are,

- Constant
- Exponential

Packet Size (Bytes): Sets the size of the packets being generated by the chosen distribution. By default 1460 bytes is entered

Inter Arrival Time

This indicates the time gap between packets.

Distribution: The options available for distribution are,

- Constant
- Exponential

Inter Arrival Time: Enter the average inter-arrival time between packets. A lower inter-arrival time would lead to a higher generation rate and vice versa. By default 20000 Micro Sec is entered.

Voice

Codec

Codec is the component of any voice system that translates between analog speech and the bits used to transmit them. Every codec transmits a burst of data in a packet that can be reconstructed into voice.

Five different standards of voice codec's are given which can be selected depending on the variations required. Packet size and Inter-arrival time value will vary depending on the codec value chosen.

Packet Size

Distribution: The options available for distribution are,

- Constant
- Exponential

Packet Size (Bytes): Sets the size of the packets being generated by the chosen distribution. By default 160

bytes is entered.

Inter Arrival Time

This indicates the time gap between packets.

Distribution: The options available for distribution are,

- Constant
- Exponential

Inter Arrival Time: Enter the average inter-arrival time between packets. A lower inter-arrival time would lead to a higher generation rate and vice versa. By default 20000 Micro Sec is entered.

Service Type

- CBR - CBR stands for Constant Bit Rate. Packets of constant size are generated at constant inter arrival times.
- VBR - VBR stands for Variable Bit Rate. The two types of Suppression Model that can be selected are,
- Markov Chain

Video

Model Type

- Continuous Normal VBR – This model is the simplest of all models. It uses Normal Distribution for the generation of bits per pixel. In this model, consecutive packet sizes are independent of each other.
- Frames per second – Number of frames arriving per second. This is in the range of 10 – 50.
- Pixels per frame -Number of pixels in each frame. This is in the range of 10000 – 100000.
- Bits per pixel (μ)– Mean value of the normal distribution used to generate the value of bits per pixel.
- Bits per pixel (Σ) – Standard Deviation of the normal distribution used to generate the value of bits per pixel.
 - The generation rate for video application can be calculated by using the formula
Generation Rate (bits per second) = fps * ppf * bpp where, fps = frames per second, ppf = pixel per frame, bpp (μ) = bits per pixel (mean)
 - Users can set the above-mentioned parameters in the Application Properties.
 - For example, if we set frames per second = 20, pixels per frame = 10000, bits per pixel = 0.52 then the generation rate would be, Generation rate (bits per second) = fps*ppf*bpp = 20*10000*0.52 = 104000 bits per second = 0.1040 Mbps
- Continuous State Autoregressive Markov –This model incorporates the autocorrelation between the frames. Also, current packet size depends on the previous packet size via the first order autoregressive Markov process.
- Frames per second – Number of frames arriving per second. This is in the range of 10 – 50.
- Pixels per frame - Number of pixels in each frame. This is in the range of 10000 – 100000.
- Constants A, B– First order autoregressive Markov process $\lambda(n)$ can be generated by the recursive relation $\lambda(n)=a\lambda(n-1)+bw(n)$.

- Eta– The steady-state average $E(\lambda)$ and discrete auto covariance $C(n)$ are given by $E(\lambda) = (b / (1-a))$ and $C(n) = (b^2 / (1-a^2)) a^n$ where η is the Gaussian parameter.
- Quantized State Continuous Time Markov – In this model the bit rate is quantized into finite discrete levels. This model takes uniform quantization step as A bits/pixel. There are $M + 1$ possible levels $(0, A, \dots, MA)$. Transitions between levels are assumed to occur with exponential rates that may depend on the current level. This model is approximating the bit rate by a continuous time process $\lambda(t)$ with discrete jumps at random Poisson time.
- Frames per second – Number of frames arriving per second. This is in the range of 10 – 50.
- Pixels per frame - Number of pixels in each frame. This is in the range of 10000 – 100000.
- No of Multiplexed Sources– This model considers the aggregate instantaneous input rate $\lambda_N(t)$ instead of the single source bit rate $\lambda(t)$. The total rate is the sum of N independent random processes each with mean $E(\lambda)$ and variance $C(0)$ at steady state. Therefore, the steady state- mean of $\lambda_N(t)$ will be $E(\lambda_N) = N \times E(\lambda)$ bits/pixel.
- Quantization Level– This model takes uniform quantization step as A bits/pixel. There are $M + 1$ possible levels $(0, A, MA)$. Transitions between levels are assumed to occur with exponential rates that may depend on the current level.
- Simple IPB Composite Model– In this model, the frames are organized as IBBPBBPBBPBBPBBPBB... i.e., 12 frames in a Group of Pictures(GOP). Generate X_0 from a Gaussian distribution $N(0, \sigma^2)$. Set initial value $N_0 = 0, D_0 = 1$.

For $k = 1, 2, \dots, N-1$, calculate Φ_{kj} , $j = 1, 2, \dots, k$ iteratively using the following formulae

$$N_k = r(k) - \sum_{j=1}^{k-1} \Phi_{kj} r(k-j)$$

$$D_k = D_{k-1} - (N_{k-1}^2 / D_{k-1})$$

$$\Phi_{kk} = N_k / D_k$$

$$\Phi_{kj} = \Phi_{k-1,j} - \Phi_{kk} \Phi_{k-1,k-j} \quad j=1, \dots, k-1$$

$$m_k = \sum_{j=1}^k \Phi_{kj} X_{k-j}$$

$$y_k = (1 - \Phi_{kk}) y_{k-1}$$

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Finally, each X_k is chosen from $N(m_k, y_k)$. Thus we get a process X with ACF approximating to $r(k)$.

The auto correlation function can be calculated in a recursive way as follows:

$$r(0) = 1, r(k+1) = ((k+d)/(k+1))r(k)$$

Where $d = H - 0.5$.

H is called the Hurst parameter $k^{-\beta}$ is used as the ACF of a self-similar process. We get the value of H parameter for a self-similar process using the relationship,

$$B = 2 - 2H$$

Distribution of these data is Gaussian. For data to be Beta distributed, the following mapping is being used.

$$Y_k = F^{-1}\beta(FN(X_k)), k > 0$$

X_k : Self-similar Gaussian process,

FN : The cumulative probability of normal distribution,

$F^{-1}\beta$: The inverse cumulative probability functions of the Beta model.

- Frames per second – Number of frames arriving per second. This is in the range of 10 – 50.
- Gamma I – Refer i-button help of Simple IPB Composite Model.
- Gamma B – Refer i-button help of Simple IPB Composite Model.

- Gamma P– Refer i-button help of Simple IPB Composite Model.
- Eta I – Refer i-button help of Simple IPB Composite Model.
- Eta B – Refer i-button help of Simple IPB Composite Model.
- Eta P– Refer i-button help of Simple IPB Composite Model.
- Beta I – Refer i-button help of Simple IPB Composite Model.
- Beta P– Refer i-button help of Simple IPB Composite Model.
- Beta B– Refer i-button help of Simple IPB Composite Model.

FTP

File Size

Distribution: The options available for distribution are,

- Constant
- Exponential

File Size (Bytes): Sets the size of the packets being generated by the chosen distribution. By default 100000 bytes is entered.

NOTE: Devices must have TCP enabled in Transport layer for implementing FTP application successfully.

File_Inter Arrival Time

This indicates the time gap between packets.

Distribution: The options available for distribution are,

- Constant
- Exponential

Inter Arrival Time: Enter the average inter-arrival time between packets. A lower inter-arrival time would lead to a higher generation rate and vice versa. By default 5 Sec is entered.

Database

Transaction Size

Distribution: The options available for distribution are,

- Constant
- Exponential

Packet_Size (Bytes): Sets the size of the packets being generated by the chosen distribution. By default 10000 bytes is entered.

Transaction Inter Arrival Time

This indicates the time gap between packets.

Distribution: The options available for distribution are,

- Constant
- Exponential

Inter Arrival Time: Enter the average inter-arrival time between packets. A lower inter-arrival time would lead to a higher generation rate and vice versa. By default 1000000 Micro Sec is entered.

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