Bachelor's Thesis

Information Technology

2011

Han Liang

Wireless Sensor Network and Monitoring for Environment

BACHELOR´S THESIS | ABSTRACT

TURKU UNIVERSITY OF APPLIED SCIENCES

Degree Programme | Information Technology

05.05.2011 | 44

Instructor: Ojala Olli

Han Liang

Wireless Sensor Network and Environmental Monitoring

In recent years, wireless sensor network technology is developing at a surprisingly high speed. More and more fields have started to use the wireless sensor network technology and find the advantages of WSN, such as military applications, environmental observing and forecasting system, medical care, smart home, structure monitoring.

The world Environmental Summit in Copenhagen on 2010 has just concluded that environment has become the world's main concern. But regrettably the summit did not achieve any useful results. Thus the environmental problem is going to be the most worrying problem in the world. In this way, the Earth's environment monitoring and management will become more important as it concerns everyone in the world. Therefore, environmental protection and monitoring should be taken into serious consideration.

This thesis mainly introduces the basic theory of wireless sensor network, including the theory of sensor network, advantages of the sensor network, focusing mainly on usage and key technologies of the sensor network. The thesis introduces different simulators for the Wireless Sensor Network experiments and compares the advantage and disadvantage between the simulators. It also describes the usage of environmental monitoring with the example of the monitoring of the Big Duck Island.

KEYWORDS:

Network, Sensor, Wireless, WSN, Simulation

Contents

List of Figures

1 Introduction

In today's era of rapid development of information technology, network represented by the Internet has brought great changes for the people. The development of Microelectronic technology, computing technology and wireless communication technology has promoted a rapid low-power multi-sensor development, that can integrated information collection, data processing and wireless communications and more multiple functions within its tiny volume . Wireless sensor network (WSN) is deployed in the test area by a large number of satellite sensors nodes through wireless communication to form a multi-hop network of a self-organizing system. Its purpose is to collaborate in perception, acquisition, and processing of network coverage area perceptual object information, and send it to the observer. Sensors, sensing the object and the observer constitute the three elements of sensor networks. If we say that the Internet constitutes a logical world of information that changed the way of communication between people, then the wireless sensor network is a logical world of information with the physical world.

The main goals of the thesis are the following:

- The foundation of wireless sensor network and study the solution of experiment.
- To study the network architecture, characteristics and the wireless sensor network for monitoring.
- Find the differences of current popular simulators

2 Foundation Study of Wireless Sensor Network

2.1 Sensor Network Architecture

2.1.1 Sensor network architecture

Sensor network architecture is shown in Figure 1. The sensor network system typically includes sensor nodes, a sink node and a management node. A large number of sensor nodes randomly deployed in the test area (sensor field) within or near the composition through self-organization network. Sensor nodes test data along the other sensor nodes. Data from more nodes during transmission may be processed through hopping, after a number of routs the data is transferred to the sink node, and finally manage to reach the Internet or satellite nodes. Users can do the sensor network node configuration and management, publishing and mobile monitoring of data monitoring tasks.

The sensor node is usually a micro-embedded system; its processing capacity, storage capacity and communication capacity are relatively weak, the energy limited by battery-powered portable. Each sensor node includes both the functions of the traditional network node terminals and routers. In addition, –local information collection and data processing are also forwarded to other nodes in the data storage, management and integration, to deal with other nodes to complete some specific task. The current sensor node hardware and software technology is the focus of this study of sensor networks.

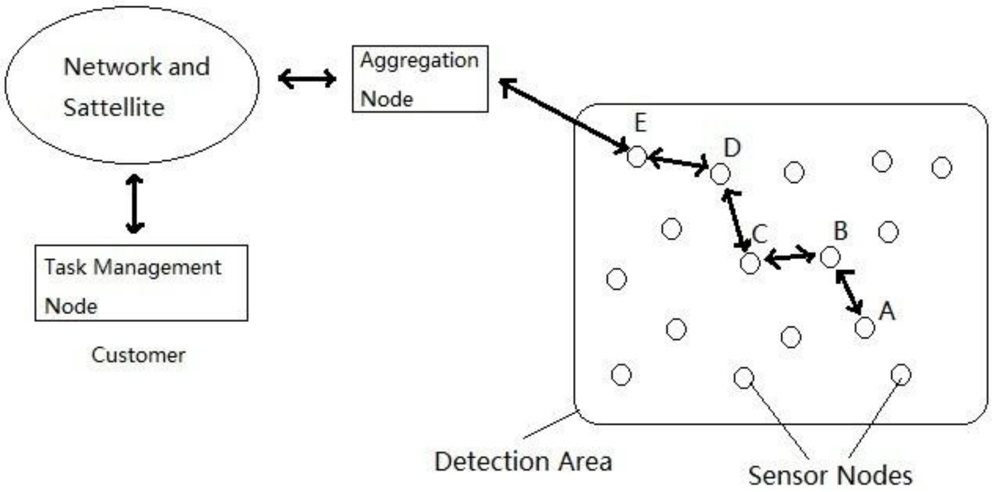

Figure 1 Sensor Network Architecture

2.1.2 Sensor Node Architecture

A sensor node is made up from sensor modules, processor modules, wireless communication modules and power supply modules, as shown in Figure 2. The sensor module is responsible for monitoring the area of information collection and data conversion. The processor module is controlling the operation of sensor nodes, storage, processing its own collected data and other nodes' received data. The wireless communication module is used for the wireless communication with other sensor nodes. It also works with exchange control messages and sends/receives data collection. The power supply module for the sensor nodes provides the energy required for working, usually using a micro-battery. [3, 4, 18]

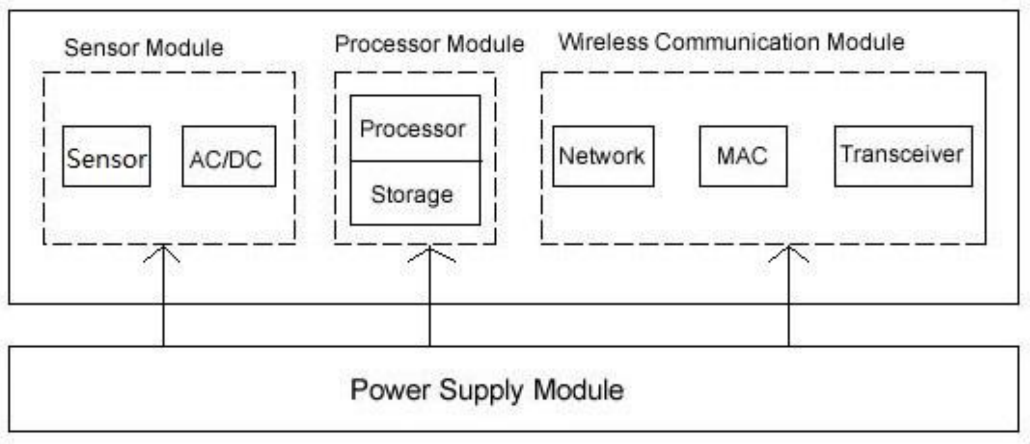

Figure 2 Sensor Node Architecture

2.1.3 Sensor network protocol stack

Figure 3 (a) shows an earlier protocol stack, including physical layer, data link layer, network layer, transport layer and application layer, and these layers relative to the five protocol of the Internet protocol stack. In addition, the protocol stack also includes energy management platform, mobile management platform and task management platform. These management platforms allow sensor nodes to work energy-efficiently, that is, forwarding data in the mobile nodes sensor network and supporting multi-task and resource sharing. The layers of protocols and the functions of the platform are as follows:

- The physical layer provides simple and strong signal modulation and wireless transceiver technology.
- The data link layer is responsible for data framing, frame detection, medium access and error control.
- The network layer is responsible for route formation and routing.
- The transport layer is responsible for the transmission control; it is an important part of the communication service's quality.
- The application layer includes a series of tasks based on monitoring the application layer software.
- The energy management platform manages the sensor nodes energy. We need consider saving energy in all protocol layers.
- The mobility management platform detects and registers the mobile sensor nodes to maintain routes of the sink node and allows the sensor node to dynamically track the location of its neighbors.
- The task management platform balances and schedules the monitoring tasks in a given region.

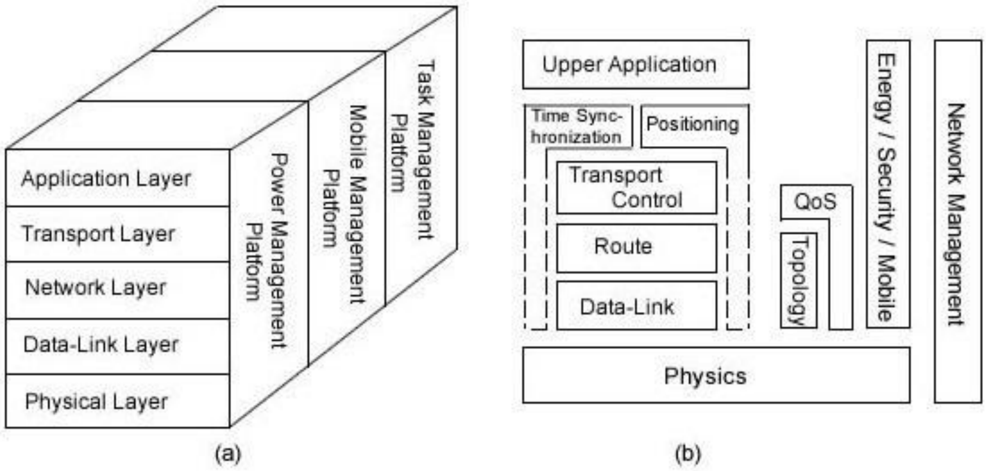

Figure 3 Sensor Network Protocol Stack

Figure 3 (b) shows the protocol stack refined and improved the original model. The positioning and time synchronization sub-layer is rather special in the protocol stack. Sensor Network Protocol Stack have to rely on the data transmission channel for positioning and time synchronization consultation, at the same time as the network protocol layers provide information support, such as the MAC protocol based, location-based routing protocols, and many other sensor network protocol need to locate and synchronize information. In Figure 3 shows the use of inverted L-type description of these two functional sub-layers. Figure 3 (b) into the right part of the many mechanisms to map 3 (a) shows the layers of the protocol. The protocol is for the optimization and management of the protocol processes, the other independent part outside of the protocol layer is configuring and monitoring through a variety of collection and configuration interfaces Such as energy management. In Figure 3(a) must be increased for each protocol layer in the energy control code, and make the decisions of energy to for the operating system. QoS management designs queue management, priority systems or bandwidth reservation systems and so on in each protocol layer, and does the application-specific data for special treatment. Topology control uses the physical layer, link layer or routing layer to complete the routing topology generation. In turn, it provides the basis for their information support and optimizes MAC protocols and routing protocol process to reduce network energy consumption. Network management requires each layer of protocol embedded in all kinds of information interfaces, and regularly gathers operational status and flow information, to coordinate the control of the operation of every various protocols. [3, 4, 7, 18]

2.2 Sensor Network Characteristics

2.2.1 The difference with the normal wireless network

A mobile ad-hoc network is composed of a ten to hundreds of nodes. The aim is to transmit multimedia information flow with service quality requirements through dynamic routing and mobility management technology. Usually, a node has a constant energy supply.

Although sensor networks and wireless ad hoc networks are similar, there are also significant differences. A sensor network is an integrated monitoring, control and wireless communication network system with much larger number of nodes (thousands or even tens of thousands) and the node distribution is more intensive. The nodes could make an error because of environmental impact and energy. In addition, the sensor node's energy, processing power, storage capacity and communications capabilities are all very limited. The primary design goal of traditional wireless networks is to provide high quality and efficient bandwidth utilization, followed by considered energy savings. The primary design goal of sensor networks is the efficient use of energy, which is the main difference between sensor networks and traditional networks. [3, 4, 7, 18]

2.2.2 The limits of Sensor Node

There are some practical constraints when the sensor node to work on a variety of network protocol and operating systems.

2.2.2.1 Power Energy Limited

Usually the sensor node just carries a very limited battery power because the nodes are very small. The method of recharging by changing the battery is not realistic because the numbers of sensor nodes are huge, and the distribution is wide and complex and, some regions cannot be reached by person. Efficient use of energy to maximize the network life cycle is the most important challenges of the sensor networks.

Sensor node consumes energy modules include 3 modules which are sensor modules, processor modules, and wireless communication module. With advances in integrated circuit technology, the processor and sensor modules consume very little power and, most of the energy consumption occurs in the wireless communication module. Figure 4 shows the report by Deborah Estrin at the Mobicom 2002 Conference Invited (wireless sensor networks, part IV: Sensor Network Protocols) and describes the energy consumption of sensor nodes in various parts of the case. The sensor node transmit ting information consumes more power than the implementation of the calculation. The energy consumption of transmitting one bit of information to 100m distance is equal to the power consumption of operating 3000 calculation instructions.

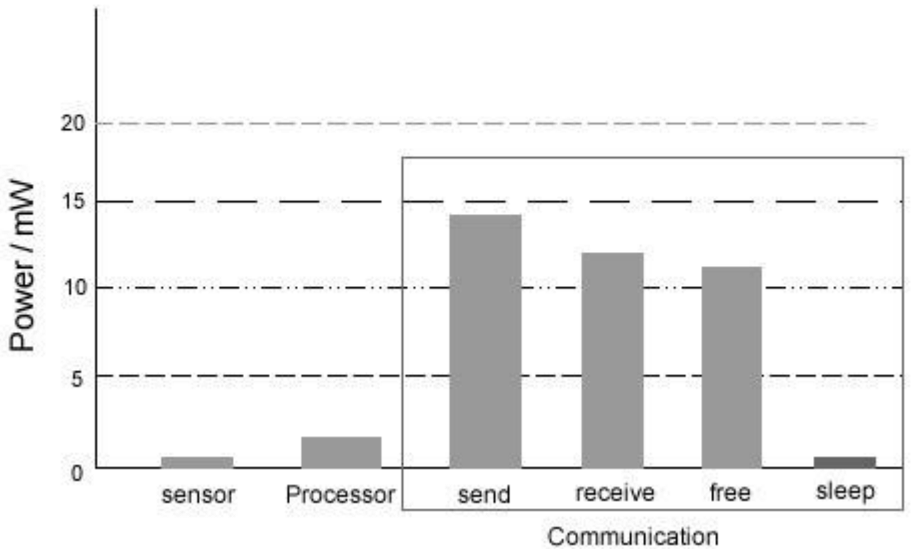

Figure 4 Sensor node energy consumption

The wireless communication module includes 4 states which are sending, receive, idle and sleep. The wireless communication module in idle state monitors the use of wireless channel, checks whether there is data sent to it, and it is shut down in sleep mode communication module. As the above figure shows, the energy consumption will be the highest when the wireless communication module is in sending state, while in sleep mode, the communication module is closed. The key considerations of sensor network protocol design are how to make network communications more efficient, reduce unnecessary forwarding and receiving and sleep as soon as there is no communication. [3, 4, 7, 18]

2.2.2.2 Limited communication capabilities

The relationship of wireless communication and communication distance is expressed as:

$$E = kd^n$$

* E: Energy consumption, K: Constant, D: distance

The parameters satisfy the relation n 2 <n <4. The values of n are related to many factors, such as sensor nodes deployed close to the ground, many obstacles interferences, the impact of signal transmission will be larger when n’s value is large. With the increase in communication distance, energy consumption will increase dramatically. Therefore, the communications connectivity should be minimized under a single hop communication distance. In general, the wireless communication radius of sensor nodes should be within 100m.

Considering the energy constraints of sensor nodes and large network coverage area, the sensor network should use multi-path routing as the main transport method. The bandwidth of Wireless sensor nodes are limited, usually only a few hundred kbps rate. The wireless communication might be changed usually because the environment changes. One of the main challenges of a sensor network is designing a suitable network communication method. [18]

2.2.2.3 Limited computing and storage capacity

A sensor node is a micro-embedded device which required lower price and lower power consumption. Because of these restrictions, it has to us weak processor and low memory. In order to complete various tasks, sensor nodes need to complete the task of testing data collection and conversion, data management and processing, the task of answering requests for cluster nodes and node control a variety of work. Using limited computing and storage resources to complete various tasks is the challenge of the network design. [18]

2.2.3 The characteristics of Wireless sensor networks

2.2.3.1 Large-scale Network

In order to obtain accurate information in the monitoring area, a large number of sensor nodes are usually deployed; the number may reach tens of thousands of sensor nodes, or even more. A large-scale sensor network consists of two aspects: on the one hand, sensor nodes are distributed in large geographical areas, for example in the primeval forest fireproofing using a sensor network for forest and environmental monitoring, requires the deployment of a large number of sensor nodes; on the other hand, the sensor nodes are densely deployed. There are large numbers of sensor nodes in a small area.

A large deployment of sensor network has the following advantages; it acquires more information through different space views. Through distributed method of processing a large number of collected information it improves the accuracy of monitoring, so as to achieve lower required precision on a single node sensor. When using a large number of nodes to increase the coverage of the monitoring area thus reduces or improves the fault tolerance performance. [8, 18]

2.2.3.2 Self-organizing Network

In the sensor network applications, sensor nodes are usually placed in places where there is no infrastructure. The location of sensor nodes can not be precisely pre-set; a neighbor relationship between nodes are in unknown condition in advance, such as through a large number of sensor nodes on the planes sowing vast area of virgin forest, or left unattended in inaccessible or dangerous to humans areas. This requires sensor nodes with self-organization ability to automatically configure and manage, through topology control mechanisms and network protocols, auto-forwarding of the monitoring data to form a multi-hop wireless network system. [11]

2.2.3.3 Dynamic Network

Sensor network topology may change due to the following factors:

- Environmental factors or a result of energy depletion of sensor node failures.
- Changes in environmental conditions may cause changes in the wireless communication bandwidth, even the pass-off.
- Sensors, sensing object and the observer of sensor network are likely to have mobility.
- When a new node joins, this requires the sensor network system to be able to adapt to this change with dynamic system re-configurability. [11]

2.2.3.4 Reliable Network

Sensor networks are particularly suitable for being deployed in harsh environments or areas where the humans cannot easily reach. Sensor nodes may work in the open air environment. Sensors might be subjected to sun exposure or wind and rain, and even– be destruction by persons or animals. Sensor nodes, such as artillery shells, are randomly deployed. These all require that sensor nodes are very strong, difficult to damage, and adaptable to harsh environmental conditions.

Since the regional environmental constraints and the large number of sensor nodes, each node cannot be cared for. So the network is almost a non-maintenance network. Sensor network communication security and safety is also important, we have to prevent the monitoring data being stolen and to be careful about obtaining fake monitoring information. Therefore, the sensor network hardware and software must be robust and fault-tolerant. [11]

2.2.3.5 Application-specific network

A sensor network is used to perceive the objective physical world and collect the information of the physical world. The physical quantities of objective world are varied, cannot be exhausted. The application of the sensor system has a variety of requirements because different sensor network applications are concerned with different physical quantities.

The application of different backgrounds should focus on the different requirements of wireless sensor networks, their hardware platforms, software systems and network protocols will have a lot of differences. Therefore, sensor networks can-not be the same as the Internet with a unified platform for communication protocols.

2.2.3.6 Data-centric network

The current Internet is a computer terminal system first, and then connected with a network system. The terminal system can exist independently from the network. On the Internet, network equipment uses a unique IP address of the network identification, resource locator and information transfer depends on the terminals, routers, servers and other network devices' IP addresses. If we want to access the Internet resources, we must first know the IP address of the server storage resources. We can say that the current Internet is an address-centric network.

Sensor networks are task-based networks. The sensor nodes do not make any sense without sensor network. A sensor node of a sensor network is identified with node number. The node number must have a unique number depending only on the need of the whole network communication protocol design. As the sensor nodes are randomly deployed, the relationship between a sensor network and its nodes is completely dynamic. The node number hasn't necessarily related with node locations are not necessarily related. When users query events using a sensor network, this will be noticed to the network directly. After the network has received the specified events, it will reports to the user. It is usually said that a sensor network is data-centric network. [18]

2.2.4 Sensor network applications

Sensor networks are very broad application prospects, they can be widely used in military, environmental monitoring and forecasting, health care, smart home, building condition monitoring, complex machine control, urban transportation, space exploration, large workshop and warehouse management, as well as airports, large-scale industrial park safety monitoring and other fields. With the sensor networks' in-depth study and extensive application, the sensor networks will gradually go deep into all areas of human life. Figure 5 shows some modern sensor network applications in research. [7, 18]

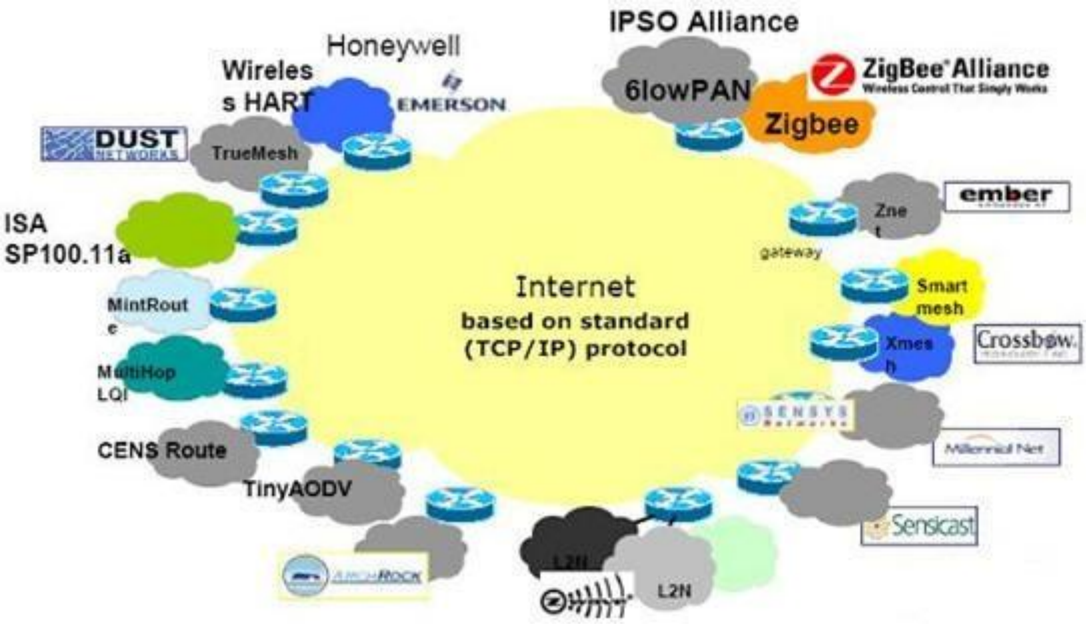

Figure 5 Some Sensor network applications in research

2.2.4.1 Military Applications

The sensor network includes such features as rapidly deploy ability, self-organization, strong imperceptibility and high fault tolerance, so it is suitable for military applications. The use of sensor networks can be achieved on the enemy troops and equipment monitoring, real-time battlefield surveillance, target positioning, battlefield assessment, nuclear attack and biochemical attacks, monitoring and search functions.

Aircrafts could deploy sensor nodes directly into the enemy positions or in the public separation area to build a sensor network, thus to collect the battleground information more easily and accurately. Another important feature is that the sensor network can be re-organized to a new network system after some nodes of the network become damaged. Sensor networks can collect very accurate targeting by analyzing the data. It is easier to control the fire and guidance system. The use of biological and chemical sensors, can accurately detect chemical and biological weapons components, to provide timely intelligence information, facilitate the proper precautions and implement effective counter-attack.

Sensor networks have become an essential part of the C4ISRT (command, control, communication, computing, intelligence, surveillance, reconnaissance and targeting) system. So there are a lot of countries that have spent a lot of manpower and financial resources on research. The U.S. DARPA (Defense Advanced Research Projects Agency) started SensIT (Sensor Information Technology) program a long time ago. The intention is combine many types of sensors, re-programmed general processor and wireless communication technology to create a cheap ubiquitous network system for monitoring the optical, phonics, vibration, magnetic field, temperature, pollution, poison, pressure, temperature, acceleration and other physical quantities. [18]

2.2.4.2 Environmental observing and forecasting system

Sensor networks can be used in research on environmental aspects of planetary exploration, meteorological and geographical research, flood monitoring, but also for tracking birds, small animals and insects.

Based on the ALERT system, a sensor network has sensors that can be used to monitor the amount of rainfall, river water levels and soil moisture, and thus predict the possibility of the outbreak of mountain torrents. Similarly, sensor networks can be realized on forest environmental monitoring and fire reports and sensor nodes are randomly deployed in the forest and can report the monitored data regularly. When a fire occurs, these sensor nodes will report the situation and location through the node collaboration immediately.

Another important application of sensor networks is the description of ecological diversity, to carry out ecological monitoring of animal's habitats. The University of California at Berkeley Lab and the College of the Atlantic's Intel laboratory jointly deployed a multi-layered sensor networking system used to monitor the island's petrels living habits on the Great Duck Island.

2.2.4.3 Medical Care

Sensor networks in medical systems and health care applications include monitoring of the body's various physiological data, tracking and monitoring doctors and patients within the hospital operations and hospital drug management. If a patient has special-purpose sensor nodes installed, such as heart rate and blood pressure monitoring equipment, the doctors use sensor networks to be kept informed by monitoring the patient's condition. Sensor nodes will be placed according to the types of medicines and, computer systems can assist with the identification of drugs prescribed, thus reducing the possibility of the patient using the wrong medicine. Sensor networks can also be used to collect a body's physiological data for long period; these data are very useful for understanding the mechanism of human activities and the development of new drugs.

Artificial retina is a biomedical application project. In the SSIM (Smart Sensors and Integrated Microsystems), the chip to replace the retina made from 100 micro-sensors. They were placed in the human eye to make the blind or very poor visually people able to return to an acceptable level of vision. The wireless communications of sensors is sufficient to meet the needs of feedback control; it is very useful on the image recognition and validation.

2.2.4.4 Smart Home

A sensor network can be used at home. Sensors Embedded in the home electrical equipment and furniture, through a wireless network connected with the internet will provide people with more comfortable, convenient and more humanness smart home environment. Appliances can be controlled, for example the air-conditioning can be remotely switched on half an hour before we return home. We can have a suitable room temperature without any warming or cooling time when we go back home. We can also remote control rice cookers, microwave ovens, refrigerators, telephones, televisions, video recorders, computers, household appliances as well, thus to do all these chores with a remote system. We can even use the image-sensing system to monitor our home security situation.

The sensor networks can be used to build an intelligent kindergarten to work with the monitoring of early childhood education environment, tracking the activities of children.

Figure 6 shows a simple smart home.

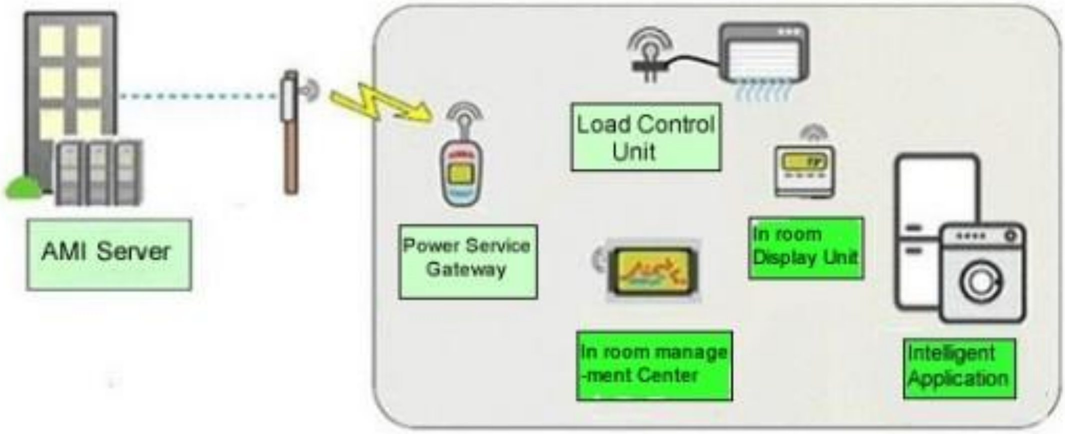

Figure 6 Simple of Smart Home

2.2.4.5 Structure health monitoring

Structure Health Monitoring (SHM) is a system to monitor the security status of ta building using sensor networks. There may be some security implications because the building may be in constant repair. Although a small vibration may not lead to visible damage, there may be a potential cracks in the pillars of the building. Checking in the traditional way usually requires closing the whole building for several months.

As a part of the plan CITRIS (Center of Information Technology Research in the Interest of Society), the Environmental Engineering department and the Computer Science department of University of California (Berkeley college) are using sensor networks to collect all information of the buildings, bridges and other structures, thus to analyze their conditions and to do the regularly-repair work. In the future, buildings will be equipped with sensor networks, which can automatically tell people whether the current building t is safe, secure and to what extent.

2.2.4.6 Other aspects of the application

Complex mechanical maintenance experiences three stages of maintenance: "no maintenance", "regular maintenance" and "conditions-based maintenance. “A "conditions-based maintenance" approach optimizes the use of machinery, keeps the process more efficient and lowers manufacturing costs. The maintenance overhead is divided into several parts: equipment cost, installation cost and manual data collection and analysis of overhead mechanical state. Wireless sensor networks can reduce these costs; in particular, wireless sensor networks are able to remove the artificial overhead. We can use wireless technology to avoid costly cable connection, using expert systems to do the data collection and analysis automatically.

Sensor networks can be used for space exploration. We can monitor a planet’s surface if we deploy some sensor network nodes with the spacecraft. In this way, we can lower the cost and can n easily achieve the data collection. NASA's JPL (Jet Propulsion Laboratory) has laboratory-developed Sensor Webs for the research of the Mars exploration.

Wireless sensor technology is also used in many other areas, but also there are many new areas can be further developed and researched. We believe that wireless sensor technology will be applied in more and more applications in the future.

2.2.5 Key technology of Wireless Sensor network

There are a lot of key technologies to be developed and researched because wireless sensor networks are involved in interdisciplinary fields of study. Here we only list a part of the key technologies as following:

2.2.5.1 Network Topology Control

For the self-organizing wireless sensor networks, network topology control has special significance. Topology control automatically generated by a good network topology can improve the efficiency of routing protocol and MAC protocol, as the foundation of data fusion, time synchronization and many other aspects of targeting. It will help to save the energy of the node to extend the lifetime of the network. Therefore, topology control is the core technology of the wireless sensor technologies.

The main research issue of the topology control of sensor network is to meet network coverage and connectivity of the premises. The unnecessarily Wireless communication data-link can be rejected through the power control and backbone network nodes, to generate and efficient data forwarding network topology. There are some example algorithms for the nodes' power control which are the COMPOW system, LINT/LILT and LMN/LMA algorithms based on the angle of nodes, the CBTC, LMST, RNG, DRNG and DLSS etc. based on the approximate algorithms of the proximity map. The hierarchical topology control is using the cluster-type system to build a backbone network to process and re-send data with some cluster node. The other backbone networks could temporarily close the communication mode to enter sleep mode for saving energy. Nowadays, there are several algorithms such as the Top Disc clustering algorithm, the improved GAF virtual geographic grid clustering algorithm, as well as the LEACH and HEED clustering algorithms as well as the self-organization clustering algorithms.

Besides the traditional power control and hierarchical topology control, there are also node wake up and sleep mechanisms. These mechanisms allow nodes to be activated in the absence of time to set the communication module to sleep. While the incident is set in a communication module for the sleep state, the system can be automatically woken up and wake-up its neighbor nodes to build a data forwarding topology structure when an incident happens. [1, 5, 18]

2.2.5.2 Network Protocol

Because there are so many limited such as the calculation ability, storage capacity communications, and energy and so on. Each node can only access local network topology information; the running on network protocols cannot be too complicated. At the same time, the sensor topology and network resources are constantly changing, so there are the higher requirements on the network protocols. Sensor network protocols are responsible for making all the independent nodes from a multi-hop data transmission network but the current study focuses on the network-layer protocols and data link into the protocol. The routing protocols of network layer determine the transmission path monitoring information, the media control of data-link layer is used to build the underlying infrastructure to control the sensor node communication process and engineering models.

In wireless sensor networks, routing protocols are not only concerned about the energy consumption of a single node. They are more concerned about the balance of energy consumption of the entire network, so as to extend the network lifetime. At the same time, wireless sensor networks are data-centric systems, in which the routing protocol is the most prominent protocol? There is a variety of types of sensor network routing protocols made, such as multiple energy-aware routing protocols, directed diffuse and rumor routing query-based routing protocols; GEAR and GEM location-based routing protocol; SPEED and ReInForM support QoS routing protocols.

The Mac protocol of Sensor network must consider the energy efficiency and scalability first, then considering equity, efficiency and real-time and so on. MAC, mainly in idle listening, accepts unnecessary data, retransmission of data and so on. In order to reduce energy consumption, MAC protocols are commonly used as a "listen / sleep" radio channel listening mechanism; sensor nodes are only listening radio channel when there are data sent or received. As sensor networks are application-specific networks, applications are not working at the same time. So network protocols usually have to customize their features depending on the application type or application target environment. There is no single protocol that can efficiently adapt to all the different applications. [1, 5, 18]

2.2.5.3 Network Security

Wireless sensor network is a task-based network, not only for data transmission, but also for data collection and integration and task coordination control. How can we ensure the confidentiality of the data implementation, the reliability of data generation, data integration and data transmission efficiency of the security? These have become the wireless sensor network security issues.

In order to ensure the confidentiality of mission deployment and task execution results of the security transfer and integration, wireless sensor networks need to implement some basic security mechanisms: confidentiality, point-to-point message authentication, authentication of integrity, freshness, authentication and security management broadcasting. In addition, in order to ensure that data fusion, data source information, reservations, watermarking technology has become a content of wireless sensor network security researches

Although there has not been much research in WSN security, WSN security is very different from the traditional network security methods. First, the performance of wireless sensor network nodes cannot be the same with the current Internet, or compared to any kind of network terminal. So we must consider the balance between the calculation ability and the security issues. The most important challenge is how to maintain security with a simple calculation algorithm. So, we cannot use too complicated codec for the security. In addition, the collaboration features and routing local features of the wireless sensor network task generates security coupling between each nodes, the security bug of single node must be affect the whole network. So while we consider t the security algorithm, we must also consider minimizing the coupling.

The SPINS security framework for wireless sensor networks gives complete effective mechanisms and algorithms for confidentiality, point-to-point message authentication, integrity, authentication, freshness and certification broadcasting areas. In the security management field, the main method is to use the model of random code; the most representative algorithm is based on key pairs of polynomial models. [1, 5, 18]

2.2.5.4 Time Synchronization

Time synchronization is a key mechanism of the sensor network which can work. NTP (Network Time Protocol) is widely used on the Internet, but it only applies to the cable network which the structure is relatively stable. The configuration of nodes need consider about the cost of receivers. It is impossible to use GPS in the forest or underwater. For that reason, GPS is not suitable for use in sensor networks.

In August 2002, Jeremy Elson and Kay Romer first proposed and elaborated a wireless sensor network time synchronization mechanism for research topics in the HotNets-1 International Conference. WHO has raised a number of time synchronization mechanisms, in which RBS, TINY / MINI-SYNC and TPSN are considered the three basic synchronization mechanisms. [20]

2.2.5.5 Positioning Technology

Location information is an integral part of the sensor node collected data as a message without location is usually meaningless. Determining the affair location is the most basic function of sensor networks. In order to provide valid location information, the random deployment of sensor nodes must be able to define their own position. As the existence of sensor nodes has limited resources, random deployment, communications is vulnerable to environmental interference or node failure and other characteristics, the positioning mechanism must satisfy the self-organization, robustness, energy efficiency, distributed computing requirements.

Once the node location is determined, the sensor nodes are divided into beacon nodes and unknown location nodes. Beacon nodes location is known, the unknown location of the node need to define its own position with some kind of positioning mechanism. During the sensor network positioning process, we often use the trilateration method, triangulation, or maximum likelihood estimation algorithm to determine the location of the node. According to the process of positioning, we measure the distance between the nodes or angle, and classify the sensor network as distance-based positioning and range-free positioning.

The distance-based positioning mechanism is achieved by measuring the actual distance between adjacent nodes or the location to determine the unknown node location, usually using positioning and correction steps. According to the method of the distance measurement or direction, positioning can be classified as TOA-based positioning, TDOA-based positioning, AOA-based positioning, and RSSI-based positioning and so on. Because we measure the actual distance and angle, the node’s hardware needs a very high performance to make the measurement more accurate. The positioning mechanism without the distance measured could locate the location of unknown nodes without measuring the actual distance between nodes. The present positioning mechanism is mainly with DV-Hop, Amorphous algorithm and APIT algorithm and so on. Because these algorithms do not need to measure the actual distance and the location between nodes, the hardware requirements could be lower, therefore making nodes more suitable for the large sensor network. [1, 5, 18]

2.2.5.6 Data Fusion

Sensor networks are energy-constrained. Reduce the amount of data can effectively save energy, and therefore the collection of data from various sensor nodes in the process can make use of the node's local computing and storage capacity to deal with the integration of data to remove redundant information, so as to achieve the purpose of saving energy. As the sensor nodes are easy to fail, sensor network data fusion techniques are also needed to offer more comprehensive data and improve the accuracy of the information.

Data fusion technology can be combined.

In the application layer design, we can take advantage of distributed database technology, data collected by stepwise selection to achieve the effect of integration; in the network layer, many routing protocols are combined with the data fusion mechanism in order to reduce the amount of data. In addition, some researchers have proposed an independent data fusion protocol layer to reduce sending conflict of the MAC layer, thus to achieve the purpose of energy saving without loss of time performance and information integrity. Data fusion technology is already used in the target tracking, targeting the areas of automatic identification and so on.

Data fusion technology will lose some other performance in order to enable energy savings and to improve the accuracy of the information. The main loss is the network delay and the reduction of relative robustness. [11, 18]

2.2.5.7 Data Management

From the data storage point of view, sensor networks can be regarded as a distributed database. By using database methods in sensor networks for data management, we can separate the logical view and the real network. Thus, the users only need to care about the logical structure of data query; there is no need to care about implementation details. The TinyDB system of University of California at Berkeley College and the Cougar system of Cornell University are the representatives of the sensor network data management system.

Sensor network data management and traditional distributed database are very different. Since the energy-constrained sensor nodes are easy to fail, data management systems must minimize energy consumption while providing efficient data services. Meanwhile, there are large numbers of nodes in sensor networks and sensor nodes generate an infinite stream of data that cannot be processed and analyzed through a traditional distributed database. In addition, the queries of sensor network data are often a continuous query or a random sample query, which makes the data management techniques of a traditional distributed database unsuitable for the sensor network.

Sensor network data management system architecture has mainly a centralized, semi-distributed, distributed and hierarchical structure, and most current research is focused on the semi-distributed structures. The storage of sensor network data uses network external storage, local storage and data-centric storage; these three ways, compared to other two methods the data-centric storage method can be work with a balance between the communication efficiency and energy consumption. The geographic hash table is a commonly used method of data-centric data storage. It can build a single Dimensional Index and can also create multi-dimensional indexing. The DIFS system is using single Dimensional Index, DIM, which is a multi-dimensional indexing method for the sensor network. The data query of sensor network is currently using the SQL language. We also need to consider the process of continuous query; the CACQ technique can deal with the continuous query and multi-row queries for the sensor network nodes. [2, 18, 3, 4, 10]

2.2.5.8 Wireless Communication Technology

Sensor networks require low-power, short-distance, wireless communication technology. The IEEE802.15.4 standard is aimed at low-speed wireless personal area network wireless communication standards. The low-power, low-cost as the main objective of the design is aimed at individuals or families within the low-speed interconnection between different devices to provide a unified standard. As the IEEE802.15.4 standard network and wireless sensor networks have similar characteristics, , so many research institutions to install it as a wireless sensor network platform for wireless communications.

Ultra-wideband technology (UWB) has a great potential of wireless communications technology. Ultra-wideband technology includes some excellent features which are non-sensitive to the channel fading, low signal power spectral density, low-intercept capabilities, un-complex system, and centimeters positioning accuracy and so on. It is very suitable for applications in wireless sensor networks. To date, there are two UWB technology solutions, one is based on Freescale’s DS-CDMA single-band system and the other one is the DFDM multi-band system by Intel, Texas Instruments and other companies. But there is no system to become to a formal international standard. [1, 2, 8, 18, 3, 4, 10]

2.2.5.9 Embedded Operating System

A sensor node is a tiny micro embedded system carrying very limited hardware resources. So the operating system has to require using its limited memory, processor and communication model to provide maximum support for a variety of specific applications.

A sensor node has two prominent characteristics. One feature is that it is concurrency-intensive, which means that it may include several logic control operating at the same time. So the operating system can effectively meet this kind of frequently, high-concurrency and short implementation logic control processes. The other important feature is the sensor node's high level modularization. It requires that the operating system allows applications to facilitate control of the hardware; the various parts of the application can be more convenient to re-mix.

Those features give a new challenge for the design of the wireless sensor networks. University of California at Berkeley College has developed the TinyOS operating system for the wireless sensor network and it has widely been used in the study of scientific research institutions, but there are still some inadequacies. [18]

2.2.5.10 Application Layer Technology

The application layer of a sensor network is made from a variety of application-oriented software systems. The deployment of sensor networks often performs a variety of tasks. The research into the application layer mainly deals with the development of a variety of sensor network applications and the coordination between multi-tasking, such as the detection and monitoring system of battle environment, military reconnaissance and heartache, intelligence acquisition system, endangered animals or rare animals' tracking monitoring system, civil and engineering facilities in the security detection systems, biomedical monitoring, treatment systems, and smart-system's maintenance.

The study of Sensor Network Application Development Environment aims to provide effective software development environment and software tools. The problems which have to be solved include the programming language of sensor network, programming methodology of sensor networks, software development environment and tools, software testing tools for research, application-oriented system services (such as location management and service discovery, etc.), perception-based data understanding, decision-making and actions of the theory and technology (such as the perception data, decision-making theory, feedback theory, the new statistical algorithms, pattern recognition and state estimation techniques, etc.).

3 Environmental Monitoring System

Environmental monitoring is a typical sensor network application.

Interconnected through the use of the large number of satellite sensors nodes in sensor networks, researchers can collect continuously high-precision data in the environment area they are interested. Compared to traditional means of environmental monitoring, environmental monitoring using sensor networks has three significant advantages: First, sensor nodes are small and only need to be deployed once in whole network. Therefore, the man-made impact is very small for the deployment of sensor networks for environmental monitoring. This point is especially important to external environment of biological activity. Secondly, a large number of sensor nodes offer high density, and each node can detect the detailed information the local environment and summarize it to the base station. The sensor network has a data collection capacity and high precision. Thirdly, the wireless sensor node itself has some computing power and storage capacity to change the physical environment. Each sensor node also has wireless communication capability and can monitor coordination between nodes. By increasing the battery capacity and improving battery efficiency, the low-power wireless communication module and wireless communication protocol can extend the lifetime of sensor networks for a long time, which ensures the practicality of sensor networks. The computing power and wireless communication capability of each node allows sensor networks to become deployed and re-deployed according to environmental changes and sensor timely response for the command change of the network control, thus sensor networks are suitable for a variety of environmental monitoring applications.[8, 9, 18]

3.1 Sensor Network of Environmental monitoring

Figure 7 shows a suitable sensor network system structure of environmental monitoring. This is a hierarchical network structure, the lowest level is the actual testing environment for the deployment of sensor nodes, the middle level is the transmission network, base stations and the final level connects to the internet. To obtain accurate data, the deployment densities of sensor nodes are often large and may be deployed in a number of unknown monitoring regions, thus constituting the multiple sensor networks. The data is sent to a gateway node by sensor nodes, and then the gateway node is responsible for the data transmitted from sensor nodes to a base station via a transmission network. The transmission network is responsible for the coordination of various sensor network gateway nodes, comprehensive information on local area network gateway nodes. The base station is a computer with internet connection; it will send the sensor data to the data processing center through the Internet. It also has a local database to cache a copy of the latest sensor data. Researchers can access the data center with any computer with internet connection or send an order to the base station. [12, 9, 18]

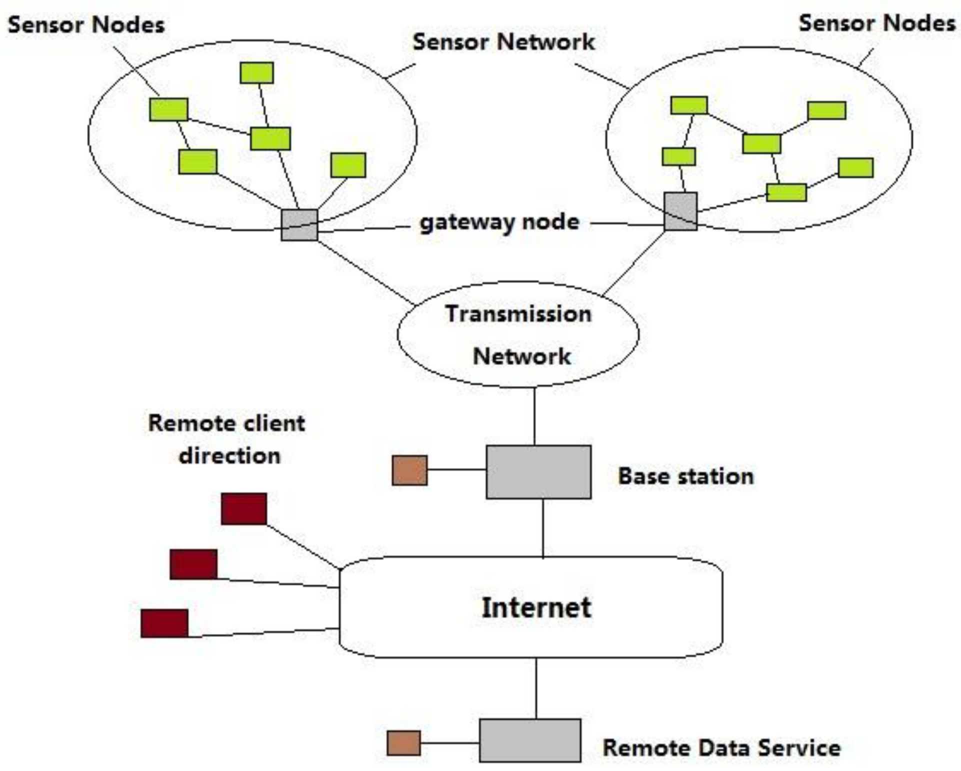

Figure 7 Sensor Network System Structure for Environmental monitoring

The researchers place the sensor nodes within the monitoring area and the sensor nodes can independently form a network. Sensor nodes have some data-processing and communications capability. Compared to traditional single-sensor devices, sensor networks can transform the goals and content of monitoring according to a researcher's interest. For example, the researchers can modify the monitoring content to follow the average of the surface temperature.

Sensor nodes can form a multi-hop network independently. Sensor nodes in the network edge must send data to the gateway through other nodes. As the sensor nodes have computing power and communication capabilities, sensor networks can collect data on the field, especially in data fusion. This can greatly reduce the data traffic and forwarding burden of the sensor nodes which are beside the gateway, thus saving the energy of sensor nodes.

Each sensor area has a gateway that collects the data which is sent from sensor nodes. All gateways are connected to the upper transmission network. The transmission network includes the number of wireless communication nodes with strong computing power, storage capacity and uninterrupted power supply. It must provide reliable broadband communication between the gateway nodes and base station.

A sensor network is connected to the Internet through the base stations. The base station is responsible for collecting all data from the transmission network, and then sending it to the Internet and saving the sensor data into the local database. The connection from base station to Internet must have enough broadband and reliable links. Considering that the environmental monitoring application might be operating in a remote region, the base station has to connect to the Internet with a wireless connection. So using a satellite link is a reliable method for monitoring a remote region. The satellite station near the monitoring region can become the base station of sensor network.

The collected data of sensor nodes is going to storage in a centric database through the Internet. The centric database provides remote data service and researchers can use the remote data service through the terminal connected to the Internet. Because of the limited process capability of sensor nodes, the collected data by sensor nodes just work with the basic process inside the sensor network, the researchers have to deal with further analysis to obtain more useful data. [18]

3.2 Key Technologies of the Sensor networks for environmental monitoring

3.2.1 Node and node deployment

The sensor nodes used for environmental monitoring must meet small size, high precision, long life cycle requirements. As the complexity and sensitivity of the environment monitoring increases, we need to minimize the size of sensor nodes and sensor nodes with special functions. In order to obtain the exact parameters of the environment, sensor nodes need to be equipped with a variety of high-precision sensors. In order to extend the effective time of the deployment of sensor networks and enhance the practicality of sensor networks, sensor nodes need to have a life cycle as long as possible.

Currently the widely used application is the mote node developed by the University of California, Berkeley College. A mote node with a dedicated sensor board which can be extended contains a light sensor, temperature sensors, humidity sensors and atmospheric pressure sensors and so on. The important point of environmental monitoring is to use replaceable and high precision sensors. Normally, the data error of similar sensor measured should not exceed 3%, this compensation mechanism can be controlled within 1% error. Another important point when selecting the sensor nodes is the start-up time. The start-up time means the time from the sensor’s start running to the stable data reading. The sensor needs a constant current during the start time, so we need a sensor with a shorter startup time to save energy. The parameter map of Mote node onboard sensors is shown in Figure 8. [18]

Sensor	Accuracy	Replaceable accuracy	Sampling frequency /Hz	Starting time / ms	Operating current /mA
Optical Sensor	N/A	10%	2000	10	1.235
L2C temperature sensor	1K	0.20K	2	500	0.150
Atmospheric pressure sensor	1.5 mbar*	0.5%	10	500	0.010
Atmospheric temperature sensor	0.8K	0.24K	10	500	0.010
Humidity Sensor	2%	3%	500	500~3000	0.775
Thermopile Sensor	3K	5%	2000	200	0.170
NTC Sensor	5K	10%	2000	10	0.126

* 1 bar = 1.0^5 Pa

Figure 8 Berkeley Mote sensor board Parameter table

3.2.2 Energy Management

Some environmental monitoring applications require continuous monitoring for several months, which is why the energy supply of sensor nodes needs high performance. Most of the current sensors use two batteries for the power supply, so the pressure in this case is about 2200mAh and 3V voltage. If the node needs to work for 9 months, each node only can spend 8.148 mA/h of electricity per day. Figure 9 gives the energy consumption of common sensor nodes operation.

Sensor Node Operation	Power consumption / nAh*
Transmitting a packet	20.000
Receiving a packet	8.000
Listening channel 1ms	1.250
One time sensor Sampling (Analog Sampling)	1.080
One time sensor Sampling (Digital Sampling)	0.347
Read the first ADC Sampling Data	0.011
Read the Flash Data	1.111
Write Data to Flash or Erase Data from Flash	83.333

* 1Ah = 3.6 kC

Figure 9 typical operation of sensor nodes and the electricity consumption

In a sensor network, different nodes demand and use different amounts of energy . For example, the nodes near the base station may require more energy to use in forwarding data packets; most energy is used in the collection of sensor data of the node located in the network edge. Therefore, some nodes consume energy faster. In practice, we need to predict which node may consume energy faster, and to take certain measures to ensure that data will not be interrupted by individual node failure.

The main method for saving energy is the dormancy mechanism. When a node is currently not on mission, there is no need for other sensor nodes to forward sensor data, and we can close the node's wireless communication module, data acquisition module and even calculation module in order to save energy. Thus, when a sensing task occurs, only the adjacent sensor nodes within the region are active, from the formation of an active region. The activity area moves according to the data transmission. So, when a node is leaving the original activity region, the nodes can go to sleep mode to save energy. The theory of activity region is shown in Figure 10. [18]

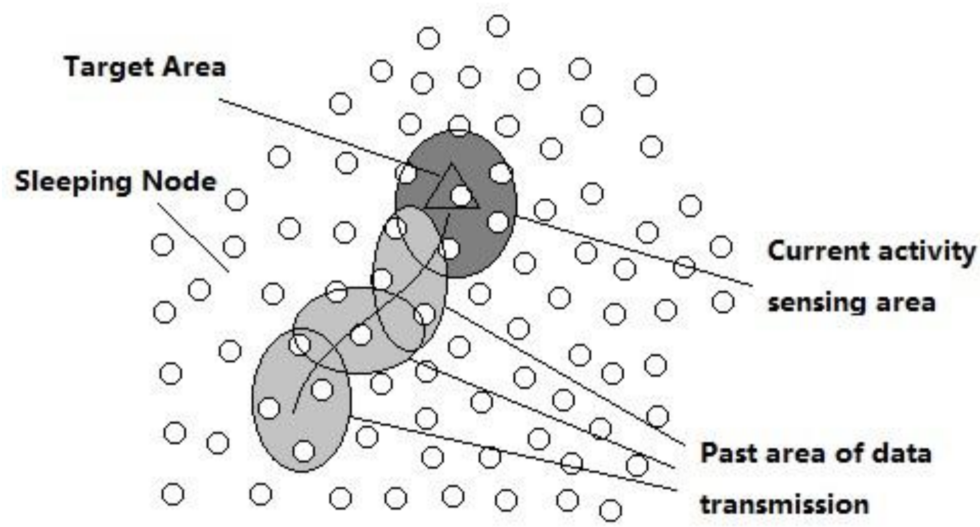

Figure 10 Network Activity region of Sensing Task

3.2.3 Remote Task Control

A sensor network is connected with the Internet through a base station; researchers can remote control the work of sensor network via the Internet. If the monitoring area is very far away, a satellite link is used as the connection between base station and the Internet. On the Internet, there is usually a centric server which is responsible for controlling and coordinating the sensor network's work and saving the sensor network forwarding data. As the base station is usually unmanned, the base station and the connection between the base station and centric server must reliable. The Base station system must be processed on time to avoid possible system anomalies. If the system crashes, the base station needs to restart the system and timely initiative to connect the central server to enable remote control to restore the remote monitoring of sensor networks.

The most important aspect of remote task control is rescheduling the mission of monitoring sensor networks. Researchers often change the monitoring task of the sensor network after a period of current monitoring mission. This change has to be sent to the whole sensor network through remote control. Researchers send the command to the base station, usually the base station periodically sends it to the whole network. In more complicated situation, we need to update the operating applications of the new nodes. A base station node sends the binary image of the new program to each node; the node self-renewal process will start to write new programs. However, the energy consumption of a lot of updates can-not be frequent.

Remote task control needs to monitor the working and health situation of sensors, and to adjust the work of the task nodes. The health situation includes residual energy, sensor components, and the work of the communication components and so on. By monitoring the sensor node status, we can promptly adjust the duty cycle of sensor nodes, re-distribution of tasks in order to avoid premature failure of the node and to extend the network lifetime. Currently we can judge the node residual energy information by the working voltage of nodes. Nodes periodically sample their operating voltage, according to the standard 3.3v voltage normalized and inform the gateway nodes. If the node voltage is too low, to the sensor data reliability is greatly reduced, so we need to extend the low voltage node sleeping time and reduce the sampling frequency. [7, 18]

3.2.4 Sampling and Collection

The final goals of environmental monitoring applications are data sampling and collection. Sampling frequency and accuracy are determined by the specific application by the control center issuing a directive to the sensor network. For the sensor nodes we need to consider the balance for the sampling data and energy consumption. In the detection zone and the edge nodes only need to collect the data as sent to the base station. If the energy consumption is relatively small, and close to the base station nodes as edge nodes also need to route data, energy consumption should be about more than two orders of magnitude. Therefore, the edge nodes must collect some data compression and fusion and then sent them to the base station.

Intel laboratory experiments using a standard Huffman algorithm and Lempel-Ziv compression algorithm to raw data, allowed data traffic to be reduced by 2~4 orders of magnitude. The language is similar to GSM loss compression algorithm for further processing mechanisms, and better compression is achieved. Figure 11 shows several classical compression algorithms.

Compression Algorithm	Huffman (pack)	Lempel-Ziv (gzip)	Burrow-wheeler (Bzip2)	Non compression
8 Bit sampling	1128	611	681	1365
10 Bit sampling	1827	1401	1480	1707
16 Bit sampling	2074	1263	1193	2730
8 Bit difference	347	324	298	1365
10 Bit difference	936	911	848	1707
16 Bit difference	839	755	769	2730

Figure 11 Compression effects of several classical compression algorithms.

Data fusion is a very important aspect in reducing data traffic. Since the random deployment of sensor nodes lead to the collection of data between neighboring nodes overlap considerably. Data fusion can reduce data traffic. On the other hand, a correction mechanism can also capture the essence of a single node data. Currently applications of signal processing techniques and software through data analysis techniques are focusing on data fusion. [18]

3.2.5 Energy efficient communication mechanism

For the applications for environmental monitoring, energy efficient communication mechanisms include a series of routing algorithms, MAC algorithm and the direct control of the communication components and access mechanisms. The routing algorithm needs to ensure efficient communication between nodes, so that the data transmission path maintains connectivity. The most simple and efficient routing protocol is a fixed allocation of nodes in the time slot to broadcast directly to the base station, but since this node is required within one hop from the base station, it limits the size of the sensor network. A more large-scale application with a multi-hop routing mechanism is required. The Intel environmental monitoring project in the laboratory used a hierarchical routing protocol. Sensor nodes are usually battery-powered, one sample per second, while the communication module has very low duty cycles. It was using solar energy power routing node, and always in working condition in order to keep transmit the sensor node data. If the normal nodes have access to energy supplement, the work efficiency of the sensor network will have substantially increased.

Network lifetime is an important issue in sensor networks. Through the use of GAF, the SPAN algorithms network topology management mechanism can improve the overall network work lifetime, but only by 2 to 3 times, and the practical application of existing sensor networks needs to increase the survival by 100 times. Therefore, in addition to routing protocols, practical applications need a low-power MAC protocol. As the

GAF, SPAN and other algorithms are independent of the specific MAC protocol, so the two protocols could be working together in practical applications.

MAC protocols need to determine the node duty cycle of wireless communication module. Most time in the work cycle, the nodes close the communication modules to save energy. Shortening the work cycle determines the sampling frequency of the sensor module. The duty cycle of wireless modules and sensor modules consistent with the sampling frequency can effectively lower the energy consumption of nodes. [10, 11, 18]

3.3 The instances of Sensor Network for Environmental Monitoring

Sensor networks can be used effectively in many aspects of environmental monitoring, which in monitoring the application of the ecological environment is very typical. The sensor network for environmental monitoring has small impact, large collected data and high accuracy features. In addition the ecological environment monitoring combined with sensor networks, compensates for the inadequacies of the traditional monitoring methods.

The Computer Science Department of California at Berkeley Lab and College of the Atlantic jointly averted a project called 'in-situ' to monitor an island environment, the Great Duck island with a sensor network. The project team established a perfect logistic system after they visited and analyzed several fields.

Biological populations are very sensitive to external factors; human involved directly in the environment monitoring may instead undermine the environmental integrity. Including the impact of the ecological environment in the habits and distribution of population, and the resulting monitoring data obtained by monitoring the environment it is also difficult to reflect the real situation. Biological researchers are drawing more and more attention to the impact of environmental monitoring activities itself on the environment, but the researchers often have to work with the monitoring activities in the region for collect enough data. So the impact on the ecological environment was difficult to avoid using the traditional methods.

The impact of these exotic biological activities is very obviously on the ecological environment especially on the island environment. Seabird habitat is a sensitive environment to the activities of the researchers. As the habitat of cormorant, even only a few minutes on the tiny island would make the mortality rate of cormorant chicks increase by 20%, and repeated human activities may cause serious damage to the habitat. As for the petrels' habitat, if they get disturbed during the first 2 weeks in the hatching period, they will abandon their nets; petrels' breeding would be severely damaged. Sensor network has a great advantage in this kind of environmental monitoring. With one time deployment, a sensor network can be working for a long period. If the sensor network is deployed before the breeding season or the dormant season, the network will automatically detect the activities during the advent of bio-active season without the need of researchers entering the monitoring environment. This is an effective method to reduce the external factors on the ecological environment.

3.3.1 Environmental Monitoring Requirements

The researchers of the Big Duck Island's environmental monitoring were mainly interested in the following three questions:

- During the petrels' incubation period, the period from 24 hours to 72 hours to be a monitoring cycle for the monitoring of the den's use.
- The change of ecological parameters for the petrels' cave and island's surface in the 7 months of incubation period.
- The impact of micro-environment on a large number of petrels' nest.

We can see that, on the one hand, a set of nodes can be carried out within a short period of continuous monitoring, on the other hand, nodes need to be able to monitor as long as possible. The data to be collected include temperature, humidity, atmospheric pressure, light and so on.

The use of sensor networks can adapt to the monitoring needs of the Big Duck Island. With the use of one-time deployed sensor network and intelligent node with a variety of micro-sensor; researchers can continuously monitor the ecological environment for any period without making any impact on the ecological environment of the island.

In addition to using sensor networks outside their self-special abilities, there are also specific needs for the whole system design and implement. In summary, Big Duck Island monitoring project application requirements were as follows:

- The ability to remote access and control. The sensor network must be accessed by the Internet; researchers can remotely control the monitoring activities of sensor network through the Internet.
- Hierarchical network structure. The environmental control system requires both internet connection and database systems; they need to have the sensor nodes in the monitoring environment. Therefore, the design of a layered network is necessary.
- Enough long lifetimes of sensor networks. The applications required continuous monitoring for more than 9 months; the node can-not add any energy from the battery supply. The sensor network needs to maintain an adequate time under this restriction.
- Low effect on the natural environment. The deployment and working of sensor network should not affect the activities of the ecological

environment and biological species.

- The capabilities of data induction and search. Sensor network need to be able to induct and collect a variety of parameters, for example, environmental temperature, humidity, light, pressure, velocity and acceleration of objects.
- Direct interaction. Although the majority of interaction with the sensor network is working through the remote network, deploying the network and the necessary human intervention operations still need to read data directly from the node.
- Data storage and archiving capabilities. A large number of sensor data can be stored to a remote database and off-line data mining can be carried out., Data analysis is also an important aspect of the system implementation.

3.3.2 Ecological environment monitoring experiment of the Big Duck Island

In summer 2002, an 'in-situ' research group deployed 43 sensor nodes to build a sensor network on the Big Duck Island. Sensor node used the Mote node of Berkeley College, the software running in the node was the TinyOS system developed by Berkeley College. The Node is equipped with various sensors to monitor different types of data on the island. Light sensors, digital temperature and humidity sensor and pressure sensor were used to monitor the micro-environment of petrels' underground nest; low power passive infrared sensors were used to monitor the usage of nests. In order to deploy the nodes into the nest of petrels, we need to consider how to control the size of the node. Sensors are integrated into the sensor board, thereby greatly reducing the size of nodes to meet the monitoring needs. Sensor board also includes a 12-bit A/D conversion period, to reduce or eliminate the noise in the analog measurements to obtain more accurate sensing data.

When deploying nodes in the physical environment, we need to consider the package in question; according to different monitoring ,tasks we can use different packages. The actual environment of sensors package is shown in Figure 11. The sensor nodes for collecting light information need transparent and closed packages and the nodes for collecting data must have a gap for temperature and humidity sensing. As the island environment is very complex, the rain and snow usually fall and the pH value of rain is often less than 3, there will be dew and fog, too. Islands often encounter extreme high and low temperature and direct sunlight, these factors may cause the failure of electronic components and sensors. T transparent plastic was used to package nodes, and adhesive to fill the gap of the package. This provides good water resistance and does not hinder the lighting of photosensitive sensor. Package size is a factor to be considered, too large a size may not put into the cave we need to monitor, and the cost of the custom package is too expensive. In addition, communication problems are related with the package method. In actual deployment, the node selected on-board antenna winding. The communication of nodes deployed beside of the rock and trees needs to be measured and tested to avoid obstacles between the nodes.

Figure 11 Deployment of sensor nodes in Physical environment [5]

3.3.3 Analysis of Monitoring Experimental

The first problem of experiment is the lifetime of sensor networks. In order to test the lifetime of sensor nodes, the nodes run an application which is sampling data once every 70 seconds and send them to the base station. The length of packet is 36 bytes, and record local time. After 123 days of the test, the whole network received about 110,000 data records. During the experiment, there was some node failure and some nodes had communication problem, some nodes received invalid sensor data. The collected statistics of the sensor network is shown in Figure 12, which shows the daily amount of data collected by sensor networks. Since the collapse of the database, the data chart in August is a blank part of the statistics because the database crashed for a period on August.

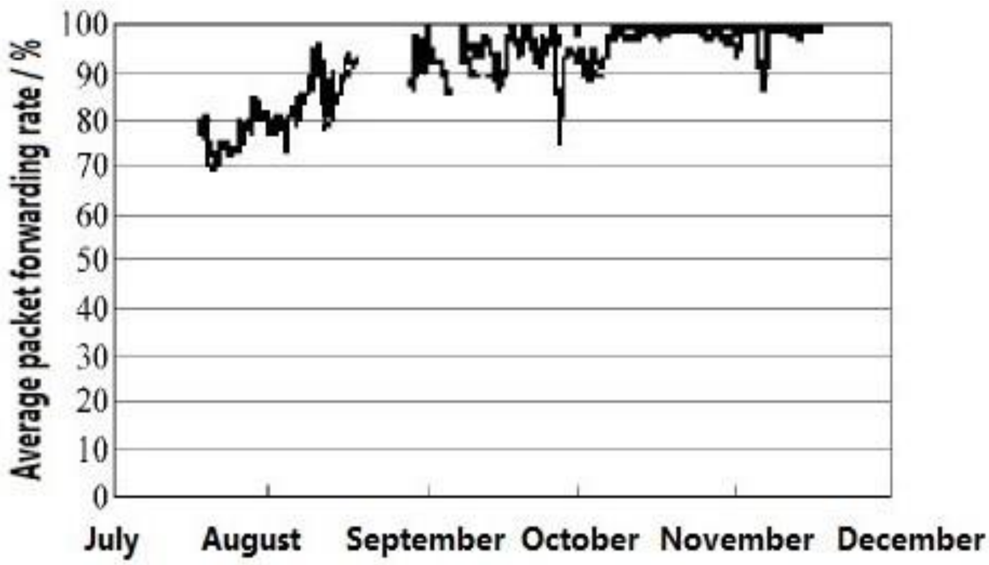

Figure 12 Statistics of Sensor Collected Data [18]

Figure 13 shows the loss rate of received data statistics, the solid curve of the figure shows the actual data loss statistics, the dotted curve represents the theoretical data loss. As the figure shows the loss rate of each packet is not independent; the data loss rate on the initial phase is higher, but after a while the performance of the network significantly improved and became stable.

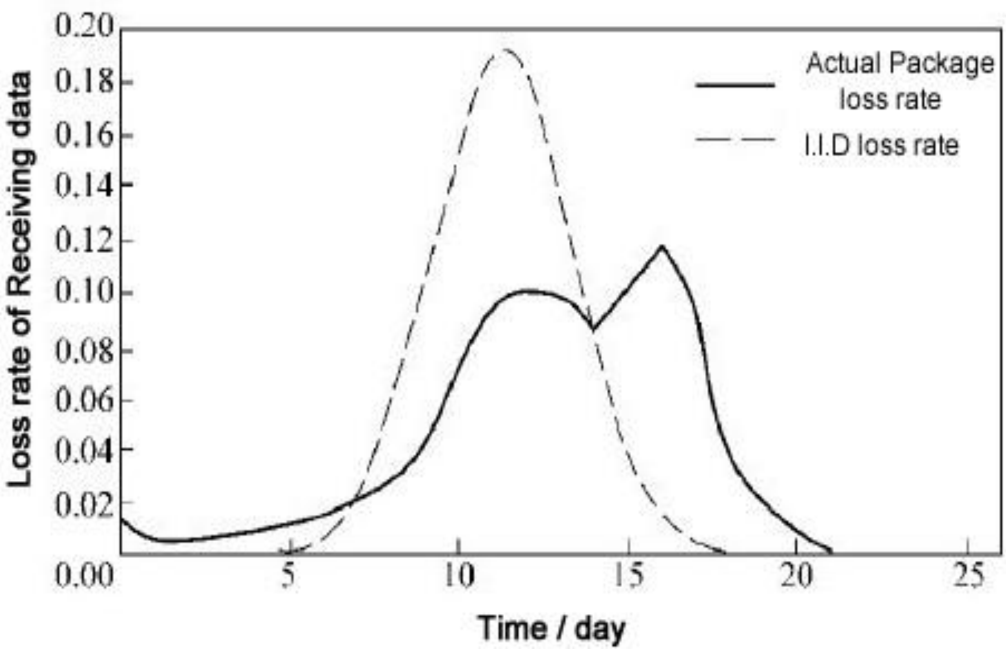

Figure 13 Data receiving statistics loss rate

3.4 Summary of sensor network of environment monitoring

Ecological monitoring applications require long testing equipment to have a low effect on the target work environment. The size of sensor nodes is very small and we only need to deploy them once for a long term data monitoring. While the sensor network has a larger amount and a certain degree of data processing and communication capabilities, it can send a large amount data to the data center for processing. Therefore, it is very suitable for sensor network environment monitoring applications.

Sensor networks use a hierarchical network of smooth structure in the ecological monitoring. A sensor node of sensor network is working on the data collection in monitoring the environment, the gateway sensor nodes collect and send the monitoring data to the transmission network. The transmission network coordination sorts the data of multiple sensor networks, summarizes and sends the data to base station. Then, the base station will send the collected data to the Internet through the broadband, reliable connection. Through the hierarchical network, researchers can achieve remote data analysis and real-time monitoring.

There are many key technologies in the actual monitoring and control of environment, including the node deployment, power management, remote control, data acquisition, communication mechanisms and so on. As the sensor network is a highly application-related network, the key technology in the ecological environment monitoring application needs studies based on the actual situation.

The example for systematic use of the current ecological environment monitoring is the Big Duck Island’s environment monitoring project by Intel labs and College of the Atlantic. Big Duck Island is a very sensitive ecological environment for outside monitoring equipment. Intel laboratory and College of the Atlantic deployed a sensor network in Big Duck Island for monitoring about 9 month to obtain a lot of primary data. The experiments show that the sensor network has a very clear advantage in such environments.

The monitoring of Ecological environment is an interdisciplinary subject. The sensor network is a new means of ecological environment monitoring with more accurate, larger data amount and lower environment impact.

4 Experiment of Wireless Sensor Network

4.1 Abstract of the wireless sensor network experiment

The experiment is very important for the wireless sensor network. The study must be tested with the experiment to find bugs, new requirements and so on. So the researchers must consider the experiment of the wireless sensor network.

Currently researchers usually use two experiment methods for the wireless sensor network testing. The first one is the physical experiments which mean the researchers deploy real sensor nodes to an area and collect the data. The advantage of the physical experiment is that the researchers can obtain real and accurate data for analysis and they also can acquire more experience in deployment methods. But there is still a huge disadvantage, researchers will spent a lot of money and time, they will have to organize a big group and do a lot of preparation. Researchers have to do a lot of work on the deployment and software design. Usually the physical experiment of a wireless sensor network takes place for a long period. Therefore the physical experiment for the wireless sensor network is not suitable for a basic WSN study. Another method is using simulation software to simulate a wireless sensor network. Because the actual network systems are often difficult to achieve, the simulation is essential during the research and building process of wireless sensor network experiments. Network simulation is a good method to test, evaluate and validate the WSN system. Reasonable simulation is able to collect and simulate the performances parameters of network which focuses on the actual application environment and hardware equipment. A specific network deployment can reduce the investment risk, modify the design stage and to evaluate the networking performance parameters such as throughput volume, delay, network efficiency and other kinds of business applications. We can also use the appropriate hardware test platform to build a physical test environment for further verification after the simulation which will make the work more efficient.

4.2 The different factors of simulator

At present there are many different simulators. The different simulators might obtain very different simulation results for the same algorithm. The difference in the simulation is usually caused by the following:

- The validity of physical layer. The physical environment is very difficult to describe and a simulator usually provides a simple, common physical model. There are huge differences between the different simulators and physical layer modules.
- The validity of existing modules. Simulators usually provide some ready-made modules, such as MAC protocol, routing protocols and so on. Each respective simulation uses their own programming language to achieve these protocols, so there will be some differences between the existing protocol of simulator and the standard protocol. These modules will greatly influence the real degree of simulation fidelity.
- The simulation parameters and simulation environment must be true. The simulation results will not be trusted by the wrong simulation parameters. The simulation of the network environment is to some extent similar to the real network environment, but not completely consistent with the real network environment. The degree of consistency will affect the simulation results of the assessment. When different simulators assess the same

algorithm, and these simulators constructed a network environment consistent with the real network environment, they are usually quite different and the simulation results also have some differences. Thus, on the same algorithm, different simulators have given the different assessment results and sometimes even opposite results of the assessment.

- Different methods for deployment of the new agreement. To describe a new algorithm, we may use a finite state machine, c/c++ code, hierarchical descriptions, graphical user interface, script, and so on. Different simulators have different methods described.

4.3 The study of current popular simulators

4.3.1 OPNET

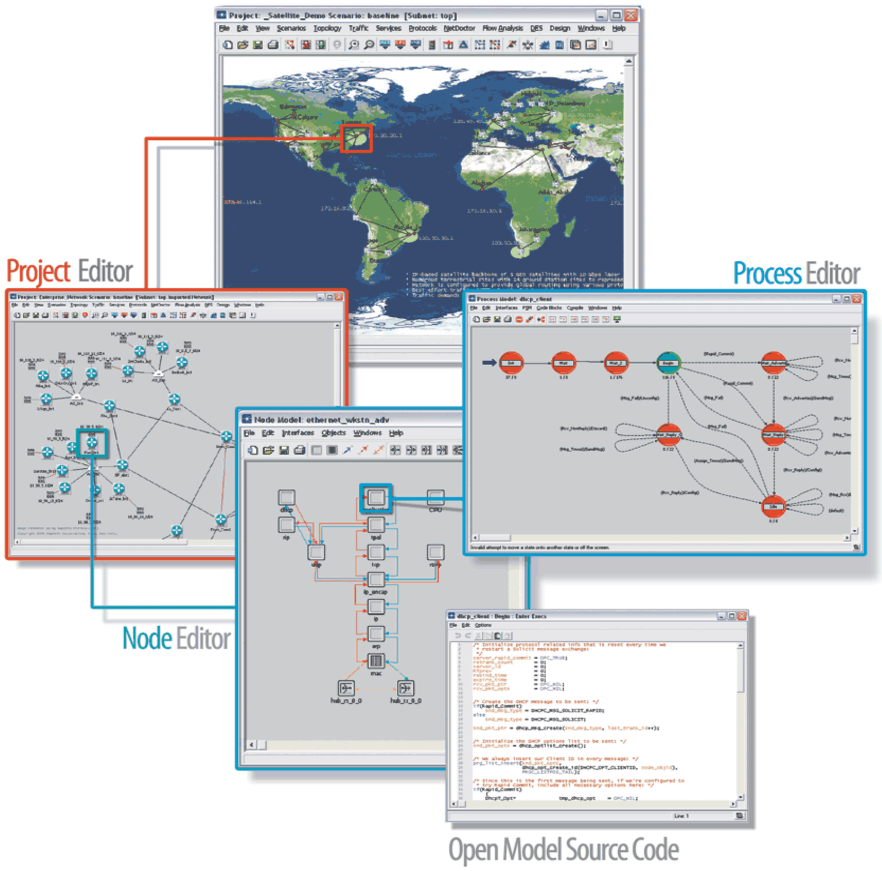

Figure 14 OPNET simulator [13]

OPNET provides a lot of models including TCP/IP, 802.1 I, 3G, etc.OPNET's main focus is a wired network and a commercial network simulation which is suitable for enterprise simulation, because it is close to reality and as such it requires that each node has its own IP, MAC, subnet mask and so on. The OPNET simulator has established the models of different manufacturers' products, such as CISCO's routing, Intel wireless card and so on. But data-centric applications have widely different, functions and need to have their own protocol stack which is not suitable for the wireless sensor network. Therefore, in the WSN simulation we need the expansion module of underlying support by OPNET.

4.3.2 NS2

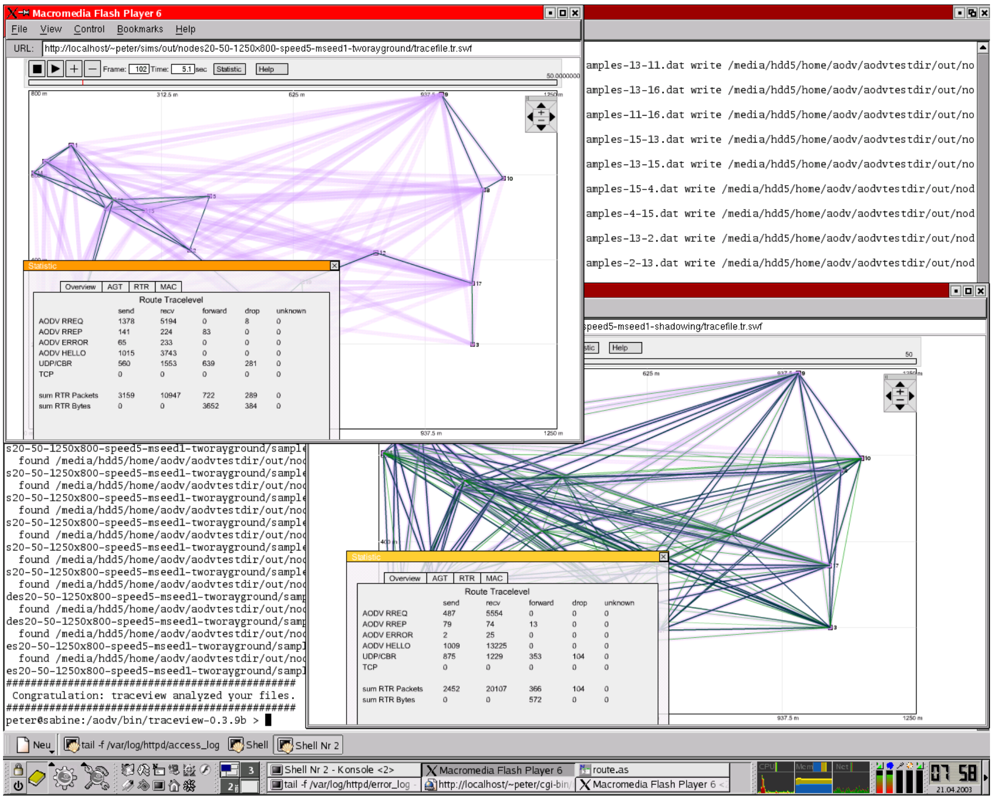

Figure 15 NS2 Simulator

NS-2(Network Simulator-2) is famous for the study of discrete event open source simulation tools, which include a large number for the wired or wireless, local connection or via satellite connection to TCP protocol, routing algorithm, multicast protocol simulation of network protocol, scheduler and tools. NS-2 simulation focuses on OSI model which includes the physical layer behavior. NS2 is free and it is not easier to use because the documentation and code organization are not very good.

4.3.3 TOSSIM

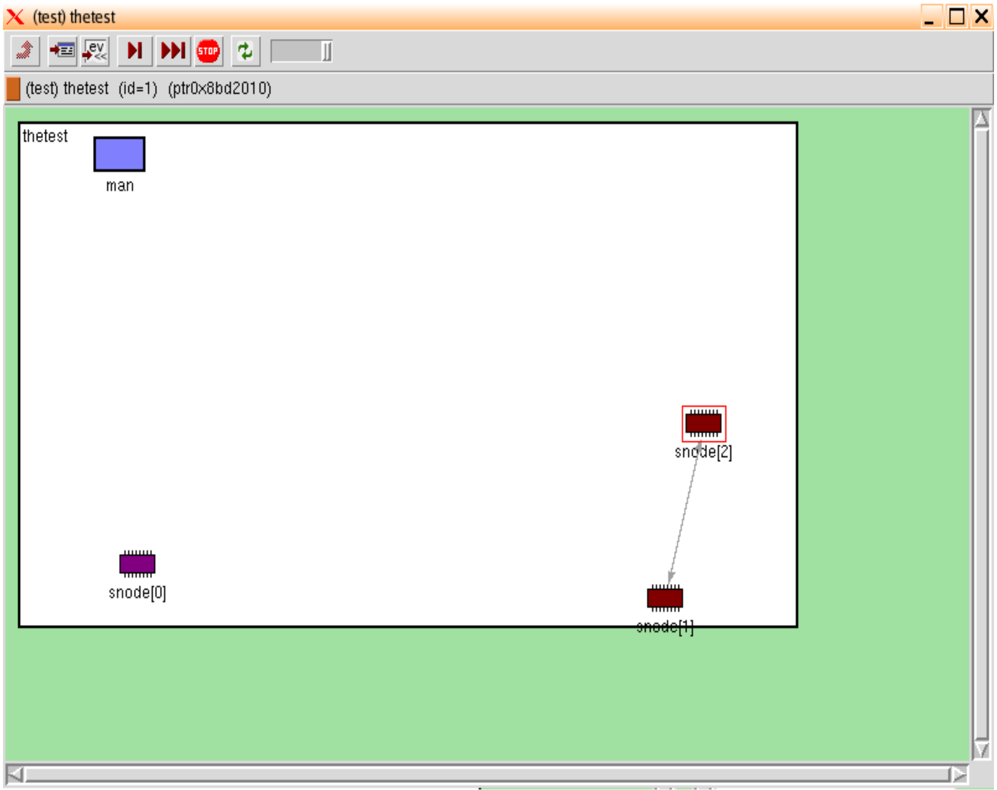

Figure 16 TOSSIM simulator

TOSSIM (TinyOS mote simulator) is used by the TinyOS Motes for bit-level simulation tool. TOSSIM is going to compile the NesC code from TinyOS environment to run in PC environment. TOSSIM also provides simulation conditions used to display the user interface TinyViz. The disadvantage of TOSSIM is that models do not provide an energy module, so it can-not be evaluated for energy efficiency.

Advantages:

- It runs the actual TINYOS code.
- Many TINYOS modules and hardware specifications, such as RF and ADC, etc.
- Simulation code and the node run the same code.
- It provides links to model the energy loss of the network.

Disadvantages:

- If only for simulation, it is a difficult portable code.
- Not all models can be simulated, such as battery module.
- MAC layer is not a good simulation.

4.3.4 QualNet (GloMoSim)

Qualnet is commercial GloMoSim. GloMoSim's original design goal is to support wireless network simulation. All levels have the appropriate modules and protocols to support wireless simulation. The programming language of GloMoSim is PARSEC which is based on C. Qualnet is a relatively good simulation for academic research because it focuses on the protocols and algorithms. Qualnet is achieved with a MAC and Routing Protocol emulator. For example for MAC, it has Aloha, TDMA, MACA, 802.11a/b/g, 802.11e, 802.16/16e, and so on. However, the latest version does not support 802.15.4, so~~t~~ building WSN requires writing a support module which is a heavy workload and difficult to achieve. Thus, this is still not a major concern about the application level of WSN simulator.

4.3.5 OMNet++

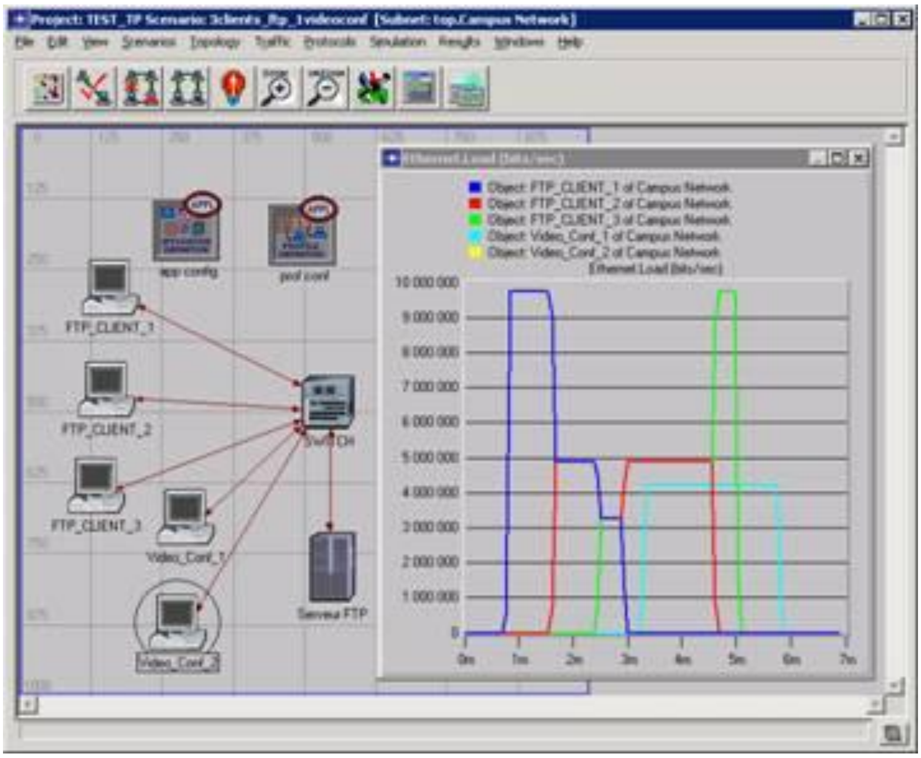

Figure 17 OMNet++ simulator

OMNet++ (Objective Modular Network Testbed in C++) is an object-oriented modular discrete event simulation tool. It is the same with NS-2 which is primarily the OSI model and can perform the simulation of thousands of nodes. OMNeT++ provides a graphical network editor and network data stream viewer. The simulation environment uses C++ language development and a custom configuration language “NED” for configuration definitions. The main goal of OMNeT++ is to provide the flexibility to configure the simulation of the component system. Components using C++ programming and through the NED configured into larger components. OMNeT++ in the simulation 802.11 MAC and Directed Diffusion protocol that is faster than NS-2.

4.4 Summary of the simulator comparison

In the real world, the WSN development and debugging is very difficult, especially when the base number is really large (>1000). In the WSN area, there are many popular simulators. They provide an advanced simulation environment and are very useful. So which simulator is more suitable for WSN is still a problem worthy of study.

Summary

After this thesis study, I learned about the architecture and characteristics of a sensor wireless network. Through the study of the architecture and characteristics, I learnt about the advantages and the limitations of the sensor network. By the comparison between the sensor network and the normal wireless network, I know the sensor network is very good to use in environmental monitoring. The sensor network will be the most important technology for environmental monitoring.

It is really difficult to find the best solution for the Wireless Sensor Network Simulation. The best way is still do the experiment in a real area. But though the comparison between those simulators, I learned a lot of background knowledge about the sensor network and simulation.

I believe the sensor network will become a very important and useful technology; it will help the humans to protect our environment.

References

[1] Estrin D, Govindan R, Heidemann J S, Kumar S. Next century challenges: Scalable coordinate in sensor network. In: Proc 5th ACM/IEEE Intel Conf on Mobile Computing and Networking, 1999, 263 ~ 270

[2] Bonnet P, Gehrke J, Seshadri P. Querying the physical world. 2000, 7(5); 10~15

[3] Pottie G J, Kaiser W J, Embedding the Internet; Wireless integrated network sensors, Communications of the ACM, 2000, 43 (5); 51 ~ 58

[4] Akyildiz I F, Su W, Sankarasubramaniam Y, Cayirci E, A survey on sensor networks, IEEE communications Magazine, 2002, 40(8); 102~114

[5] Pister K, Hohlt B, Jeong J, Doherty L, Vainio J P. Ivy—A sensor network infrastructure. 2003. http://www-bsac.eecs.berkeley.edu/projects/ivy

[6] Rentala P, Musunuri R, Gandham S, Saxena U, Survey on sensor networks. Technical Report, UTDCS-33-02, University of Texas at Dallas, 2002

[7] Estrin D. Tutorial 'Wireless Sensor Networks' Part IV; Sensor Network Protocols. Mobicom, 2002

[8] Mainwaring A, Polastre J, Szewczyk R, Culler D, Anderson J. Wireless sensor networks for habitat monitoring, In: Proc of ACM WSNA'02, 2002

[9] Polastre J, Szewczyk R, Mainwaring A, culler D, Anderson J, Analysis of wireless sensor networks for habitat monitoring, Wireless Sensor Networks, 2004, 399 ~ 423

[10] Cerpa A, Elson J, Estrin D, et al. Habitat monitoring: Application driver for wireless communications technology. In: Proc ACM SIGCOMM Workshop on Data Communications in Latin America and the Carribean. 2001. 20 ~41

[11] Yao Y, Gehrke J, Query processing for sensor networks, In: Proc 1st Biennial Conf on Innovative Data Systems Research (CIDR), 2003, 1364

[12]Wang H B, Estrin D, Girod L. Preprocessing in a tiered sensor network for habitat monitoring, in: EURASIP JASP Special Issue of Sensor networks, 2003, Vol.4 392 ~401

[13]Figure14: http://www.opnet.com/solutions/network_rd/modeler.html

[14]Introduction Page: http://www.isi.edu/nsnam/ns/

[15]Figure 16:http://www.eecs.berkeley.edu/~pal/pubs/nido.pdf

[16]Figure 17&Introduction: http://www.omnetpp.org/

[17]Sun Limin, Li Jiangzhong, Chen Yu. Wireless Sensor Network, Tsinghua University Press, 2005.05.01

[18] Introduction: http://www.fzis.net/shownews.asp?id=164