COMPARISON OF ZIGBEE AND LORAWAN TECHNOLOGIES: A COMPREHENSIVE ANALYSIS

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Annotation: This article, titled “Comparison of Zigbee and LoRaWAN Technologies: A Comprehensive Analysis,” focuses on an in-depth examination of two leading wireless communication technologies in the IoT (Internet of Things) ecosystem - Zigbee and LoRaWAN. The paper explores the history, development, and core technical characteristics of both technologies. A comparative analysis is conducted based on parameters such as operating frequencies, data transfer rates, coverage ranges, and energy consumption.

Keywords: Zigbee, Radio signal, IoT, LoRaWAN, IEEE, star topology, cluster tree topology, mesh topology, JSON.

Annotatsiya: "Zigbee va Loravan texnologiyalarini taqqoslash: har tomonlama tahlil" nomli ushbu maqola IOT (Internet of Things) ekotizimidagi ikkita yetakchi simsiz aloqa texnologiyalari-Zigbee va Loravanni chuqur o'rganishga qaratilgan. Gazeta ikkala texnologiyaning tarixi, rivojlanishi va asosiy texnik xususiyatlarini o'rganadi. Qiyosiy tahlil ish chastotalari, ma'lumotlarni uzatish tezligi, qamrov diapazoni va energiya sarfi kabi parametrlar asosida o'tkaziladi.

Kalit so'zlar: Zigbee, Radio signal, IoT, Loravan, IEEE, yulduzlar topologiyasi, Klaster daraxtlari topologiyasi, to'r topologiyasi, JSON.

Аннотация: Эта статья, озаглавленная “Сравнение технологий Zigbee и LoRaWAN: всесторонний анализ”, посвящена углубленному изучению двух ведущих технологий беспроводной связи в экосистеме IoT (Интернет вещей) - Zigbee и LoRaWAN. В статье рассматриваются история, разработка и основные технические характеристики обеих технологий. Проводится сравнительный анализ на основе таких параметров, как рабочие частоты, скорости передачи данных, диапазоны покрытия и энергопотребление.

Ключевые слова: Zigbee, радиосигнал, Интернет вещей, LoRaWAN, IEEE, звездообразная топология, древовидная топология кластера, сетчатая топология, JSON.

Introduction:

In today's modern world, there is an increasing demand for IoT (Internet of Things) systems that enable various devices and sensors to connect and exchange data with each other over the internet. This technology is being applied and yielding effective benefits in industries such as manufacturing, healthcare, transportation,

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household appliances, and many other fields. Wireless technologies allow devices to communicate without the need for cables. Technologies like Wi-Fi, Bluetooth, Zigbee, LoRaWAN, and 5G are the primary means of communication for IoT devices.

The importance of IoT and wireless technologies is manifested in the following:

1. Increasing efficiency: IoT devices optimize processes by collecting and analyzing data in real-time.
2. Saving resources: They enable efficient use of energy, time, and funds.
3. New opportunities: They lay the groundwork for creating innovative products and services, such as energy control in smart buildings and improved security systems.
4. Continuous communication: Wireless technologies establish constant and reliable communication between devices.
5. User convenience: They make life easier through smart home appliances and automated systems.

Overall, IoT and wireless technologies are bringing changes to various sectors of society and are expected to have significant importance in the future.

The main purpose of this article is to provide detailed information about the Zigbee and LoRaWAN wireless technologies that are widely used in IoT systems. The article examines the technical characteristics, advantages, limitations, and application areas of these technologies. Additionally, it analyzes the differences between them and discusses which technology is suitable in specific situations.

About Zigbee Wireless Technology

Zigbee is a personal network technology developed based on the IEEE 802.15.4 standard [1], and it is currently widely used for efficient communication among smart home devices. Its popularity is related to the large number of devices connected to routers based on Wi-Fi technology, which can lead to network delays and interruptions.

Zigbee technology allows for the creation of a separate local network for smart homes. This network ensures high reliability and efficiency and does not interfere with other Wi-Fi devices. For this reason, Zigbee stands out as a convenient and economically efficient solution in home automation systems.

IEEE 802.15.4 supports star and peer-to-peer topologies [2]. The ZigBee specification supports two types of star and peer-to-peer topologies—mesh and cluster tree topologies [2]. Devices compatible with ZigBee are sometimes claimed to support point-to-point and point-to-multipoint topologies [2].

Types of ZigBee Devices:

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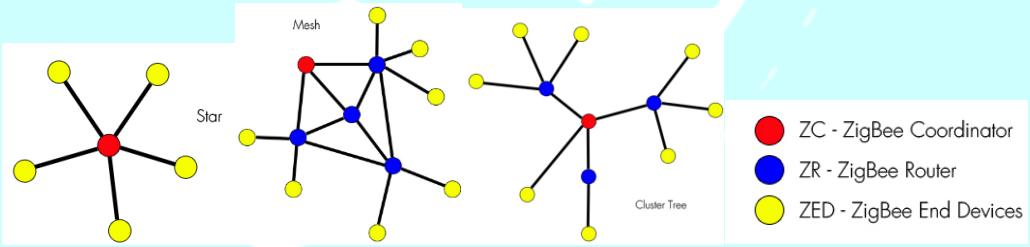
1. This is a device that manages and transmits messages and is considered a Full-Function Device (FFD)[3]. The coordinator acts as the main controller of a Personal Area Network (PAN)[4]. If the coordinator functions as the PAN controller, it is called the PAN Coordinator.

1.1.**PAN ID:** Each Zigbee network is identified by a unique Personal Area Network Identifier (PAN ID). This identifier is common to all devices within the network [4].

1.2.**Joining:** Zigbee devices can join a network using a pre-configured PAN ID or search for nearby networks and select an appropriate PAN ID.

2. **Zigbee End Device (ZED)** is the simplest and lowest power-consuming device in a Zigbee network. It is designed to perform only basic functions and does not have the capability to directly send or receive data with other devices [5]. ZED is primarily adapted for executing commands and sending data.

3. **Zigbee Router (ZR)** is an important part of the Zigbee network that provides data transmission between devices and/or from the Zigbee Coordinator (ZC) [6]. Additionally, the ZR has the capability to run applications operating within the network [6].



1.1- Figure

Zigbee often constructs networks using three types of topologies, as shown in Figure 1.1: star, mesh, and cluster tree. Depending on the usage scenario, the appropriate topology is selected.

1. **Star Topology** - This topology is used in small installations or when there are few devices in the network.

1.1. **Structure:** A Zigbee Coordinator (ZC) is located at the center of the network. Zigbee End Devices (ZED) connect directly only to the ZC.

1.2. **Features:** ZED devices exchange data only through the ZC. It is characterized by its simplicity and low energy consumption. There is a strong dependency on the network center (if the ZC fails, the entire network stops working).

2. **Mesh Topology -** This topology is used for larger and more reliable networks.

2.1. **Structure:** The Zigbee Coordinator (ZC) sends and receives data to devices. Zigbee Routers (ZR) exchange data with each other and with Zigbee End Devices (ZED). ZR devices can send data within the network through multiple routes.

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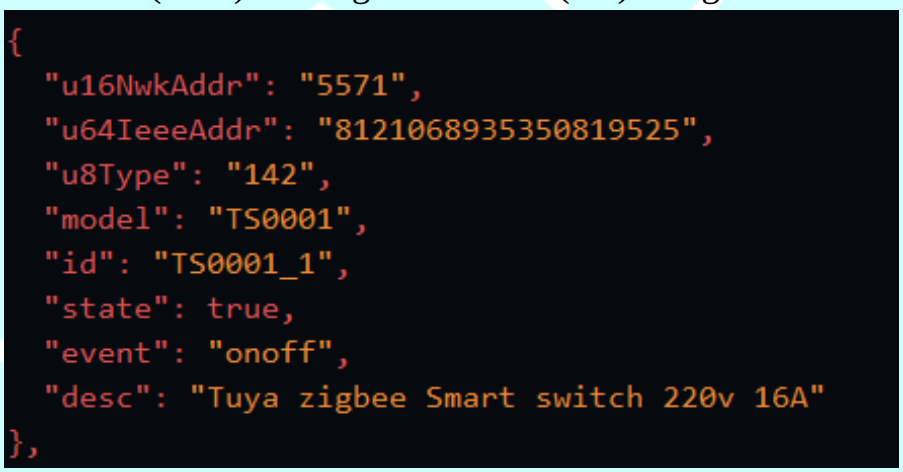
2.2. **Features:** ZRs connect and exchange data with nearby ZRs and ZEDs. The network has high stability (if a ZC or ZR fails, data is transmitted through alternative routes). Ideal for use in wide areas.

3. **Cluster Tree Topology** - This topology has a tree-like structure and transmits data in a hierarchical manner.

3.1.**Structure:** The Zigbee Coordinator (ZC) sends data only directly to the ZR and ZED devices connected to it. Zigbee Routers (ZR) exchange data only with the ZEDs assigned to them. ZRs do not connect directly with each other (this differs from mesh).

3.2.**Features:** Data is transmitted in a tree-like direction. The network has a specific rigid structure. Less flexible than mesh topology, but data exchange occurs in a definite direction.

In the network of Zigbee devices, the main communication medium is the Zigbee Coordinator, which connects to the internet and maintains constant communication with the server. The Coordinator receives commands coming from the server and converts them into JSON packets. It then transmits these packets to Zigbee End Devices (ZED) and Zigbee Routers (ZR) using hex codes.



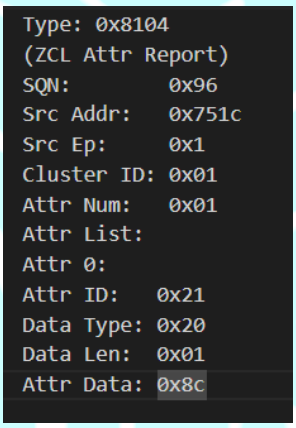
```
{
  "u16NwkAddr": "5571",
  "u64IeeeAddr": "81210689353508195 25",
  "u8Type": "142",
  "model": "TS0001",
  "id": "TS0001_1",
  "state": true,
  "event": "onoff",
  "desc": "Tuya zigbee Smart switch 220v 16A"
},
```


Picture 1. Typical JSON command packet for a smart home system might look like the following:

When Zigbee End Devices (ZED) connect to the Zigbee Coordinator (ZC) in a Zigbee network, the ZC initially sends a connection request to the device. If the request is accepted, the ZC confirms the connection and assigns a PAN ID (Personal Area Network Identifier) to the ZED device. At the same time, it stores the device in its memory.

In subsequent processes, when the ZC needs to transmit data, it sends a signal to all devices connected to the network. If a device's PAN ID matches the coordinator's PAN ID, it accepts the signal and performs the corresponding action. Otherwise, the signal is rejected, and the actions are not carried out.

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Picture 2. Transmiting data

This mechanism enhances the security and efficiency of the Zigbee network because each device accepts only signals and commands that belong to its own network. At the same time, the network's control capabilities are further strengthened.

The main advantages of Zigbee technology are as follows:

1. **Designed for Low Power Consumption -** Zigbee technology consumes very little energy, allowing devices to operate for extended periods using simple batteries. Such efficiency not only enhances energy savings but also strengthens trust in the technology.
2. **Low Latency -** The Zigbee network transmits data at high speeds, which is ideal for devices that require real-time operation.
3. **Easy Scalability -** Adding additional devices to the network is a very simple process. The Zigbee architecture facilitates quick and easy integration of various devices with one another.
4. **Stable Communication** - The Zigbee network can operate with low load, ensuring a high level of communication reliability. This technology can be successfully applied even in large-scale networks.

The main disadvantages of Zigbee technology are as follows:

1. Low Data Transmission Rate - Zigbee technology transmits data at a low speed (maximum 250 kbps)[7], making it unsuitable for applications that require the transmission of large volumes of data.
2. Limited Range - The Zigbee signal is transmitted over relatively short distances (maximum 100-200 meters in open areas). In buildings or through thick walls, the transmission range can decrease even further.
3. Need for Additional Equipment - To expand the network or obtain a stronger signal, additional repeater or router devices are required, which increases the overall cost.
4. Low Security Level - Although security protocols exist in Zigbee technology, they are not sufficient to protect against high-level threats. There is a possibility of compromising a Zigbee network using specialized equipment.

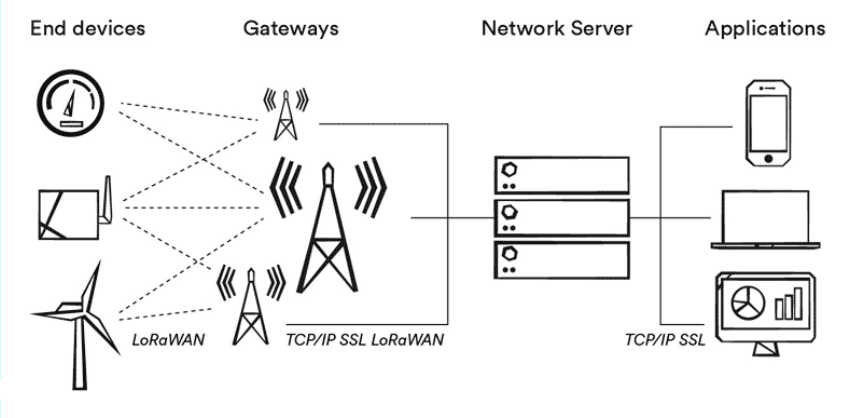
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5. Interoperability Issues - Compatibility problems sometimes arise between Zigbee devices from different manufacturers. This can create difficulties in implementing and managing the technology.

6. Limited Application Scope - Because Zigbee is designed for low speed and short distances, the technology is mainly useful for networks that require low energy consumption and the transmission of small amounts of data. It is not suitable for large-scale industrial applications.

About LoRaWAN Wireless Technology

LoRaWAN, or Long-Range Wide Area Network, is one of the most advanced technologies in the field of license-free Low Power Wide Area Networks (LPWA). This technology is particularly convenient and efficient for Internet of Things (IoT) devices, providing stable and reliable communication over long distances while consuming minimal power [8]. LoRaWAN networks operate based on a star-shaped topology [8]. This topology connects gateways to a central network server, allowing messages from end devices to be delivered to the server or, conversely, sent from the server to the devices.



Picture 3. LoRaWAN networks star-shaped topology

One of the main advantages of LoRaWAN is its low power consumption and wide coverage range. With this technology, devices can use their batteries for an extended period. For example, devices can operate continuously for several years on a single-use battery. In the territory of Uzbekistan, the EU433 frequency plan has been adopted for LoRaWAN technology, covering a network range from 433.05 MHz to 434.79 MHz. This frequency range allows for efficient and long-distance communication among IoT devices in the region [9].

Tabel 1.

LoRaWAN network range

Uzbekistan	433.05 - 434.79 MHz	EU433

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This feature makes LoRaWAN an ideal choice for use in locations where remote control is required and energy resources are limited.

Furthermore, LoRaWAN networks are used in various industrial and domestic sectors. They are successfully applied in numerous IoT projects such as energy consumption metering, monitoring the movement of transport vehicles, environmental monitoring, managing city infrastructure, and many others. The high sensitivity and long-distance operating capabilities of this technology ensure a high level of stability even in densely populated urban areas or rural regions with limited infrastructure. LoRaWAN's security measures are at a very high level, utilizing individual authentication and encryption for each device. This, in turn, allows for maximum protection of data transmission.

LoRaWAN's operating principle and the devices integrated into the system enable effective use of this technology. Below is more detailed information about the LoRaWAN architecture and operating mechanism [10].

The main elements of a LoRaWAN network are as follows:

1. **Sensors and End Nodes:** These devices are used to collect data entering the LoRaWAN network. Sensors monitor environmental parameters such as temperature, humidity, or other physical indicators and send this data to the central network through end nodes [1]. End nodes are primarily equipped with LoRa modules, allowing them to transmit signals over long distances with low power consumption.

2. **Gateways:** Gateway devices receive the signals and transmit them to network servers. A gateway has the capability to receive signals from several hundred nodes and send them to central servers via the IP protocol. This device is a key part of the LoRaWAN network, acting as a bridge that connects LoRa radio waves to the Internet [10].

3. **Network Servers and Application Servers:** Network servers manage the operation of the LoRaWAN network and are responsible for device authentication and data integration. Application servers are used to view and analyze the collected data. Network servers perform the task of managing uplink and downlink signals [10].

Signal Transmission Process: Uplink and Downlink Mechanisms In the LoRaWAN system, uplink and downlink mechanisms facilitate data transmission:

1. Uplink: A sensor or end node transmits data to the gateway. In this process, devices have the capability to send signals over long distances with low power consumption. During the uplink process, gateways receive the signal and forward it to the network server [10].

2. Downlink: Data returned from the network server to the device is transmitted. This mechanism is typically used for sending commands or managing nodes. The

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downlink process is used less frequently compared to uplink since sensors are primarily used for monitoring and data collection [10].

Advantages:

1. Wide Coverage: LoRaWAN technology is capable of transmitting data over long distances. It can cover several kilometers in urban areas and tens of kilometers in open spaces. This advantage is particularly suitable for agricultural and industrial monitoring systems.
2. Energy Efficiency: LoRaWAN sensors operate with low power consumption, allowing them to work for extended periods, even several years, without battery replacement. This advantage is very important for long-term operation in IoT (Internet of Things) networks.
3. Modular Usage Capability: LoRaWAN modules can be used in standalone devices, which facilitates the integration of the technology and creates opportunities for widespread use in various emerging IoT applications.

Disadvantages:

1. Low Network Bandwidth: While LoRaWAN offers wide coverage, it is also known for its low data transmission rate. This technology is designed for transmitting small volumes of data, making LoRaWAN unsuitable for applications that require sending videos or large files. The low network bandwidth makes real-time transmission of large amounts of data challenging.
2. Susceptibility to Signal Obstructions: The long-range capability of LoRaWAN signals can be diminished by physical obstructions such as buildings or dense forests. These obstacles can interfere with signal transmission, reducing the quality of communication. Therefore, it may be necessary to avoid obstructions within the coverage area or to deploy additional gateways to maintain reliable connectivity.

Conclusion

Zigbee and LoRaWAN are distinct technologies, each suited to addressing different tasks. If the goal is to establish high-speed communication over short distances and relatively low power consumption is required, Zigbee technology is the optimal choice. However, if the requirement is to cover wide areas and operate for extended periods without battery replacement, LoRaWAN technology is preferable. Both technologies play a significant role in various sectors of the IoT ecosystem, each standing out with its unique advantages.

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