Review Article

Satellite Technology for Internet of Things: An Overview

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Abstract: This article is about satellite review which is essential for internet connectivity and also the development of IoT and other applications, this article contains history, performance, challenges, and research opportunities in the field of satellite development. Satellite development can be applied to improving the performance of various applications such as IoT, Education, and Medical, as well as real-time monitoring such as monitoring pets such as horses and cows in large numbers, as well as other essential applications such as the medical world. Satellite development is essential for applications in the world today and in the future. Satellite technology development is tailored to the needs, for example with the Mini Cube Satellite used for the development of LPWAN IoT technology orbiting in Low Earth Orbit (LEO).

Keywords: Internet, satellite, Performance, Quality of Services, Systematic Literature Review, Internet of Things

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1. Introduction

Satellites have been proposed since 1945 by Arthur C. Clarke in his writing about "Repeaters" in space. With the launch of Sputnik 1 which has the function of transmitting data quite successfully. After that, Telstar 1 appeared in 1962 which functioned for the development of telecommunications, namely telephone transmission and also intercontinental television.

Then from 1970 to 1980 satellites continued to develop in more reliable data transmission, namely with the Geostationary Satellite (GEO) orbiting at 36,000 km above the earth, which looks motionless because the distance is quite far, in contrast to satellites in low orbit (LEO). Using GEO satellites allows for a wide communication system and has a high latency. Table 1 shows the difference between GEO and LEO in latency and distance.

Moreover, from Table 1 it can be concluded that latency depends on the distance of the satellite from the earth, the closer like LEO with 1200 km, the Latency is 30 ms to 150 ms. Satellites in Low Earth Orbit (LEO) have several functions, namely internet and communication services for remote areas, such as SpaceX's Starlink which provides fast internet services of 25 Mbps to 220 Mbps. With upload speeds of 5 Mbps to 20 Mbps.

The functions of LEO satellites are weather observation, climate change monitoring, and natural disaster detection. In addition, LEO Satellite is used for vehicle navigation and tracking during delivery. It is also used for military and security. In the world of aviation, satellites are very useful for aircraft navigation and also the movement of aircraft and ships. LEO satellites are capable of being used for data and internet communications to meet the internet needs of aircraft and their navigation. LEO satellites are also still used for research and exploration development such as planetary exploration, space research, and the development of the Internet of Things (IoT) as used by Lacuna Space using the Mini-Cube Satellite orbiting in LEO. Lacuna Space develops LPWAN communication systems used for the Internet of Things (IoT).

LEO supports IoT device connectivity and enables data collection and transmission in remote and hard-to-reach areas. Compared to Geostationary satellites, LEO is superior in terms of Latency [1,2]. After the 1990s, the internet continued to grow rapidly, with early satellite internet providers HughesNet and DirecTV providing slow internet services and high latency, but becoming a mainstay in remote areas.

Furthermore, in the 2000s, LEO orbits the earth lower, between 200 to 2000 km above the earth. One of the first types of LEO satellites was Iridium, which was launched in 1997. The satellite constellation is used for communication between satellites in one orbit. SpaceX and OneWeb exist to provide high-speed broadband satellite internet. The OneWeb constellation was launched in 2019, went bankrupt, and was relaunched in 2021 after the acquisition of a British company. After 2021, the satellite constellation continued to grow in size with ever-increasing internet speeds like StarLink. And continues to be a leader in providing super-fast internet anywhere and anytime, reaching remote areas, including areas that are difficult to reach or have no internet access in Indonesia.

Furthermore, Human needs in various fields with the use of fast internet that is evenly distributed and comprehensive in society make several developers and also large companies such as SpaceX continue to innovate to provide fast internet services. However, it does not rule out the possibility of other providers being able to compete at a cheaper price than StarLink to provide fast internet services to the world. The development of IoT technology is also inseparable from the role of satellite internet.

The total use of IoT globally is 15.9 billion connected devices, while in Indonesia it could reach 13 million IoT-connected devices by 2023, and this calculation is not yet 2024. With 871 million Smart Homes globally in 2023 and revenue (USD) on the use of IoT in Indonesia is 8.32 billion in 2024 projections.

2. Literature Review

This article comprehensively compares some of the related research on Satellites and their development for various fields and also compares them in terms of methods and approaches of other researchers in seeing various developments in the world of research and also the development of satellite research in particular. However, various perspectives are taken to improve the performance of satellite use in supporting and obtaining super-fast internet connections that can have a significant impact on various fields of human life throughout the world.

2.1 The Internet and its development

The keyword on the internet is data transfer or data communication from sender to receiver. Internet is an abbreviation of interconnected networks. In this research, the application of the internet, for example in the application to IoT, can be analyzed in terms of Quality of Service (QoS). With the internet, anyone can communicate anywhere and anytime.

The Internet is not only about the Web and its development and Google, but also various social media that continue to grow on mobile platforms such as Instagram, and e-commerce which is very useful for the economy of the Community and MSMEs. The role of the internet in e-commerce such as Shopee, Tokopedia, etc., and also transportation platforms, as well as financial applications, e-money, QRIS, and various complex features in supporting financial processes and people's lives, whether personal or business. The devices or hardware used for developing internet capacity such as LANs and WLANs are TCP/IP. TCP/IP is Transmission Control Protocol or Internet Protocol is a transmission used to communicate from one Node to another.

In addition to TCP/IP, in the internet management system when viewed from the hardware structure and connectivity starting from network connections, types of internet network connections, to network security, and overall network and hardware management, several important terms such as Domain Name System (DNS), Hypertext Transfer Protocol (HTTP), Web Browser, Web Server, Router, Firewall, Bandwidth, and Latency are some of the essential terms in the internet connection system and its management.

Table 1. Difference between GEO and LEO Satellites

Satellite	Distance from Earth	Latency
Geostationary (GEO)	About 35,786 km	240 ms to 280 ms
Low Earth Orbit (LEO)	About 1200 km	30 ms to 150 ms

Moreover, in office systems, and complex work, the internet also continues to be developed with various security systems such as Firewalls and also security systems from viruses and hackers, considering that the Company's financial system is very essential, especially banking institutions such as banks and online credit, and also other financial institutions. For the general public, the internet is used for browsing social media, sending emails, video calls with family, online scientific meetings, Zoom Meetings or Online Meetings for work and online lectures, watching movies online, listening to music, playing games, and many more. Table 1 shows the fundamental difference between GEO and LEO Satellite.

2.2 *Satellite Communication*

In general, satellite communication is shown in Figure 2, where there are three segments, namely the Space Segment, Ground Segment, and User Segment, on the Space Segment side there is a Communication Satellite to Ground Station called Uplink and Downlink and User Terminal or Device called Tx and Rx Signal. Figure 2 shows the interoperability of the LPWAN satellite communication system [3,4,5]. Interoperability is the ability of different systems, devices, or applications to communicate, exchange data, and use the information exchanged effectively. In detail, the ability to transmit data with different devices or components is called Interoperability or Cross Technology communication in Satellite LPWAN shown in Figure 1.

2.3 *Satellite orbit*

Satellite Orbit talks about how far the position of the satellite is from the earth as a Ground Station, and the satellite as a Space Station, classified into three namely Low Earth Orbit (LEO), Medium Earth Orbit (MEO), and Geostationary Earth Orbit (GEO). The satellite used for IoT Technology is LEO such as Lacuna Space. LEO is ideal for broadband connectivity, IoT, and Satellite Internet applications. LEO distance is 160 to 2000 km above the earth, while MEO is at 2000 to 35,786 km, and GEO is at 35,786 km.

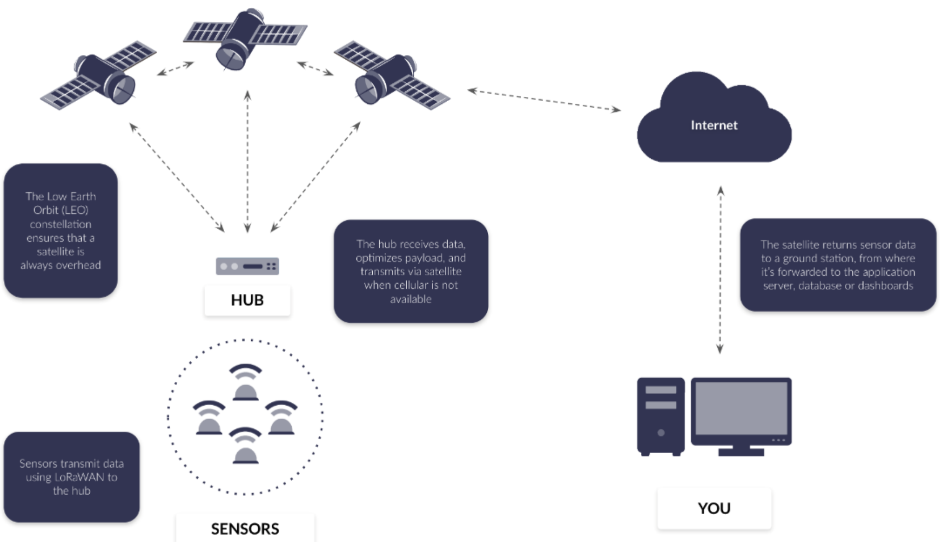

Figure 1. Interoperability in LPWAN Satellite Communications (*Source:* ground control)

2.4 Satellite Frequency

Satellite Frequency is divided into various types, as shown in the following table, including L-Band, S-Band, C-Band, X-Band, Ku-Band, Ka-Band, V-Band, Q-Band, UHF, and P-Band. Each type of band depends on the function or use of the project. As seen from Table 2, there are 10 different frequencies on the satellite and they have different functions and characteristics. This article review focuses on satellites for the development of Internet of Things (IoT) technology [6,7,8,9].

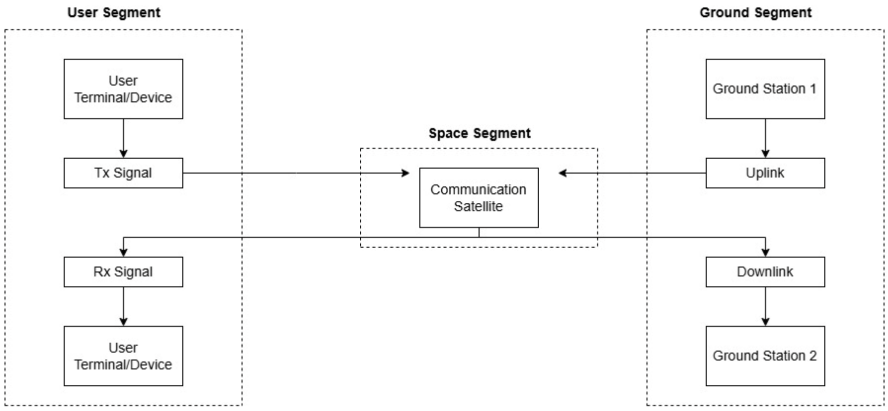

Figure 2. Satellite Communication Flow General

Table 2 shows comprehensively the characteristics of currently developing satellite technologies, such as Lacuna Space using the UHF Band for its IoT-based satellite development. The disadvantages of this technology include Low Bandwidth which does have special specifications only for sensor data by utilizing Low Bandwidth. We will comprehensively discuss the technology of UHF satellites for IoT applications. UHF band works in the range of 300-1000 MHz using LEO Satellite [10,11,12]. Table 3 states the changes in materials, and methods in working on satellites from time to time, until now satellite technology uses Metamaterials and flat Panel Arrays.

Table 2. Satellite Frequency

No	Band	Frequency Range	Uplink (GHz)	Downlink (GHz)	Main Application	Characteristics
1	L-Band	1-2 GHz	1.6-1.7	1.5-1.6	Mobile satellite, GPS, Navigation	Good weather penetration, Ideal for Mobile
2	S-Band	2-4 GHz	2.025-2.120	2.200-2.300	Telemetry, mobile satellite, weather radar	Penetration balance, moderate bandwidth
3	C-Band	4-8 GHz	5.925-6.425	3.700-4.200	Satelit tetap, siaran TV, Backhoul	Severe weather resistance, high reliability
4	X-Band	8-12 GHz	7.900-8.400	7.250-7.750	Military, Government, Radar	High security, Medium bandwidth
5	Ku-Band	12-18 GHz	14.0-14.5	10.7-12.75	DTH TV, VSAT, Broadband	High bandwidth, Rain prone.
6	Ka-Band	26.5-40 GHz	27.5-31.0	17.7-21.2	Internet broadband, High throughput	Extremely high bandwidth, Highly vulnerable to weather
7	V-Band	40-75 GHz	42.5-47.0	37.5-42.5	Future communications, Extremely high bandwidth, Experimental	Extreme high bandwidth, Atmosphere sensitive
8	Q-Band	33-50 GHz	42.5-43.5	37.5-38.5	Research, Experimental	Very high bandwidth, Development
9	UHF	300-1000 MHz	300-500	500-1000	Mobile satelit, IoT, M2M	High penetration, Low bandwidth
10	P-Band	0.23-1 GHz	0.23-0.5	0.5-1.0	SAR, Earth observation	High vegetation penetration, Special applications

Table 3. The development of satellite technology over time

Era/Period	Technology Type	Key Characteristics	Application	Excellence	Limitations
Early Era (1957-1970)	Antena Dipole, Antena Helix, Antenna Parabola	Simple structure, Radiation pattern omnidirectional, High-gain	Communication Basic, Telemetry simple, Satellite TV	Easy Construction, Low cost	Low gain, Limited bandwidth, Large size
Development Era (1970-1990)	Phased Array Awal	Mechanical beam steering	Communication military	High efficiency, good directivity	Heavy, Expensive
Modern Era (1990-2010)	Reflector Arrays, Active Phased Arrays	Beam steering electronics, Digital beam forming	Communication Broadband, Remote sensing	Flexibility High, Multiple beams	Complexity, High Power consumption
Contemporary Era (2010-present)	Metamaterial, Flat Panel Arrays	Miniaturization, Software-defined	5G/6G, IoT, LEO Constellation	Ultra-compact Reconfigurable	High cost, Complexity system

Table 4. Focus on satellite technology development

Aspects	Old Technology	New Technology	Future Trend
Materials	Conventional metals	Composites, Metamaterials	Quantum materials
Polarization	Single, Linear	Dual, Circular	Adaptive, Multi-mode
Bandwidth	Narrowband	Multi-band	Ultra-wideband
Control	Mechanical	Electronics	AI-driven
Manufacturing	Conventional	3D Printing, Precision	Nano-fabrication

Broadly speaking, the development of satellite technology is obtained from several aspects such as Materials, Polarization, Bandwidth, Control, and Manufacturing Processes as shown in full in Table 4. Broadly speaking, the development of satellite technology is seen from various sides ranging from satellite technology that continues to evolve, technical specifications that continue to change to become more dynamic, performance that continues to increase, and more detailed analysis to reduce weaknesses and increase the effectiveness of how the satellite works, and also see developments or trends & Forecast in the future.

3. Method

3.1 Flowchart System

LPWAN Satellite can be applied to IoT, considering LPWAN (Low Power Wide Area Network) is the right satellite technology for IoT, with low bandwidth, previously using Terrestrial Communication, using Satellite will ensure the application of Non-Terrestrial Communication that can reach remote and difficult to reach areas, and certainly expand the distance of coverage more broadly and globally. The next is low power consumption which can prolong the work of sensor nodes in operation. The advantage of LPWAN Satellite [13,15] is that infrastructure does not depend on land network conditions, but can also be applied at sea, mountains, and remote areas.

IoT development using LPWAN can be applied to various fields such as Agriculture, Aquaculture, Smart Cities, and Autonomous Vehicles for several components such as positioning by involving GPS modules, and also other applications. LPWAN satellite-based is a Non-Terrestrial Communication development that can provide services without boundaries or obstacles. Terrestrial-based LPWAN communication [16,17,18] depends on the capacity or capability of the LoRa Module [14] and antenna used, as well as other components related to the data transmitting process. Depending on the conditions and also the situation when the data transmitting process takes place.

Moreover, Figure 3 shows the flowchart of the simulation built, including how to set up the network and IoT devices that will be used for simulation, the process of adding IoT devices to the network is also essential and needs to be initialized first for addressing, the next step is to carry out the simulation process based on the specified period, after which the results or data from IoT devices will be obtained which can send data in real-time even though using simulation, but this can be used as a reference for real measurements. Then the statement that is there data? This means that the data sent must pass through several stages from the end node to the satellite and sent back to the device via the ground station. After the data is successfully received by the end-user, the next process is to analyze the transmission results, namely Uplink and Downlink [19,20].

Furthermore, the essential parameter is Latency, Latency is the delay time between the process of sending data from end devices to the satellite, then vice versa, from the satellite received by the ground station back. Latency depends on the distance between the sensor end-node and the presence of the satellite. Latency is also influenced by how large the data size or payload is carried by end nodes and sent to the satellite. In the satellite, there is a process of receiving and sending the data. Besides the satellite, the process of reading or transmitting data also takes place at the Ground Station.

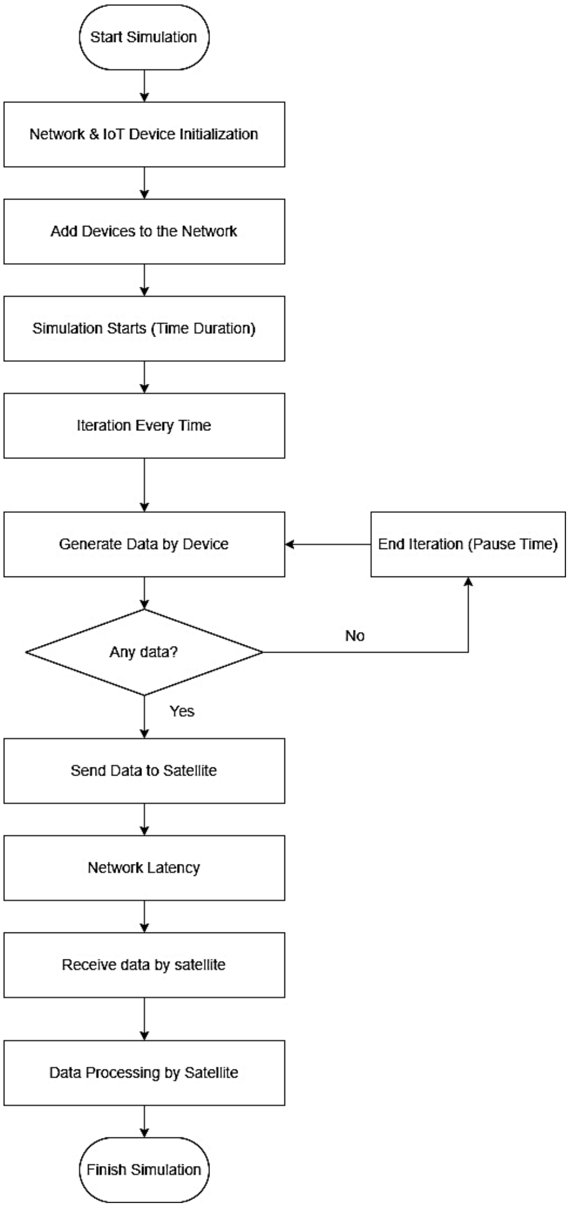

Figure 3. Flowchart of LPWAN satellite communication simulation

4. Result and Analyzes

4.1 Satellite LPWAN

Furthermore, to simplify the understanding of the IoT satellite, in this review paper, we will create a simulation that shows the Quality of Service (QoS) of an LPWAN-based satellite used for the Internet of Things. Parameter 1 shows the satellite and environment parameters used on the LEO Satellite for IoT Application.

```
# Satellite parameters
self.altitude = 550  # km (LEO orbit)
self.frequency = 868  # MHz
self.bandwidth = 125  # kHz
self.transmission_power = 14  # dBm
self.sensitivity = -140  # dBm

# Environment parameters
self.temperature = 290  # K
self.noise_figure = 6  # dB
self.implementation_loss = 2  # dB
```

------------------------**Parameter 1**: LPWAN Satellite Parameters for IoT---------------

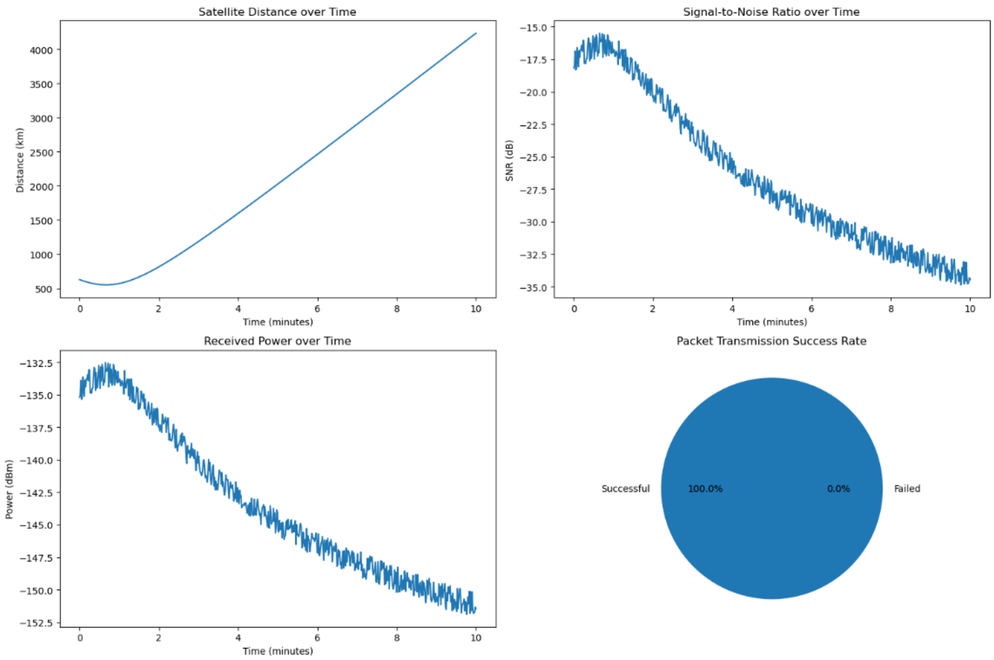

Figure 4. Output dari simulasi komunikasi satellite LPWAN

Moreover, from the results of the simulation analysis that was successfully run using Python, the results of the Quality of Service Satellite LEO Communication graph were obtained which showed the performance of the communication system built. From the simulation, it is found that the increasing distance (km) will cause the time required to reach the destination of data transmission to also increase. The signal-noise ratio (SNR) in dB will also decrease, for example, starting at -17.5 dB can decrease to -35 dB with increasing time and distance. While Power (dBm) also weakens from -135 dBm to -152.5 dBm with increasing time or distance, such simulation results can be improved and applied to Satellite-based IoT communication systems in the real world. The details of the simulation output can be seen in Figure 4.

```
Starting LPWAN simulation...
Device_001 generated: Data from Device_001 at 1737335013.290528
Device_001 sending: Data from Device_001 at 1737335013.290528
Latency for Device_001: 1.62 seconds
Satellite received: Data from Device_001 at 1737335013.290528 from Device_001
Device_001 power level: 75
Device_002 generated: Data from Device_002 at 1737335014.9152994
Device_002 sending: Data from Device_002 at 1737335014.9152994
Latency for Device_002: 2.83 seconds
Satellite received: Data from Device_002 at 1737335014.9152994 from
Device_002
Device_002 power level: 55
Processing data...
Processing Data from Device_001 at 1737335013.290528 from Device_001
Processing Data from Device_002 at 1737335014.9152994 from Device_002
Device_001 generated: Data from Device_001 at 1737335019.7440267
Device_001 sending: Data from Device_001 at 1737335019.7440267
Latency for Device_001: 1.60 seconds
Satellite received: Data from Device_001 at 1737335019.7440267 from Device_001
Device_001 power level: 70
Device_002 generated: Data from Device_002 at 1737335021.3471448
Device_002 sending: Data from Device_002 at 1737335021.3471448
Latency for Device_002: 1.46 seconds
Satellite received: Data from Device_002 at 1737335021.3471448 from Device_002
Device_002 power level: 50
Processing data...
...
Device_001 power level: 60
Device_002 generated: Data from Device_002 at 1737335034.6656969
Device_002 sending: Data from Device_002 at 1737335034.6656969
Latency for Device_002: 1.75 seconds
```

-------------------------**Output 1**: Latency of Simulated LPWAN Satellites for IoT--------------

```
=== Simulation Cycle 1 ===
[09:36:08] Uplink Transmission Started
Device ID: DEV001
Satellite ID: SAT001
Path Loss: 147.26 dB
Received Power: -133.26 dBm
Transmission Duration: 2.56 ms
Transmission Failed
Remaining Battery: 99.7%

[09:36:08] Uplink Transmission Started
Device ID: DEV002
Satellite ID: SAT001
Path Loss: 147.46 dB
Received Power: -133.46 dBm
Transmission Duration: 6.08 ms
Transmission Failed
Remaining Battery: 99.4%

=== Simulation Cycle 2 ===

[09:36:09] Uplink Transmission Started
```

```
Device ID: DEV001
...
Received Power: -133.39 dBm
Transmission Duration: 5.76 ms
Transmission Failed
Remaining Battery: 98.1%
```

------------- **Output 2**: Simulated LPWAN Satellites for IoT more comprehensive ---------------

5. Conclusions

Satellite technology for various purposes and types or types of bands can be applied optimally by prioritizing many factors such as the type of antenna to increase Antenna Gain and other factors. Satellite technology for the Internet of Things (IoT) may be able to maximally provide detailed information from end-node data that is real-time, fast, low bandwidth, non-obstacles, low-power consumption, and also low latency (ms). From the simulation, it is found that the increasing distance (km) will cause the time required to reach the destination of data transmission to also increase. The signal-noise ratio (SNR) in dB will also decrease, for example, starting at -17.5 dB can decrease to -35 dB with increasing time and distance. While Power (dBm) also weakens from -135 dBm to -152.5 dBm with increasing time or distance, such simulation results can be improved and applied to Satellite-based IoT communication systems in the real world. This approach illustrates that the longer the distance, the latency increases, the SNR decreases, and the power decreases. LPWAN satellite development based on LEO continues to be developed to get the best performance, especially to support IoT in the future.

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