Wireless IoT Protocol Report

Purpose of the Report

This report aims to guide in selecting wireless communication protocols for IoT devices, focusing on efficiency, cost, scalability, and reliability. We compare WiFi, Bluetooth, Bluetooth LE, Zigbee, Z-Wave, and NFC across various parameters such as range, data rate, power consumption, and security, to aid stakeholders in making informed decisions for IoT applications.

Areas to Investigate

- Protocol Overwiev
- Range
- Power Consumption
- Security
- Other Considerations for IoT

Authors

Simon Thorell, Erik Pettersson, Nathan Tewelde Bahta, Milad Isho Saeb and Abdihakim Abdisamad Roble.

Report Last Updated: 2024-02-09

WIFI

Here is some text...

Protocol Overview

- Here is also some variant.
- Here is also some variant.
- Here is also some variant.

Range

Some text...

Power Consumption

Some text...

Security

- Here is also some variant.

- Here is also some variant.
- Here is also some variant.

Other Considerations for IoT

1. List item
2. List item
3. List item

Bluetooth

Here is some text...

Protocol Overview

- Here is also some variant.
- Here is also some variant.
- Here is also some variant.

Range

Some text...

Power Consumption

Some text...

Security

- Here is also some variant.
- Here is also some variant.
- Here is also some variant.

Other Considerations for IoT

1. List item
2. List item
3. List item

Bluetooth LE (Low Energy)

Bluetooth Low Energy (BLE), enabled in Bluetooth 4.0, marks a significant evolution in the Bluetooth technology spectrum, focusing on novel applications across various industries including healthcare, fitness, and home automation. Distinguished from Classic Bluetooth by its drastically reduced power consumption and cost, BLE maintains a comparable communication range, making it an optimal choice for IoT devices.

Protocol Overview

- **Low Energy Operation:** BLE is engineered for minimal power consumption, enabling devices to operate on a coin cell battery for months or even years. This is achieved through sophisticated power management protocols and an optimized communication strategy that limits active transmission time.
- **Adaptive Frequency Hopping (AFH):** To mitigate potential interference from other wireless devices operating in the 2.4 GHz ISM band, BLE utilizes AFH. This technique dynamically switches channels during communication to avoid areas of noise, enhancing the reliability of data transmissions.

Range

- **Extended Communication Range:** BLE is capable of reaching up to 100 meters in open space, although practical range is influenced by environmental conditions and the antennae of the devices involved. This flexibility makes it suitable for both indoor and outdoor applications, from smart homes to fitness trackers.

Power Consumption

- **Energy Efficiency:** The hallmark of BLE's design is its ability to provide long-term operation with minimal energy use. It accomplishes this through low duty cycle operations, where devices spend a significant amount of time in sleep mode, awakening briefly for communication. This approach significantly extends battery life without compromising the device's functionality.

Security

- **Robust Encryption and Authentication:** BLE incorporates AES-128 bit encryption, ensuring a high level of security for data transmission. This is complemented by robust authentication protocols that verify the identities of the connecting devices, safeguarding against unauthorized access.
- **Enhanced Privacy Measures:** To combat tracking and other privacy concerns, BLE employs random address techniques. These periodically change the device's address, making it difficult to track a device over time.
- **Layered Security:** Beyond encryption and authentication, BLE offers additional security layers including secure key distribution and identity resolution, which further protect against eavesdropping and man-in-the-middle attacks.

Other Considerations for IoT

- **Cost-Effectiveness:** The production cost of BLE devices is relatively low, encouraging their adoption in a wide array of consumer electronics.
- **Ubiquity and Community Support:** With broad support across smartphones, tablets, and PCs, BLE benefits from a vast ecosystem of development tools and libraries. This extensive support simplifies the process of integrating BLE into IoT applications, from conceptualization to deployment, backed by a large and active community.

BLE's combination of low power consumption, secure communication, and extensive support makes it a cornerstone technology for the burgeoning IoT landscape, enabling a new generation of connected applications that are both energy-efficient and secure.

Zigbee

Zigbee is a short-range protocol with high scaleability for use of upwards to 65000 units. The protocol is typically used for cases where you have multiple devices with low range that sends low data-rate and low-power consumption applications and is an open standard.

The criterias for comparison were choosen to make it clearer wether or not a certain protocol is right for your specific use case. Or more likely a brief introduction to the different protocols and their capabilities.

Protocol Overview

As mentioned before the most common use case for Zigbee is indoors, why? Because the most effective range for Zigbee is 1-10m indoors. So what does this mean? Well Zigbee can be a great protocol for home automation, industrial automation aswell as smart metering system.

Because of it's low data rate and power consumption you can use Zigbee for devices like garage doors, locks, lights, motion sensors and much more. Think of all the things you have home such as smoke alarms etc connected that sends data to for example your smart phone for you to monitor. All of this can be acheieved with Zigbee, at a lower power consumption than Bluetooth and Wifi, 20-50% cheaper than for example Z-Wave devices. Zigbee is also backed as a protocol by Philips, Samsung, Siemens & Whirlpool.

It also recently started to being used by Amazon, Apple and Google where they integrate it into their smart speakers and smart screens. Zigbee also uses the 2.4 GHz band as WiFi does. Which makes Zigbee protocol available to all around the world so you can use the devices anywhere you want.

Range

Indoors up to 10-100 meters Outdoors up to 250 meters

Depends on interference with the signal, by that it means if obstacles in the environment and the power output from the devices. Zigbee devices in some cases also uses a mesh networking feature which extends the signal by make the signal "bounce" off of or through multiple devices.

Power Consumption

Since Zigbee uses a low power consumption compared to other wireless protocols like WiFi, it is great suited for devices that is powered by battery. Zigbee is designed to consume a minimal power in idle mode or "sleep" mode. Which means it consumes in the range of microwatts or minimalwatts. It is hard to say what the lifetime is for different batteries inside Zigbee devices, but in devices that sends low data rate the battery can last months or years on a single charge.

Security

Network:

Key Establishment: Devices with zigbee protocol, uses network keys to make communication between devices secure on a Zigbee network.

Link key Encryption: You can also use link keys or encrypted keys which makes communcation between devices confidential.

Frame Counter: Frame counters are for to prevent replay attacks. Which makes each message unique so there wont be replays of other messages sent before.

Application:

Application-Level Encryption: The Zigbee protocol also support encryption on the application layer. It is a symmetric encryption that is being used AES (Advanced Encryption Standard). This is to ensure that sensitive data exchange between devices are being protected inside the network.

Message Authentication Codes(MACs): "MACs" Media Access Control are also used in the Zigbee protocol. Which means that the integrity is ensured so unauthorized modification is not made to the data during transmission. This makes all the messages tracable back to the device, which makes it easy to see if a specific device "belongs" on the network or not.

Key Transport: Within the network it also securly transports keys between devices which makes the distribution of keys effecient and secure.

Trust center: Within Zigbee there is also a "trust center" which is responsible for management of keys. It distributes and facilitates key establishment. The trust center is also responsible for the authentication process. It authenticates devices joining the network and establish each devices privileges.

Cryptographic Techniques: As mentioned before it primarily uses AES for encryption and decryption of data in both the network layer and application layer. Zigbee uses hash functions aswell for example SHA-256 to ensure the generation of message authentication, that ensures data integrity. Random number generations is also used to prevent patterns that are predictable inside security protcols. How? they generate cryptographic keys.

Security settings: Zigbee has configurable security settings that can be specified to your certain use case. This let's network admins to make changes to the security settings for their application. The typical settings are encryption length of keys and the rotation intervals for the keys. This is changed through the trust center settings.

Pros & Cons

Pros:

- low power consumption
- high scaleability upwards to 60000 units.
- backed by big companies and used by big companies
- secure connections (CIA)
- costs less than other devices using for example Z-Wave

Cons:

- low data rate transfer
- short range
- interupted signal if there are obstacles
- latency with more devices
- may need complex knowledge to use to it full potential

Conclusion

Zigbee as a protocol should mainly be used for low data rate transmissions such as home automation for garage doors, lamps, smoke alarms, monitoring water usage and such. That doesn't require more than 10 meters in distance between the devices and as little as possible obstacles between the devices for the best signal. It can also be used for industrial automation and monitoring different sensors outside. But be aware that it needs to be some kind of amplifier to make the signal reach longer outside. Also to take in to consideration is that you need a pretty good understanding in IT to use the protocol to it's full potential. Over all the protocol is very secure to use in the sense that the protocol is both backed and used by companies such as Amazon, Google, Philips, Siemens etc. The protocol uses "CIA" in different layers and can be configure to suit the specific use case for the admin or admins on the network.

Z-Wave

Z-Wave is a wireless communications protocol used primarily for home automation. It is designed to allow smart devices to communicate with each other within the home via low-energy radio waves. Developed by Zensys, a Danish company, it is now managed by the Z-Wave Alliance, a consortium of over 700 companies dedicated to the development of Z-Wave technology.

Protocol Overview

- **Mesh Network Architecture:** Z-Wave's architectural foundation is a mesh network, facilitating inter-device communication through the relay of messages. This topology not only enhances network resilience but also extends operational range.
- **Low-Energy Design:** Emphasizing power efficiency, Z-Wave devices are engineered to optimize battery longevity, a critical attribute for residential automation devices.
- **Repeater Functionality:** Within the mesh, devices double as repeaters, bolstering network coverage and reliability, a feature that markedly distinguishes Z-Wave in the realm of wireless communication.

Range

- **Indoor Range:** Z-Wave's effective communication range stands at approximately 30 meters (98 feet) indoors, a specification that caters to the conventional home environment. The mesh network's cooperative relay capability allows for significant flexibility in overcoming physical barriers and extending coverage.
- **Outdoor Range:** Z-Wave's outdoor communication range significantly exceeds its indoor capabilities, typically achieving up to 100 meters (328 feet) in open space environments. This extended range is due to the fewer obstacles present outdoors that can attenuate or disrupt the radio waves used for communication. The mesh network topology of Z-Wave further enhances this range outdoors, as each device can act as a repeater, extending the signal distance beyond the initial range of the transmitter. This characteristic makes Z-Wave highly effective for outdoor smart home applications, such as garden lighting, outdoor security systems, and irrigation controls, allowing seamless network coverage across both indoor and outdoor areas of a property.

Power Consumption

- **Battery Life Optimization:** A hallmark of Z-Wave technology is its power management strategy, which ensures that devices such as sensors and automated locks sustain functionality over years with minimal battery replacements.
- **Sleep Mode Integration:** Devices incorporate a sleep mode, minimizing energy consumption when inactive, yet remaining responsive to network communications.

Security

- **Advanced Encryption Standard (AES-128):** Z-Wave employs AES-128 encryption, a highly secure and globally recognized standard, to safeguard data transmissions against unauthorized interception. This encryption algorithm is designed to protect sensitive information, ensuring that all communications within the Z-Wave network remain confidential and tamper-proof. AES-128 offers a robust level of security that is deemed sufficient for governmental and financial institutions, making it a reliable choice for home automation security.

- **S2 Security Framework:** Elevating Z-Wave's security capabilities, the S2 framework introduces a comprehensive suite of security measures designed to enhance network integrity and user privacy. It features an advanced layer of encryption, secure key exchanges, and a dynamic device pairing process that significantly reduces the risk of Man-in-the-Middle (MitM) and brute force attacks. The S2 framework employs Elliptic Curve Diffie-Hellman (ECDH) for key exchange, providing a higher degree of cryptographic security while optimizing for the low-power operation essential to Z-Wave devices. This framework also supports a multi-layered encryption strategy, applying different keys for the access control, device-to-device, and network-wide communication, thus compartmentalizing security to minimize risk exposure.

- **Device Authentication:** Z-Wave enhances network security through rigorous device authentication protocols. Before a device can join a Z-Wave network, it must undergo a stringent authentication process to verify its identity and integrity. This process ensures that only devices with the correct credentials and security keys can participate in the network, effectively preventing unauthorized devices from gaining access. Device authentication plays a pivotal role in maintaining the overall security posture of the Z-Wave network, protecting against potential vulnerabilities introduced by counterfeit or compromised devices. Additionally, the authentication procedure facilitates the secure inclusion of devices, ensuring that each new device is recognized and trusted by the network controller and other devices within the ecosystem.

Other Considerations for IoT

- **Interoperability Excellence:** Z-Wave's design principle of interoperability ensures seamless integration and functionality across devices from disparate manufacturers.
- **Extensive Device Ecosystem:** With over 2,600 certified products, users are afforded a vast selection, accommodating a wide spectrum of automation needs.
- **Dedicated Operational Frequency:** Z-Wave operates on designated frequency bands (908.42 MHz in the US, with variations globally), mitigating interference from other household wireless technologies.

Z-Wave's synthesis of efficient power use, robust security architecture, and unmatched interoperability positions it as a technology of choice for integrating smart home and broader IoT solutions, paving the way for advanced home automation.

NFC (Near Field Communication)

NFC is a short-range wireless communication technology operating at 13.56 MHz, and the NFC Forum has helped to both define and promote the technology commonly used in access pairing, contactless transactions, device pairing, mobile payments, and ticketing. This is because it facilitates communication between devices when those are brought within proximity of each other, typically a few centimeters.

NFC operates through electromagnetic induction, providing a secure and convenient method for data transfer, device authentication, and transactions by supporting two modes:

1. Active, where both devices generate radio frequency (RF) field.
2. Passive, where one device generates an RF field while the other modulates data onto it.

Protocol Overview

- NFC is known for its short-range communication capabilities, typically within a few centimeters, making it suitable for secure transactions and data exchange at near proximity.
- Low Power Consumption: NFC technology is designed to operate with minimal power, making it efficient for battery-operated devices.
- Secure Communication: NFC provides secure data transmission through encryption algorithms, ensuring confidentiality and integrity of transmitted information.
- Ease of Use: NFC-enabled devices can establish connections simply by bringing them close together, without the need for complex setup procedures.

Range

NFC operates within a short range, typically a few centimeters, facilitating secure data transfer and interaction between devices.

Power Consumption

NFC technology is known for its relatively low power consumption:

- NFC-enabled devices operate efficiently on a single charge or battery, thanks to their effective power management.
- Power usage depends on factors like NFC interaction frequency, activation duration, and communication complexity.
- These devices are passive and don't need their own battery; they draw power from the active device they're connected to, like a smartphone or NFC reader.

Security

- Encryption: NFC uses different encryption algorithms depending on the protocol used. The most common encryption algorithms within NFC are AES (Advanced Encryption Standard), RSA (Rivest-Shamir-Adleman), and ECC (Elliptic Curve Cryptography). The choice of algorithm depends on the security requirements of the task.

- Authentication: It includes features to verify the identity of connected devices, ensuring a secure connection between them.
- Privacy: NFC employs random address techniques to prevent device tracking, enhancing user privacy.
- Short Range: NFC's short-range communication limits the risk of interception, making it more secure for sensitive transactions.
- Secure Element: Some NFC-enabled devices have a secure element, a tamper-resistant area for storing sensitive information like payment credentials, further enhancing security.
- Trusted Execution Environment (TEE): TEE provides a secure environment for executing sensitive operations, adding an extra layer of protection against malicious attacks.

Other Considerations for IoT

NFC technology brings numerous benefits and factors to consider for its integration into IoT applications:

1. Cost-effectiveness: NFC devices are cost-effective to produce.
2. Contactless Communication: By bringing devices close together, NFC enables fast and convenient transactions.
3. User-Friendly: NFC is known for its user-friendliness and requires minimal installation or configuration.

The combination of short-range, contactless communication, low power consumption, security, and user-friendliness makes NFC a suitable choice for specific IoT applications.

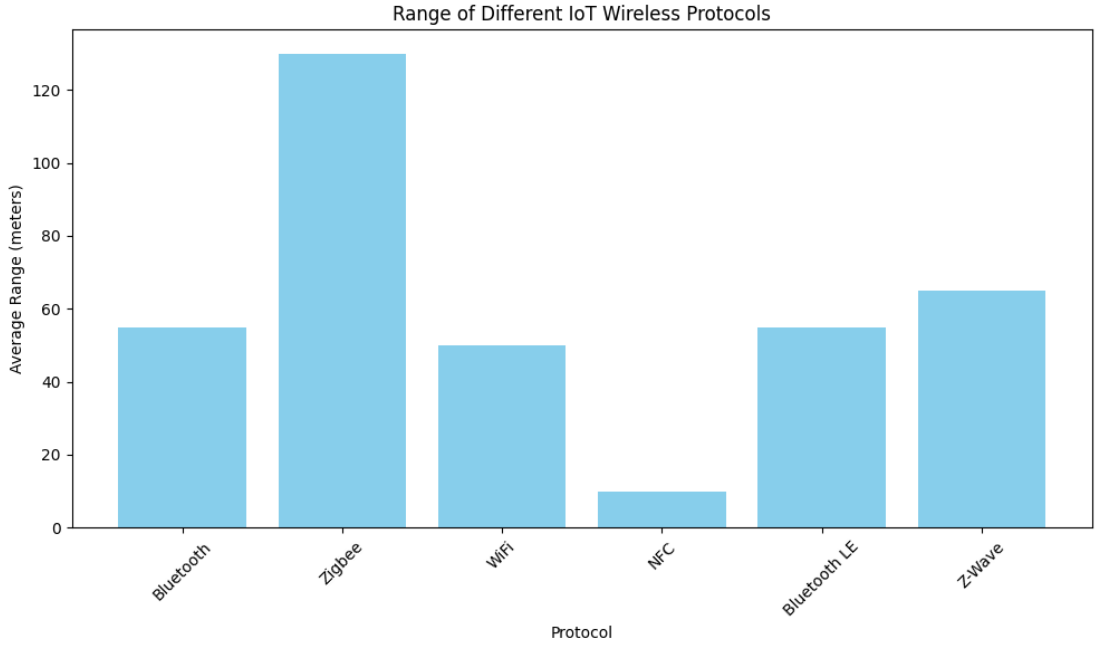
Protocol Summary

- **WiFi** emerges as the go-to choice for high-bandwidth applications requiring internet access, although at the cost of higher power consumption.
- **Bluetooth** and **Bluetooth LE** offer versatility, with BLE being particularly advantageous for battery-operated devices due to its low energy profile.
- **Zigbee** and **Z-Wave** stand out in creating extensive, low-power mesh networks, ideal for home automation and sensor networks.
- **NFC** offers a unique niche in close-proximity, secure transactions and data exchange.

The diversity in wireless communication protocols is highlighted by their range, data rate, and frequency utilization, each catering to specific application needs within the IoT ecosystem.

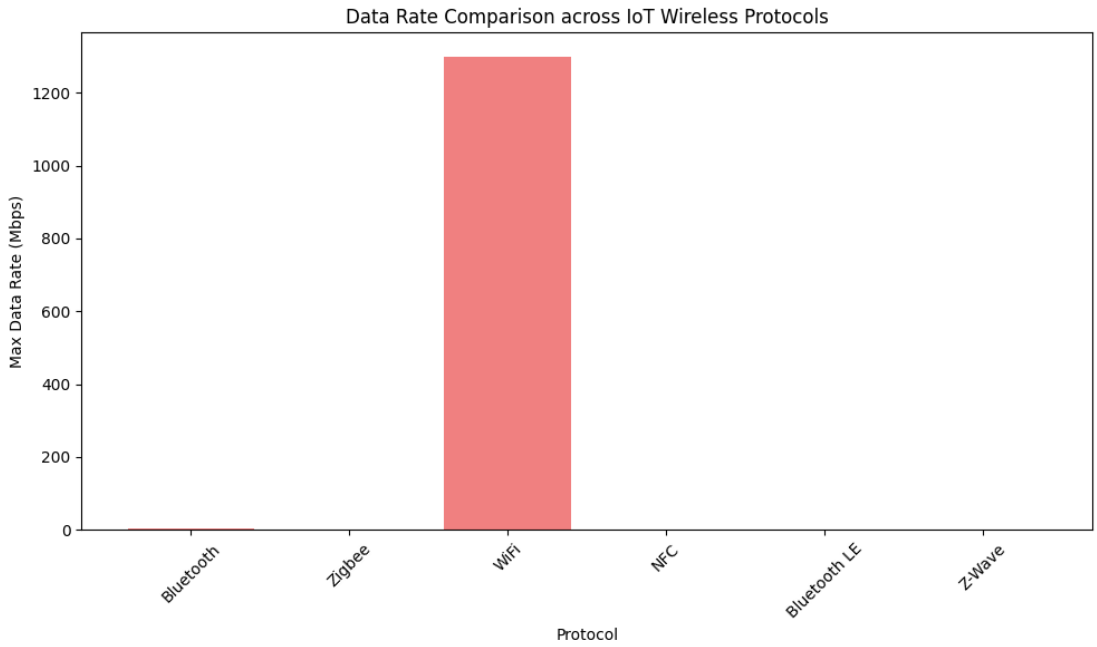
Range Insights

The range of a protocol determines its effectiveness across different environments. WiFi, with its capability for substantial coverage, is well-suited for a variety of applications, both indoors and outdoors. Zigbee also offers a wide coverage area, making it ideal for sensor networks spread across a large area. In contrast, NFC is designed for very short-range interactions, typically a few centimeters, making it perfect for secure, close-proximity tasks such as payments and quick data exchanges.



Data Rate Capabilities

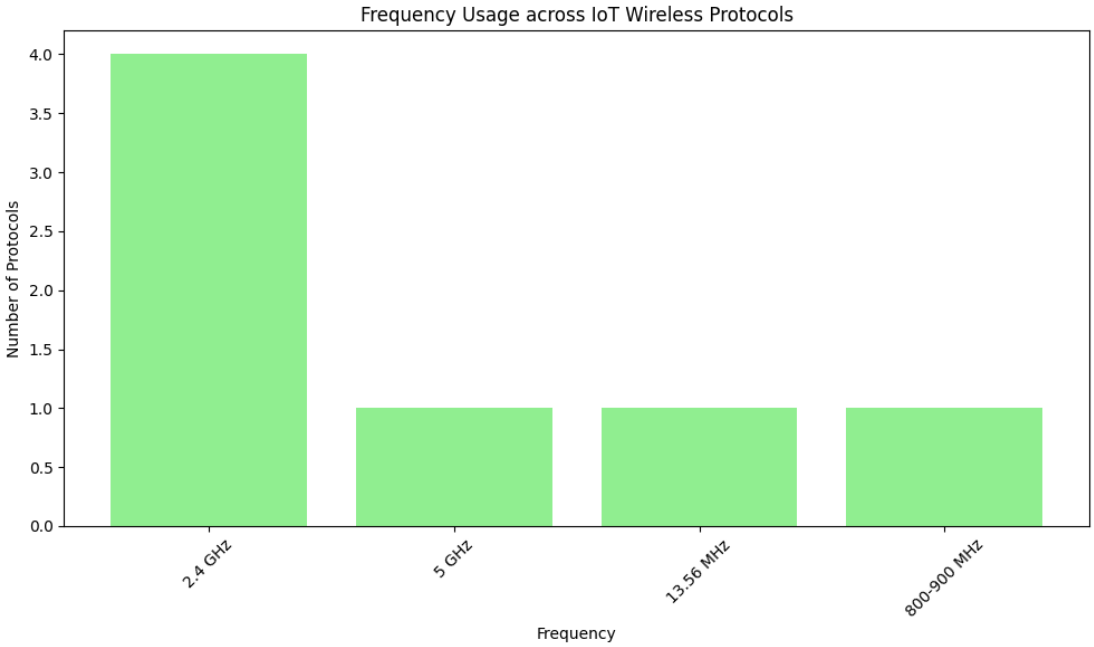
Data rate is a crucial factor for applications requiring fast data transmission. WiFi excels in this area, supporting high data rates that are ideal for streaming and other data-intensive applications. On the other hand, Bluetooth LE is designed to provide a balance between efficient power consumption and adequate data rates, making it suitable for IoT devices that prioritize energy efficiency. Zigbee, with its focus on low-power sensor networks, offers lower data rates, which is sufficient for the transmission of small amounts of data over a network designed for efficiency and longevity.



Frequency Utilization

The choice of frequency band impacts a protocol's susceptibility to interference and its ability to coexist with other wireless technologies. Both WiFi and Bluetooth predominantly operate in the 2.4 GHz band, a common frequency that is shared by many devices, leading to a higher potential for interference. Zigbee also operates in the 2.4 GHz band but is designed to efficiently manage coexistence with other technologies in this crowded

space. Z-Wave, by contrast, utilizes the 800-900 MHz frequency band, which is generally less congested, offering advantages in terms of reduced interference and improved reliability for home automation systems.



Security Considerations

Security is a paramount concern in IoT applications, where the integrity and confidentiality of data must be safeguarded. Each wireless protocol incorporates distinct security features tailored to its use cases.

- **WiFi** employs WPA3 encryption, providing comprehensive security with complex cipher suites for data protection and user authentication, suitable for bandwidth-intensive environments.
- **Bluetooth** incorporates Adaptive Frequency Hopping and ECDH key exchange for enhanced security, facilitating encrypted communications in personal and commercial settings.
- **Bluetooth LE** extends Bluetooth's security features with LE Secure Connections (security layers), including FIPS-approved algorithms for encryption and secure key distribution, optimizing for power efficiency.
- **Zigbee** uses network and link key encryption, frame counters to prevent replay attacks, and AES for application-level encryption. It employs MACs for data integrity and a trust center for key management and device authentication, ensuring comprehensive security.
- **Z-Wave** uses AES-128 encryption and Secure S2 framework for advanced network security, ensuring encrypted communication in smart home applications with minimal power usage. Z-Wave also enhance network security though a rigorous device authentication process.
- **NFC** utilizes advanced encryption (AES, RSA, ECC) tailored to specific security needs, with authentication to ensure secure device connections. It enhances privacy through random addressing, reducing trackability. The inherent short range limits interception risks, while a secure element and TEE offer additional protection for sensitive transactions and operations, ensuring robust security

Security in wireless communication protocols is continuously evolving to address emerging threats and vulnerabilities. Choosing a protocol with adequate security features is essential for building trustworthy IoT

systems that users can rely on.

Conclusion: Choosing the Right Wireless Protocol for IoT

Selecting a wireless protocol is crucial, with each serving specific IoT needs. The choice hinges on application, range, throughput, power, and interoperability. This report aims to help IoT developers in making protocol choices, the key to efficient and scalable IoT solutions. Embracing the right protocol is strategic, essential for IoT innovation and advancement.

About This PDF

This PDF was generated using a Continuous Integration (CI) pipeline, leveraging Python scripts for merging markdown files and creating diagrams, followed by a markdown-to-PDF conversion process. This automated workflow ensures the report is always up-to-date with the latest contributions from all authors. For more information and to contribute to this report, visit the GitHub repository: https://github.com/simonthorell/wl-iot-protocols-report.