WHIOCE PUBLISHING PTE. LTD.
PROVIDING
FIRST-CLASS SCIENTIFIC INFORMATION
FOR TOP SCHOLARS

2026 Volume 4, Issue 3
Educational Innovation Research
ISSN: 3029-1852 (Online)
ISSN: 3029-1844 (Print)

Review of Research on Low-Power Communication Technologies for Smart Homes

Yuting Yang*
Foreign Language Teaching Department, Hainan Vocational University of Science and Technology, Haikou 571126, Hainan, China

Author to whom correspondence should be addressed.

Abstract: As smart home devices grow larger, the lifetime of their batteries and the robustness with which they communicate has become an important limitation on usability, which has made low-power communication technology an important area of industry research. In this paper, we provide a systematic review on low power communication technologies for the smart home, considering four aspects including basic technical properties, the performances of typical technologies, the system optimization methods, and future trends. Power management concepts are discussed in the context of power requirements, power limits, networking features, protocols supportability, and techniques for optimizing the networks. The study aims to clarify existing networking structures as well as possible ways of optimization, providing theoretical support and practical guidance to improve the communications efficiency, reduce device overall power consumption, and improve the reliability of systems used in a smart house.

Keywords: Smart home; Low-power communication; Wireless networking; Power consumption optimization

Online publication: March 26, 2026

1. Introduction

With the booming development of Internet of Things (IoT), a smart house evolves from individual smart controls into full-house communications and multiple devices coordination [1]. With the deployment of abundant sensors, the introduction of low-end devices (i.e., intelligent terminals, intelligent switches, and intelligent IEDs) has higher requirements for the communication power consumption and service lifetime. The traditional large-power communication method reduces equipment lifetime while increasing communication overhead and power consumption. Low-power communication technology, with features such as low stand-by power consumption, large connectivity, and low installation cost, has gradually developed to be the key supporting technology of intelligent home systems. Deep exploration on the operating mechanism, performance differences, and improvement methods of low power communications in smart homes is important both theoretically and practically to promote an energy-efficient, stable, and sustainable development.

2. Fundamental characteristics of low-power communication technology for smart homes

2.1. Principle of power consumption control in low-power communication technology

The main idea behind the low-power communication is to control accurately the transmitted signal power transmission time, and operating period. For a smart home scenario, the communications are always in an information collecting state or a stand-by state, is active for a short time, i.e., only when exchanging data with the other nodes. As this is the case only in short intervals, it does not consume too much power unnecessarily. the underlying technology reduces the energy usage for each piece of information transmitted by, e.g., shortening the length of data frames, reducing the complexity of authentication processes, and improving transmission techniques so that each node can achieve very low energy costs for its normal working process. Appropriate power management strategies help prolong the battery life of devices in use as well as lower the average resource usage on the whole network or improve the efficiency when many devices are used at once simultaneously.

The decentralization of the distribution location and the small activity range of smart home devices make their operation scene relatively fixed, which is suitable for power saving technologies that are not easy to move. The power management strategy often involves both hardware circuits and software programs: from the perspective of the hardware layer, it uses low-power processors or voltage regulators to reduce idle consumption; while software level schedule is not frequently cycled or repeated transmission. With this integration, we can ensure that the communication module keeps connected but also keep its average current in μA. Such a power consumption control mode suits the characteristic of smart home– long term monitoring and intermittent transmission, which provides important technical help for wireless operating and long-life batteries and simultaneously provide a power saving platform for mass deployment of devices in networks.

2.2. Analysis of energy consumption constraints for smart home communication nodes

The power budget available for the smart home devices' communication nodes depends on several aspects but in particular on the transmit distance, environmental obstacle, and data transmission frequency are the main influencing factors. The larger the transmission distance is, the more serious the attenuation will be, forcing them to increase their transmit power in order to maintain the same level of communications thus increasing energy consumption. The presence of obstacles (e.g., indoors walls/furniture) also reduces the received signal strength, forcing the nodes to consume extra energy for maintaining connectivity – especially, in buildings with complicated geometries (i.e., with a higher variance of energy usage). Besides, the rate at which the device reports this information is a direct determinant of how much power it consumes: frequent sensing, processing, and transmitting of information uses more power, while too small frequency reduces the real-time ability of the system. The tradeoff between them is one of the key constraints for power consumption [1].

Hardware performances of nodes as well as the network topology are two main factors that restrict the power consumption. Sensors and communications low-performant components have a high value of current leaks, contributing to extra power consumption even during the idle time period and negatively impacting on total battery lifetime. As for network topology, the star topology allows for a straight-forward communication from terminal node to gateway providing an easy route with some distance limitation; the mesh topology decreases power consumption for each node due to relay forwarding but it raises routing maintenance energy consumption.

2.3. Basic characteristics of short-range low-power communication protocols

Low range and power short-range communications usually have the characteristics of small volume of transmitted data, low speed of transmitting information, a large number of connections, making it ideal for light-weight communication in a Smart Home environment, compared with existing WiFi and Bluetooth protocol standards have focused on controlling the power consumption, lowering the idle current and operating current in order to improve devices' battery life, they can transmit a packet of information in less than one thousandth of second because of its short frames and low communication overhead, minimizing the module operation duration.

The majority of low-power communications standards have the capability for ad-hoc networking and dynamic routing which enables automatic adjustment of the transmission route depending upon the location of a node as well as the strength of the signal in order to improve the robustness of the network. They also require very little from the nodes themselves in terms of hardware resources, enabling compatibility with low-cost micro-controllers, and lowering the cost of a smart home device as a whole.

Moreover, the protocol stack is compact and has low runtime overheads to be operated stably in resource, constrained embedded platforms. Such features enable the short-range, low-power communication standard that is especially appropriate to the many small, widely dispersed devices in the smart home, where power consumption (battery lifetime) is tightly constrained. The basis of inter-device connectivity and intelligence, it will be essential to the success of this technology and with good compatibility to the further technology extension and system upgrade.

3. Performance comparison of mainstream low-power communication technologies

3.1. Relationship between transmission rate and power consumption of different communication technologies

The transmission rate is usually positively related to the power consumption which is one of the key considerations when choosing low power communications technology. The higher rate technologies enable more efficient data transmission at the cost of increased power consumption, making them well suited for devices with high volume of traffic, e.g., video/audio; low-rate solutions have better energy efficiencies, yet they are not capable of supporting bandwidth hungry applications. In the context of a smart home, devices such as sensors or switch panels produce a small amount of information and need to be transmitted at low rate: these are more suitable for very low power communication techniques; whereas some smart terminals have to send big files, so that there is the possibility to make a trade-off between transmission rate and power consumption. An optimal matching between rate and power consumption allows an efficient use of the energy without losing in terms of functionalities.

The methods of trade-off between data rate and power are different among these technologies. Dynamic rate adaptation is used in some approaches to realize power-adaptive transmission, i.e., decreasing the rate to reduce power usage when load is low; and increasing the rate accordingly when load is high. In this way, such mechanisms can adapt well with the dynamics of a smart home operation. The comparison also reveals that focusing too much on high rates causes excessive energy expenditure, where excessively large decreases in the rate can lead to loss of responsiveness.

3.2. Analysis of communication signal penetration capability and coverage range

Penetration ability and coverage distance directly decide the performance of low power communication network for smart home. For indoors, wall structures, materials' thicknesses, and electromagnetic interferences of electric appliances also impact the transmission. The technologies that have lower penetration capability will create signal dead zone, which leads to device offline statuses or response latency, technologies that have longer coverage distances decrease the numbers of gateways and make networks simpler, but too much coverage will cause co-channel interference and higher power consumptions.

If it is a high-rise building or a villa cluster, then the first choice is to use technology with good penetrating power and medium range so that the devices can have reliable networking in any part of the house.

The different LPWANs have significantly varied performances on signal diffracting ability and penetrating resistance, some of which use a low frequency band for better penetrating effect, while the others increase their effective range by enhancing their receivers' sensitivity. In practice, signals attenuate in a nonlinear manner as they travel further and further away from the source , with especially severe loss at corners, restrooms, storeroom etc., a comparison between different technologies shows that there is not one technology to satisfy both the demand for wide area coverage and high penetration; where usually other techniques like relay networks or optimal node positioning must be employed to mitigate this drawback .

Scientific evaluation of signal penetration and coverage performance helps build a more stable and low-power smart home communication network.

3.3. Technical compatibility: Applicable scenarios for smart home devices

Different low-power communication technologies are more suitable to different scenarios; they should also be chosen according to the functions of smart home devices. The door/window sensor, human body sensors, and temperature/humidity sensors that produce low data volume while requiring long battery lifetime is better served by ultra-low-power communications technologies, enabling battery-less operation during a couple of years. Real time responsive devices like smart switches and lighting controls, should use communications technology with acceptable tradeoff between power usage and delay for its intended application, and for applications requiring many networked devices, technologies that are highly connected in terms of capacity, and can flexibly connect to form a network without causing congestion or disconnecting nodes [2].

The technical compatibility is different for each unit type and interior design; small ones have a simple structure and fewer interferences from other devices, support reliable operations of a variety of low power devices; whereas larger appliances or duplexes demand greater requirements on coverage and connectivity. Various services, such as smart home, applications (e.g., environmental monitoring, smart control) have different requirements with respect to the real-time performance of communications, reliability, and power consumption, which require tailor-made technical solutions. Appropriate definition of applicable situations, we are able to take full advantage of different low-power communications technology and improve the whole system performance, reduce the energy wastage, and provide a more reliable smart house service to customers.

4. Optimization strategies for low-power communication systems in smart homes

4.1. Optimized design of the communication node sleep wakeup mechanism

Sleep/wake cycle is the fundamental approach to energy saving of smart homes devices that communicate, where the trade-off between deep-sleep mode and quick wake up time is considered. In idle state, nodes switch into a deep sleep state in which non-essential peripheral devices as well as the wireless transceivers are turned off; leaving only some clock monitoring low power consuming signals for wake-up purposes. When an upload of information is needed or when receiving instructions from the server, nodes quickly wake up, build communication links and immediately go back to sleep upon task completion. Efficiently optimizing sleep/wake-up logic minimizes idle running time and considerably improves battery lifetime, especially suitable to passives and/or low power devices.

The existing periodic awakening techniques usually cause resource wasting, which cannot adapt to the dynamic interaction features in smart home applications. A novel mechanism that integrates event-based awakening and variable periodicity is proposed by prolonging the sleeping time under steady state and decreasing the awakening frequency when more status variations occur, enabling on demand activation. Moreover, we employ a pre-synchronization scheme which decreases the connection setup delay after waking up, thus reducing the energy consumed in communications.

4.2. Multi-device collaborative communication power consumption balancing method

The simultaneous communications of a number of smart home devices usually cause concentrated energy consumption as well as the contention in networks, requiring collaborative efforts in order to reach equilibrium of the powers. Each device is prioritized by the system; high-priority devices request for access, where the former is used in common sensors using timesharing transmission for avoiding simultaneous interference, reducing extra power cost due to re-transmission. Moreover, the gateway centrally schedules when nodes can communicate so that they can take turns accessing the network without wasting as much energy transmitting unnecessarily [3]. In this way there is a more even spread of power avoiding excessive battery drain of single devices through constant communication.

In the case of multi-device dense scenario, through data aggregation and batch sending, we could decrease the number of independent nodes communication times by transmitting multiple small data packages together, thus reducing the waking up and connecting overhead, some nodes can work in relay forwarding mode so that they will share the power consuming responsibility for far away devices , avoiding unnecessary energy waste due to high-power transmissions of one node. Moreover, thanks to dynamic adjustment in the transmit power, nodes work with just enough powers to communicate, minimizing extra losses as well. Multi-dimensional cooperative power consumption balance method can effectively improve the system energy efficiency rate, extend the overall network life-time, and supports a large scale of smart home deployments in a reliable manner.

4.3. Application of lightweight data transmission processing technology

Lightweight Data Transmission. Lightweight data format and redundancy elimination are two key aspects for the lightweight data transmission, the transmission time and power cost could be greatly lowered. The data transmitted from the smart home appliances is mostly composed of basic numbers or statuses, that does not need complicated format encapsulations. With the use of customized light-weight protocols, we are able to significantly compress frame length, improving the throughput for each Joule spent in transmission. Further, deduplication by filtering out duplicates avoids retransmitting same content again and again, thus minimizing communications. The light-weight processing reduces the communication module's runtime, but does not affect critical information.

Besides optimizing data format, the use of edge computing technology also realizes light weight data transmission. The nodes make simple judgment and logic processing on-site, uploading only anomalous data and critical commands thus minimizing frequent communication between the cloud and end-points. It minimizes data to be transmitted, reduces traffic in the networks, and minimizes energy consumed due to long lasting node transmissions. The combination of data compression techniques with fault tolerance data accuracy tolerance may be increased to certain extent and compressions rates are improved. Lightweight data transmission protocols have a significant impact on power-efficient communications and battery lifetime extension of devices.

5. Development trends and improvement directions of low-power communication technologies

5.1. Integration path of communication technology and smart terminals

Low-power communications in the future would be integrated with intelligent devices to achieve system co-integration of hardware and convergence of software ecosystems. The size and power consumption of communications systems will shrink further enabling direct embedding into sensors, controllers, and smart household appliances in order to avoid unneeded power dissipation of stand-alone hardware. End devices are equipped with on-board multi-protocol adaption capability, automatically switching into a suitable communication mode according to particular situations in order to improve compatibility and flexibility. At the same time, the communication module can work together with the main control chip to realize joint power consumption control, which improves the overall power utilization of the whole system.

Smart terminal combined with intelligent communication technology will promote the integrated development of sensing, computation, and transmission abilities. The terminal will have the ability of intelligent decision making locally to reduce dependence on cloud service and lower down the frequency of communications and power consumption. With the unified interface standard and protocol specification, devices of various brands could work well together and eliminate the barrier between ecosystems. If such cooperative integration mode is adopted, device engineering simplified and costs reduced as well as systems' reactivity and robustness enhanced laying out the foundation of ubiquitous connectivity and very effective, low-power smart home operation, which in turn pushes the industry towards higher level of intelligence and unification.

5.2. Measures to enhance interference resistance in low-power communications

As mentioned, improving the anti-interference capability is an important development trend of smart house low power communication technology. Indoor WiFi has a complex and messy electromagnetic environment. Bluetooth, and electrical devices cause more BER and re-transmission which increase the power consumption in future technology interference effect is reduced with optimization of frequency hopping mechanism, expanding available channels, and increasing signal modulation fault tolerance. With the addition of a new adaptive channel assessment mechanism, it can monitor channel quality in real time and switch automatically to other channels that are less interfered with, ensuring stable communications and lowering the increase in power consumption due to interference [4].

On the hardware side, one can enhance the received signal strength and immunity against disturbances via optimizing antennas' design or implementing filters, thus limiting further power usage due to lost signals. On software side, redundancy checking, re-transmission limit, and bufferization techniques for preventing redundant communication. Moreover, with network layer cancellation and adaptive node sleep/wake-up control, a multi-dimension anti-interference mechanism is built, and improved anti-interference ability can ensure the reliable work of low-power communication under complex environment; minimizes redundant power consumption, and enhances reliability and quality of service for SHSs.

5.3. Cross-protocol communication compatibility and standardization development approach

Interoperability between protocols and standardization are two important aspects that facilitate mass deployment of LPWANs. Nowadays, multiple communication protocols co-exist, leading to interoperability issues among the devices increasing their complexity as well as their energy consumption. Going ahead, a phased-in deployment of protocols translation, common interfaces standards to achieve interoperability between the various systems; lowering the cost of adapting existing gateways and terminals. By defining a common authentication method, as well as communications architecture, devices of different manufacturers are compatible with each other, thus reducing the unnecessary transfer of information and power losses due to incompatible communication protocols.

Normalization: Normalization of some parameters like energy usage rate, transmission distance etc., will also be done through standardization, speeds and security technologies, promote healthy competition among the industries, as well as technology development. Unified standard can also reduce R&D costs, accelerate technology adoption, and provide a stable basis upon which systems can expand and be upgraded. Combining cross protocol compatibility with standardization, an open and interoperable smart home communications ecosystem which enables effective device-to-device connectivity as well as energy saving, thus promoting more general and healthy development of low power communication technology in the field of smart homes.

6. Epilogue

Low-power communications is one of the key enablers of smart homes and has a direct impact on the lifetime of devices' batteries, network stability, and the user experience. In this paper we provide an organized survey on low power communications for smart homes, including design details, benchmarking, optimization methods and directions, as well as providing insights on power management; network planning, configuration management and interference coordination. While existing solutions are mostly sufficient to satisfy day-to-day needs, there is still some space to improve inter-protocol interoperability, robustness of the protocol in harsh environments as well as scalability in terms of power consumption at scale deployment.

Disclosure statement

The author declares no conflict of interest.

References

[1] Wu T, 2023, Research and Industrialization of Key Technologies for Highly Reliable, Low-Power Multi-Scenario Intelligent IoT, thesis, Xiamen University.

[2] Gao J, 2025, Implementation of Low-Power Wireless Communication Technology in Smart Homes. Smart China, 2025(3): 42–43.

[3] Ding Y, 2025, Research and Application of Low-Power Wireless Communication Technology in Smart Homes. In Proceedings of the Jiangxi Provincial Engineers Association Academic Symposium on Engineering Technology and New Energy Economics (Volume 1), Henglong Communication Technology Co., Ltd, 99–102.

[4] Du W, 2025, Hardware Design Strategies and Performance Optimization for Low-Power Sensor Nodes in Smart Home Applications. In Proceedings of the 14th Academic Conference on Engineering Technology Management and Digital Transformation (Volume I), Guangxi Cybersecurity and Informatization Federation, 2–5.