Journal scientific and applied research, vol. 27, 2024
International Journal

ISSN 1314-6289 (Print)
ISSN 2815-4622 (Online)

Original Contribution

COMMUNICATION MODULES FOR DATA TRANSMISSION IN PHOTOVOLTAIC PERFORMANCE MONITORING AND ANALYSIS SYSTEMS

Iliyana St. Ivanova

DEPARTMENT: SECURITY OF INFORMATION AND COMMUNICATION TECHNOLOGIES, FACULTY OF TECHNICAL SCIENCES, KONSTANTIN PRESLAVSKY UNIVERSITY OF SHUMEN, SHUMEN 9712, 115, UNIVERSITETSKA STR., E-MAIL:
i.s.ivanova@shu.bg

ABSTRACT: *The paper discusses the wireless communication modules used for monitoring photovoltaic systems-ZigBee, Wi-Fi, Bluetooth, GSM and LoRa. The aim is to compare the main features, advantages and disadvantages of each of these technologies. The analysis identifies the need for reliability, low power consumption and secure data transmission in the design of the systems.*

KEY WORDS: *wireless monitoring, photovoltaic systems, communication modules, ZigBee, Wi-Fi, Bluetooth, GSM, LoRa.*

1. Introduction

The rapid depletion of energy resources and the problems of carbon emissions are transforming traditional energy systems towards renewable ones. With the increasing need for energy security worldwide, there is a growing emphasis on renewable energy generation. Among these sources is solar photovoltaic (PV) energy, which is considered a secure source of electricity generation. The construction of solar PV systems is becoming increasingly popular due to their ease of installation, relatively low maintenance costs, durability and zero fuel costs. The reduction in the cost of solar PV installations is due to factors such as improved technology including automation of panel manufacturing processes, supply chain competitiveness and growing developer expertise.

2. Exposition

The development of advanced systems to monitor the performance and functionality of solar PV systems is becoming a necessity due to the influences of various environmental factors. These factors include panel contamination, ambient atmospheric conditions (temperature, humidity, cloud cover), solar radiation, shading, etc. Real-time reporting and recording of the parameters from the solar PV system provide performance information. This allows the evaluation of the return on investment, minimizing operating costs and maximizing the energy produced. On the other hand, time, frequency of data updates, quality of sensors, data transmission mechanism used-wireless or wired, etc. can influence the accuracy of the data obtained from monitoring.

The use of wireless surveillance systems is increasingly common and preferred over wired systems due to their significantly lower susceptibility to environmental conditions. Another advantage of wireless systems is their ability to provide remote access, which suggests faster decision-making in real-time. Technologies for wireless monitoring of solar PV systems include a variety of monitoring modules using data transmission protocols as a basis. Sensors located on the panels transmit information to the controller. The controller sends the received data, via the selected module, to a computer or server over a local network or the Internet. The integrated modules in the system are essential for monitoring, control, and automation. The primary communication modules used for this purpose include ZigBee, Wi-Fi, Bluetooth, GSM, and LoRa.

ZigBee based modules

ZigBee modules are compliant with the IEEE 802.15.4 standard. They operate with low power consumption of 1 mW and are extremely suitable for short-range monitoring in wireless sensor networks. The transmission range of ZigBee can range from 40 m indoors to 300 m outdoors in direct line-of-sight. ZigBee is a simple and lightweight wireless network module that uses radio frequency (RF) to support the network within the sensors. ZigBee operates at a 2.4 GHz frequency with transmission rates up to 250 kbps. ZigBee networks can be built with star, tree and mesh topologies. These modules are the preferred choice for use in PV installations striving for energy efficiency and long lifetime operation. Sensors connected via Zigbee monitor both the PV panel performance and environmental conditions. The collected data can be sent to a cloud platform or local server where it can be analyzed in real time. ZigBee modules can be organized into a network structure specifically designed to provide redundancy. Thus, if one module fails, another can take its place, ensuring uninterrupted operation and protecting the installation. Due to the small coverage range, these modules are used in installations that require multiple sensors and devices to be connected near the controller, such as in manufacturing plants in industrial areas, factories with warehouses, commercial buildings, etc. [2].

Wi-Fi based modules

The range of the Wi-Fi modules can reach up to 150 m with data rates between 11 Mbps and 54 Mbps. The data rate for Wi-Fi is variable and depends on the protocols and frequency used. The topology used is a star type, which makes it easy to add new panels or sensors and does not require complex network reconfiguration. However, the Wi-Fi module consumes more power when transmitting data, reaching up to 1 W, which can be an important factor in system design. The use of unauthorized devices when monitoring over Wi-Fi can lead to vulnerabilities and attacks. Users who bypass access points become susceptible to external threats and attacks on each other. Unauthorized persons can intercept and monitor LAN traffic and must be within range of an access point (approximately 90 m for 802.11b). In addition, they can use illegitimate traffic to block legitimate users from accessing the access point. This can interfere with real-time performance monitoring and lead to technical failure and economic losses. This may impose additional security costs [1].

Bluetooth based modules

Bluetooth is a wireless technology for data exchange over short distances up to 100 m. Bluetooth functions using the IEEE 802.15.4 standard and Low-Rate Wireless Personal Area Networks (LR WPANs). Radio interference is removed in Bluetooth technology and replaced with a frequency hopping technique (SFH) that allows devices to fully access the radio spectrum. Users have access to data transmission and communication between different devices by forming small "ad hoc" networks without the need for a central controller.

The Bluetooth module offers various advantages but comes with several disadvantages including factors such as authorization, encryption and authentication. One of the main security concerns of Bluetooth is the pairing process. Unauthorized individuals can mimic users, terminate connections between devices, and alter data. A disadvantage is the limited operational range and high-power requirements, which results in slow data transmission compared to other monitoring technologies. In the case of investigating environmental parameters, transmitting a large amount of data at short intervals would require a routing protocol with multiple transitions. It can cover larger areas using other devices in the network to reach the endpoint [3].

GSM based modules

The Global System for Mobile Communications (GSM) is built using Time Division Multiple Access (TDMA). The data rate in a 2G network is up to 64 kbps, which is not sufficient when transmitting large amounts of data. It is still used in areas with limited access to other communication networks. In areas with better established networks, the basic mode speeds of 3G is up to 2 Mbps, and 4G networks between 200 Mbps and 1 Gbps. Although GSM modules provide reliable connectivity, their power consumption is 1 W to 5 W, which compared to Zigbee and LoRa is significant. The GSM modules provide coverage from 10 to 30 km. They support 2G, 3G and 4G SIM cards and are suitable for IoT applications and provide wireless communications and real-time telemetry.

Connecting a GSM module to a controller allows the PV system performance to be monitored in real time and receive notifications (SMS) of its status. The transmission is based on the GSM cellular network. The message first arrives at a local SMS center, which stores it if the receiving mobile station is switched off or unreachable and attempts to resend it for up to three days until the mobile becomes available. Typically, the message takes 0.5 to 2 s to be delivered, depending on network congestion. Experimental tests confirm that the information collected by the PV installation can be accessed by a remote user with a maximum delay of 2 s. Therefore, the remote monitoring and control functions can be considered fast but not strictly real-time.

The cost of purchasing and integrating the module is reasonable, especially given the provision of 24-hour monitoring. However, GSM lags behind in some aspects related to messaging, such as data interruptions and email connectivity issues when many users are using the same bandwidth. In addition, SIM card cloning can lead to fraud and data theft [4].

LoRa based modules

LoRa (Long Range) is a wireless radio frequency technology developed by Semtech company. It operates at the physical layer of the stack and is based on a spread spectrum modulation technique known as Chirp Spread Spectrum (CSS), in which "chirp" pulses are used as a carrier signal to encode information. It provides long-term and low-power communication. It is designed for applications on the Internet of Things (IoT). LoRa is a low-power broadband module with low power consumption (about 25 mW) and long transmission range (LPWAN). This technology can be used in long-life battery-powered devices where power consumption is essential. A typical LoRa network follows a "star of stars" topology. LoRa's advantage is the ability to transmit data over long distances-from 10 to 30 km-without using cellular Internet or Wi-Fi.

The module can be connected to any microcontroller or sensor using the fast SPI (Serial Peripheral Interface) communication protocol. The data collected by the sensors is transmitted via LoRa modules. The information can be uploaded to a webserver using applications which helps in monitoring and analyzing the system performance by the user.

The module can be integrated in systems located in remote areas where there is no network coverage and even in urban environments with limitations of direct visibility between modules.

LoRa has some operational limitations, such as limited network size from long cycling. The performance of LoRaWAN (Low Power Wide Area Network) depends on the physical layer (PHY) and the media access control (MAC) layer. These layers identify the connected devices in the network. Long-cycle regulations in the industrial, scientific and medical (ISM) purposes bands are important constraints. They impact network capacity and performance [5].

Parameters	**ZigBee**	**Wi-Fi**	**Bluetooth**	**GSM**	**LoRa**
Data Transmission Rate	250 kbps	11 Mbps	1 Mbps	200 Mbps – 1 Gbps (4G)	5469–293 bps
Range	300 m	150 m	100 m	10-30 km	10-30 km
Operating Temperature (° C)	-40°C÷ +105°C	-20°C ÷ +60°C	-35°C÷ +45°C	-40°C÷ +85°C	-40°C÷ +85°C
Power Consumption	1 mW	1 W	10–500 mW	1–5W	25 mW
Sampling Rate	8 MHz	20 MHz	44.1 kHz	8 kHz	500 kHz
Topology	Mesh	Star	Point to point	Star	Point-to-point, Star, Mesh
Receiver Sensitivity Requirements for modules	-85÷ -92 dBm	-40 dBm ÷ -80 dBm	-70 dBm ÷ -100 dBm	up to -120 dBm	up to -130 dBm
Remote monitoring	Yes	Yes	No	Yes	Yes
Requiring internet connectivity.	Yes	Yes	No	Yes	No
Security	High level provided by AES-128 encryption algorithm	WPA/WPA 2/WPA3 encryption	AES CCM encryption algorithm	SSL/TLS encryption	AES-128 encryption algorithm
Application	industrial equipment, PV home installations	industrial equipment, PV home installations	industrial equipment, PV home installations	industrial equipment, PV Power station	industrial equipment, PV Power station
Frequency band	2.4 GHz	2.4/5 GHz	2.4 GHz	800/900/1800 /1900 MHz	868/915 MHz

Fig. 1. Comparison of basic parameters of communication modules

Fig. 1 compares the main parameters of communication modules, with the most optimal values indicated in green, and the unfavorable ones in yellow.

3. Conclusion

The selection of the appropriate communication module for monitoring and control of PV installations depends on the application.

ZigBee modules are a good choice for applications requiring low power consumption and short-range monitoring, being suitable for sensor networks in multi-device installations where energy efficiency and fast transmission of small amounts of data is an important factor.

Wi-Fi modules provide high data transmission speed. They are easy to integrate into the network, but have a high-power consumption, which can be a disadvantage in prolonged use where power is limited.

Bluetooth modules provide close range coverage and easy device connectivity. The downside is their lower data transmission efficiency and security issues with pairing, which limits their application in larger installations.

GSM offers global coverage and is suitable for installations that require communication over long distances, especially in areas with limited access to other networks. GSM modules have high energy consumption. Furthermore, they are not suitable for fast transmission of large volumes of data.

LoRa modules are distinguished by their ability to cover long distances at low power consumption. They are best suited for remote PV installations or applications requiring long periods of battery operation. Network capacity and bandwidth constraints can hinder the use of LoRa, which can create problems in certain cases.

The selection of a wireless module in PV systems should be based on specific range, speed, power consumption and cost requirements to ensure efficient control and system reliability. Appropriate technology can increase the performance of PV systems and improve their performance monitoring, leading to greater energy efficiency, cost savings and increased security.

Acknowledgments

This article is supported by project RD-08-147/02/02/2024 "Enhancement of capabilities to create a vulnerability testing scenario in a simulation security operations center", "Konstantin Preslavsky" University of Shumen, Faculty of Technical Sciences, Department: Security of information and communication technologies.

References:

[1] S. Ansari, A. Ayob, M. S. H. Lipu, M. H. Md Saad, A. Hussain, "A Review of Monitoring Technologies for Solar PV Systems Using Data Processing Modules and Transmission Protocols: Progress, Challenges and Prospects", (2021).

[2] I. Dochev, K. Valkov, "ZigBee based data collection systems", (2014).
[3] J. Padgette, J. Bahr, M. Batra, NIST Special Publication 800-121 Revision 2, "Guide to Bluetooth Security", 2017.
[4] M. Gagliarducci, D. A. Lampasi, L. Podesta, "GSM-based monitoring and control of photovoltaic power generation", Measurement 40 (2007) 314–321.
[5] K. Angelov, N. Manchev, S. Sadinov, T. Ivanov, "Planning and survey of radio coverage in LoRa WAN communication network", International scientific conference 2020, Gabrovo.