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Development of a Wireless Sensor Network Using User Datagram Protocol

Ngo Phuong Le, Luong Ngoc Giap,
Nguyen Binh Khanh, Bui Tien Trung, Truong Nguyen Tuong An
Institute of Energy Science, Vietnam Academy of Science and Technology
A9 Building, 18, Hoang Quoc Viet str., Cau Giay dist., Hanoi, Vietnam
Corresponding Author: NGO Phuong Le

ABSTRACT: *This paper presents a development of a wireless sensor network (WSN) for the purpose of collecting experimental data in a small area. Based on WiFi and UDP the wireless sensor network is easy to develop and to deploy. The WSN consists of a Server and wireless sensor devices. The Server running on Windows PC to gather data from wireless sensor devices and to display real time graph of aquired data. The wireless sensor devices are ESP32 microcontroller based device reading sensored values from variety of sensor modules. The WSN was used to assess the operation of a smart lighting automatic control system according to natural light.*

KEYWORDS – *Wireless sensor network, WiFi, UDP, ESP32, Smart lighting*

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I. INTRODUCTION

In recent years, the Internet of Things (IoT) has received a lot of attention due to its ability to easily access data. A Wireless Sensor Network (WSN) is an application of the IoT that cooperatively monitors physical, environmental conditions such as temperature, sound, light, pressure, motion, or dust. at various points [1]. IoT devices often have to be energy-efficient, compact, and low-cost for distributed deployment. Efficient communication processing with low power is one of the most important tasks in IoT.

WSN has some major communication solutions that can be listed as [2]:

– 2G, 3G, 4G high-speed telephone networks, with large coverage, but not yet covered in remote areas, especially in areas without electricity

– 2.4GHz band radio network including ZigBee, Bluetooth, Wifi with high speed, but narrow range

– LPWAN low energy wide area network has high coverage, low speed, low energy.

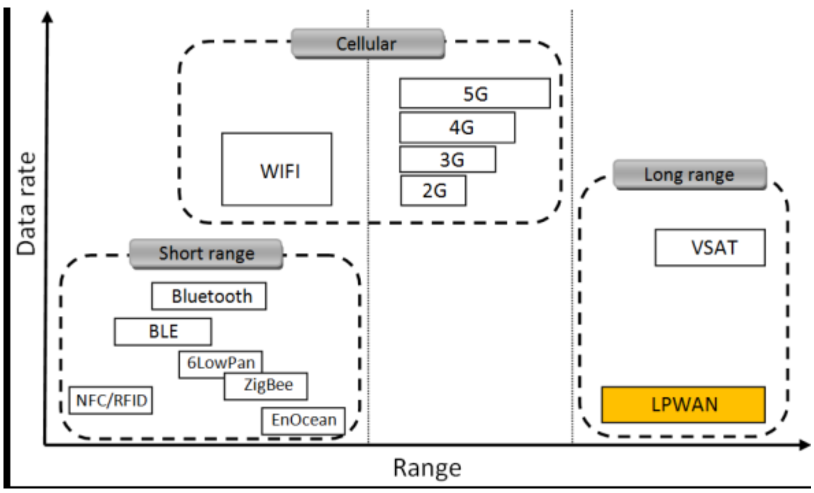


Figure 1. The amount of data and the distance of wireless communications technologies [2]

For a short range WSN, WiFi is the most convenient option. WiFi is a wireless networking technology based on the IEEE 802.11 standard, commonly used for local area networks, in which compatible devices can connect via wireless access points to each other and to other wired devices in the network.

One of the current trend in IoT communication is to use Internet Protocol (IP) to establish a connection between wireless sensor devices [3]. A TCP/IP network requires strict reliability and data transfer verification are not suitable for IoT devices since many devices are not often online but sleep to save power. In addition, low-latency IoT devices cannot use TCP because the protocol requires 3 handshakes each time a connection is made [4]. In addition, if data is lost, the delay will be longer because the process has to be redone [5].

The connectionless UDP (User Datagram Protocol) protocol is a good alternative for IoT devices. Unlike TCP, it does not require strict reliability and is suitable for low-latency and low-power applications [4]. UDP is commonly used for Voice over IP (VoIP) and streaming applications . In an IoT network, UDP comes in handy when focusing on low latency instead of reliability. The UDP header is also smaller than that of TCP, thus also contributing to energy efficiency.

Therefore, the authors choose UDP as the communication protocol for WSN in short range indoor experiments. The WSN using UDP was implemented to test the operation of the lighting automatic control system according to natural light, which is implemented and presented in the article [6].

II. DESIGN OF WIRELESS SENSOR NETWORK USING UDP

A. System overview

The Wireless sensor network using the UDP was designed as following:

– Server: A Windows application that acts as a UDP Server, a database for data storage and data plotter;

– Wireless sensors: The sensor devices act as a UDP Client and a sensor that measures environmental and physical values and sends measured values to UDP Server via UDP protocol over WiFi.

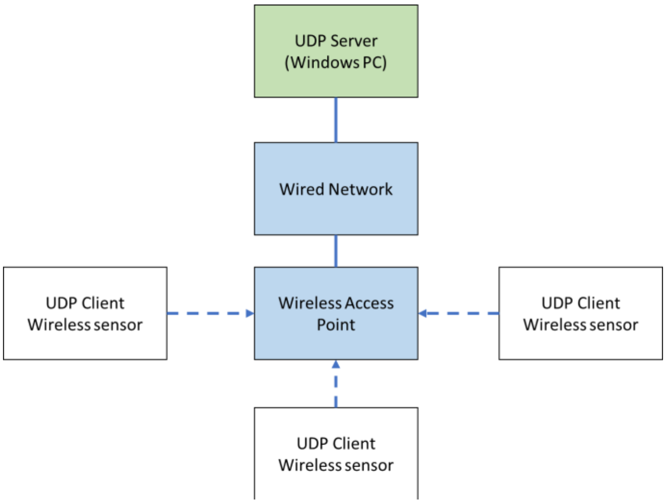


Figure 2. Diagram of an UDP sensor network for short range experiments

Server has the following functionalities:

- UDP Server listening for data on a specified port
- UDP Discovery Service allowing UDP Client to automatically find UDP Server to send measurement data
- Historical data storage
- Chart plotter showing charts of all the measured data over time

Server has two parts:

– Backend to collect data from wireless sensors and to store data in database. Backend is powered by Nodejs technology.

– Frontend is an Electron program to create an interface to display system operation data.

Wireless sensor's functionalities:

– Measure required environmental, physical, chemical, ... values

– Automatically search for Server in LAN

– Send measured data to Server

Wireless sensors are comprised of an ESP32 microcontroller and measurement modules. ESP32 microcontroller fully integrates WiFi protocol, has high processing speed, large memory, low cost, large development community, very suitable for wireless sensor network applications.

B. User Datagram Protocol (UDP)

User Datagram Protocol (UDP) is one of the core members of the Internet protocol suite. With UDP, computer applications can send messages, in this case referred to as datagrams, to other hosts on an Internet Protocol (IP) network. Prior communications are not required in order to set up communication channels or data paths.

UDP uses a simple connectionless communication model with a minimum of protocol mechanisms. UDP provides checksums for data integrity, and port numbers for addressing different functions at the source and destination of the datagram. It has no handshaking dialogues, and thus exposes the user's program to any unreliability of the underlying network; there is no guarantee of delivery, ordering, or duplicate protection. If error-correction facilities are needed at the network interface level, an application may use Transmission Control Protocol (TCP) or Stream Control Transmission Protocol (SCTP) which are designed for this purpose.

UDP is suitable for purposes where error checking and correction are either not necessary or are performed in the application; UDP avoids the overhead of such processing in the protocol stack. Time-sensitive applications often use UDP because dropping packets is preferable to waiting for packets delayed due to retransmission, which may not be an option in a real-time system [7].

User Datagram Protocol is a simpler message-based connectionless protocol [8]. Connectionless protocols do not set up a dedicated end-to-end connection. Communication is achieved by transmitting information in one direction from source to destination without verifying the readiness or state of the receiver.

– Unreliable – When a UDP message is sent, it cannot be known if it will reach its destination; it could get lost along the way. There is no concept of acknowledgment, retransmission, or timeout.

– Not ordered – If two messages are sent to the same recipient, the order in which they arrive cannot be guaranteed.

– Lightweight – There is no ordering of messages, no tracking connections, etc. It is a very simple transport layer designed on top of IP.

– Datagrams – Packets are sent individually and are checked for integrity on arrival. Packets have definite boundaries which are honored upon receipt; a read operation at the receiver socket will yield an entire message as it was originally sent.

– No congestion control – UDP itself does not avoid congestion. Congestion control measures must be implemented at the application level or in the network.

– Broadcasts – being connectionless, UDP can broadcast - sent packets can be addressed to be receivable by all devices on the subnet.

– Multicast – a multicast mode of operation is supported whereby a single datagram packet can be automatically routed without duplication to a group of subscribers.

C. Server

The Server performs the following functions:

– Listen for unicast data on a specified port to receive sensor data

– Listen for broadcast data packet that asks for UDP Server address information from the Client and send reply

– Storing historical data into database

– Real-time chart of system operational data (Figure 3)

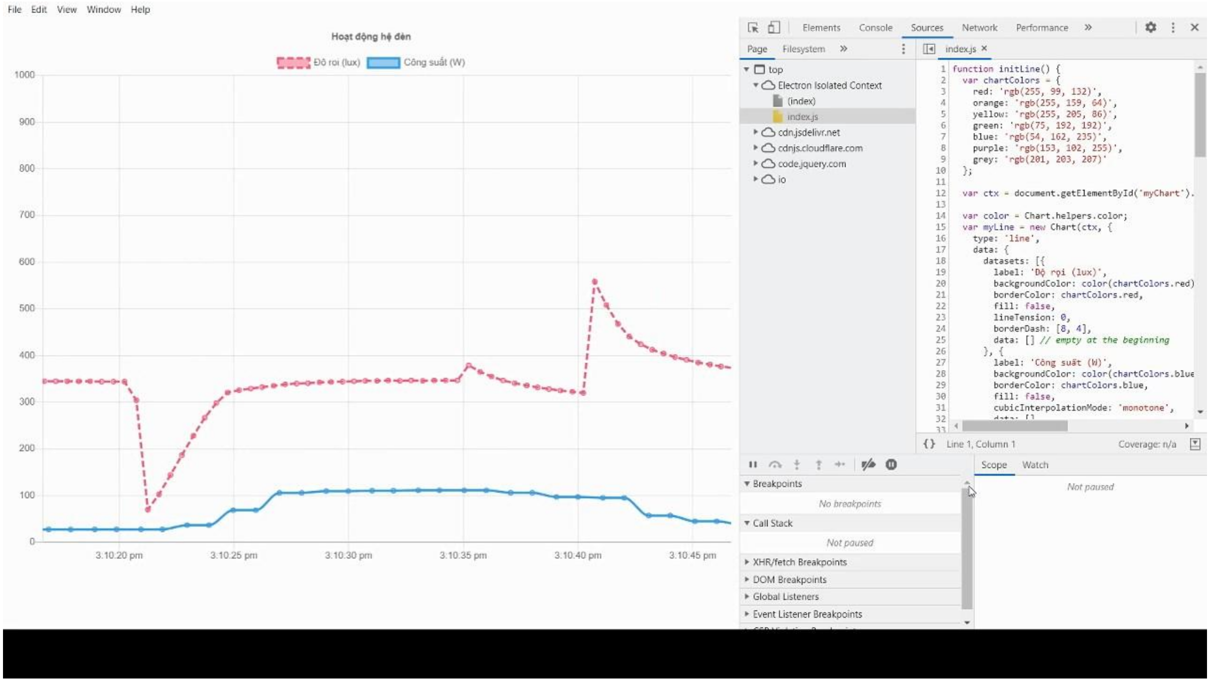


Figure 3. User interface of the UDP Server, using Electron framework

D. Wireless sensor devices

Wireless sensors are comprised of an ESP32 microcontroller and measurement modules.

ESP32 is a series of low-cost, low-power system on a chip microcontrollers with integrated Wi-Fi and dual-mode Bluetooth. The ESP32 series employs a Tensilica Xtensa LX6 microprocessor in both dual-core and single-core variations and includes built-in antenna switches, RF balun, power amplifier, low-noise receive amplifier, filters, and power-management modules. Some features of ESP32 are the following:

– CPU: Xtensa dual-core (or single-core) 32-bit LX6 microprocessor, operating at 160 or 240 MHz and performing at up to 600 DMIPS; Memory: 520 KiB SRAM, 448 KiB ROM;Wireless connectivity: Wi-Fi: 802.11 b/g/n;

– 34 × programmable GPIOs; 12-bit SAR ADC up to 18 channels; 2 × 8-bit DACs; 4 × SPI; 2 × I²C interfaces; 3 × UART; Motor PWM; LED PWM (up to 16 channels); Hall effect sensor; Ultra low power analog pre-amplifier

The Wireless sensor device has the following functionalities:

– Measure the required sensor values. Depending on the type of values to be measured, the microcontroller can be connected to the measurement module and receive the value through one of the supported protocols such as: I2C, UART, SPI, ...

– Automatically search for Server in LAN. The Wireless sensor device broadcasts a request packet to all devices on the network that are listening on a specified port. The Server listens to this port and send a response packet which contains the information of its address to Wireless sensor device.

– Send measurement data to Server via UDP protocol. Data can be up to 65536 bytes long (8 byte header + 20 byte IP header + 65508 bytes of data).

III. IMPLEMENTATION OF THE WIRELESS SENSOR NETWORK

The wireless sensor network is implemented to test the operation of the smart lighting automatic control system according to natural light for the classroom designed and implemented by the authors, described in [6]. The system is installed in room 308, building A9, Institute of Energy Science, Vietnam Academy of Science and Technology, 18 Hoang Quoc Viet, Hanoi.

The lighting system includes (Figure 4):

– The LED lights automatically change the power, hence the luminous flux according to natural light (1)

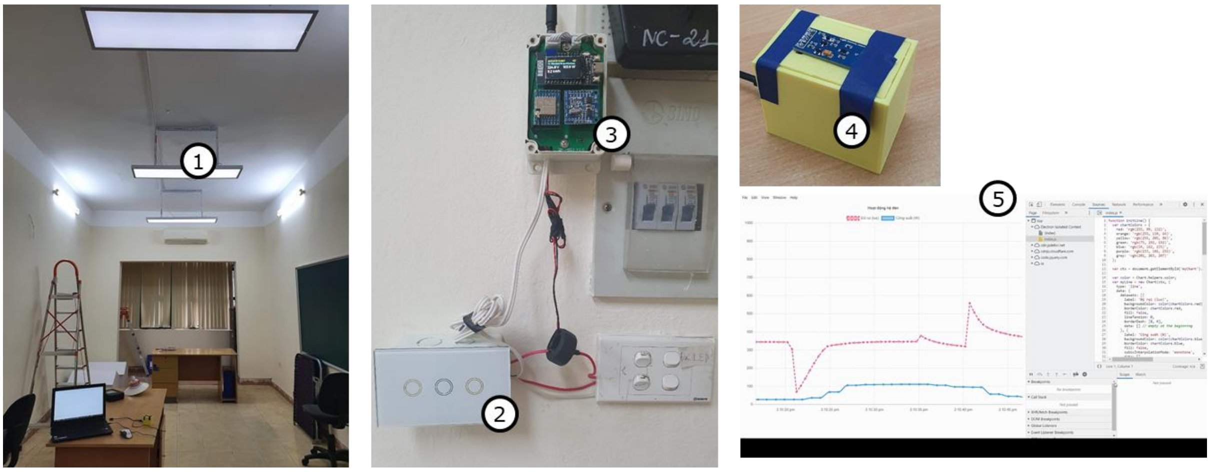
– Center control panel to configure individual LED lights (2)

The wireless sensor network consists of devices (Figure 4):

– A light sensor (wireless sensor) measures illuminance on the desk (4)

– AC meter (wireless sensor) measures the power consumption of the lighting system (3)

– The computer runs the Server program, collects data and displays the measurement results in a graph (5)



1 – 3 smart LED lights; 2 – Control panel; 3 – Electronic WiFi-integrated power meter; 4 – WiFi-integrated illuminance sensor; 5 – Real-time graph of power and illuminance by time

Figure 4. The smart lighting automatic control system according to natural light and the wireless sensor network consisting of 2 sensors

Data is measured by wireless sensors and is sent to the Server every 0.5s. The data loss rate is about 0.02%. However the data loss rate may vary, depends on how busy the LAN is.

Server receives the data and displays real-time graph of the power consumption of the lighting system and the illuminance on the desk (Figure 6).

Figure 5 shows the measurement results of the handheld illuminance sensor and the electronic power meter in the presence and absence of the external light. Figure 6 is a real-time graph showing the change in power consumption and the stability of illuminance on the desk when the external light is changing.

a) b)

a) External light is ON: power consumption is 104W, illuminance is 418 lux; b) External light is OFF: power consumption is 27W, illuminance is 528W

Figure 5. Power consumption and illuminance on the desk in the presence and absence of external light

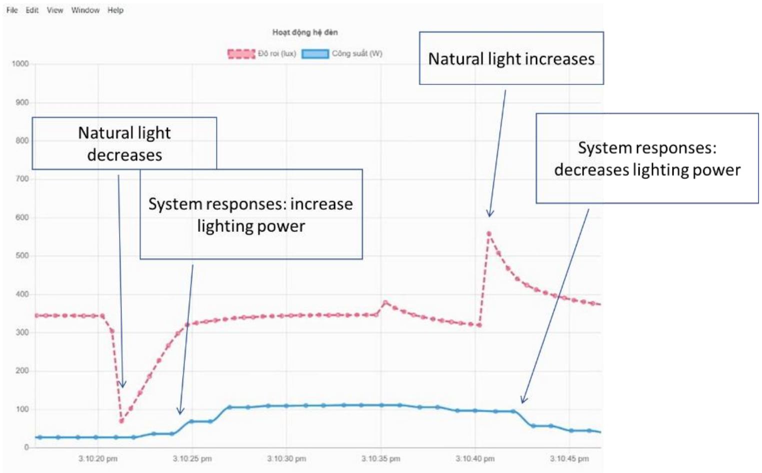


Figure 6. Real-time graph showing the change in power consumption and the stability of illuminance on the desk when the external light is changing

Figure 6 proves that the lighting system has worked as intended: when the external light is not available, the illuminance on the desk falls, the power consumption of the LED lights increases and after a while, illuminance on the desk comes back to the set value; when the external light is available again, the illuminance on the desk raises, the power consumption of the LED lights decreases and after a while, illuminance on the desk comes back to the set value. The power consumption change is as much as 70% of maximum power consumption.

IV. CONCLUSION

The paper presented the results of the development of a wireless sensor network to monitor and aquire the data of short range indoor experiments. The wireless sensor network consists of the following:

– Server with functions: Listening to unicast data on a specific port to receive measurement data from the wireless sensors; Providing auto discovery service for the wireless sensor device to find the server in the LAN; Storing historical data into the database; Presenting the realtime data and realtime graph of the data over time;

– Wireless sensor devices with functions: Measuring required data from the sensor modules via supported protocols such as I2C, UART, SPI, ...; Searching automatically for Server in LAN; Sending measured data to Server via UDP;

The Wireless sensor network was implemented to test the operation of a smart lighting automatic control system according to natural light for classrooms designed by the author's team. The Wireless sensor network helped research team to have a clearer view of the operation of the system in real time. Data is measured by wireless sensors and is sent to the Server every 0.5s. The data loss rate is about 0.02%, however the data loss rate may vary, depends on how busy the LAN is.

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