TESTING OF TRANSFER SIGNAL QUALITY OF RF-BASED SYSTEM

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The article deals with the creation of an IoT system based on the Hardwario platform. In the first part, the options for signal transmission were analyzed. The selected and tested system utilizes radio frequency signal propagation at 868 MHz. Signal quality was tested in indoor and outdoor conditions, where the reliability of the proposed solution was verified. Systems built on the proposed solution can be used for remote monitoring of desired parameters on a sufficiently large area.

KEYWORDS

Internet of things, data transfer, low frequency, long range, wireless communication

1 INTRODUCTION

Internet of Things is term for network of physical devices, vehicles, home appliances and other devices, which integrate electronics, software, sensors, movable parts and network connectivity, which allows to connect and interchange data [Kumar 2022, Saban 2023].

The main fields of the current IoT solutions:

- Safety: Monitoring of objects, buildings, etc.
- Health: Control of the environment, where we live and work, and make action based on our health status
- Economics: improved planning, optimalisation and simplification of processes, and life
- Ecology: save sources and nature
- Entertainment: new forms of entertainment.

The risk associated with IoT:

- Misuse of data
- Invasion of privacy
- Incorrect interpretation and use of data
- Overwhelmed by an excess of poorly structured data.

IoT means that things around us can communicate - send information, or exchange information between each other. This allows to significantly speed up and make more effective activities and better decisions, better plan our time, control and remotely finish activities, without any further support or help [Akin-Ponnle 2023, Vagas 2021].

In terms of IoT hardware we have to talk about devices which measure, control and communicate. These devices are the sensors, actuators and controllers. In more complex look we can talk about these things as vehicles, industrial machinery, home appliances [Beniak 2019, Galajdova 2020 and 2021].

All of the above-mentioned devices have common that they:

- are physical devices,
- use electronic parts,
- integrate network connectivity,
- are clearly identifiable.

The central device of most IoT solutions is typical part of the networked devices. This allows the internet connection, with the connected nodes of the local network. The local network is usually separated from the internet and the central device – hub creates a “bridge” to the online environment. One of the most used hubs is for example the Raspberry Pi [Kelemenova 2020 and 2022].

The software of these devices is called firmware for the embedded systems. This defines the purpose and working of the devices, i.e. measurement of statuses, and sending data.

One of the very important functions of the firmware is to control the energy consumption of the device, which is critical for the battery powered devices [Gregor 2019, Janota 2019].

One of the most important added value of the IoT solutions is the analysis of the gathered data. Sometimes this data is called Big Data and they are processed on online platforms like Amazon (AWS), Microsoft (Azure) and Google. Some systems include own solution with hardware, software, and own infrastructure. Additionally, a lot of support applications are available for mobile devices like IFTTT, Ubidots, Blynk etc. [Vaclavova 2018, Vagas 2013].

2 IOT CONNECTIVITY

Transport protocols

Protocol is a set of rules for electronic communications and data transfer between the end nodes, typically computers. All the members of the networked devices have to support the selected communication system. For internet-based communication the typical transfer protocols are TCP/IP and application protocol HTTP/HTTPS.

Nowadays the IoT systems integrate various communication methods, one of the most common is MQTT.

Message Queuing Telemetry Transport protocol is a publish subscribe method communication.

Example of the message is the following:

Topic: plant/floor1/switches/switch1

Content:1

The message describes that the switch1 of the group of switches on the first floor of the plant is in state 1, which means its ON. Similarly, to this message we can bind a device, bulb or any appliances and control them.

Devices of the MQTT network communicate with the server, via a network member which is called broker. This member ensures that the messages are delivered from publishing members to the subscribed devices.

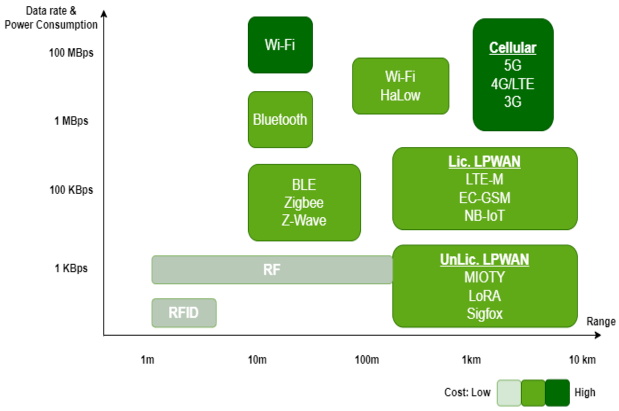

Figure 1. Data rate, power consumption and range characteristics of various wireless communication systems

While the communication between the devices is based on MQTT standard the transfer is realized via wired or wireless channels. Further the wireless transfer is divided into local and global, depending on the range. In the field of IoT for local transfer usually Wi-Fi, Bluetooth, ZigBee and similar protocols are used. One of the most important aspects of the communication protocol is the frequency band, which

influences the transfer quality, range reliability and power consumption (Fig. 1). In most cases where small amount of data is transferred one of the most suitable wireless transfer band is the Sub-GHz band with predefined restricted frequencies (868 MHz for Europe and 915 MHz for USA).
The Sub-GHz band can be freely used for various industrial, scientist and medical applications, where long range, system cost and long battery life concerns are critical. The most typical applications can include fields as home automation, security, industrial control, remote sensing, weather stations and many other.
The advantages of 868 MHz transmission:

- In free space range is up to 800 m with 1/4 wavelength antenna.
- Radiofrequencies can go through concrete walls.
- The radio transmission is not distributed by obstacles.
- Interferences are rare.

Based on the frequency propagation characteristics of sub-GHz greatly extended ranges can be obtained at much lower current consumptions than 2.4 GHz band solutions. In addition, these frequencies are free of various interferences like microwaves, Bluetooth, Wi-Fi.
The working principle of Sub-GHz communication is based on radio wave transmission between transceiver and receiver antennas. In these bands different radio signal modulations can be applied. The 868 MHz band is technically from 865 MHz to 870 MHz and split in 6 different sub-bands. Sigfox and LoRaWan used these sub-bands for communicating also.
For further capabilities and accessibility, other transfer methods like the NB-IoT and LoRa communication are also applicable. These are similarly supported by the experimental hardware setup, like the RF method, but were not tested.

2.1 NB- IoT

The Narrowband Internet of Things is radio technology standard for low-power wide are networks. The main focus of this standard is on indoor coverage, low cost, long battery life, and high connection density. The NB-IoT is limited to a single narrow-band at bandwidth of 200kHz. The transmission characteristics of NB-IoT varies for different versions of LTE standards, where the downlink rate is between 26 to 127 kbit/s and downlink rate 16.9 to 159 kbit/s.

2.2 LoRa

LoRa stands for ´Long Range´ communication technology, based on spread spectrum modulation. LoRaWan defines the communication protocol and system architecture for networking of wireless battery-powered devices. The typical application includes IoT systems with bi-directional communication, end-to-end security, mobility, and localization services. The data rate varies from 0.4 kbit/s to 50 kbit/s per channel.

3 HARDWARIO ECOSYSTEM

For the experiment the Hardwario ecosystem was used. In general, it combines a powerful hardware platform with open software options.
The concept of the Hardwario ecosystem is the following: Similar wirelessly connected nodes, with various sensors and software connection to a PC or network service via gateways or networks to collect and process data.
With the available low-powered microcontrollers and suitable deep sleep mode integration a battery powered node is usable for longer wireless applications [Hardwario 2023].
The details on the hardware and software are described in the following subchapters.

3.1 Hardware

The "brain" of each node is a core module consisting of a MCU with additional radio and wire interfaces. Its technical details are listed in the table 1.

Table 1. Hardwario technical specifications [Hardwario 2023]

Specs	Hardwario Core unit
MCU	32-bit ARM Cortex M0+ STM32L083CZ
Radio communication	SPIRIT1 868 or 915 MHz
Memory	192 kB flash / 20 kB RAM
Voltage level	2 V to 3.6 V
Idle power consumption	< 30 µA
Interfaces	18× GPIO 3× UART 2× I2C 1× SPI 5× ADC 2× DAC

The Core module is extendable by additional "shields" which integrate functionalities for special measurements or capabilities.
Currently, there are available shield for the following purposes:

- Environment monitoring (temperature, humidity, light intensity and atmospheric pressure).
- CO_2 measurement in the ambient environment (office, laboratory, home).
- Movement detection module.
- Display module - to show relevant data.
- Programmable button module.
- Relay module to control a connected circuit.
- Sensor interface to integrate further measurement units.
- Localization module (GPS, Galileo, GLONASS).
- and others.

Examples of the listed hardware shields are shown in Fig. 2.

Figure 2. Core module, Display and button shield for Hardwario

For the experiment purposes the Hardwario Radio Dongle was used. This device represents the central network element for radio-based communication. Its suitable to be used via a PC or Raspberry Pi to connect up to 32 nodes. Its technical details are summarized in the Table 2.

Table 2. Hardwario technical specifications [[Hardwario 2023]]

Specs	Hardwario Core unit
MCU	32-bit ARM Cortex M0+ STM32L083CZ
Memory	192 kB flash / 20 kB RAM
Radio module	868/915 MHz
Voltage level	4,5 V to 5,5 V
Interfaces	USB to UART (FTDI) USB-A for communication and power

To power the wirelessly communicating nodes a mini battery module is available. It is designed to power the Core module with a shield via 2x AAA alkaline cells. Also, a bigger 4 pcs battery module is available for bigger nodes.

3.2 Software

For software development multiple option are supported.

A free Windows application Playground is developed. Its suitable to prototype or develop projects, to create a working base. Later an own server (i.e. on Raspberry Pi or other) is recommended. The Playground application integrates tools to manage communication with the Radio Dongle and Core modules (Fig. 3).

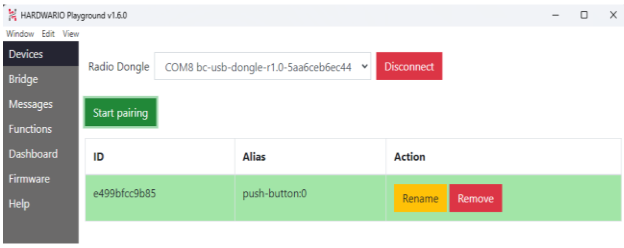

Figure 3. Playground application and Devices tool

To manage the ongoing communication, for monitoring the messages a monitoring window shows the received and transferred data (Fig. 4).

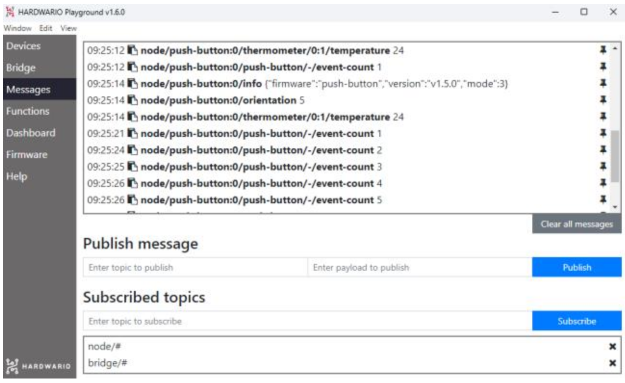

Figure 4. Playground application and Devices tool

Node-RED interface is available, as a built-in window to program relations and reactions between the captured information and the ongoing system.

The example view of the Node-RED and the debugging window is shown on the following figure (Fig. 5). With this tool communication, visualization, database management, data processing and further functions are available. The developed project can be divided into separated "Flows" to be more readable for the programmer. The environment can be further expanded with online available functions like data processing and communication to other platforms.

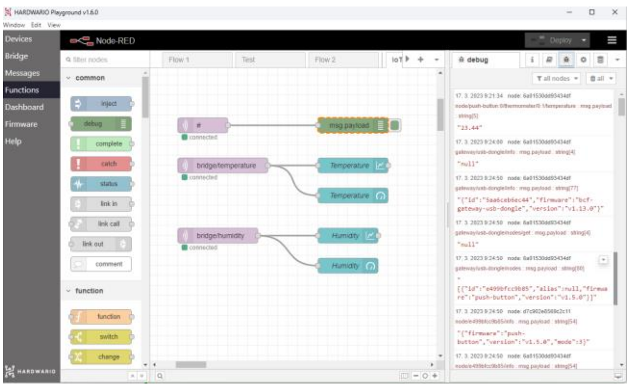

Figure 5. Playground application with NodeRED window

A visualization window of Playground software provides a readable graphical interface for a user, or to visually represent the measured values, also control elements are optional. Basic graphical element like charts, graphs, numerical fields etc. are included. An example of basic data visualization is shown on Fig. 6.

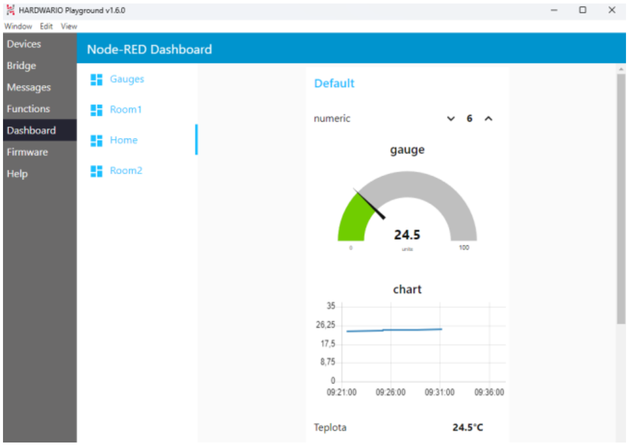

Figure 6. Playground application and UI

Last functionality is to update or change the firmware of the connected module - related to the hardware configuration (connected shields and peripheries). In this module the predefined firmware or custom firmware can be downloaded to the board (Fig. 7).

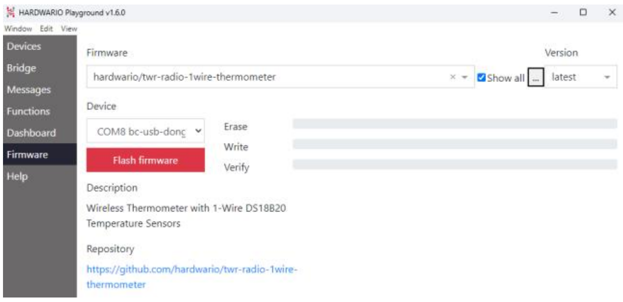

Figure 7. Playground application and Devices tool

To develop firmware for custom applications or devices that are new for the platform of Hardwario the Visual Studio Code and its extensions are usable, while also Command Line Interface tools are supported.

The Firmware is pure C language, for very effective hardware usage, longtime support and syntax advantages.

The development includes the following steps firmware development application.c file creation, this is followed by a compilation and flashing to the hardware. Example of a view on Hardwario Code environment is shown on Fig. 8.

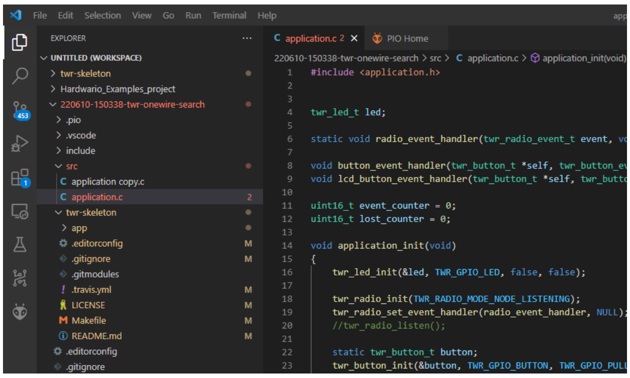

Figure 8. Playground application and Devices tool

Last but not least the nowadays IoT applications usually include remote cloud services. Similarly Hardwario supports REST API and callback setting to seamlessly connect or integrate to an already existing or remote cloud application like Ubidots, Blynk, ThingsBoard and others.

4 EXPERIMENTAL SETUP

In our case, we decided to create and test a system based on RF technology with a frequency of 868 MHz. The system consisted of a portable device composed of a core module, a battery module, and a button module. Communication was carried out using a radio dongle, which can provide communication via RF with up to 32 modules, which is a sufficient number of stations to create a large monitoring area. In our case, the radio dongle was connected to a notebook, where a control program was created in the NodeRED environment (Fig. 9).

Figure 9. Measuring chain

The aim was to verify the range of the IoT system when used both indoors and outdoors (Tab. 3). At the test site, 10 button presses were performed, during which the quality of the signal in dBm was recorded at the location, where successful signal transmission was detected. We considered the point where at least 50% of the signal was transmitted as a reliable location. Subsequently, the achieved signal quality values were averaged and plotted in the resulting graph or table.

Table 3. Signal strength

Signal Strength [dBm]	Quality
> -60	Excellent
-60 to -89	Good
-90 to -99	Fair
< -100	Weak

5 INDOOR RESULTS

In the first case, the base was located at point S (Fig. 10), and the signal quality was measured at multiple locations indoors and in the immediate vicinity of the building. Stable signal locations are marked on Figure 10 as points (1-29). Their average signal values are shown in Table 4.

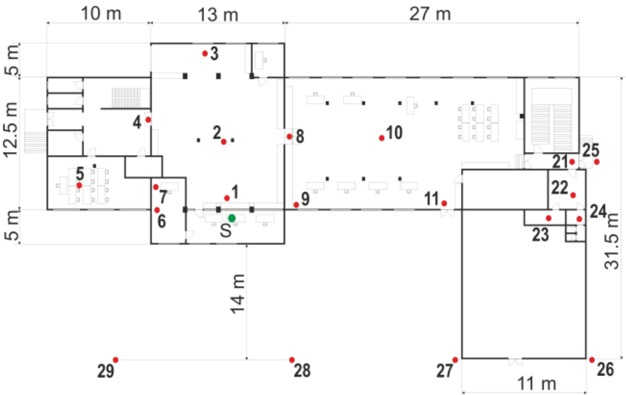

Figure 10. Indoor measurement

Although in some locations, the signal quality does not reach a reliable value (<-89 dBm) (Tab. 3), signal was still recorded in most cases, and the location can be monitored assuming it is not a place with high demand for signal transmission reliability. Alternatively, by adjusting the method of signal transmission, the location can still be used. More distant locations indoors or in the vicinity of the building were also tested, but if the desired amount of transmitted signal was not achieved, such a location was not evaluated.

Table 4. Indoor - measured values

Place	Signal strength [dBm]
1	-67.1667
2	-78.3333
3	-91.5714
4	-93.1667
5	-90
6	-79.25
7	-85.125
8	-84.6667
9	-94
10	-91.1667
11	-93.5
21	-109
22	-109.667
23	-106.167
24	-110.625
25	-111.5
26	-101.167
27	-102.167
28	-95.8333
29	-98.1667

6 OUTDOOR RESULTS

During the measurement of signal quality in the exterior, the measurement was carried out in the area of TUKE, which means not in an open space but in a built-up area with a larger number of trees. The base station S was located among the trees, and the signal measurement was carried out in three directions (D1, D2, and D3), with direct visibility between the measurement point and the transmitter (Fig. 11).

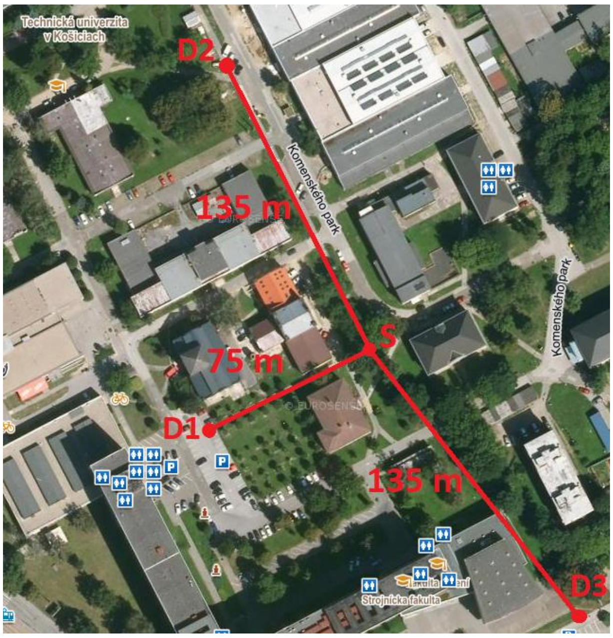

Figure 11. Outdoor measurement - map

Signal measurement was carried out in the chosen direction in 15-meter intervals. In each place, 10 measurements were taken, and a location was considered valid if more than 50% of the measurements were recorded (Fig. 12).
Then we moved in the same direction by another 15 meters and repeated the measurement process. Measurement in each direction was terminated at the point where the success rate of signal reception dropped below 50%. This measurement process was repeated over time. After evaluating all the values, we created a signal quality graph for the changing distance. This process was carried out in all three directions.

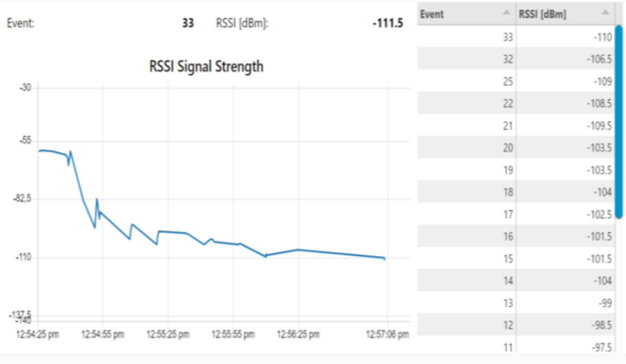

Figure 12. Example of measurement 2

Direction D1 (Fig. 13) achieved a shorter distance of reliable signal - between buildings, trees, and cars - measurements 1 and 5 (Fig. 14).

Figure 13. Photo of direction D1

Figure 14. Final values of D1

Direction D2 (Fig. 15) is the direct distance along the sidewalk without significant obstacles - measurements 2 and 4 (Fig. 16).

Figure 15. Photo of direction D2

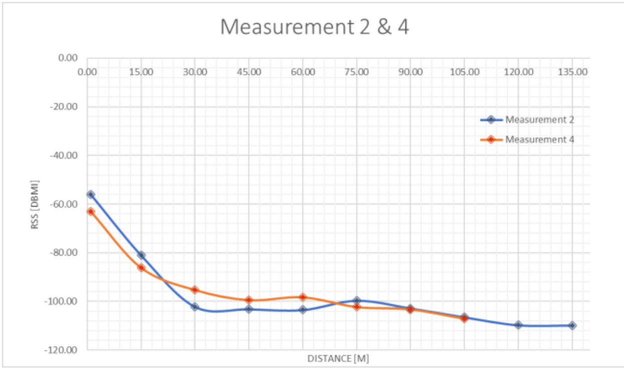

Figure 16. Final values of D2

Direction D3 (Fig. 17) leads between trees, along the building - measurements 3 and 6 (Fig. 18).

Figure 17. Photo of direction D3

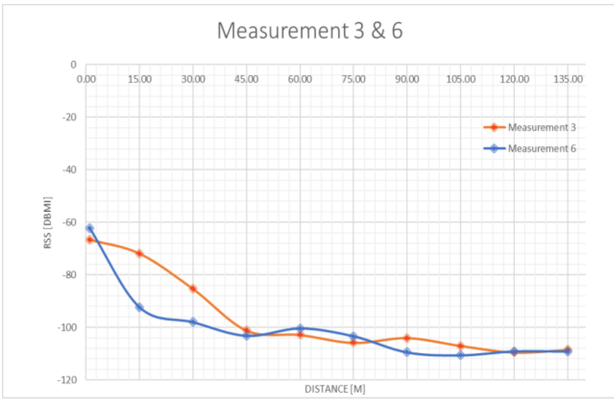

Figure 18. Final values of D3

During the measurement on the S-D1 section, we achieved the shortest distances. The main difference between these measurements is the density of buildings and lower line of sight visibility. Based on the measured results, we can conclude that trees did not have an impact on the transmission quality. Factors such as electromagnetic or atmospheric interference were not analyzed. In case of a need to achieve a higher range, we recommend replacing the antenna with a higher transmission power unit.

7 CONCLUSIONS

The results show that it is possible to cover a sufficiently large area in both variants - outdoors and indoors, which can be further increased by using an external antenna that can be connected to the radio dongle. However, this change results in a reduced battery life of the entire wireless communicating node in the network. A complementary solution could be the use of the so-called deep sleep mode.

The created measurement chain can service a total of 32 measuring stations, allowing us to create a sufficiently large and dense monitoring network both indoors and outdoors.

Subsequently, the entire system can be implemented on Raspberry Pi and with integration with InfluxDB and the Grafana graphical interface, we can achieve a solution that can operate 24/7 with local data storage. This will achieve a monitoring system that is not dependent on external service providers but still has sufficient coverage. In case of a need to cover a larger distance, it is possible to use, for example, a LoraWAN network, which is also supported by the TOWER modular system.

Our created system can also be connected to any cloud platform (e.g. Blynk), allowing us to have constant access to monitored parameters on mobile devices.

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