Documentation of Wireless Sensor Network

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Contents

1 About

This documentation is used for thoughts, theory, and calculations in regards to creating the IoT-like device. The project is to be used as a learning board for low-power digital uses and IoT technologies, as well as general programming. The design should mirror realistic engineering principles, with some components being designed fully, while relevant components are simply bought as integrated circuits.

2 Idea

The project will result in slave boards that utilize an STM32L microcontroller in low-power and shutdown-mode to conserve battery life. The battery should be a button cell type, like the CR2032 or a rechargeable variant. The microcontroller will get measurements of temperature and humidity and communicate these through a wireless IoT communication type to a master controller, which is responsible for multiple nodes. This will log the data for separate locations and continuously save these, for example to a web-based solution for graphical output. To incorporate RFID communication, the master controller could implement one as well, which would transfer data to USB or similar action when a correct key is detected.

3 Electrical Considerations

This section outlines the considerations and requirements for the electrical parts of the system.

3.1 Analog Circuits

The analog circuits must accommodate the use of a battery. As a small 4-5 V solar panel is accessible, which can be used to supply current for the circuit. For design flexibility, both a non-rechargeable and a rechargeable variant of the same battery will be usable. The rechargeable variant will be powered by the solar panel, which also supplies the circuits themselves. The battery will supply the current when the sun is not present. For this reason, a voltage regulator must be used to correct the voltage for use in the battery. As a common cell battery is 3 V, a similar voltage is expected for the rechargeable variant. To avoid undervoltage and overvoltage of the battery, a window comparator or voltage monitor must be used as well as a charging circuit. To reduce power consumption further, a low-voltage supply should be used. As a voltage regulator is needed for the solar panel's voltage output anyways, this can easily be implemented.

The master controller will not be battery-driven, but instead powered through for example micro-USB, as it will be placed in a stable environment with easy access to power sources. It will still need use of a voltage regulator, but is much more flexible.

3.2 Digital Circuits

As mentioned, a low-power variant of the STM32 microcontroller will be used to reduce strain on the battery. This will be used in shutdown-mode most of the time, and occasionally in low-power mode for gathering measurements and sending messages. In shutdown-mode, it is expected to use no more than 250 nA, while it will draw at most 1 mA when active. Additionally, a transceiver must also be used for the chosen IoT technology. Once more, this will not use more than 500 nA in shutdown-mode, but up to 15 mA when transmitting. This will be only for a short amount of time, with large intervals.

By estimating use of a 50 mAh battery with a 750 nA stop-mode 99.9% of the time, only drawing 15 mA 0.1% of the time, the battery will last 132 days without charging. This means that the microcontroller can transmit for 0.3 seconds every 5 minutes. This seems reasonable for real-life use, as temperatures and humidity changes very slowly. A more expensive battery will contain a charge of up to 250 mAh, greatly prolonging the lifetime of the slave boards.

The master controller will not be using a battery, and thus its RFID and IoT transceivers can realistically use any amount of power. The microcontroller used in the master controller can be any STM-type, so long as it is powerful enough to collect and distribute data both via antennas and ethernet. Additionally, a flash storage connected to the microcontroller with QSPI would also be great for storing the collected data.

3.3 RF Technology

As mentioned, RFID will be used for the master controller. This requires an antenna of a sort, which can simply be routing on the PCB, for example by purchasing an RFID-RC522 PCB and connecting it to the master controller board. Alternatively, another option is designing an antenna manually, which requires precision, but is cheaper and requires less space. As the project should mirror actual in-company engineering, the latter option is the best.

For communication between master and slave boards, the 2.4 GHz ZigBee protocol will be used, which is a well-defined IEEE 802.15.4-based specification. The range is relatively short, but due to the limited distances within the apartment to be used, this should not matter. There are many alternatives in IoT communication, some of the biggest being Z-Wave, LoRa, and SigFox. ZigBee has been chosen solely because it has a cooler logo, as the downsides as opposed to other technologies will not impact this project.

3.4 Summary

The considerations made through this section is summarized by creating block diagrams for both the Master and Slave boards. The Master board block diagram can be seen in Figure 1, while the Slave block diagram can be seen in Figure 2.

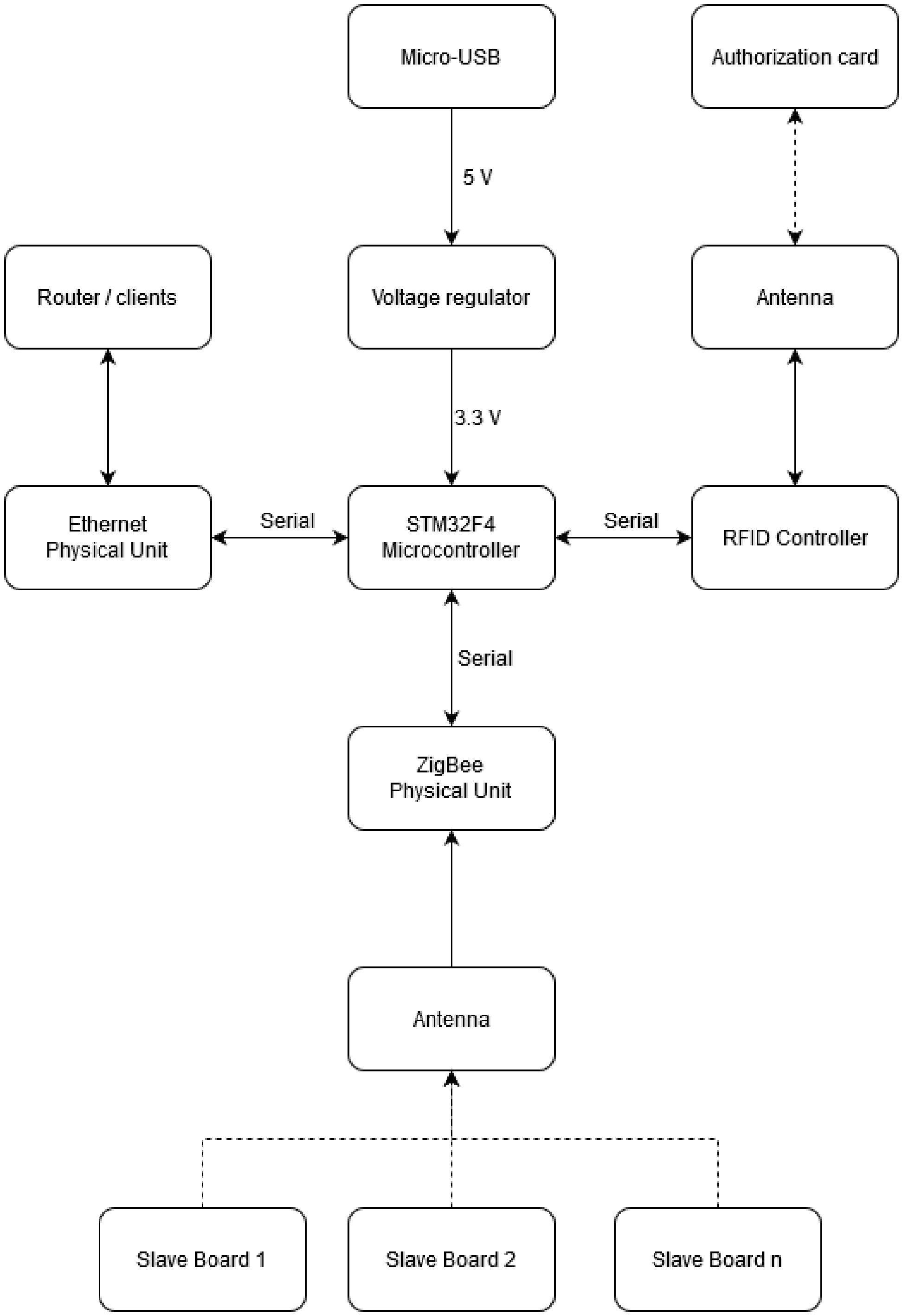

Figure 1: Block diagram of IoT Project Master Board

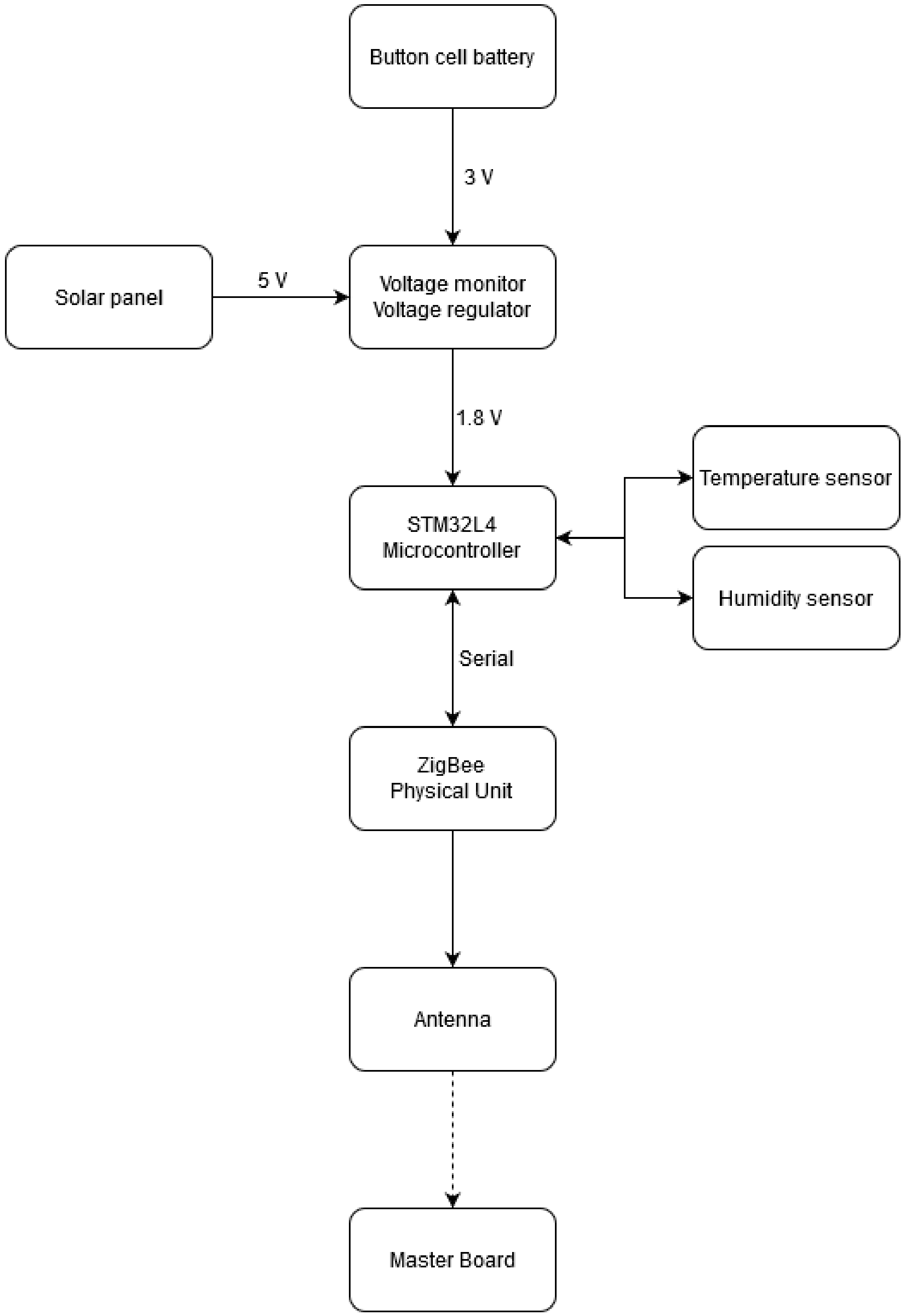

Figure 2: Block diagram of IoT Project Slave Boards

4 Mechanical Requirements

This section similarly outlines the requirements for the mechanical parts of the system.

5 Hardware Choices

Using the electrical considerations, hardware can be chosen and electric circuits designed for both the slaves and master.

5.1 Slave Boards

The Slave Boards are designed initially, as they have the most limitations. The design choices made are clarified in the coming sections.

Microcontroller

A development board with the low-power microcontroller STM32L412RBT6P is available, for which reason the MCU is chosen for the slave board. The additional benefit of using an L4 microcontroller is the higher performance at lower power, at a higher cost. The P-suffix indicates that the microcontroller can be used with an external SMPS, as opposed to internal LDO, for increased power efficiency in run-mode. This function may be left unused if it is deemed to be too pricey. Flash memory accessed by QSPI should be placed on the board for future-proofing.

IoT Transceiver

The transceiver chosen for ZigBee is the AT86RF232-ZX from Microchip, which is cheap and allows use of an external antenna, which exists within KiCad. Communication with the microcontroller is through SPI, and also allows for GPIO pins to indicate interrupts and reset. The transceiver is clocked by the ECS-160-16-33B-CKM-TR 16 MHz crystal oscillator.

Battery

The battery chosen for the slave board is the LIR2450 with a capacity of 120 mAh and nominal voltage of 3.6 V. This battery can be recharged with 4.2 V. If the rechargeable battery is deemed unneeded, a CR2450 can be used instead. This would have a nominal voltage of 3 V, but a capacity of up to 500 mAh.

The battery will be placed in the SMTU2450-LF from Renata, a holder designed for batteries of size 2450.

The output voltage is regulated to 1.8 V with the MYRGP180100B21RA from Murata, as it has high efficiency and small size. The 1.8 V are supplied instead of battery voltage as it reduces power consumption of the microcontroller and used ICs. A 1.0 V variant of the MYRGP is used for supplying the core voltage and disabling the internal LDO of the microcontroller, if found to be efficient.

Due to current consumption, the battery voltage cannot be measured by the microcontroller. If this is found to be needed, the DC-converter RP605Z183B-E2-F from Ricoh Electronics has high efficiency for supplying 1.8 V, and also divides the battery voltage with low current consumption so that it can be measured by the microcontroller. For the time being, a high-resistance voltage divider is implemented to measure the voltage. The target current consumption is around 1 μA, which doubles the idle consumption. If this impacts battery life too much, the resistors should be desoldered.

A connection is made for a solar panel to supply the MCP73831T-2ACI/OT battery charging IC. This IC automatically regulates the voltage to supply a Lithium-Ion battery with 4.2 V, and is designed to automatically end the charging when the current falls below a threshold, as determined by the battery datasheet. Aside from the solar panel, a USB connector is also connected to the IC, allowing a USB cable to charge the battery as well. The USB data is connected to the microcontroller for future-proofing.

Sensors

Both a temperature and humidity sensor is needed for the slave board. While temperature sensors exist in many varieties, humidity sensors generally only exist as ICs that must be communicated with to retrieve data. The two-in-one solution SHTC3 from Sensirion contains both a temperature and humidity sensor with accuracies of $\pm 0.2°$ C and $\pm 2\%$ respectively. The IC can be supplied by as little as 1.62 V, communicates with I2C, and has an accuracy up to 16 bits. All this in a DFN-4 SMD package. The IC is low-power and has sleep-mode capabilities.

The battery voltage may also need to be measured. This is easily implemented by a resistor divider and measuring with the microcontroller ADC, however this increases power consumption.

5.2 Master Board

With the Slave Board design in place, the Master Board can now be designed to interface with these. There are fewer limitations, as size and power consumption is not crucial.

Microcontroller

An earlier project used the STM32F469II high-performance microcontroller, which has the connections needed for ethernet, QSPI, and multiple RF PHYs. For this reason, it will be used on the master board. In the event that the microcontroller is not available, the STM32MP151 microprocessor series is cheaper and faster, while still allowing all the needed connections. This would allow it run Embedded Linux for webpage hosting, although it would make the PCB much more complex due to the large amount of RAM needed for this. Another drawback is the BGA package, which is more difficult to use for designs and to place for soldering.
The 32 Mbit QSPI NOR flash memory W25Q32JVSS is chosen for storing data.

IoT Transceivers

The Master Controller will use the same Zigbee transceiver.
For NFC communication, the CLRC66303HNY from NXP Semiconductor will be used as front-end for transceiving. It will be clocked by an ECS 27.12 MHz Crystal Oscillator chosen according to datasheet specifications.
The RFID/NFC antenna can be designed with the NXP NFC Antenna Design Tool.

Ethernet

The Ethernet on the Master Board will be using the MII protocol between the microcontroller and Ethernet PHY. The PHY chosen is the KSZ8081MNX. This allows transfer rates up to 100 Mbit/s. The IC's supply is well-filtered, and pull-up and pull-down resistors are added for correct configuration.
The differential output signals for Tx and Rx are routed to an RJ45 with integrated magnetics and LEDs.

Power Supply

The Master Board will be supplied through a micro-USB connection to a charger, PC, or other module. This 5 V supply must be filtered. As none of the modules can use the 5 V supply directly, it must be converted. It is estimated that no more than 500 mA at 3.3 V will be used under any circumstances. For converting from 5 V to 3.3 V, the Murata MYRGP330100B21RA high-efficiency converter, with an output current up to 1 A, is chosen.