

High Level Design

Solar-Powered Wi-Fi Extender

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1 Introduction

Our proposed project is a solar powered Wi-Fi range extender. This device would not require AC power for operation, and would not be powered from the user's laptop or phone, draining their device battery. To demonstrate the effectiveness of the extender, we will isolate a mobile device, such as a smartphone or laptop, from connecting to other routers and connect it to our device. The device is intended to be low cost and easily replicable. Some potential applications include amplifying signals outside of buildings, such as boosting a Wi-Fi signal from campus buildings to include the quads as well. By extending Wi-Fi accessibility, the device would open up additional spaces for potential use at work or school.

2 Problem Statement and Proposed Solution

We address limited Wi-Fi coverage in outdoor college campus spaces. With the ongoing global pandemic, there has been an increased need for strong internet connection in outdoor spaces for various tasks such as Zoom for class sessions and other meetings. In addition to ease of use and access to Zoom in outdoor spaces, our device will also encourage students and faculty to spend more time outside.

Our device will be presented as a 802.11n Wi-Fi AP with WPA2 security to protect users' privacy and limit access to the network. The device will operate on the 2.4 GHz Wi-Fi range, which features longer range at the cost of raw throughput. Upon connecting, the user will be able to access a web interface to connect the device to an existing wireless network or change the default password and SSID. To cover a larger area, the devices can be chained together (albeit with a latency penalty).

The device will contain a power system consisting of solar cells, batteries, power regulators, and a charge controller. When external conditions do not allow the solar cells to output enough to power the device, the batteries will allow the device to continue to run, as well as provide a steady source of power. From preliminary research, a generic 10 W solar panel occupies a footprint of approximately 35 cm by 20 cm, so our device will likely share this footprint. The charge controller will balance solar charging across all the

battery cells, ensuring even wear. In the event the user wishes to charge the device in the absence of sunlight, the device will also feature a micro USB-B connection for DC charging.

At the heart of the device will be a microcontroller—the ESP32-WROVER-IE—both servicing web requests and providing routing for Wi-Fi signals. The ESP32-S2 comes with extensive Wi-Fi functionality onboard, and the connectivity will be enhanced with an external antenna. The device could also feature a Wi-Fi scan that sets the channel to the least-used channel in the environment to reduce signal interference.

To package the device, we will create an enclosure that may be 3-D printed for prototyping. Since the device is intended for outdoor use, the enclosure must feature water and dust resistance. We are targeting the IP65 standard rather than stricter standards since the device is not likely to be used in heavy rain.

3 System Requirements

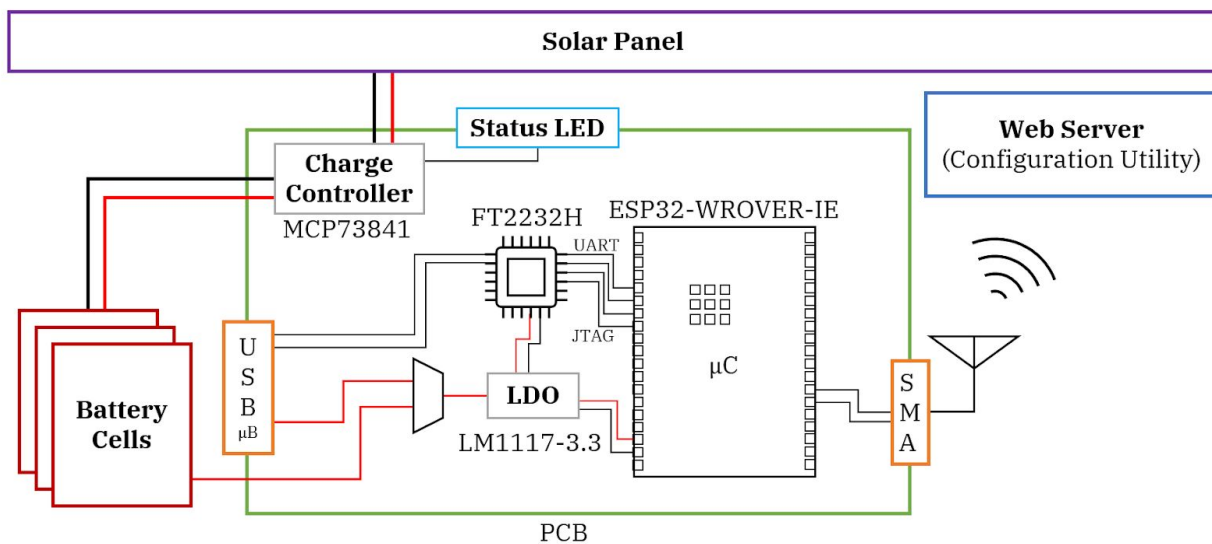
- Our system will need an embedded microcontroller capable of running a network stack and a web server for web-based configuration. We have selected the ESP32-WROVER-IE.
- Consistent with our problem description, the device will need to be operated outside and in remote areas of buildings, presumably far from wall power sources. It will consequently be powered by batteries charged using DC or solar power. The solar option will allow the device to be charged when away from wall power and will also extend the time the device is able to be used between DC charges.
- The extended will act as a typical wireless access point, aside from extending an existing network (i.e., it will use another wireless access point instead of a wired connection to the WAN). This means that it should support an arbitrary number of concurrent connections, with connection quality decreasing as the number of connections increases.
- Configuration of the device will occur through a web interface hosted on the extender. This will be a very simple interface we will write ourselves- the device SSID and password will be set through this interface, and the device will be connected to the target (extended) network.
- The physical dimensions of the device will be limited by the solar panel array, which has dimensions of 13.25" x 8". The device will be portable, approximately the size of a larger laptop, and will also be IP65 dust and water resistant, since the intended use case is to "set and forget" the device in an area to improve Wi-Fi

connectivity. The device will thus need to be weatherproof for, e.g., light rain as well as dust and debris.

- Battery life: After researching potential batteries, and with some conservative estimates of device power usage, we should be able to target continuous operation of the device without a DC power source (i.e., using the solar supply and battery power). The device should thus be able to be "set and forget" in a location to semi-permanently enhance the local Wi-Fi network.

4 System Block Diagram

4.1 Overall System



The overall system is shown above. The solar panel will be used to charge the battery and power the system. The battery cells will hold this additional charge and allow the system to operate if it is not plugged in or there is not sufficient sun. The charge controller will monitor the charge on the battery cells and limit the charge rate depending on the battery levels. The status LED will communicate with the charge controller and display what the current battery level is at. The micro USB will allow the system to be powered from an AC adapter if the battery runs out. The LDO will regulate the voltage going to the FT2232H USB module and the microcontroller. The USB module will allow the microcontroller to interface with the USB using UART and JTAG communications. The microcontroller will be connected to an RF antenna with an SMA connector, and a matching network

implemented using a microstrip line. Finally, a web server will be hosted by the system to allow the user to connect to the network.

4.2 Subsystem and Interface Requirements

4.2.1 Board

The board will provide circuitry for interfacing the different hardware components of the project with each other, and most importantly, with the microcontroller - design considerations will be similar to the Kit Board designed in class. The FT2232H chip allows UART (for programming the board) and JTAG (for testing and debugging) to be connected to the microUSB-B port on the device. This allows the ESP32 to show up as a virtual COM port on a PC and be programmed in a manner similar to Arduino microcontrollers. Power and ground will be delivered from the battery or USB connection through the LM1117 LDO. The trace for the antenna will have additional RF design considerations, such as impedance matching- our group will use prior RF design experience to implement this.

4.2.2 Enclosure

Our enclosure will be low-maintenance and designed for ease of use. The prototype of our enclosure will be designed in CAD and 3-D printed. It will be IP65 dust and water resistant to allow for outdoor use. Our enclosure design will include shielding for EMI from RF sources and additional access points.

4.2.3 Software

In software considerations, we need a TCP/IP stack with routing capabilities. A web server will be run off the microcontroller, which will host the configuration site.

The configuration site will be relatively simple and will be designed using web programming APIs provided with the ESP32 microcontroller. In particular, serving the configuration server will be trivial with the provided libraries, as will changing configuration based on user requests. Thus, our main design task in this subsystem will be the HTML/CSS for the actual interface, as well as the choice of how configurable to make the device (balancing ease-of-use considerations with configurability considerations).

4.2.4 Power System

Our power system will allow the user to use either solar or DC input. The device will be powered with either a solar or DC input by a standard USB AC power adapter that will charge batteries contained in the enclosure. Since the charging current for the battery is low, any USB AC adapter capable of delivering more than 100 mA will suffice. Power regulation circuitry will be needed on the board to output a clean and stable DC level to the microcontroller. This will prevent any unstable battery voltage levels vulnerable to unexpected voltage fluctuations.

4.2.5 Battery Level

The charge controller supports a charge status output, directly driving an LED for charge and battery status. This output can also be used with a pull-up resistor to communicate with the ESP32 microcontroller. The LED will be solid lit when the device is charging from solar or USB power, turned off when the device is discharging, and blinking when the battery level is low.

4.3 Future Enhancement Requirements

Future enhancements to the design may include:

- Extending support to the 802.11ac standard
- Extending support to the 5 GHz Wi-Fi band with corresponding configuration options in the web interface
- An ergonomic enclosure design better suited for mass production

5 High Level Design Decisions

The requirement for our device board will include a FT2232H μ C USB Module and an ESP32-WROVER-IE microcontroller, both interfacing with each other using UART and JTAG. We will design the web interface ourselves, which will run on the ESP32 directly, using provided web server and networking libraries. The web server will configure the ESP32 networking stack using provided ESP32 networking API calls. The device enclosure will be designed and 3D printed on campus with IP65 dust and water resistance. The power system will use individual solar cells or a DC input with a LP705176JS battery. All other components including the charge controller, solar panel, and antenna will use standard connectors, and do not require specific communication protocols. The antenna

will use an IPEX connector, and will need an RF matching network for optimal performance (implemented using microstrip lines of varying widths and lengths, as well as open-circuited stub lines if needed). The charge controller will protect batteries and a balanced load that also supports a charge status output, directly driving an LED for charge status.

6 Open Questions

Several areas of the project need to be addressed before the low level design can be completed. We are using a different microcontroller than was used in the Senior Design classroom assignments. The microcontroller we currently have selected, the ESP32, has Wi-Fi capability baked in. We plan on ordering a demo board for the microcontroller which will allow us to do most of our prototyping.

The key open question is the ability of the device to interact with the target network and treat the connection differently than the connection to the client devices- the target Access Point should be treated as a gateway, unlike the client connections. Furthermore, while the device should be able to maintain a connection, the ability of the user to utilize this connection for functional use of their mobile device is key, and so questions of interface design remain somewhat open.

In addition, there remains an open question with respect to the solar panel and its practicality in our device. While the solar panel should be able to charge the battery, the necessity of this feature remains open. If users plan on only using the device for a few hours before recharging at home, the additional weight and size created by the solar panel may not be necessary.

7 Major Component Costs

Our major system components include Wi-Fi compliant transceivers, an omni-directional Wi-Fi antenna, and power systems components. Our enclosure will be 3D printed on campus. The following table outlines our main components and their costs.

Description	Part name	Quantity	Approx. Cost per Item	Total Cost
10W Solar Panel	Eco-Worthy 10W Solar Panel	1	\$26	\$26
Battery	LP705176JS (3150 mAh, 3.7 V)	2	\$24	\$48
Charge Controller	MCP73841	3	\$1	\$3
Microcontroller	ESP32-WROVER-IE	3	\$3	\$9
µC USB Module	FT2232HL-REEL	3	\$7	\$21
LDO	LM1117-3.3	3	\$1	\$3
Microcontroller Demo Board	ESP32-DevKitC-VIE	2	\$11	\$22
Omni-directional Wi-Fi Antenna	W1049B120	2	\$4	\$8
PCB (cost for 3 boards)	N/A	3	\$5/inch ² for 3 boards	\$40
Enclosure Material (PLA)	N/A	N/A	Free from university lab	\$0
Wiring and Discrete Components	Misc. (inc. resistors, capacitors, switches, connectors, crystals)	N/A	N/A	\$10
Total Cost:				\$190

8 Conclusions

Due to the global pandemic, the ability to work outside and connect to strong Wi-Fi has become increasingly important with physical distancing and other covid precautions. By proposing a low-cost, easily replicable solar-powered Wi-Fi extender, our device's main use case will be to amplify Wi-Fi signals in outdoor spaces. This extension of Wi-Fi accessibility will open up additional spaces as places for work. It will provide a stable signal and extended range to students, faculty, and other individuals working online in outdoor spaces such as the quads. The subsystems involved in our core design blocks include the circuit board, low-maintenance IP65 enclosure, software, power system and battery level. Our overall engineering design goal through these main systems will be ease of use, functionality, and reliability. This will prove to be incredibly useful with its intuitive and easy web configuration, portability of the device, robustness of the enclosure, and ability to function with either batteries or solar power with extended periods of time between charges.

9 References

- Datasheets:
 - [Battery](#)
 - [Charge Controller](#)
 - [Microcontroller](#)
 - [Microcontroller USB Module](#)
 - [LDO](#)
 - [Antenna](#)
- [Solar Panel Product Page](#)
- [Getting Started with the ESP-WROVER-KIT](#)
- [ESP-WROVER-KIT Schematic](#)
- [Create A Web Server w/ ESP32](#) [Tutorial]
- [Project Github Repository](#)
- [ESP32-eduroam Repository](#)