Senior Design Proposal
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 device 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.

2. Problem Description

The problem we are addressing is the limited Wi-Fi coverage in outdoor spaces. In environments like college campuses, Wi-Fi strength outside of university buildings, such as on the quads, can be insufficient for student and faculty use. Given the current global pandemic, there has been increased usage of outdoor spaces for tasks requiring a strong internet connection; for instance, the increased reliance on Zoom for meetings and class lectures. Outside of a pandemic context, the ability to conduct tasks outdoors that used to be restricted to indoor spaces could allow students and faculty more opportunities to spend time outside.

3. Proposed Solution

At a high level, this device will present itself to users as a 802.11ac Wi-Fi AP with WPA2 security to protect users' privacy and limit access to the network. The device will, by default, operate on the 2.4 GHz Wi-Fi range, which features longer range at the cost of raw throughput. Upon connecting, the user can 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 providing a steady source of power. From preliminary research, a generic 10W 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 barrel plug for DC charging input.

At the heart of the device will be a microcontroller, such as the ESP32-S2, servicing both web requests and providing routing for Wi-Fi signals. The ESP32-S2 comes with extensive Wi-Fi functionality onboard, which 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 rain.

4. Demonstrated Features

The final demonstration will exhibit several key features that will solve the identified problem:

- The ability to provide a Wi-Fi signal at longer range than would be available without the repeater while remaining the same level of stability (i.e. no loss of signal)
- The ability to function at the required level without AC power
    - Onboard battery level indicator with 4 hours battery life without solar power.
- Portability that allows the device to be brought out using a small bag (backpack, briefcase)
- Intuitive/easy web configuration for the non-technically savvy end user

5. Available Technologies

Wi-Fi compliant transceivers are relatively cheap and widely available. We will need to choose among the available hardware considering power usage (perhaps our most important consideration) and cost. Since there are other design considerations which may provide significant difficulties (power considerations with the solar panels, design of the configuration system and integration of components), we should use as many off-the-shelf components as possible, especially in an area as standardized and scaled as Wi-Fi interfaces.

We will also need an omni-directional Wi-Fi antenna, which we can also buy off-the-shelf. Considerations of directionality (we cannot predict the exact orientation an end user will choose for the device) and the Wi-Fi standard (bandwidth, etc.) should sufficiently determine our options here.

Being a wireless access point, the device will need to perform at least basic routing, as well as run a web server to host the configuration portal. We will use a microcontroller, such as the ESP32-S2 which features onboard Wi-Fi modules, to perform these tasks and coordinate the other hardware on the device.

For the power systems, individual solar cells and battery cells are ideal for achieving the appropriate voltage and current characteristics. Although pre-packaged, off-the-shelf solutions exist for both solar arrays and batteries, purchasing individual cells and wiring them together will allow us to create a power system that is specifically designed for our use-case. To protect the batteries and balance load, we will employ a pre-existing charge controller, which contains complex circuitry and many protections we would be unable to replicate with discrete components. Finally, the PCB will feature voltage regulation to provide the microcontroller and other circuit components with a clean, steady DC operating voltage.

A summary of the core components and their (conservatively) estimated prices is given below :

10W Solar panel: ~$30
ESP32-S2: ~$8
Antennae: ~$10
Charge controllers: ~$20
PCB: ~$50
Enclosure: ~$15
Miscellaneous wiring and discrete components: ~$15
Total: ~$150

6. Engineering Content

Our project will consist of several core design blocks: the circuit board, the enclosure, the software, the power system, and the battery level. The function of each block and some of the design challenges therein are defined below:

- Board: provides 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 (I/O pins, microcontroller communication protocols, power regulation and control, etc.)
- Enclosure: This device is intended to be "set and forget"- it should be as low-maintenance as is feasible. The enclosure will aim for IP65 dust and water resistance, which will allow for outdoor use in calm conditions. Rapid prototyping of the enclosure will likely involve CAD and 3-D printing. Considerations from the size and design of the board itself will figure heavily into the enclosure design, as will our choices of solar cells and Wi-Fi antennas. Additional considerations for the enclosure will include EMI from other access

points and RF sources- since we will have Wi-Fi hardware operating on the board, we may want to design the enclosure to incorporate shielding which will improve the performance of our extender.

- Software: We will need a basic TCP/IP stack and routing capabilities (many options already exist for these capabilities which may need to be modified for our exact design considerations). Additionally, for configuration, we will need to run a web server off the microcontroller which will host the configuration site. Again, free and open source options exist for this application which may need to be adapted to our architecture and use cases.
- Power system: To power the device, the user may either use solar or DC input (through an AC power adapter), both of which charge the batteries contained in the enclosure. Batteries allow the device to run in a variety of conditions and without an AC outlet, but must be carefully charged and discharged through a dedicated charge controller, which accepts both the solar output voltage and the DC input voltage. Since the battery voltage level is unstable and susceptible to sudden voltage fluctuations, the board will contain power regulation circuitry to provide a clean and stable DC level to the microcontroller and other circuitry.
- Battery level: To display the battery level, the microcontroller will receive information on the battery charge level from the charge controller via SPI or I2C (different charge controllers use different communication protocols). In the case where the charge controller does not have communication options, external circuitry will allow the microcontroller to measure the battery voltage on one of its analog input and ADC. The decoded battery level will then be shown to the user via LEDs on the enclosure.

Across all these systems, we will have several overarching engineering design goals. One of these goals will be ease of use- this consideration is most heavily seen in the software for the web interface and the battery monitoring system, but also extends to the enclosure (placing the device so that it can be powered and project a strong signal). Additionally, power and cost considerations cut across all blocks of our design- to be most useful, this device should be relatively inexpensive and therefore scalable, as well as relatively low-power, and therefore reliable when in use for extended periods of time (given sufficient lighting).

7. Conclusion(s)

This proposal provides a preliminary outline for our project. The solar-powered Wi-Fi extender prototype will be low cost, have an easy configuration and use, and be easily replicable. Our main use case will allow for amplification of Wi-Fi signals in outdoor spaces. The team believes that a prototype repeater is a feasible project to construct in the second semester. We expect that changes will be made as we go through the design process and that we will likely encounter challenges that we cannot foresee at this time. Key areas of concern are the ability to run solely on solar power, the strength of the Wi-Fi connection, ease of configuration and use, total cost of the device, and the ability of the device to maintain a stable and strong enough connection as to be useful.