Wireless IntraNetwork

ECE 445 Design Document

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1 Introduction

1.1 Objective

The internet is such an important part of modern life that the UN has defined it as a basic human right. Unfortunately, 60% of the human race (over four billion people) still lack any kind of connection to this invaluable service. There is a giant gap in internet availability between the developed and developing world today. In regions such as Sub-Saharan Africa, less than 0.5% of people [1] have a fixed internet broadband subscription. This leads to social, educational, and economic isolation. LTE and HSPA coverage, the two leading standards of mobile connectivity, have a combined coverage of just 25% of the region [2]. In comparison, in the US a phone will spend over 85% of its time covered by an LTE signal [3] and 70% of adults have an active broadband subscription [4]. A contributing factor to this massive difference in connectivity may be that sub-Saharan Africa is significantly less urbanized than the US - 64.2% of residents in the United States live in an urban environment versus 10.6% in Zimbabwe and 2.8% in Uganda [5]. Studies show that a 10% increase in internet access in a developing country brings a 1.7% increase in exports and 1.1% increase in imports [6]. Without reliable access to the wealth of educational, medical, and economic resources provided by the internet, WiFi enabled devices donated to villages in the developing world by organizations such as OLPC (One Laptop Per Child) will never achieve their full potential.

Our goal is to bring the internet to the developing world using an entirely new form of infrastructure. Instead of installing miles of fiber optic cables, our 'infrastructure' is almost entirely wireless. We will use a large number of solar-powered nodes to build a mesh network capable of transmitting data throughout a community, creating an intranet. These nodes will use WiFi so any device (whether it's been donated or purchased by a villager) can connect to the intranet and will adapt to the failures of other nodes using a reactive routing protocol.

1.2 Background

Efforts by Facebook, SpaceX, and Google attempt to solve the internet problem through low-flying satellites or drones, which suffer the same throughput bottlenecks as traditional satellite communication [7]. A mesh network that is easily-installed and expanded, while existing independently of expensive global connections, is the solution to connect remote areas of the world. Other attempts have been made to connect the world with remote, portable mesh networking [8]. Unfortunately, these have failed in the long term due to costs of over $200/node.

Our nodes must be as affordable as possible, to ensure that they can reasonably be purchased with the disposable income a rural villager might earn. A subsistence farmer in Nepal, for example, has a disposable income of about $5 per year [9]. We also plan to partner with NGOs to provide a subsidized distribution program so the node is cheaper (or even free) for the customer.

1.3 High-Level Requirements

- Nodes must be able to connect to each other automatically, allowing data stored on any node in the network to be available from any access point.
- Nodes must be able to operate indefinitely on solar power.
- Nodes must be as low-cost as possible, ideally under $20.

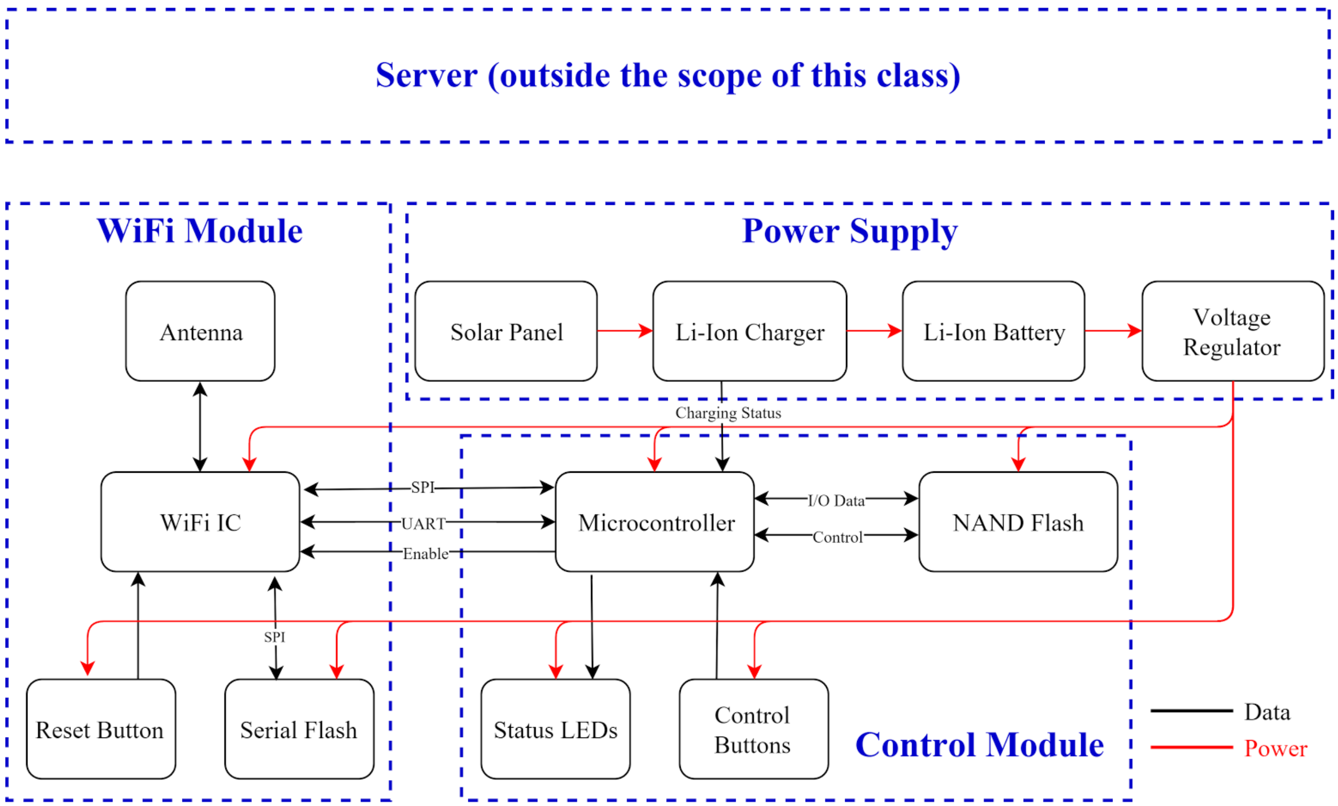

Fig. 1. Block Diagram

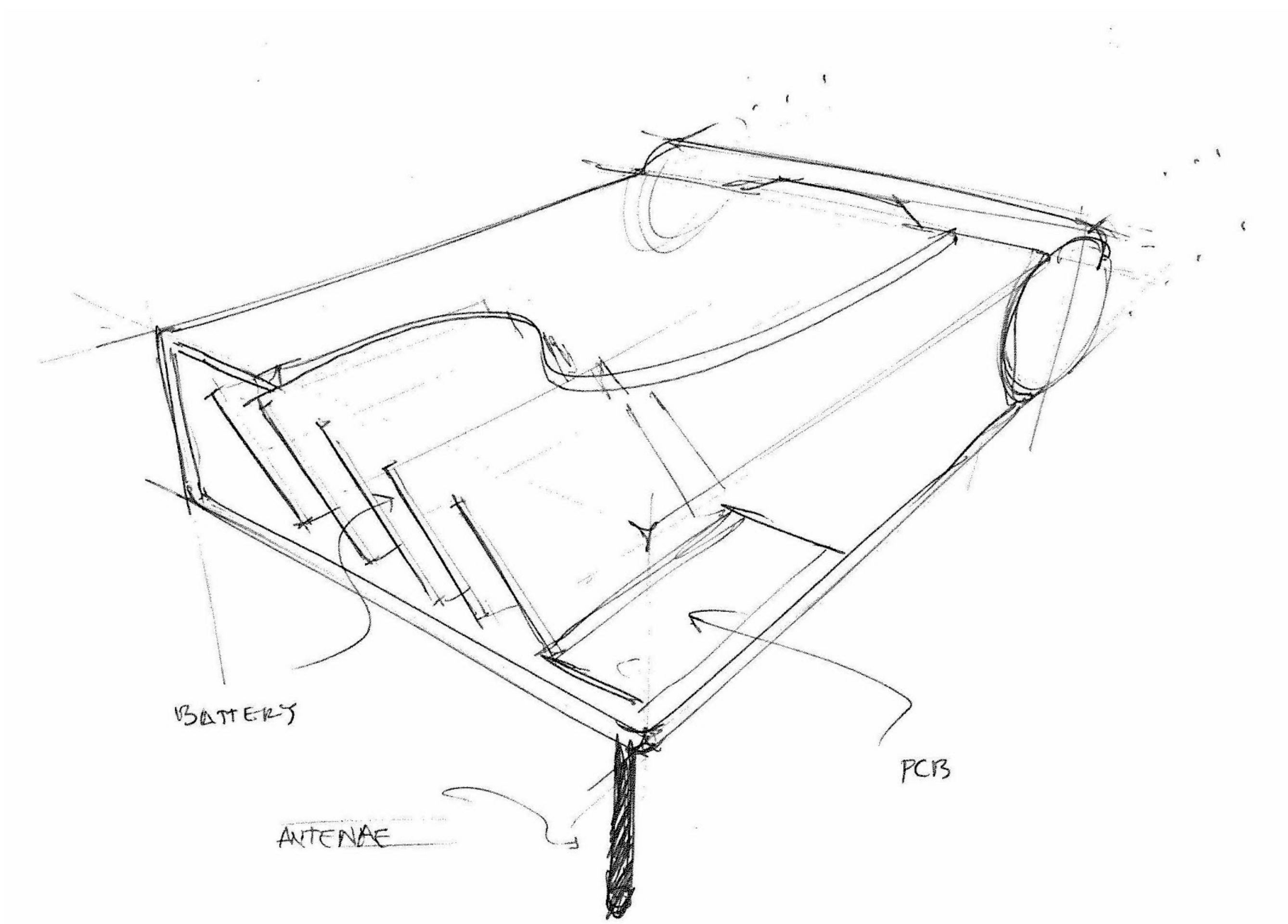

Fig. 2. Physical design sketch

2.1.1 Solar Panel

Requirement	Verification
Outputs 300mA-1A between 4.40V-7.50V in no more than full sunlight (110,000 lux [10])	A. Place a solar panel in 110,000 lux. Confirm that the sunlight has no more than this intensity using a 1% tolerance photoresistor B. Measure the open-circuit voltage with a voltmeter, ensuring that it is below 7.50V C. Terminate the solar panel with a resistive load such that the voltage drop is 4.40V D. Ensure that the current through the load is above 300mA using an ammeter in series

2.1.2 Li-ion charger

Requirements	Verification
1. Li-ion battery charges to 4.16-4.23V when a continuous 4.4-7.0V input voltage is applied 2. Charging at maximum current and voltage can be sustained below 125°C	1. A. Discharge a li-ion battery to 3.7V cell voltage. B. Charge the battery at the output of the AAT3693 from an input of 7V, without limiting current. C. At the termination of the charge cycle, signified when the “charge status” pin of the AAT3693 goes high, we will ensure that the battery is charged between 4.16-4.23V 2. A. Throughout the charging cycle outlined in verification 1.B-C, observe the temperature. Use an IR thermometer to ensure that the IC does not reach temperatures greater than 125°C.

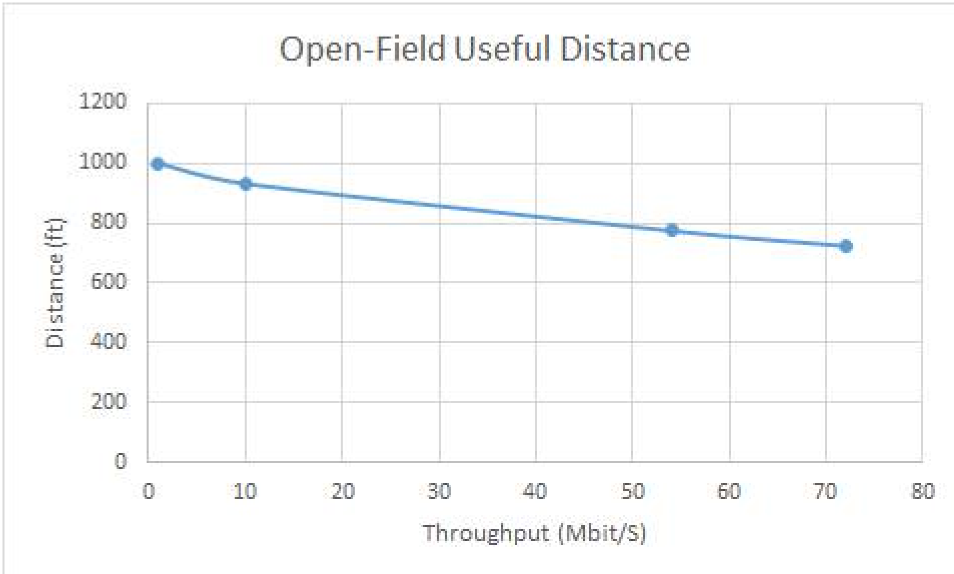

Fig. 4. Experimental Throughput vs. Open-Field Separation [12]

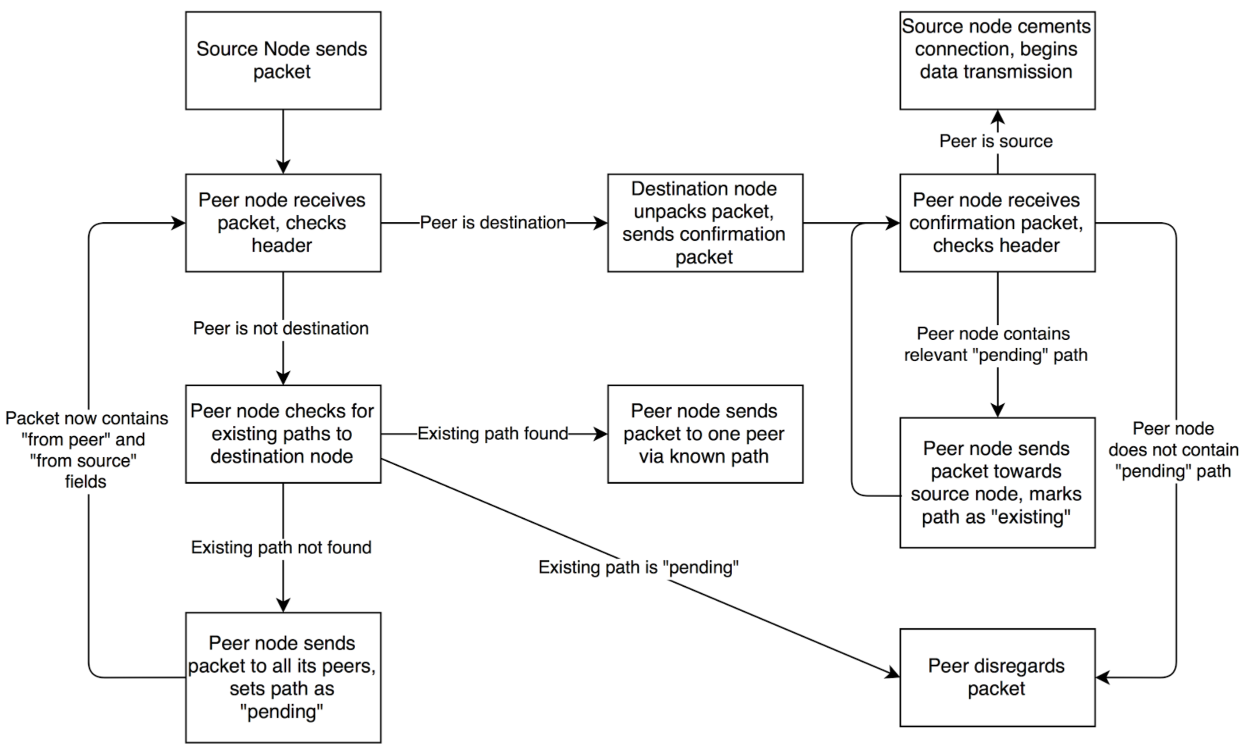

Fig.10. Routing Algorithm

2.9 Tolerance Analysis

One important tolerance we must maintain is the antenna match to the WiFi IC. The target impedance is the characteristic impedance, 50Ω, within the IEEE 802.11 frequency band, 2402-2484MHz, to optimize the RF output power. The reflection coefficient, Γ, is the fraction of the signal amplitude that is reflected back to the source (in this case, the WiFi IC), and can be calculated as:

$$\Gamma = \frac{Z_L - Z_0}{Z_L + Z_0} = \frac{Z_L - 50\Omega}{Z_L + 50\Omega} \qquad \text{Eq. 1}$$

Ideally, the reflection coefficient should be minimized with the network impedance approaching 50Ω, meaning that a minimal amount of power is dissipated as noise. Based on the above equation, the reflection coefficient is zero if Z_L=Z_0, which is 50Ω in this case. Using Eq. 1, we can calculate the transmitted power ratio below in terms of the mismatch ratio. The transmission coefficient τ represents the ratio of voltage that is transmitted to the antenna with respect to the applied voltage. The value of tau τ can be solved for through the conservation of power, which is proportional to the square of voltage.

$$\tau^2 = 1 - \Gamma^2 = 1 - \left(\frac{Z_L - 50\Omega}{Z_L + 50\Omega}\right)^2 \qquad \text{Eq. 2}$$

$$Power\ loss\ (dB) = 10log_{10}\left(1 - \left(\frac{Z_L - 50\Omega}{Z_L + 50\Omega}\right)^2\right) \qquad \text{Eq. 3}$$

As our goal is to keep the transmission through the antenna at a maximum, we hope not to reach this point. We will test the impedance match with a small coaxial cable (“pigtail”) soldered to the LNA (RF I/O) ESP8266 trace as close to the chip as possible. This pigtail will be connected to a network analyzer, which will display the distance-corrected complex impedance on a Smith chart. This data will allow us to modify the inductors and capacitors that make up the 2-stage RF match. The match will likely be of a high-pass topology, meaning a capacitor in series and an inductor in parallel with the load. There is a larger selection of capacitors around j10-50Ω, at 2.4GHz (1.3-6.6pF), which are most useful for matching at 50Ω, than inductors around j10-50Ω at 2.4GHz (0.6-3.3nH). This leads us to match with a higher-impedance inductor in parallel and a lower-impedance capacitor in series.

Our impedance requirement to meet power transmission specifications is 50Ω +/-2.5Ω (+/-5%). The worst-case scenario is if the antenna’s unmatched impedance approaches zero or infinity, which can be proven by the limits of Fig. 2. At zero (short), the circuit is essentially the capacitor as a load. Thus, the tolerance on the capacitor in this case must be 5%, though this is an unreasonable case as the real impedance can never equal 50Ω with only a capacitor. If the load is open (infinite impedance), the circuit consists of the matching capacitor in series with the matching inductor. Here, the total error must stay below 5%. The error magnitude on either component can add together with respect to the total impedance, and must stay below 2.5Ω total. Therefore, regardless of nominal values, the total error will stay within a 5% tolerance if both components are within +/-1.25Ω impedance of the nominal value. This 1.25Ω tolerance can yield more useful percentages using the below equations for capacitor and inductor impedance once nominal values are found.

$$Z_L = j\omega L \qquad \text{Eq. 4a}$$

$$Z_C = \frac{-1}{j\omega C} \qquad \text{Eq. 4b}$$

5 Ethics and Safety

There are several potential safety hazards with our project. Lithium-ion batteries can explode if overcharged or brought to extreme temperatures [13]. A li-ion cell can experience thermal runaway, where a positive feedback loop between cell temperature and discharge rate can lead to battery failure and potential explosion. To close this feedback loop, we will closely monitor cell temperature with a thermistor and isolate the battery from both the charging circuitry and the node hardware if it reaches a temperature of above 45C or below 0C. Additionally, over-charging the battery can lead to a breakdown of the cathode, a highly exothermic process. Before attaching a battery, we will thoroughly verify our charging circuitry as per section 2.1.2 and the ECE445 battery safety document in [14] to ensure that the battery will not be charged over 4.21v under any circumstance.

As an outdoor electrical device, moisture could cause damage to the nodes leading to short-circuits. The case will need to adhere to strict IP66 guidelines, which keeps the internals dry from water jets in any direction.

Working in in an electronics lab carries its own challenges. We will be assembling the boards with soldering irons and hot air, as well as powering our boards with lab power supplies. We have attended lab safety training to learn how to use this equipment safely to avoid risk of burns, electrical shorts, and electric shock.

We are responsible for the information that is sent through our technology. This spread of valuable knowledge is an implementation of the IEEE Code of Ethics, #5: “To improve the understanding of technology; its appropriate application, and potential consequences” [15]. We hope to bring education and communication to the most remote corners of the world.

Unfortunately, risks surrounding the spread of information include piracy and mental health. Every day, people pirate music, movies, and even books via the conventional internet - and there is no reason to believe that our network will be any different. We are not explicitly giving out the tools to commit piracy or copyright infringement of any kind, but in a decentralized network it is impossible to track with any degree of certainty what information is shared. This would go against #7 and #9 of the IEEE Code of Ethics - the people committing piracy are not properly crediting the work of others, and they could be injuring the copyright holders by sharing content without paying for it [15]. We do not currently have a solution to this - we do not believe it would be the right course of action to limit the utility of our network simply because we anticipate a small subset of our users engaging in piracy.

On the internet, where a certain degree of anonymity is assured, there are fewer barriers to behaviors like cyberbullying. This type of harassment will adversely affect the mental health of those on the receiving end. It is entirely possible that the network will be used to discriminate by race, gender, or sexual orientation, violating #8 of the IEEE Code of Ethics, “to treat fairly all persons and to not engage in acts of discrimination based on race, religion, gender, disability, age, national origin, sexual orientation, gender identity, or gender expression” [15]. We plan to introduce the ability for node owners to “ban” certain devices from services hosted on their node. The “banned” user would have no knowledge of this action; their packets would simply not return a response as the node hosting the service would throw them away instead of processing them. We believe this is the best course of action - any harassment can be stopped by an automated system, and the harasser(s) will never know that their messages aren’t being delivered.

Our mitigation techniques align with the IEEE Code of Ethics, #1: “To accept responsibility...” [15]. There are many risks that present themselves as a consequence to access and free communication, but we believe that the advantages of open resources, which include free education and the potential for economic development, far outweigh the potential negative effects.

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