Mesh Network Headphones

Team 12 - Abigail Starr, Aditya Bawankule, Alex Ortwig, David Hickox
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TA: Dhruv Mathur

1 Introduction

1.1 Objective

When using an audio system, it is very difficult to come up with an organized and presentable solution that offers a quality listening experience. Such a system is even more challenging when there is a desire to make it portable and shareable with friends and family. Bluetooth has made its mark on recent technology as the dominant close-range wireless communication protocol in the electronics industry. It offers a unique solution to a portable, modular, and shareable audio system that lets consumers take their music where they want to and share it with who they want to, all without the clutter of cables and other hardware restrictions.

The proposed solution allows for multiple headsets to form a mesh network, in order for all of their audio to be completely synced. Only one of the headsets will be connected over Bluetooth, while the rest of them will connect over a proprietary connection, in order to reduce interference with Bluetooth and increase the ease of use.

1.2 Background

One solution would be to simply play the audio out loud, but that isn't always an option. Additionally, many people will share earbuds, but that can be unsanitary, and can actually cause more health problems [1]. This cannot be done with headsets either, because it is not possible for them to come apart, and sometimes it is preferable to use headsets.

The original group that had this project is Team 6 from this semester. The original proposed solution is a Bluetooth audio splitter, like an aux splitter, so any device can connect to the system. This would have the same audio in each of these devices, but both of the devices would have the need to connect separately to the Bluetooth enabled device. This then limits the maximum amount of devices to two, because there are two transmitters in the bluetooth splitter device. On the other hand, the solution proposed in this document has only one Bluetooth connection, which connects to a master headset, whichever headset the user chooses to connect over Bluetooth, as each headset can be connected to over Bluetooth. The headsets are then daisy chained through a separate connection that runs at a different frequency. This allows each headset to connect to each other, with an increased maximum number of devices, and an interchangeable master and slave configuration due to each headset being identical.

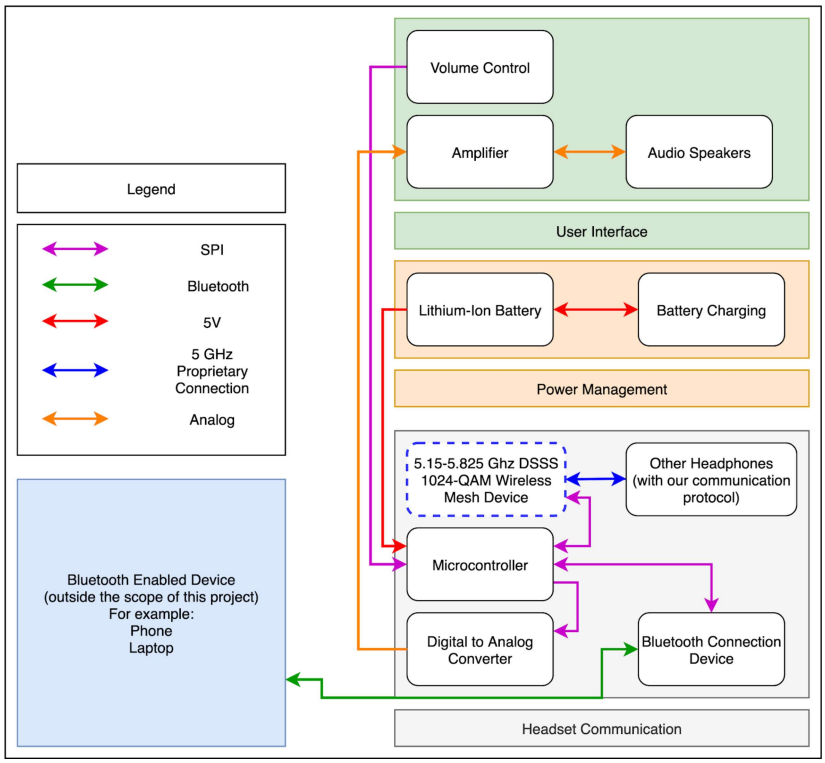
Other products exist in the marketplace that function using the same theory as the original group's implementation. Examples would include the Monoprice 109722 [2] and the Anker Soundsync [3], both

of which are available commercially and utilize the Bluetooth 5.0 protocol. These commercially available devices do not have the capability to connect to more than two Bluetooth audio devices at the same time. Our product intends to extend the quantity of Bluetooth devices that can be connected to the host audio source by implementing a mesh network instead of utilizing the two-device feature seen in commercial products.

1.3 High-Level Requirements List

- Can support listening for at least 3 devices
- Can last at least 8 hours on battery charge
- Can support a distance of at least 3m from the Bluetooth device to the acting master headset, as well as from the acting master headset to any one of the acting slave headsets

2 Design



2.1 Physical Design

The physical design of this solution mimics a standard headset. Ideally, people would not notice the difference between the proposed solution and an off the shelf version, except for the added functionality. Each of the headsets should be exactly the same, so they each can be used normally on their own, but can act as a mesh network of headsets if multiple are used.

2.2 Functional Overview

2.2.1 Lithium-Ion Battery

This is the battery to store charge for the system. The battery must be rechargeable, thus the choice of the lithium-ion battery, as that is commonly chosen for projects that need rechargeable batteries. Lithium batteries are lightweight and have good power density, but can pose some safety concerns that we will have to address.

Block Requirement: Should be able to last for 8 hours of listening.

2.2.2 Battery Management Circuitry

This should allow for battery charging over USB, and should have current protection to make sure that there is no fire or other hazard when charging is happening. Additionally the circuitry should not allow the battery to be discharged below dangerous levels.

Block Requirement: Must be able to charge over USB-C.

2.2.3 Proprietary Connection Hardware

Because there can be interference with Bluetooth, as well as pairing issues, the headsets should be able to talk to each other over a proprietary connection to avoid the user having to do any of this set up. This should be around 5GHz in order to avoid interference with WiFi and Bluetooth, among other common

radio frequency applications. Bluetooth and Wifi can both run at 2.45 GHz, which can cause non-negligible interference. However, Wifi can also run at 5 GHz, but this will cause much less interference, so it will not be a problem for this project. Each headset must have this hardware, and up to 3 devices should be able to connect to the master at any one time.
Block Requirement: Must have a range of at least 10 feet and support at least 3 devices.

2.2.4 Bluetooth Connection Device

There needs to be a Bluetooth connection from the main headset to a cellular telephone or other Bluetooth enabled device, so the user can connect this system to their device with ease. Any of the headsets need to be capable of being the master device, so each one must be Bluetooth compatible.
Block Requirement: The main headset should be able to connect to the main device within a range of 8 ft.

2.2.5 Digital to Analog Converter (DAC)

This is an audio grade DAC to take the Bluetooth data and produce a waveform that can be read by the microcontroller. Because Bluetooth is a digital waveform, this cannot be read directly from the microcontroller, so the DAC is necessary for the conversion from Bluetooth signal to an analog signal in the form of a differential pair that can be read by the microcontroller.
Block Requirement: Must be accurate to at least 16 bit precision.

2.2.6 Amplifier

The amplifier takes the audio signal from the DAC and amplifies it, in order to adjust the volume of the analog signal. This will take input from the microcontroller based on the user selected volume level and amplify it accordingly.
Block Requirement: Peak 500mW output

2.2.7 Audio Headset

The speakers must be able to output to the ear, and be acceptable quality. The range on the volume control should have a maximum of at least 75 decibels [4], and should be able to go down to 0 decibels with at least 10 increments.
Block Requirement: Must be able to output a range of 0-75dB.

2.2.8 Microcontroller

The microcontroller is a necessary component in order to connect the Bluetooth and the proprietary connection together, as well as the volume control and the audio output. The MAX32660 can support up to two of each SPI, I2C, UART, and RTC outputs. This gives enough necessary GPIO to support these four functions. Additionally, the microcontroller needs to be low power in order to prolong the battery life.
Block Requirement: Must be able to support four channels of communication with two signals each.

2.2.9 Volume Control

Because different volumes are useful in different scenarios, it is essential for the user to be able to adjust the volume at any point in the listening experience. On the headset, there should be volume adjustment buttons to ensure that the volume is able be set to their desired value.
Block Requirement: The volume must be able to have 10 separate preset values that the user can switch between.

2.3 Risk Analysis

The hardest part of this project will be ensuring that our proprietary radio transceiver will work properly without being susceptible to interference from other devices that use similar spectrums (ie 5GHz WiFi). We have chosen the 5GHz band due to the wide availability of transceivers that can be purchased allowing us to avoid the tuning and testing of a system which requires equipment not available to us. This will allow us to build a mesh network with a custom protocol over the same widely used bands. The protocol itself is the highest risk item. 5GHz Wifi uses anywhere from 20-160 mhz bands where our solution will need significantly less than that so we cannot use wifi off the shelf. We will also have many more devices that require transmission than most people have wifi routers. This means we will have to find out how to implement narrow band communication over many devices without interference but at data rates higher than bluetooth. With narrow band communication DSSS starts to fail, FHSS may be required which would increase collisions and decrease total number of allowable devices. FHSS though would allow configuration to be easier due to no channel claiming. Also with this many small bands there may be an issue with 5 GHz wifi not realizing a channel is being used and broadcasting over it causing interference. We will most likely use QAM1024 encoding since that provides a suitable 5 b/s/hz going any higher will make interference more significant but it would allow more total devices since it allows a narrower band and that is another optimization problem.

3 Ethics and Safety

We intend to follow the IEEE Code of Ethics 7.8.1-7 and 7.8.9-10 [5]. Some of the Code of Ethics is not applicable due to the nature and methods of our project. In the case of any violations of this code we will take them seriously. Due to the physical nature of our device we do not foresee any sort of physical injury possible without extreme misuse. For this reason we will focus on the nonphysical component when designing and operating our device according to the Code of Ethics 7.8.1 [5].

It is important to ensure that our device will not harm the user's ears, or emit excess radiation as per FCC regulation. Our device is classified as an intentional radiator by the FCC [6]. The chosen frequency is well within the FCC regulations, so any radiation emitted is within the healthy limit [7] that will not negatively impact the users quality of life any more than any other consumer devices. Additionally, as with any battery charging, it is necessary to ensure that the battery will not catch on fire, either when the battery is charging or during normal use. To solve the charging issue, a standard off the shelf charging system will be used that is UL rated in order to limit the amount of power that can enter the system at any one time.

To prevent harming the users ears we will ensure that our internal amplifier is limited to being able to drive any common off the shelf headphone speaker to a maximum of 130db (roughly the spl of a rock concert) with a warning at 80db to alert the user that long term effects could occur. This works out to anywhere from 3mw on earbuds to 16,000 mw for the highest impedance large form factor headphones. This exact value will be chosen based on our voice coil selection specifically [8] We will also not exceed the maximum voice coil rated power and current in order to prevent destruction of our products and burns to the customer.

References

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