Improving Wi-Fi Performance Using Directional Antenna

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Introduction

Signal strength can greatly affect throughput in Wi-Fi systems. When the signal to noise ratio (SNR) is low, throughput gain through traditional MIMO system is limited, since the omnidirectional antennas are also receiving noise from other directions. The simplest way to obtain an SNR gain is to replace current antennas by directional antennas. However, since the field of view (FOV) of a directional antenna is narrow, it has to be rotated to find a specific degree that has the highest signal strength. This is low efficient and requires complicated hardware mechanical implementation. Therefore, we present a novel hardware configuration that changes one of those omnidirectional antennas into a directional antenna in seek of filtering out most of the noise and have a gain in the desired signal.

Algorithms

Due to the indoor multipath effect, we need to apply the MUSIC algorithm in order to compute several possible arriving angles. One problem is that the number of measurements at the antenna array that can be written as a linear combination of the same steering vectors, should be greater than the number of paths, but that is not necessarily true in the complex indoor condition.
To address this problem, we apply the "Super Resolution MUSIC" algorithm from "SpotFi: Decimeter Level Localization Using WiFi" [1]. This algorithm takes advantage of the phase differences between subcarriers due to the different times of arrival. We only have three antennas, but with the help of 30 subcarriers, we can obtain a much bigger measurement matrix by permuting the elements of the original measurement matrix. Find more details in their paper.

Conclusion and Discussion

In this project, we proposed a novel NIC hardware configuration that uses one directional antenna to aim at the incoming direction of the desired signal. Instead of using a directional antenna as a radar to scan all the directions, we exploited CSI provided in 802.11n to determine the direction with the strongest signal strength. We tested RSSI in different directions and found out a strong correlation between them. The new hardware configuration is also tested using the same methodology as evaluating RSSI to have at most 14dB RSSI gain and 15% throughput gain. Some future work, including online AoA calculation, motorized gimbals are also to be added to this system to make it applicable to some point-to-point scenarios such as (unmanned aerial vehicle) UAV image transmitter.

References

[1] Manikanta Kotaru, Kiran Joshi, Dinesh Bharadia, and Sachin Katti. Spotfi: Decimeter level localization using wifi. *SIGCOMM Comput. Commun. Rev.*, 45(4):269–282, August 2015.

[2] Anmol Sheth Daniel Halperin, Wenjun Hu and David Wetherall. Linux 802.11n csi tool. http://dhalperi.github.io/linux-80211n-csitool/.

Device and Setup

Our hardware consists of an AP and a NIC. The antenna of the AP is covered by aluminum to weaken the signal. The NIC is Intel 5300, which has three changeable antennas. It also features a modified driver that provides channel state information (CSI) in 30 subcarriers [2]. We give two configurations for the NIC for normal usage, and one more configuration for validating our assumptions. The first configuration is the same as a normal one — Three identical omnidirectional antennas are connected to this NIC. The second configuration is the one aforementioned, which has two identical omnidirectional antennas and one directional antenna that bears 15-degree FOV. The third configuration is only for validating (and evaluating) our angle of arrival (AoA) estimation results. This configuration only consists of one directional antenna.

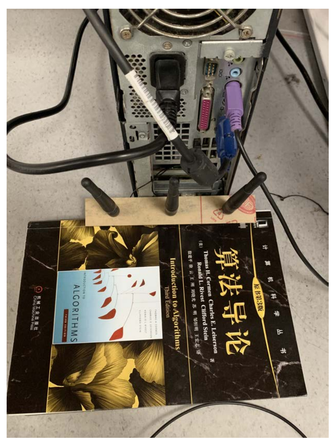

Figure 1: Config. 1

Figure 2: Config. 2

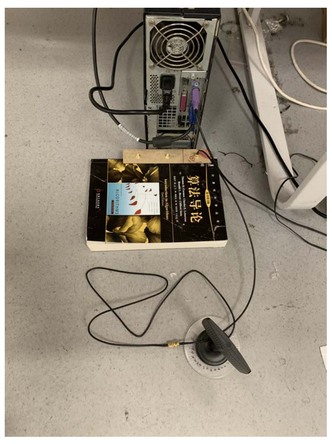

Figure 3: Config. 3

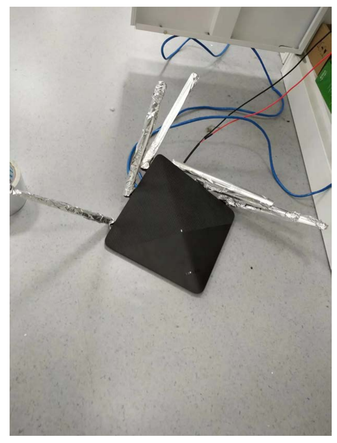

Figure 4: The AP

AoA Estimation Evaluation

To ensure the maximum SNR gain, we need to aim the directional antenna at the arrive angle with the strongest strength of the signal. As was introduced in algorithm section, we use MUSIC to split the signals from the combination of its multipath incident signals. We then plot the MUSIC spectrum and test the incident signal's RSSI to see if it corresponds to the AoA. We test the RSSI every 10 degrees, starting from minus 90 degrees (on the left) to 90 degrees (on the right).

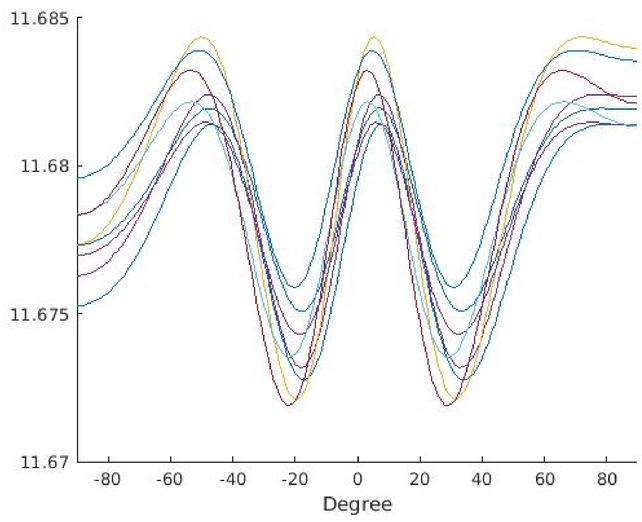

Figure 5: MUSIC Spectrum

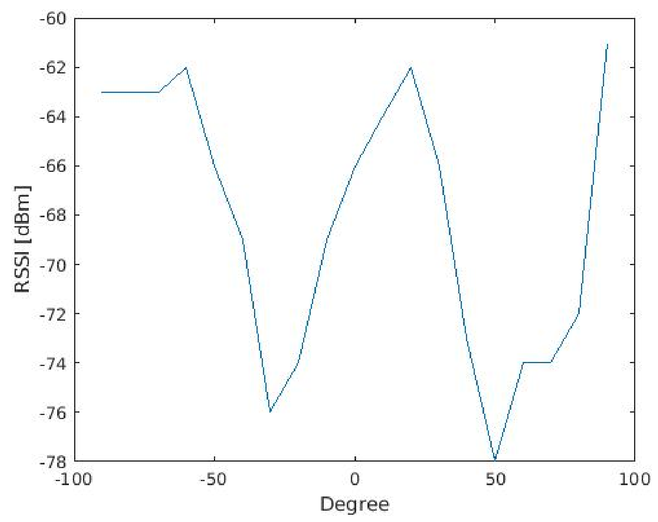

Figure 6: RSSI

The RSSI changes in the same trend exactly as the MUSIC spectrum.

Throughput Evaluation

We evaluated throughput using the same methodology as evaluating AoA. iperf is used to measure the throughput between the computer with new NIC configuration and another cable connected computer attached to the AP (wireless router). Using directional antenna, the RSSI is tested to be stronger than with three omni-directional antennas. While for throughput, configure 3 is inferior to configuration 1, since there is only one available antenna, the MIMO scheme is not working. With only one of the antennas changed into a directional one, the throughput is higher than configure 1 by 15% when the directional antenna aims at -50 and 20 degrees, which is approximately the peaks of MUSIC spectrum. The inconsistency here is caused by the computation performance limitation of the PC as well as some optimization brought by MIMO.

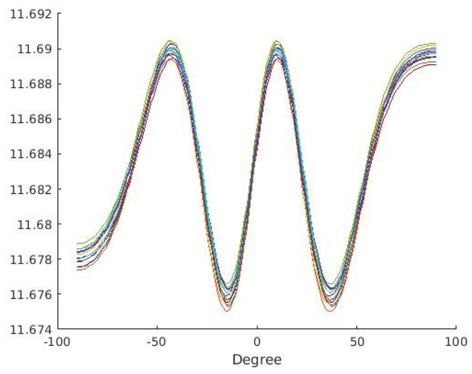

Figure 7: MUSIC Spectrum

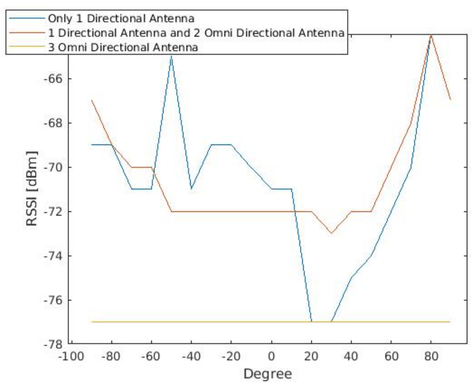

Figure 8: RSSI

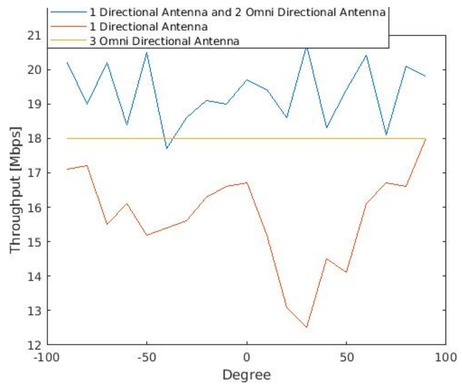

Figure 9: Throughput