ECE 484 Final Report

Limitations of WiFi with the use of Multiple Devices

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I. Introduction

The purpose of this project was to explore the capabilities of wireless networks when multiple devices are used. The team explored bandwidth, network speed, bit and packet error, as well as causes of WiFi interference to complete this project. Matlab Communication System Toolbox and Simulink were used to simulate multiple channels with one receiver. IEEE 802.11 standards were used to develop this project.

II, Research

When exploring the use of multiple devices on one wireless network, the team found that the theoretical and practical limits of connected devices were much different. Theoretically, standard wireless routers with one access point (AP) are able to have up to 255 connected devices. In practice however, the general rule of thumb was found to limit the number of connected devices per AP to 45. The reasoning behind this is the available bandwidth of the wireless network. When multiple devices are on the same network, they share the bandwidth. This limits the available bandwidth for devices that require a lot of bandwidth for downloading, streaming, or other high use activities, thus slowing the speed of the devices.

Other factors that were found to slow the speed of wireless networks were WiFi interference When an 802.11 client device hears another signal, whether it is a Wi-Fi signal or not, it will defer transmission until the signal ceases. Interference that occurs during transmission also causes packet loss, which forces WiFi retransmissions and dramatically lowers the network speed.

Some of the main causes of WiFi interference are Co-Channel and Adjacent-Channel interference. Co-Channel interference occurs when two transmissions happen in the same area. The transmitter checks to see if the transmitter is idle or not. If not, the transmitter must wait until the receiver is done receiving. This type of interference is common in high density areas. Adjacent-channel interference is when signals from adjacent channels or overlapping channels bleeds through. This often happens when there is a weak channel signal, or an overly strong alternate channel signal.

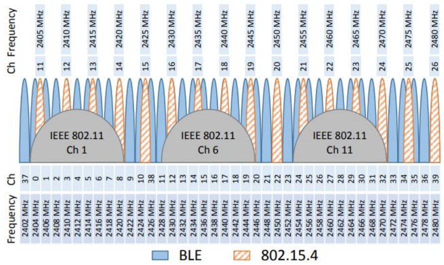

Fig. 1. 2.4 GHz ISM band: IEEE 802.15.4, BLE and IEEE 802.11 channels

Figure 1 above shows the overlap of the bluetooth low energy (BLE) and the IEEE 802.15.4 over the three non-overlapping channels in the 2.4 GHz range. This figure is from the *Analysis of Coexistence between IEEE 802.15.4, BLE and IEEE 802.11 in the 2.4 GHz ISM Band [3],* where the signal's interference is evaluated. The findings of this article show that BLE is affected more by IEEE 802.15.4 interference than vice versa. This could be attributed to longer channel-occupancy of IEEE 802.15.4 compared to BLE. Inversely, BLE has less interference with the 802.11 bands, which can be attributed the the shorter channel occupancy of the BLE.

This article demonstrates the co-channel and adjacent-channel interference of several bands over the 802.11 channel.

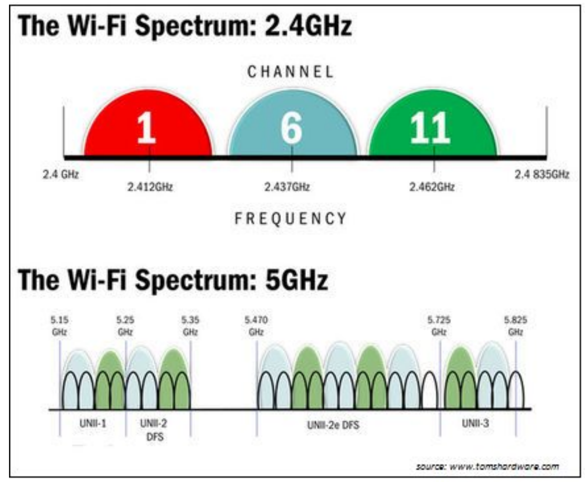

Fig. 2. Comparison of 2.4GHz ISM to 5GHz ISM

Figure 2 above shows the difference between the non-overlapping channels in the 2.4GHz and 5GHz spectrums [2]. As seen above, the 2.4GHz spectrum only contains three non-overlapping channels, making channel switching harder. The 5GHz spectrum has 23 non-overlapping channels, and therefore channel switching due to interference is a little more prevalent. Therefore, the 5GHz spectrum is not as prone to congestion or interference as the 2.4GHz, while sacrificing some range and object penetration.

Two ways to evaluate a transmitter and receiver are to examine the bit rate error and packet rate error. The bit rate error is the comparison between the transmitted bits and the receiver bits, and is a good metric to measure the network's strength. Real world testing of bit rate error is complex, and often times lengthy evaluation times are needed to guarantee accurate results.

III. Simulation

After research was done to explore bandwidth, network speed, causes of WiFi interference, and bit and packet error, the team used Matlab Simulink and the communications toolbox to simulate a wireless network, the Beacon Frame [1] example was used as a template.

Figure 3 below was the model used to measure packet error. As seen in the figure, three channels were used to create artificial noise. The error outputs can be seen to the right of the figure.

Fig. 3. Simulink Test Setup [1]

The Beacon Frame example was only slightly modified in order to ensure correct operation and allow for measurement of the PER. This testing setup was iterated multiple times in three stages. First, the setup was used with one channel. Next, two channels were used. Finally, the three channel model seen above was used. The results received when using either one or two channels did not yield meaningful data in the noise range of interest. Ultimately three channels were used, as shown in the setup, and provided satisfactory results that mimicked the same trend of only a single channel.

A major hurdle in using the Beacon Frame example was how to actually measure either the bit error rate (BER) or packet error rate. A successful measure of BER was not achieved as the transmitter populated non-transmissions as zeros. To compensate for this the PER was selected to be measured that then would have to be scaled. Using the single channel setup, the MPDU error rate ranged from 0.95 for 1000dB Es/No to 1 for -1000dB. These two values were then mapped to 0 and 1 respectfully. Figure 4 belows shows three tests of PER using a different frequency offset on the bottom channel.

Fig. 4. PER Testing Results

The main channel is the center channel in Figure 3 and its SNR was adjusted to form the above graph along with the offset adjustment from 0 to $1x10^{-5}$ with $1x10^{-6}$ being the baseline. The non main channels were also set to 0dB Es/No with a signal strength of 10μW.

Increasing the frequency offset to $1x10^{-5}$ caused the PER to remain larger for longer while decreasing it 0 allowed PER to decrease more sharply as SNR was increased. While no specific devices or channel frequencies were tested, analysis of the results proved more devices, regardless of signal strength, hurts PER but incorporating a slight frequency offset can help to improve the rate.

IV. Results

As seen in the sections above, the team was able to research and simulate the effects of multiple devices on a wireless network. Research of multiple devices yielded information on bandwidth limitations, common bandwidths, and causes for WiFi interference. The simulations of packet error rate concurred with expected results. PER increased with a lower Es/No ratio. PER also increased when a frequency offset was applied. The team was unable to adequately model bit error rate with the beacon frame model. Instead, the team chose to model packet error rate instead to show trends in the data that could be used to assist in the design of WLAN for senior housing. [4]

V. Resources

1. "IEEE 802.11 WLAN - Beacon Frame" Mathworks, https://www.mathworks.com/examples/matlab-communications/mw/comm_product-commwlan80211Beacon-ieee-802-11-wlan-beacon-frame#2
2. E. D. Ngangue Ndih and S. Cherkaoui, "On Enhancing Technology Coexistence in the IoT Era: ZigBee and 802.11 Case," in *IEEE Access*, vol. 4, pp. 1835-1844, 2016.
3. R. Natarajan, P. Zand and M. Nabi, "Analysis of coexistence between IEEE 802.15.4, BLE and IEEE 802.11 in the 2.4 GHz ISM band," *IECON 2016 - 42nd Annual Conference of the IEEE Industrial Electronics Society*, Florence, 2016, pp. 6025-6032.
4. D. C. Yacchirema, C. E. Palau and M. Esteve, "Enable IoT interoperability in ambient assisted living: Active and healthy aging scenarios," *2017 14th IEEE Annual Consumer Communications & Networking Conference (CCNC)*, Las Vegas, NV, 2017, pp. 53-58.