Full Duplex in Wireless Network

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ABSTRACT

This paper presents the design and implementation of full duplex WIFI radios that can simultaneously transmit and receive on the save channel in wireless network. Our design uses a two-antenna node for simultaneous TX/RX, one antenna for TX, the other for RX. We focus on the digital interference cancellation. We use USRP to build our system and do the cancellation off-line by matlab. We show experimentally that our design works well in full duplex mode.

Keywords

Full duplex, self-interference, digital cancellation, USRP

1. INTRODUCTION

It seems common sense that the full duplex, i.e. transmit and receive at the same channel, is impossible in wireless network.

The difficulty of realizing full duplex is the self-interference as in the Figure 1. The two antennas are so close that the interference from self-signal is much larger than the signal from true transmitter.

The cancellation of self-interference is come up with two parts, analog cancellation and digital cancellation, the first one works in time domain and the second one works in frequency domain. Our work focuses on digital cancellation. For analog cancellation, we just use a RF absorb to cancel some power of self-interference.

This paper presents the method design of digital cancellation in section 3. In section 4, we show how we build the experiment environment. In section 5, we analyze the result we achieve from experiment. Then we give some discussion about the questions on class and problem we met during the project. The last part is the conclusion.

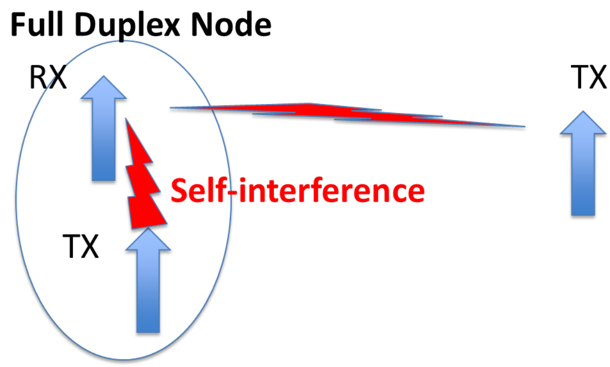

Figure 1: Full Duplex Node

2. RELATED WORK

Some researchers are attempt to invalidate this assumption [1, 2]. They try to build a circuit to remove the self-interference[1] and place the two antennas some special position to do the antenna cancellation[2]. Also some prior research has done related work, but not for full duplex exactly. Zigzag decoding[3] is a form of interference cancellation that can be applied here.

3. METHOD DESIGN

We design two methods to do the digital cancellation, one in frequency domain, the other in time domain.

3.1 Frequency-domain Cancellation

In full duplex, it is equalized that the receive antenna of full duplex node receive two signals, one from TX antenna of himself, the other from TX antenna of the true transmitter.

As in the Figure 2, full duplex remove self-interference after FFT, i.e. in frequency domain. X is the signal in frequency domain sent by himself. Y is also the signal in

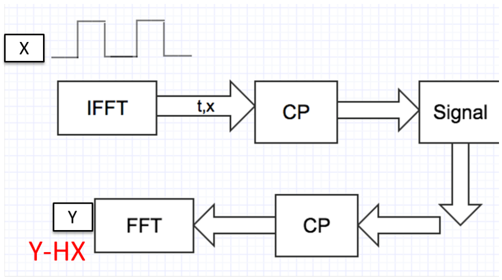

Figure 2: Frequency-domain Remove

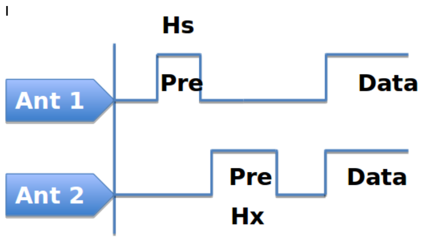

Figure 3: Scheduling of USRP

frequency domain, which is received by full duplex node. H is the channel estimation. Self-interference is removed by $Y - H. * X$. i.e.

$$Y_x = H_x. * X \tag{1}$$

To do that, the point is to do the channel estimation. It is necessary for us to schedule USRPs to transmit like the Figure 3, first transmitter is full duplex node, it just transmits preamble; then half duplex node transmits preamble. After this procedure, RX should have got the channel estimation of two channels. After decoding, RX should get $(Y_s + Y_x)$, then $Y_s = (Y_s + Y_x) - H_x. * X$ is what we want.

3.2 Time-domain Cancellation

The frequency-domain cancellation requires scheduling of USRPs to get $(Y_s + Y_x)$. However, time-domain cancellation doesn't have this limit.

Time-domain cancellation is as Figure 4. y' is the estimation of receive waveform according to the known X. How can we get y'. We also need to estimate channel first. The difference is that we use the Y_x to estimate the y'. Then decode the residual of signal $y - y'$ and we will get the true signal from true transmitter.

Using time-domain cancellation, the signals are not aligned. We need to detect two cascaded packets as in Figure 5. Here, we assume packet one is self-interference. First, we need to extract the cascaded signals, from start of packet one to then end of packet two. Then y' is the waveform of packet one. We remove packet from the cascaded signals.

At last, decode from index of packet 2. That's what we want.

3.3 Packet Detection

To detect the beginning and the overlapped part of the packet, we use cross correlation on collided signal and preamble signal, the result can be seen in Figure 6, where the highest peak means the beginning of the collided signal, while the

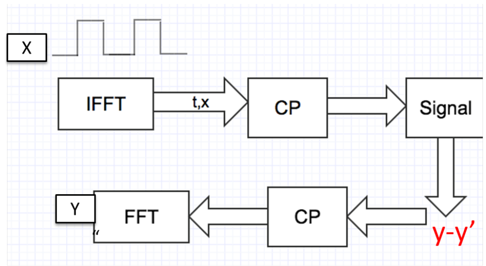

Figure 4: Time-domain Remove

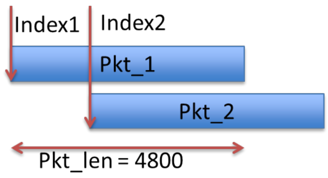

Figure 5: Packet Detection with preamble cross correlation

second highest peak means the the index where the signal of full-duplex node and half-node overlap.

4. EXPERIMENT SETUP

Our experiment environment is made up with three USRPs, one switch and a RF absorber:

- We use three USRP as transmitter and receiver, specifically, we use two USRP as a full-duplex node, one is transmitter, the other is receiver. The third USRP is used as an half-duplex transmitter. In this experiment, we will only focus on the effect of self-interference cancellation, thus we put a RF-absorber between transmitter and receiver of full-duplex node.

- First We send signal from transmitter of full-duplex node, let receiver receive the signal, calculate the channel estimation H_1. To make sure H_1 is correct, subtract the received signal from $H_1 x$, after the subtraction, there should be nothing in the result.

- Then send signal from half-duplex transmitter, calculate the channel estimation H_2, use the same way in 1 to make sure H_2 is correct.

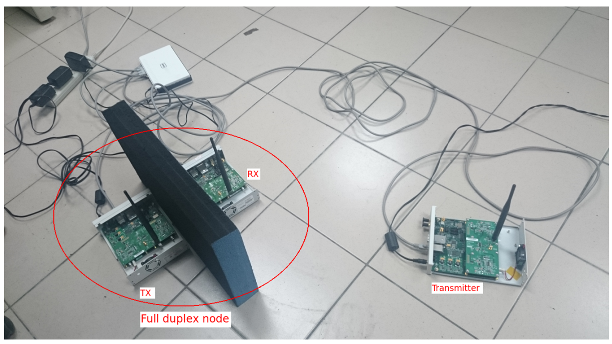

Figure 7: Environment

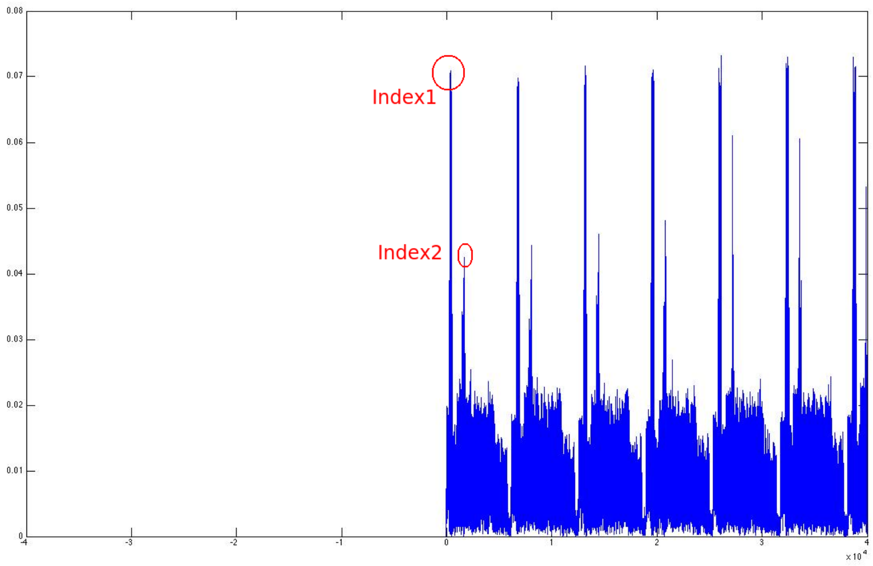

Figure 6: Cross correlation on collided signal and preamble

- After we get H_1 and H_2, we send known signal from full-duplex node, send another unknown signal from half-duplex transmitter. Since we know the channel estimation of H_1, we know the self-interference of the full-duplex node, we can subtract the self interference from the received signal.

5. EXPERIMENT RESULT

The performance evaluation is by two ways, SNR and constellation.

5.1 Only Self-interference

Step 1, we setup a full duplex node with two USRPs. Only one node, i.e. one USRP transmits to another USRP. Receive signal of RX is as in Figure 8. A cluster of blue means a packet.

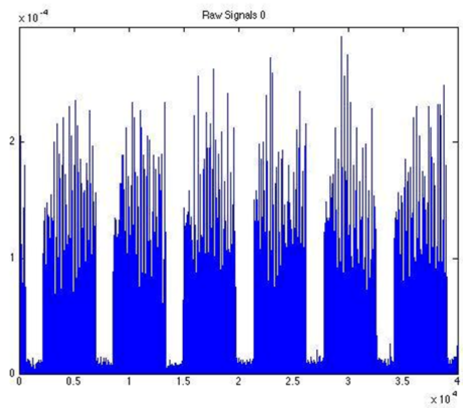

Figure 8: Raw data of only self-interference

Before cancellation, we find the SNR of each subcarrier is relatively higher , which is around 15. After cancellation, SNR reduce to around -2. Which means that self-interference has been removed almost.

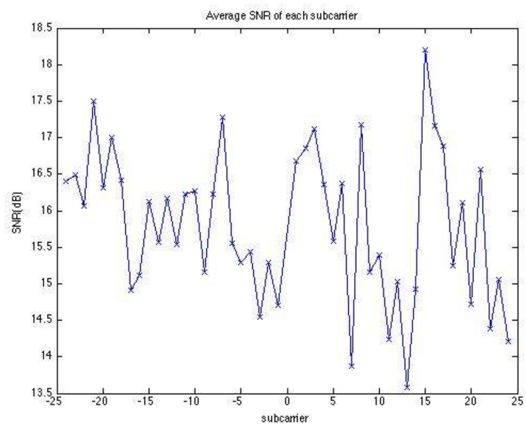

Figure 9: SNR of only self-interference before cancellation

5.2 Self-interference with half duplex transmitter

Step 2, we also stepup a half duplex node to form a true full duplex transmission. Now, two TX transmit to RX simultaneously.

As we see in Figure 11, the shape of a cluster is different from step 1. It is because two packets from different TX cascade with each other.

We evaluate the cancellation by constellation. As in Figure 12, red points means points before cancellation. Blue means after cancellation. We find that red points are almost

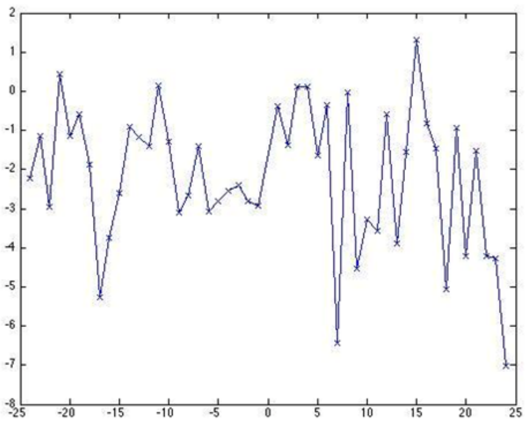

Figure 10: SNR of only self-interference after cancellation

locate in the graph uniformly while blue ones aggregate at two points, +1 and -1. That means packet two has been decoded correctly.

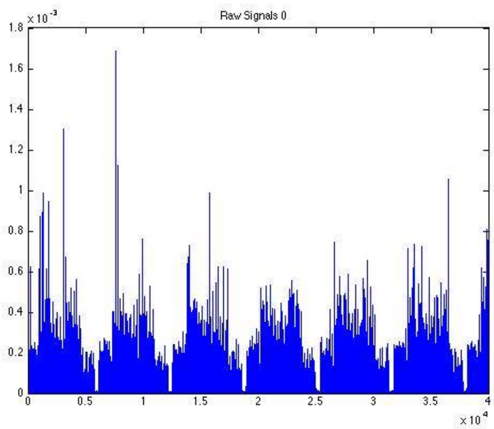

Figure 11: Raw data of self-interference with half duplex transmitter

6. DISCUSSION

Problems we met. And questions given by others.

- Weakness in our experiment.

  Because we didn't schedule the USRP. We estimate the channel separately,i.e. we store the H estimated when only one TX transmit, and we use that H for other estimation. Problem is that channel information is time-variant, i.e. H is time-variant. But we assume it is fixed during the period of our experiment. It will lead some error. Luckily, it didn't ruin our design.

- Why don't we synchronize the transmission of full-duplex node and half-duplex node?

  Indeed, this is the best way to do our experiment, since the channel estimation varies with time, doing this experiment in "step by step" way may get different estimation, which worsens the self interference cancellation. However, since synchronizing three USRPs need external clock, which we haven't considered since the announcement of the final project, the current procedure is the best method that we can come up with.

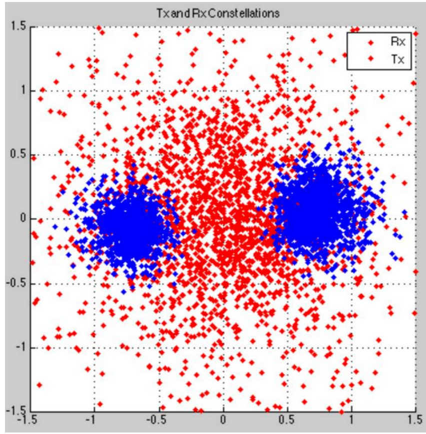

Figure 12: Constellation of self-interference with half duplex transmitter before cancellation

7. CONCLUSION

In this final project, we learn how to set up USRP to emulate full-duplex node; train channel estimation from signals; let signals of two transmitters(full-duplex node and half duplex node) collide; then we use the information of the channel and self-interference from full-duplex transmitter; at last we can get the signal sent by half-duplex transmitter.

Actually, the most difficulty of full duplex in wireless network is analog cancellation. However, prior work has proposed some method to solve this problem. Though some problem still exists, for example, the circuit is too big to implement as a product, we can see the road to full duplex radios is not far away.

8. REFERENCES

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