An in band full duplex practical implementation applying passive self-interference cancellation

Sergio Armas-Jiménez SARMAS@CICESE.EDU.MX
Electronics and Telecommunications Department, CICESE Research Center, Ensenada B.C., México

Jaime Sánchez-García JASAN@CICESE.MX
Electronics and Telecommunications Department, CICESE Research Center, Ensenada B.C., México

Abstract

This paper presents the physical layer implementation of a wireless communications system composited of 3 nodes, one of them operates in Full Duplex (FD) mode and the others work in Half Duplex (HD) mode. The simultaneous operation of these 3 nodes is intended to simulate a hidden node structure, where one of the HD nodes is sending information to the FD node, which is expecting the signal of interest at the receiver antenna and sends a different signal thru the transmitter antenna to the other HD node, simultaneously, making use of the same frequency channel. Passive self-interference (SI) cancellation in the propagation domain is applied, performing an orthogonal alignment between the radiation fields of these antennas. By doing this, a good level of cancellation is achieved, which allows the simultaneous transmission and reception at the FD node. In order to guarantee the discrimination between the two communication links OFDM symbols with different sizes are used, both over the same bandwidth. GNU Radio Companion platform (software) and USRP boards (hardware) were used for the implementation.

1. Introduction

Given the increasing demand by the wireless network users on the utilization of the spectrum, it is necessary to implement techniques for make an efficient use of it. It has been common practice that a frequency channel be used to transmit a single flow of information (Goldsmith, 2005). However, in recent works it has been demonstrated that it is possible to transmit and receive simultaneously, using for both processes a same frequency band, thereby increasing the spectral efficiency by almost hundred percent, which is called Full Duplex or in band Full Duplex (IBFD) (Duarte, 2012) (Wu et al., 2014), for simplicity, in the sequel we use the FD term.

The main challenge in a FD system is to cancel the self-interference that produces the transmitter antenna over the receiver one, both of them working on the same device at same time.

An advance of our project, consisting of establishing 2 communication channels between 3 devices, 2 operating in HD mode and one in FD mode, is shown in this paper. One of the HD nodes acts as transmitter, sending information to the FD node, which is receiving and transmitting different information, simultaneously, to the other HD node, that is acting as receiver.

So far only passive cancellation is applied in the propagation domain, later we will also apply active cancellation to improve the results.

The remainder of the article is structured as follows: Section I details what FD mode operation means. Section II explains how cancellation was applied to the propagation domain. Section III presents the characteristics of the experiment developed, the environment in which it was made and the equipment used. The simulation to obtain the bit error rate (BER) curve is presented in section IV. Section V describes some of the problems that appear during the implementation of the experiment. The future work is described in section VI. Finally, we conclude the paper and list the consulted references.

2. In Band Full Duplex

For a long time it was considered a rule that a frequency channel could be used to establish communication between two devices in a single way, i.e. send or receive information, never for both tasks simultaneously (Goldsmith, 2005).

The term FD has been used to refer to links in which infor-

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mation travels in both directions (sending and receiving) using the same channel, but not at the same time; the channel is used a few moments to transmit and then to receive. This type of FD is known as time division FD. In some systems FD is used in frequency, which implies the use of 2 channels, one to transmit and one to receive.

Recent works (Duarte, 2012) (Wu et al., 2014) (Chung et al., 2015) has shown that it is possible to have a device transmitting and receiving, simultaneously, using the same bandwidth. In this way the spectral efficiency improves at almost double, compared to the traditional schemes HD or time/frequency division FD.

The complexity to achieve bidirectional communication, simultaneously, over the same bandwidth, lies in the presence of the signal in the transmitting antenna that strongly interferes to the receiving antenna, which is waiting to receive information that comes from a distant node. Due to the proximity between the transmitting and receiving antennas (both in the same device), the signal from the transmitting antenna will be saturating the receiving one with radiation, preventing it from receiving the signal of interest, which will arrive at the receiver antenna with a much lower power than the interference signal from the transmitting antenna on the same device (SI signal).

In order to avoid the SI, and to obtain the operation in FD mode, different cancellation techniques have been proposed, which have been classified in 3 stages (Sabharwal et al., 2014) according to their nature; passive cancellation in the antenna domain, active in the analog domain and active in the digital domain. The maximum cancellation is achieved by properly applying cancellation techniques in all 3 domains. In the experiment presented in this paper only cancellation in the antenna domain was applied, having an orthogonal arrangement between the radiation fields of them, achieving a very good cancellation value.

2.1. Passive SI suppression at propagation domain

Cancellation in the antenna domain is achieved with an orthogonal arrangement between the transmitting and receiving antennas. It is important to emphasize that the intended orthogonality is over the radiation fields, without this implying the physical orthogonality between the antennas. With this arrangement a very good SI cancellation value is achieved, however residual interference remains significant. To prevent the signal transmitted in the FD node, through the transmitting antenna, to be received by the receiving antenna on the same node, we used different sizes FFT for the OFDM symbol to be transmitted and the OFDM symbol to be received, thus the residual interference is detected as noise at the FD node. For both transmissions the same bandwidth is used.

3. Environment, equipment and experiment design

The experiment was mounted in the Signal Processing Laboratory for Communications (a reduced 6.22 by 11 feet space), where three nodes were implemented. Each node was emulated by an Ettus Research USRP B210 board, operating at 5 GHz, which receives instructions from a computer that uses the GRC platform to control the device, running over OS Linux distributions. The antennas used are also made by Ettus Research; the VERT2450.

Figure 1 shows a block diagram of the 3 nodes implemented in GRC, their operation is described below; Node 1 works in HD mode, it transmits OFDM symbols with a 128 bins transform. The antenna is in a horizontal position, co-polarized with the antenna located on node 2, which receives information from node 1. Node 2 operates in FD mode. It receives information from node 1 and transmits information to node 3. The transmitter and receiver antennas of this node are cross-polarized, in order to reducing the SI at receiver. Node 3 works in HD mode, it receives OFDM symbols with a 64 bins transform from the FD node (node 2). The antenna is positioned vertically, co-polarized with the transmitting antenna on node 2. The 3 nodes go into operation simultaneously, getting 2 channels of communication over the same bandwidth. The distance between node 1 and node 2 is approximately 10 feet, while node 2 and node 3 are spaced approximately 7 feet apart.

4. Results

Around 42 dB of passive cancellation in the antennas (propagation) domain are achieved by applying cross-polarized accommodation between them, similar to those obtained by (Chung et al., 2015). In (Chung et al., 2015) they used special dual-polarized antennas (Oh et al., 2015), while we are using general-purpose commercial antennas (VERT 2450 from Ettus Research). The orthogonal arrangement can be seen in Figure 2.

With the amount of cancellation obtained, simultaneous transmission and reception in the FD device is possible. We used BPSK and QPSK modulation schemes for the header and payload, respectively, of the OFDM symbols.

To carry out the tests we made transmissions of an image file with .jpg format. For good values of SNR+interference the recovered file is seen exactly the same as the one transmitted. For error correction, we used a rate $1/2$ convolutional code with $k = 7$ and generator sequences Octal $(155, 117)$ (GNU), which doubles the amount of information to be transmitted but offers a considerable reduction of

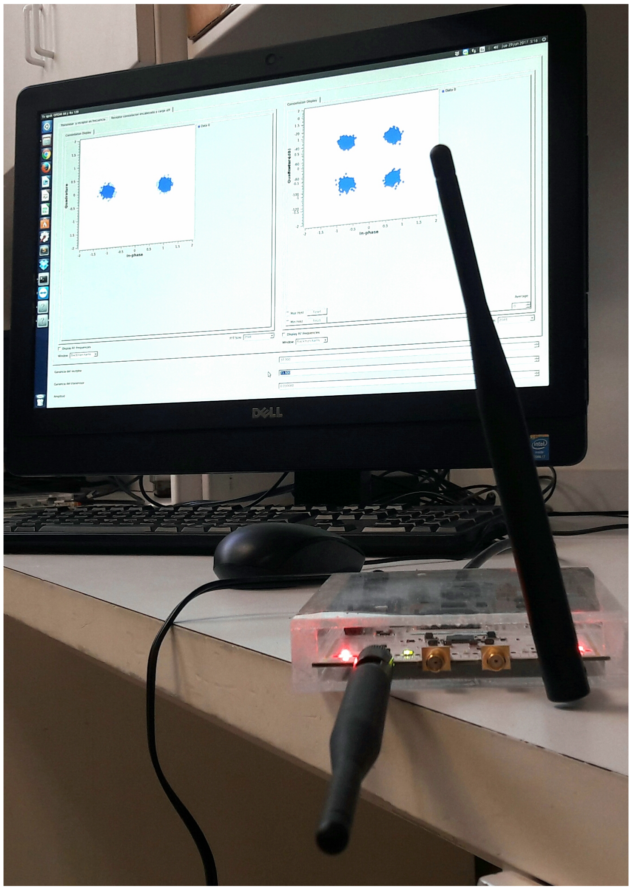

Figure 2. Antenna alignment at FD node, at the front. Modulations bpsk (header) and qpsk (payload) reception at FD node, at the back.

errors in the receiver. When using the code, it appends 4 bytes of value 0 to the beginning of the file, which must be removed later in the reception in order to correctly recover the image. It is also necessary to add 0s at the end of the transmission to empty the code registers and ensure that all the information contained in the file is sent.

The bandwidth used was 960 KHz. It could not be greater due to the limitations of the computer equipment that served the receiver. In Figure 2, at the back, it can be seen how the modulation points, BPSK for header and QPSK for payload, are clearly defined in the receiver, despite self-interference.

5. Simulation

The following problem arose when performing the transmissions: when the receiver loses one or more bits of the transmitted file, because of the channel, the BER can not be calculated because it is not possible to compare the data sent with the received data. In order to solve this problem, a simulation, using the same GRC tool, was used to estimate the SNR+interference vs BER curves for different levels of hostility in the channel, using real SNR+interference values measured from the experiment. The simulation results are shown in Figure 3 and Figure 4.

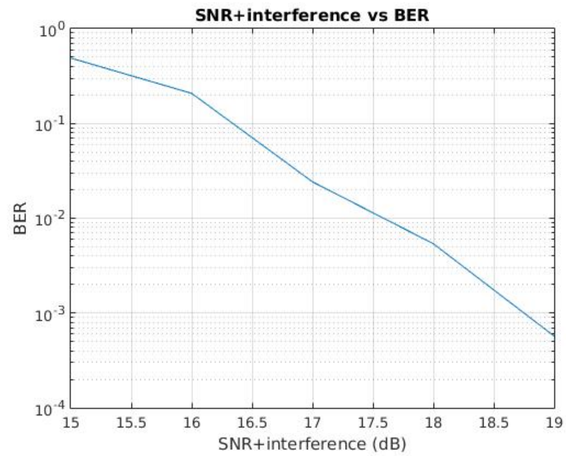

Figure 3. SNR+interference for the link node 1 - node 2.

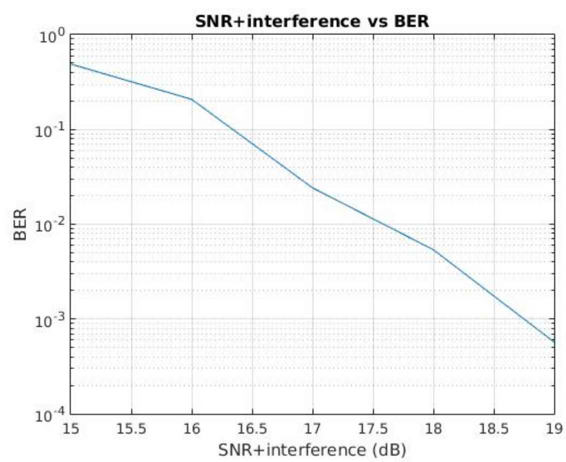

Figure 4. SNR+interference for the link node 2 - node 3.

It should be noted that results were obtained only for 5 SNR+interference values, since with higher values of transmission power the interference is also increased considerably, impeding the communication, and for lower values of power the received signal contained too many errors, resulting in the above mentioned problem to calculate the BER. We expect to have a wider functional operating range in the future, with the addition of cancellation stages.

6. Deployment Issues

It is a complicated task to place the nodes in such a way that node 1 (transmitter) and node 3 (receiver) do not interfere with each other. Node 3 should not listen to node 1, with the intention of representing a hidden node communications system. However, due to the size of the space where the test was made and the number of reflectors/interferers, a considerable level of interference is received at node 3 from node 1. The said residual interference is considered as noise interference since it is transmitted with a transform of 128 bins and it is expected to receive one of 64, guaranteeing that these nodes will never synchronise.

Since not all the computers in our laboratory have i7 processors, we had to limit the sampling rate to less than one Msps, which resulted in a experimental bandwidth of 960 KHz, because both parameters are closely related.

7. Future work

We plan to measure the radiation patterns of the antennas in an anechoic chamber, to find areas of power fading and to perform orthogonal accommodations between fields, achieving better results in SI cancellation.

Additionally, in the passive cancellation stage at the propagation domain, it is intended to place a RF absorbent material between the transmitter and receiver antennas, thereby increasing the amount of cancellation of SI.

A digital signal processing stage will be added to the system using the GRC platform, in order to apply active cancellation, for best results in the total cancellation amount.

In order to improve the quality of the transmissions, it is also intended to bring the system to MIMO type transmissions, over the FD platform. Using MIMO communications it is possible to implement the Alamouti encoding, which reduces the BER (Armas-Jiménez et al., 2015). Once the Alamouti encoding is implemented, the convolutional code can be removed and the transmission rate doubled, or the code can be retained and the number of errors in the receiver reduced.

8. Conclusions

It is possible to achieve communication in FD mode in certain scenarios, even applying only passive cancellation in the antenna domain. Better results can be achieved by complementing the work with active cancellation techniques.

The discrimination between the two communication channels, which are operating simultaneously, with different sizes of OFDM symbol, helps to avoid mixing the signal of interference with the one of interest.

The use of the convolutional code considerably improves the quality of the communication link by decreasing the number of erroneous/lost bits.

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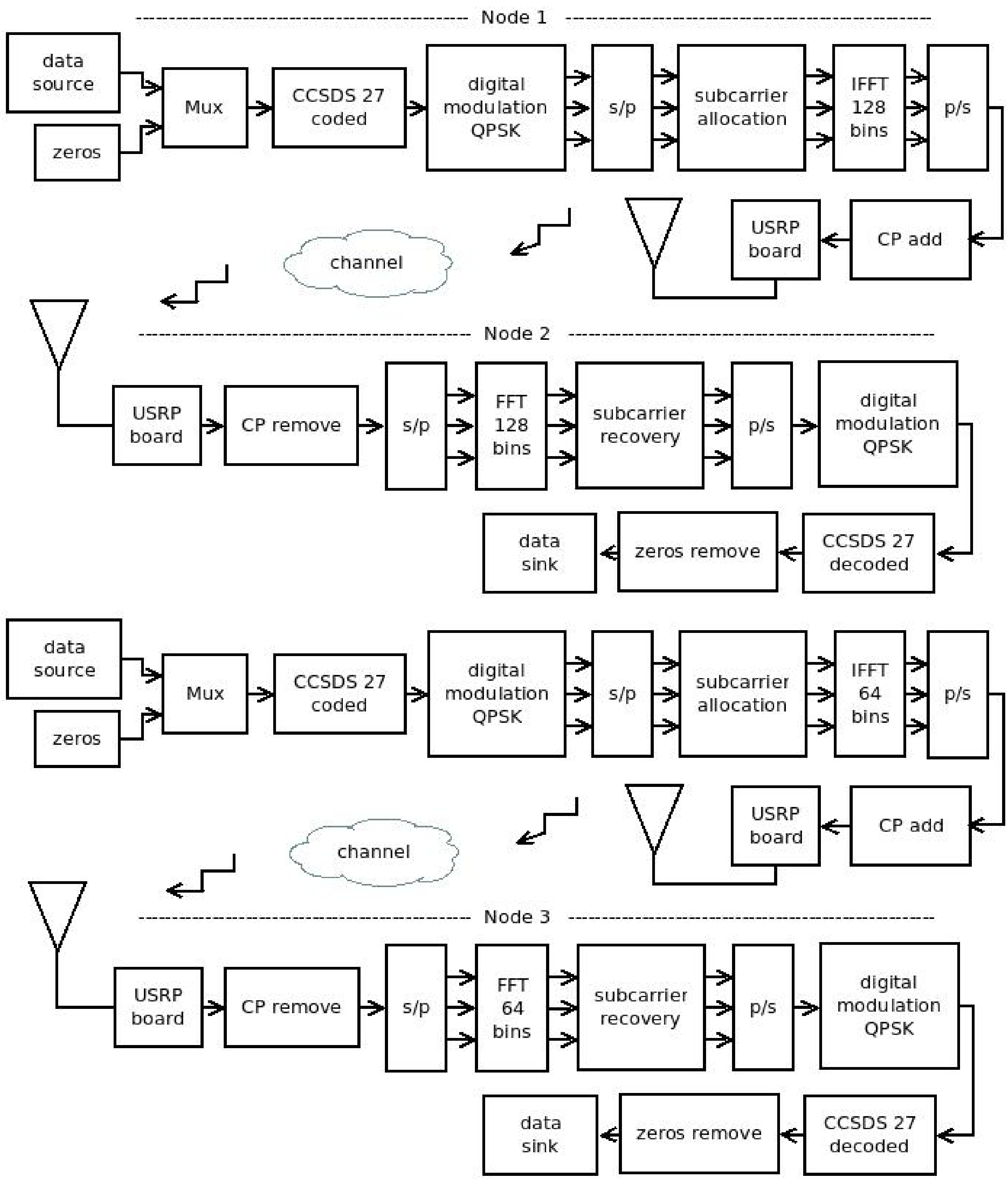

Figure 1. Block diagram of the three nodes mounted in the experiment.