ACTIVE SELF INTERFERENCE CANCELLATION TECHNIQUES IN FULL DUPLEX COMMUNICATION SYSTEMS - A SURVEY

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Abstract

In this paper we present a survey based on vast research done in the area of various important factors relating to full duplex communication revealing several facts. In fact these revelation has served to be vital in the future design of any full duplex communication system . The major problem or challenge faced in such a system was the interference caused from the transmitting antenna on the receiver antenna placed at the same node. The interference was termed as ' self interference'. Wireless transceivers nodes can select between transmit and receive functions on the same frequency band at different time (Time Division Duplex-TDD) or they can transmit at the same time at different frequencies (Frequency Division Duplex-FDD). Recently researchers have put forth a new radio system, that can operate full duplex over a single channel , that is transmitting and receiving at the same time on the same frequency band. This kind of system is overwhelmed by interference. Interference need to be reduced to the point where the receiver can detect even the weakest signal of interest. Several active interference cancellation techniques that can help in self interference reduction have been proposed. The in depth survey was helpful enough to come out with a novel solution to an antenna design based on passive suppression techniques using polarization and other diversity techniques so as to reduce the self interference problem.

Keywords: *Self Interference, Time Division Duplex, Frequency Division Duplex, Polarization, Passive suppression.*

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1. INTRODUCTION

Full duplex communication has the potential to double the capacity through the removal of a separate frequency band/time slot for both forward and reverse links, and there has been much recent interest in full-duplex communication systems operating on a common carrier. Advances in antenna designs and analog/digital interference cancelation circuits have shown significant progress in canceling the self interference, and make the design of a single channel full duplex (SC-FD) communication system a possibility.

Efficient approach and use of available spectrum resource is the main challenge in wireless communication system. In conventional wireless communication systems, the two main processes for preventing interference are time-division and frequency-division, which separate the uplink and downlink channels in the time domain and frequency domain to achieve bidirectional communication, both approaches are so-called half-duplex communication techniques. There are several techniques which put forwards the possibility to transmit and receive signals in the same frequency band simultaneously. Comparing with traditional methods, single channel in place of two ones is used for duplex, thus in theory, channel capacity can potentially be twofold comparing with half-duplex.

The key challenge in achieving true full-duplex communication is the large power differential between the "self-interference" created by a node's own radio transmission and the signal of interest originating from a distant node. The large power differential is simply because the self-interference signal has to travel much shorter distances compared to the signal of interest. As a result of the large power differential, the signal of interest is swamped by the self-interference in digital baseband due to finite resolution of analog-to-digital conversion[16].

Achieving such a system capable of full duplex communication would overcome several drawback in wireless communication networks such as bandwidth constraints, ubiquitous demand for high transmission rates reducing self interference effects in full duplex operation, enhancing performance in packet collision detection and mitigating hidden terminal problems etc.

A Single Channel Full Duplex System alleviates several wireless bottleneck situations. With no time division, the hidden node problem is reduced since the access point respond without delay to the first transmitting node .Other nodes hear that response and delay their transmissions reducing collisions. Full Duplex reduces loss of network throughput and the delay in multi hop networks. Earlier, Full Duplex prototypes with off-the shelf parts and incorporating IEEE 802.15.4 Modulation/Demodulation schemes with 1mw Transmit power achieves performance within 8% of an ideal system to a distance maximum up to 8m LOS[1].

The full-duplex communication causes wide attention, although it has been proposed in a short while, and it sounds a little unapparent and extraordinary. Some recent researches have verified the feasibility of full duplex wireless device in practice [1,3,4,8,9]. To realize full duplex operation, the key issue is that how to as much as possible, cancel the large self-interference signal.

2. BACKGROUND STUDY

Wireless communication is becoming increasingly pervasive in day to day life. The one and old perception regarding wire free communication is that information through radio cannot be transmitted in the same frequency band at the same time. In normal case a transmitting node cannot receive data from another node, until its own transmission is over. Even if it happens to receive or attempts to receive while transmitting, packet collision occurs. This one way communication is termed as the half duplex wireless communication. Wireless communication has made it possible to transmit and receive simultaneously with self interference cancellation and suppression techniques. This is called full duplex wireless system. Shortcomings in transmitting and receiving at the same time have led on to several problems in wireless system.

It was way back in 1997 the idea of integrated active antenna capable of full duplex operation came up. Metal–semiconductor field-effect transistor (MESFET) centrally mounted on the edge of the patch to form an oscillator and another MESFET [2], configured as an amplifier on the orthogonal edge to act as the first stage in a receiver. The inherent isolation of the center points of orthogonal edges of a square patch was used as the basis for the transmit–receive isolation. This transceiver was linearly polarized with transmit and receive channels on orthogonal polarizations. The channels were of the same frequency, but could be offset depending on the application. A method to improve the isolation of the single patch is that of sequential rotation. Here, the receiver outputs were taken from opposite edges of the two patches and the phases of the direct feed through signals from transmit to receive were adjusted so that they are 180̊ out of phase which upon combining, will cancel.

The received signals are forced to be 180̊ out of phase by the positions of the receiver outputs; thus, when combined they will add in-phase. This method increased the isolation by 20–30 dB.

Several works in the design of single channel full duplex wireless transceivers have already being done of which a work[1] where a combination of RF and baseband techniques were used to achieve full duplex with minimal effect of link reliability. The work also proposes a novel technique for self interference cancellation using multiple antennas (up to 30dB cancellation). This technique in conjunction with RF and digital baseband interference cancellation offers up to 60 dB suppression. They evaluated how antenna placement affects cancellation and the signal profile at the transmit antenna's intended receiver. For narrowband systems, the technique was sufficiently durable and long lasting. The three basic limitations to this design were: transmit power, size and bandwidth .It proposes ways to overcome the challenges in full duplex wireless systems like hidden terminal problem, where for. node A and C can communicate with node B but are hidden from each other, throughput loss due to congestion, and large transmitter end-to- receiver end delays.

Another simple, low calculative cost and a technique with sufficient convergent rate and low maladjustment[1] was proposed few years back , which was done using adaptive digital interference cancellation technique based on adaptive filter. The adaptive filter can track the real-time changes of the self-interference signal and adaptively adjust own coefficients with the error signal to minimize fine delay, amplitude and phase offsets between the self-interference signal and the recreated signal. This method is possible to cancel about 20 dB of self interference signal.

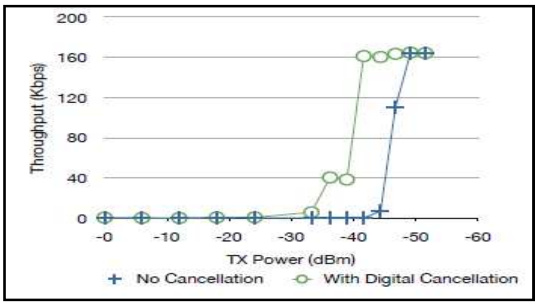

Fig 1: Receive throughput at a node with self interference using digital interference cancellation [1]

The analog domain cancellation provides good cancellation at centre frequency. Discussing about the analog approach to self interference cancellation ,analog techniques employs a second transmitting wire to produce an analog cancellation or suppression signal, which is subtracted from the received signal. Some other analog interference cancellation mechanisms use QHx220 noise canceling chip to remove a known analog self-interference signal from the received signal. Recently most researches concentrate on antenna placement and analog interference cancellation, the study of digital interference cancellation is only a few in [1, 14, 16, 11], and the performance is not very desirable. For example, the digital interference cancellation achieves only around 10-20dB reduction of self-interference signal in [1].

The antenna cancellation technique discussed in [1] employs cancellation with three antennas to create radiation pattern null that totally cancels out the self interference at the receiver antenna at the same full duplex node, and also uses antenna placement as an additional cancellation technique with this.

For a wavelength λ, of the three antennas two are for transmit purpose placed at a distance 'd' and d +λ/2 apart from the receiver antenna. Transmit antennas add destructively to cancel out each other, causing a null position where receiver antenna hears a much weaker signals .The input signal to the closer antenna is attenuated to get the received amplitude to match the signal from the second transmit antenna ,thus achieving better cancellation up to 20dB.

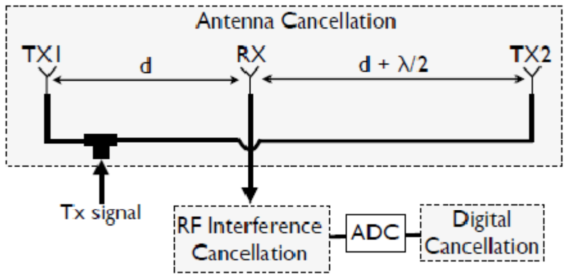

Fig 2 : Multiple Antenna Self interference cancellation + RF and Digital cancellation.[3]

Balun cancellation is proposed [3], using a balanced-to-unbalanced converter (balun) in an absolutely new way. In this proposal, the inverse of self interference is obtained by a balun and uses this generated inverted signal to cancel the self-interference signal. The transmit antenna of a node transmits the positive signal which produces the self-interference signal. For canceling the self-interference signal, the radio combines the negative signal from the balun with its received signal. The inverse signal is a modified signal by a variable delay element and a variable attenuator to as far as possible match is obtained to the self-interference signal. The balun based cancellation technique theoretically has no limitation on bandwidth or power, and can offer self-interference suppression perfectly, by at least 45dB.

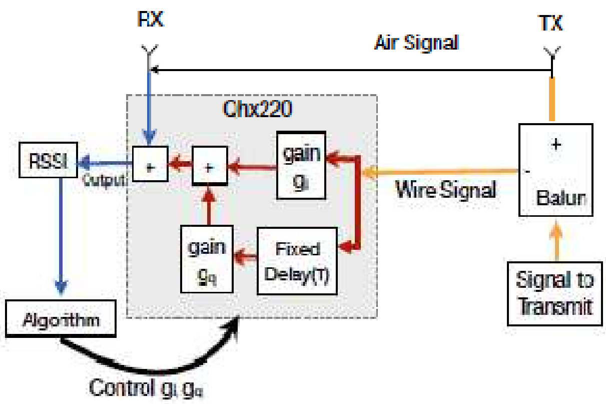

Fig 3 : Block diagram of full duplex system with Balun active cancellation[3]

Another way in which the isolation between the transmit and receive antenna is increased with low insertion loss was proposed [4] in full duplex communication using on a common carrier operating with a single antenna.

In the single antenna configuration setup two feed points which helps the antenna to radiate and receive signals with polarization diversity. The feed points are given equal amplitude but with 90 degree relative phase difference. A balanced feed network as shown in figure satisfies the requirements providing isolation up to 40 dB.

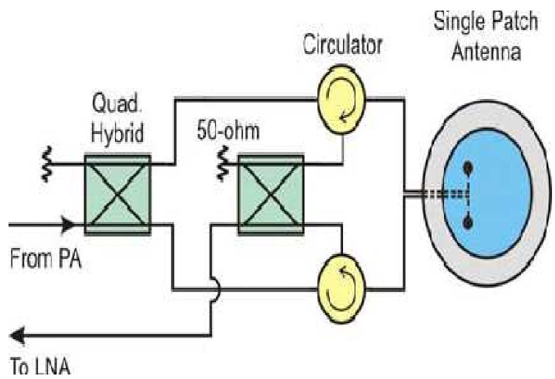

Fig 4: Diagram of the single antenna with balanced feed network providing high transmit channel to receive channel isolation.[4]

Directional diversity [5] unlike the other active self -interference cancellation techniques where active components are used and an active cancellation signal is being produced. In this idea a passive approach where directional antennas in wireless networks was used with three main motivations. (1) Decreasing interference between devices and (2) improving power efficiency and (3) Pushing the range limitations of full duplex communication systems. Thus directional diversity provides additional passive suppression for self interference. Passive suppression via directional antennas also allows full-duplex to achieve significant gains over half-duplex even without resorting to the use of extra hardware for performing RF cancellation as has been required in the previous work. The measure of the angle in between the uplink and downlink directions is important, the larger this angle, the more one can isolate the transmitter from the receiver via antenna directionality factor.

Very recently an RF interference cancellation technique combined with a combination of variable attenuator and phase shifter [9] with a general antenna was proposed. Along with digital interference cancellation techniques a self interference suppression of -75dB was achieved.

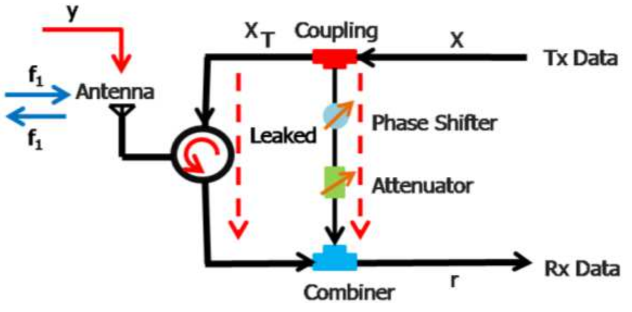

Fig 5: Proposed RF interference cancellation technique [9].

2.1 Summary of Cancellation Techniques:

Analog Domain Cancellation: ~30dB
Radio Frequency Interference Cancellation (RFIC): ~45dB
Feed Forward Technique: 40-45dB
Antenna Cancellation Technique: ~30dB
Using Baluns +RFIC + Digital Cancellation: ~73dB

After a thorough study through the various self interference cancellation techniques we come to know that most of them use active signals or components like noise cancellation chips for self interference cancellation. However our work concentrates on passive self interference reduction using techniques like polarization and directional diversity.

3. PROPOSED WORK

Every self interference cancellation technique primarily need to overcome the noise floor range ,which is the measure of signal created from the sum of all noise sources and unwanted signal . For example for 802.15.4 systems, which use 0dBm transmit power[1], the power of the transmit antenna's signal at a receive antenna placed 6 inches away is ~-40dBm. The noise floor is ~-100dBm, hence if we can remove 60dB of self-interference by cancellation, we can decode the receive antenna's signal.

Our proposal improves on the complexity of design of all prior related works on a full-duplex wireless system that can transmit and receive at the same time in the same frequency band. Since they require at least two antennas having one for transmit and one for receive antenna. The key challenge in realizing such a system lies in addressing the self-interference generated by the transmit antenna at the receiver end antenna. For example, one can implement the above self-interference cancellation idea completely in analog domain using noise cancellation circuits as reported by Radunovic [6] But practical noise cancellation circuits can only handle a dynamic range of at most ~30 dB.

We consider designing the antenna and applying the technology to IEEE 802.11 radio where the transmission power and bandwidth are larger ,where much larger interference need to be suppressed. Polarization and directional diversity of Transmit/Receive antennas were tested during design for achieving better isolation of self - interference between the Transmit and Receive antenna parts. Measured values of self interference suppression is expected to be acceptable considering the already proposed ideas where ,approx.~73dB as in case of combined analog and digital cancellation techniques 40-45dB was reduced using balanced feed networks.

The objective in the design by directional orientation and polarization diversity applications makes it capable for reducing the self interference problem , there by increasing the efficiency in Single Channel-Full duplex Communication systems with single propagation paths .

4. CONCLUSIONS

Self interference cancellation techniques can be too prejudicing as it would need to ignore several technical limitations. The prospects and consequences of each method was surveyed and studied to understand the actual contribution from each technique, mostly the active cancellation ones. The suppression levels of self interference that was achieved was worthily noted.

Extending full duplex communication to a longer range could remain a challenge primarily due to the residual self interference even with the combination of passive and active cancellation methods. Proposed work concentrates on passive cancellation ideas where less complexity, power, and size is ensured .The novel idea of polarization diversity in suppressing self interference at full duplex nodes is brought up. Investigate and overcome the effect of self interference problem in the design of a novel patch antenna at a transceiver node at 2.4Ghz.Carry out polarization and space diversity to maximize isolation. Directional diversity by orientation, Design possibility of Transmit and Receive antennas on same substrate reducing size and cost., Higher total self interference reduction is expected out of the total work.

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BIOGRAPHIES

Basim Basheer received his BTech Degree in Electronics & Comm. from College of Engg, Attingal (IHRD), Kerala in 2010. He is currently pursuing his MTech degree in Wireless Technology under Cochin University of Science and Technology. His areas of interest include hardware design, RF planning, Antenna designing and Microwave engineering.

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