Demo: Flexible Array of Inexpensive Radios

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ABSTRACT

In this demo, we propose to use multiple inexpensive off-the-shelf radios to build the FAIR system that can be flexibly configured to realize (1) non-contiguous spectrum access (2) MIMO and beamforming (3) constructing wider-band radio. While non-contiguous spectrum access and MIMO/beamforming are naturally supported by the FAIR system, we further develop radio bonding technique for constructing wider-band radio. Radio bonding provides a cost effective alternative to proprietary radio development that it can realize a non-existing wider-band radio using multiple commodity narrower-band radios. We demonstrate FAIR and radio bonding based on Sora 2.0.

Categories and Subject Descriptors

C.2.1 [**COMPUTER-COMMUNICATION NETWORKS**]: Network Architecture and Design—*Wireless communication*

Keywords

FAIR; Radio Bonding; Wider-band Radio; Sora2.0

1. INTRODUCTION

Non-contiguous spectrum access [4, 6] has been shown effective for handling spectrum fragments in unlicensed bands, *e.g.* the fragments due to narrow-band devices like zigbee in ISM bands or the fragments due to incumbents in white spaces. Recently, non-contiguous spectrum access has even been adopted into WiFi standards that a 80+80 MHz mode is introduced in 802.11ac [3]. However, from radio design point of view, non-contiguous spectrum access posts new challenges. First, the fragments could span a very wide range in spectrum. For example, in 802.11ac 80+80MHz mode, two 80MHz channels can span up to 645MHz. Second, there can be strong interference in between the fragments for which we need to either do analog filtering or reserve additional dynamic range to prevent radio saturation. To construct a radio for non-contiguous spectrum access, if we follow the traditional way of building a single radio chain, the radio will be very difficult (if not impossible) to realize. Particularly for the ADC component, the requirements will be 645MHz sampling rate to fulfill Nyquist sampling rate as well as over 100dB dynamic range to tolerate possible strong interference in between. Adding dynamically configurable band-reject filters could be a way to reduce the requirements, but these analog filters are non-trivial to design and implement.

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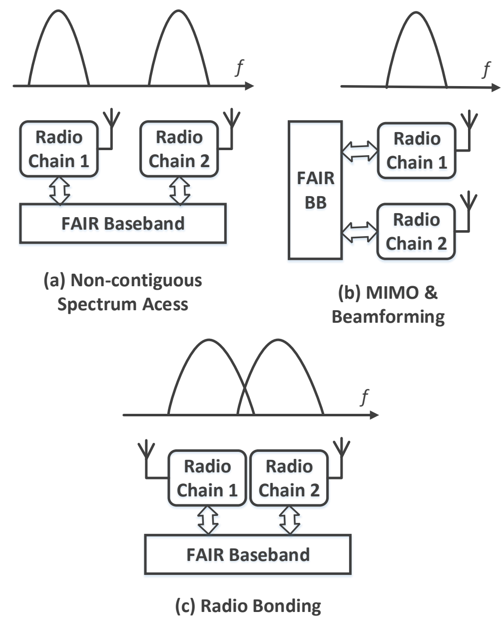

Figure 1: (a) FAIR naturally realize non-contiguous spectrum access (b) As a multiple radio system, FAIR supports MIMO and beamforming (c) radio bonding in FAIR provides a cost effective alternative to proprietary radio development for constructing wider-band radio

Using multiple radio chains is a more practical solution. Take 802.11ac as an example, if we use two radio chains to implement the 80+80 mode, each radio will only need 80MHz sampling rate and the interference in between will be naturally rejected by baseband filter of the radios. Recently, benefit from the adoption of MIMO (Multiple Input Multiple Output) technique, wireless devices equipped with multiple radio chains have already been ubiquitous in access points and laptops. Moreover, the chipset industry are keeping devoting effort for more compact and more energy efficient solution. Nowadays, chipset with multiple radio chains can be even equipped in mobile devices like Microsoft Surface and some other latest tablets [2].

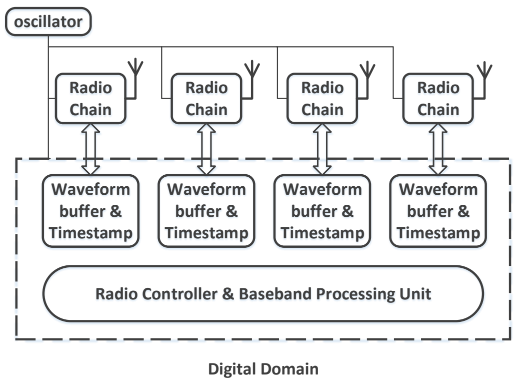

Figure 2: FAIR Architecture

In this demonstration, we propose the system FAIR (Flexible Array of Inexpensive Radios) in which multiple inexpensive off-the-shelf radios can be flexibly configured to realize many features that are in high demand, including (1) Non-contiguous spectrum access (2) MIMO and beamforming (3) constructing wider-band radio. While non-contiguous spectrum access and MIMO/beamforming are naturally supported in FAIR by setting multiple radio chains into different or the same central frequency, we further develop radio bonding technique which bonds multiple radio chains to construct a wider-band radio. Radio bonding provides a cost effective alternative to proprietary radio development if we need to construct a wider-band radio which is not available as commodity. Technically, radio bonding is also different from previous multi-radio architecture [5] because it can be viewed as a single radio from PHY/MAC layer and above. Figure 1 (c) illustrates the idea of radio bonding while Figure 1 (a)(b) shows FAIR can naturally support non-contiguous spectrum access and MIMO/beamforming.

We implemented FAIR using Sora 2.0 which equips four 20MHz 802.11a/g radios. The demonstration scenario focuses on radio bonding. We implemented a 40MHz 802.11n PHY using two 20MHz FAIR radios for radio bonding. Then we demonstrate a wireless link between this FAIR based implementation and a commodity 40MHz 802.11n access point.

2. FAIR ARCHITECTURE

The architecture of the FAIR system is shown in Figure 2. FAIR contains multiple radio chains that each can independently transmits and receives waveform in a limited bandwidth. These radio chains are off-the-shelf radios thus inexpensive and sophisticated, like 20MHz/40MHz 802.11n radios presently or 80MHz/160MHz 802.11ac radios in the near future. All the radio chains in FAIR share a common oscillator to drive ADC/DAC and generate carrier frequency. Clock sharing facilitates FAIR baseband by avoiding central frequency offset and sampling frequency offset among the radio chains.

All the radio chains are connected to a common digital domain logic via ADC output and DAC input. Inside this digital domain, each radio chain has a corresponding TX waveform buffer and RX waveform buffer. Then, all these buffers are connected to a common baseband processing unit for various FAIR baseband processing. In order to realize different features, different baseband algorithms are invoked from this baseband processing unit. Besides, there is a radio controller which controls parameters for all the radio chains, *e.g.* central frequency, bandwidth, gains, *etc.*. This centralized radio controller fulfills the basic frequency configuration requirement for enabling different features, *i.e.* MIMO/beamforming, non-contiguous spectrum access and radio bonding, in a single FAIR system. For example, we configure the radio chains to be different central frequencies for non-contiguous spectrum access, whereas we configure the radio chainss to be the same central frequency for MIMO and beamforming. Radio bonding could be viewed as a special case of non-contiguous spectrum access that the radio chains are configured on adjacent frequencies.

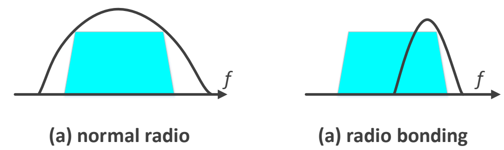

Figure 3: In radio bonding, each narrower-band radio receives only a portion of the whole signal which is distorted by non-rectangular analog filters

The whole digital domain logic could be implemented in different forms, *e.g.* ASIC, programable hardware like FPGA, graphic processor, general purpose processor, or a combination of several/all. In this demo, we use Sora software radio system that most of the digital domain logic is implemented in CPU while the other is implemented in FPGA.

2.1 Time Synchronization

Besides clock sharing mentioned above, time synchronization among multiple radio chains is also critical. For example, MIMO transmitter requires precise control that samples on different radio chains are sent out at exactly the same time, whereas at receiver side baseband processor needs to exactly know which samples are taken from the same time. Similarly, time synchronization is also critial to radio bonding and non-contiguous spectrum access.

In order to enable time synchronization, we added a hardware clock in FAIR which is shared for all the radio chains. At each ADC output, timestamps are inserted to digital samples based on this shared hardware clock. On the other hand, this hardware clock will be checked when digital waveform is going to DAC inputs. With the help of this shared hardware clock, FAIR transmitter can precisely synchronize waveform for all the radio chains and FAIR receiver can identify samples taken at the same time.

2.2 Radio Bonding

Radio bonding is to bond two or more radios to construct a wider-band radio. It provides a cost effective alternative to proprietory radio development while a wider-band radio is not yet available as commodity. For example, at the time of this demonstration that 160MHz 802.11ac device is not available, by applying radio bonding, we could build a 160MHz 802.11ac radio by bonding four 40MHz 802.11n radios or two 80MHz 802.11ac radios, thereby enabling 802.11ac 160MHz mode.

The biggest challenge which makes radio bonding non-trivial to accomplish is the distortion caused by band limited analog components and rate limited ADC of the narrower-band radios. As shown in Figure 3 (b), each narrower-band radio in radio bonding only receives a portion of the whole signal. Since the filters are not ideal rectangular filters, the received signal is distorted. In contrast, as shown in Figure 3 (a), in a normal radio the filters always have wider passband than signal width therefore the signal is never distorted. In addition to distortion, there is also a unique phase offset added by each radio chain. This phase offset is introduced in down-

Figure 4: Sora 2.0 Hardware

converter where the received signal is mixed with a phase-unknown carrier frequency LO (Local Oscillator).

In oder to address these challenges, we introduce modeling and compensating techniques. Specifically, to deal with signal distortion, we build a model for the filters and measure parameters for all the radio chains. To deal with phase offset, we estimate phase offset among the radio chains in advance. Then during signal receiving, we compensate both signal distortion and phase offset before adding the signal from multiple radio chains together. Finally, the whole signal is recovered and can be viewed as if it is received by a single wider-band radio.

3. SORA 2.0

We implemented FAIR using Sora 2.0 [1]. As shown in Figure 4, sora 2.0 hardware is a stand-alone box which connects to a PC via a up to 8-lane PCIe cable. Each sora 2.0 box equips four 20MHz 802.11a/g radios or 40MHz 802.11n radios. These four radios share a common reference clock for sampling and synthesizing carrier frequency so that it is capable to implement MIMO and beamforming. All the radios are mounted on a RAB (Radio Adapter Board) for radio configuration and further mounted to a RCB (Radio Control Board) to transmit digital waveforms into and from PC through the PCIe link.

Sora 2.0 comes with a SDK (Software Development Kit) which contains Windows drivers and a 802.11n baseband sample featuring 2x2 MIMO. The FAIR baseband implementation is based on sora UMX (User Mode eXtension) with which all the baseband codes are runing in user mode.

4. DEMONSTRATION

The demonstration scenario is shown in Figure 5. We focus the demonstration on radio bonding that we implemented the single stream 40MHz mode of 802.11n PHY using two 20MHz radios. To demonstrate, we set up a wireless link between this FAIR based 40MHz 802.11n and a commodity 40MHz 802.11n radio. We show that this FAIR based implementation can seamlessly communicate with the commodity 802.11n device by transmitting bidirectional bitstreams between them.

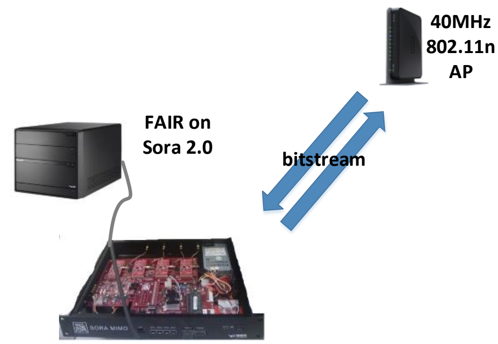

Figure 5: Demonstration scenario

4.1 Facility Requirements

Our facility requirements can be listed as follows.

- **Equipment Requirement:** A Sora 2.0 kit is needed which contains a Sora hardware box, a desktop PC running software radio algorithms and accessories. In addition, a 802.11n AP is needed as a wider-band radio and a laptop is needed to control the AP.

- **Space Requirement:** There is no special requirements for the exhibition space. A normal desk or table will work. On the desk or table, a Sora 2.0 box, a desktop PC, an AP and a laptop will be placed.

- **Power and Internet Requirement:** The power plug is needed for Sora 2.0 box, desktop PC, AP and laptop. In the demo, the Wi-Fi connection might be required.

5. REFERENCES

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