Dynamic Spectrum Access for Advanced Wireless Networks

Dr. G. Vinoda Reddy, Md. Hafeena

Professor of CSE (AI & ML), CMR Technical Campus, Hyderabad, Telangana, India.
Assistant Professor of CSE (AI & ML) Department, CMR Technical Campus, Hyderabad

Abstract: Considerable research effort has been paid to spectrum management and device coordination for dynamic spectrum access (DSA) networks. However, because it is challenging to achieve spectrum-agile communications, contemporary wireless devices have not yet completely embraced DSA networks. More effective spectrum utilization is required by next-generation wireless networks in order to meet growing data demands and a variety of communication needs. One important way to maximize spectral efficiency and enhance network performance is through the use of spectrum shaping, a method for dynamically allocating frequency resources. An overview of quick spectrum shaping methods designed for next-generation wireless networks is provided in this research. We examine the fundamental ideas, difficulties, and prospects related to spectrum shaping and talk about the most current developments in this area. In addition, we assess how our quick spectrum shaping architecture could improve the effectiveness and adaptability of next wireless networks.

Keywords: Software defined radio, hybrid radio, spectrum agility, per-frame spectrum shaping, spectrum agile preamble detection.

I.INTRODUCTION

The issue of spectrum scarcity in wireless networks has gained traction with the use of dynamic spectrum access (DSA), also known as spectrum agility [6]. By merely expanding their bandwidth, new devices that are intended to exploit a monolithic piece of spectrum may no longer hope to boost throughput. In fact, when facing 20-MHz interference from another 802.11 g or 802.11n device, the throughput of an 802.11n device running at 40 MHz may even be lower than its throughput at 20 MH,. When rate or bandwidth is naively raised in an effort to extract greater throughput from an overloaded spectrum, several additional studies have documented performance problems. With the advent of 802.11ac, which supports bandwidth up to 160 MHz, we can only anticipate that these issues will get worse. Although this example focuses on Wi-Fi networks for clarity in explanation, non-Wi-Fi networks also frequently experience the impossibility of improving performance by simply adding bandwidth. A wideband device cannot function within the GSM band without some kind of spectrum agility, for instance, according to a study of GSM usage trends.

Building effective spectrum-agile devices is still difficult for two key reasons, despite the apparent issue and the list of well-researched remedies. First off, since most commercial wireless devices on the market today are made to employ static, monolithic spectra, they are not well suited for DSA networks. For instance, channel-switch durations on the order of milliseconds are seen in all spectrum- and bandwidth-agile platforms, including SampleWidth [5] and FLUID [20].

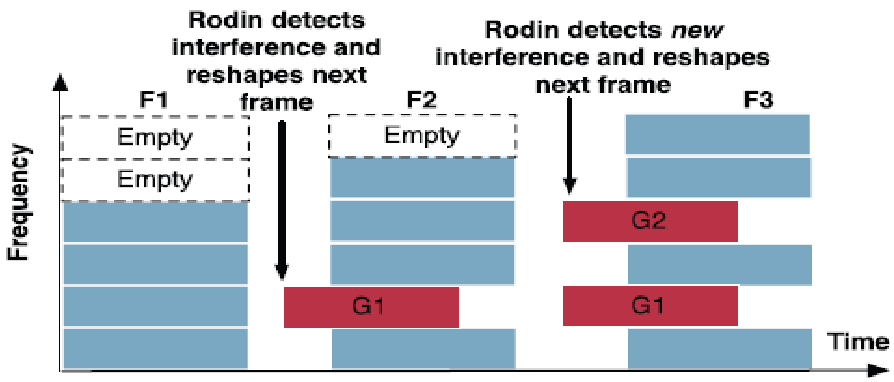


Figure 1. Transmission of three frames.

Secondly, there is a partial support for spectrum agile communications in the protocol stack. As an illustration, take into consideration 802.11n OFDM frames that are identified by taking advantage of the preamble's self-correlation feature. When the preamble is dispersed throughout a noncontiguous spectrum or encounters interference from devices with smaller bands, this method is ineffective. Noncontiguous OFDM (NC-OFDM) methods can be used, although synchronization can only be carried out at the receiver if and when the set of noncontiguous subcarriers is known in advance. We contend that the essential function lacking from the most advanced radio gear available today is per-frame spectrum shaping. This is a crucial functional basic that enables a radio to adjust to difficult channel circumstances at the lowest feasible transmission unit.

II. SPECTRUM SHAPING

The implementation of real-time spectrum shaping necessitates two prerequisites: 1) a low latency spectrumshaping technique; and 2) minimum synchronisation between the spectrum shapers on the transmitter and receiver. The shaper's efficiency is determined by Property 1, which states that it must swiftly and with little delay reshape the spectrum when the required subbands are specified. On the other hand, Property 2 deals with the spectrum shaper's ability to withstand mistakes brought on by timing, channel distortion, frequency shifts, and other factors. Because different PHY protocols utilise different strategies to counteract distortions, this is very crucial.

The Schmidl-Cox algorithm is used in OFDM-based protocols, whereas Rake receivers and equalisers are used in DSSS-based protocols. It is evident that supporting the large range of synchronisation primitives required to achieve protocol independence is not possible for RODIN. Therefore, protocol-specific DSP tasks (such pilot handling) are left to the COTS device, while RODIN concentrates on spectrum shaping. In wireless communication, signals travel via radio frequency from a source to a receiver. This technique is used by everything from radio and television to GPS and mobile phone services to transmit data in little chunks over the air. A group of radio frequencies that are available for transmission is known as the wireless spectrum.
A COTS device's spectrum is divided into several non-contiguous frequency bands using a process known as spectrum shaping.

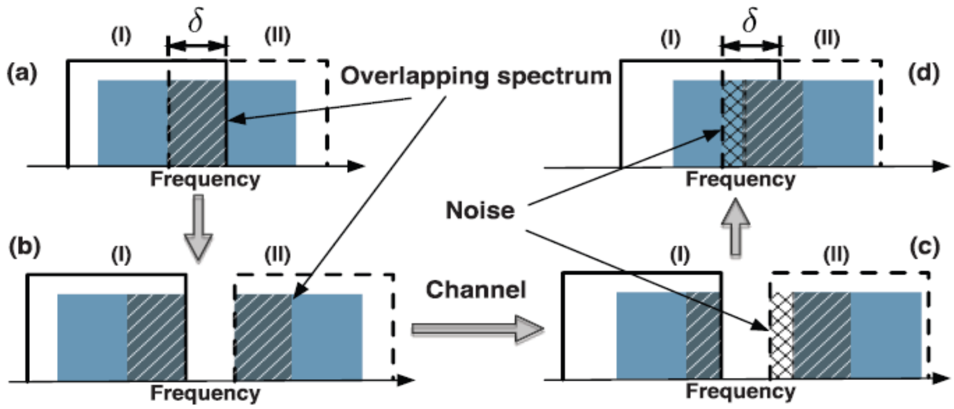


Figure 2. Spectrum shaping using two partially overlapping filters.

Here a,b,c,d represents

a) Two subbands share an overlapping band
b) After postfilter modulation, each subband contains a copy of the overlapping spectrum
c) As a result of frequency drift at the receiver, only a portion of one subband is recovered while the other subband is recovered along with a noise band
d) The overlapping spectrum ensures that the original spectrum can be reconstructed even if one subband is not recovered completely.

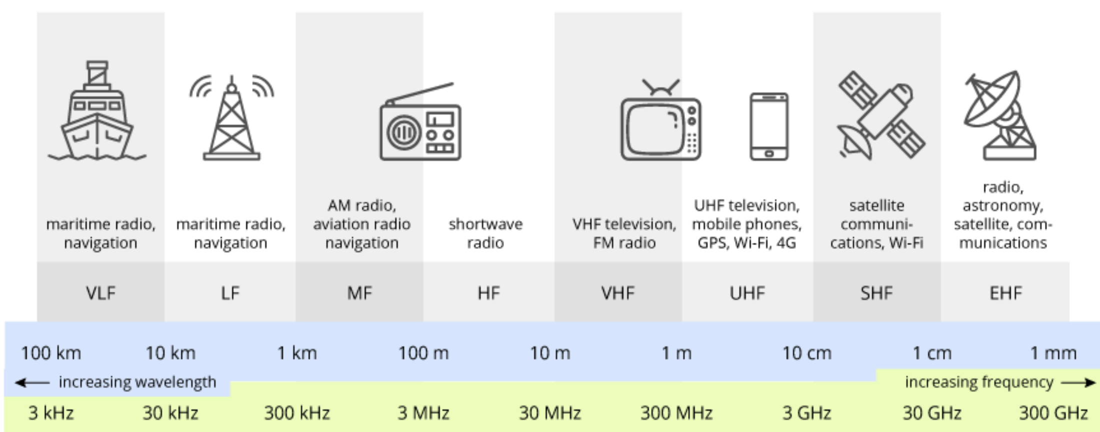


Figure 3. Application and radio frequency.

varied bands have somewhat varied features because cellular communications may use a broad variety of spectrum frequencies. Low-, mid-, and high-band spectrum are the three categories into which wireless spectrum falls in wireless communication. Reliable spectrum 5G networks need all three. This is so because some applications and forms of communication need the usage of a certain spectrum band:

fewer than 3 GHz low-band spectrum has a greater range with fewer signal interference. Modern wireless networks are created by Wireless Communications Inc. using low-band spectrum. Using this frequency, wireless may create high-speed networks that span 99.7% of the US population.

When comparing low-band and high-band spectrum, the former spans far longer distances (think metres, not miles), while the latter offers enormous capacity and very quick speeds. A combination of low- and high-band characteristics are combined in mid-band spectrum (between 3 and 24 GHz) to provide a range of coverage and capacity. For instance, the IoT spectrum.

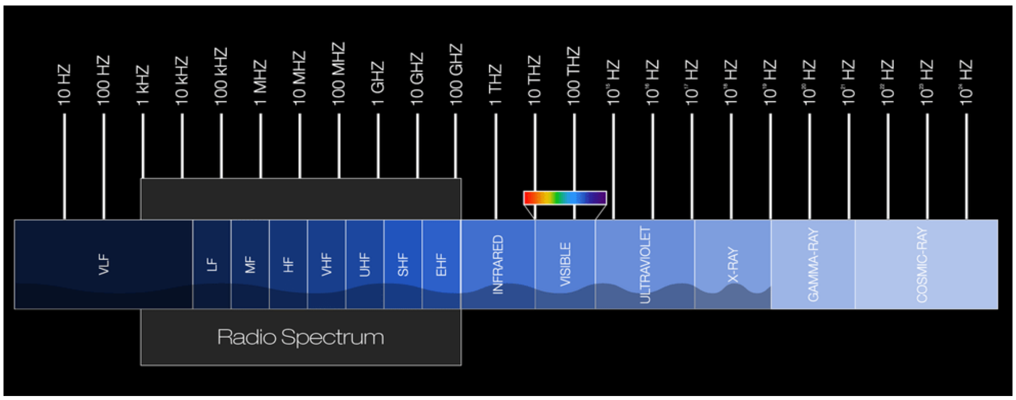


Figure 4. Radio spectrum.

Cell sites and our mobile devices interact using certain wireless radio frequencies. Today's most common cell sites are the 150-foot cell towers that we are used to seeing along roadsides or atop tall buildings. Small-scale antennas, also known as tiny cells, are now being built at a quick pace in order to increase the frequency of connection sites for 5G's mid- and high-band spectrum and to densify network coverage.

III.WIRELESS SPECTRUM WORK

The electromagnetic (EM) spectrum includes the radio frequency (RF) spectrum, which powers every wireless device, including our smartphones and home Wi-Fi. In contemporary communication, radio broadcasts travel across invisible channels called spectrums. Depending on their intended function, frequency bands within the RF spectrum are divided. A small portion of the electromagnetic spectrum, which also includes visible light, X-rays, and other wavelengths, is made up of these bands. The following diagram illustrates the various frequency bands as well as those of the radio frequency spectrum.

All of the radio frequencies that are accessible for transmission together make up the wireless spectrum. Wireless communications uses radio frequency to transfer signals from a source to a receiver. Wireless systems that employ this technique to transmit data in bits over the air include anything from radio and radar broadcasting to Internet of Things wireless technologies like Bluetooth and Wi-Fi.

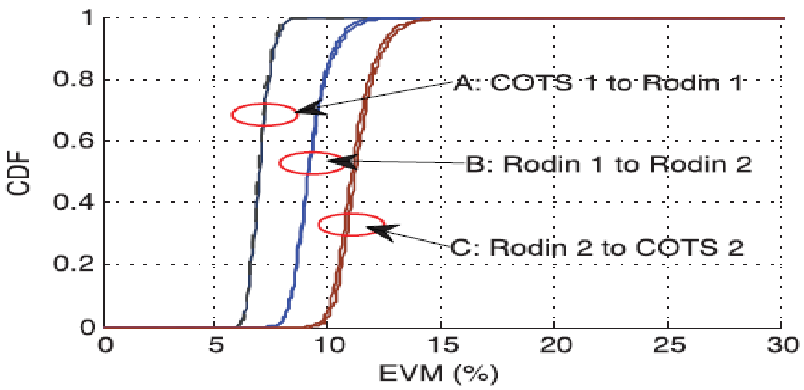


Figure 5. EVM of symbols in an OFDM frame with and without spectrum shaping.

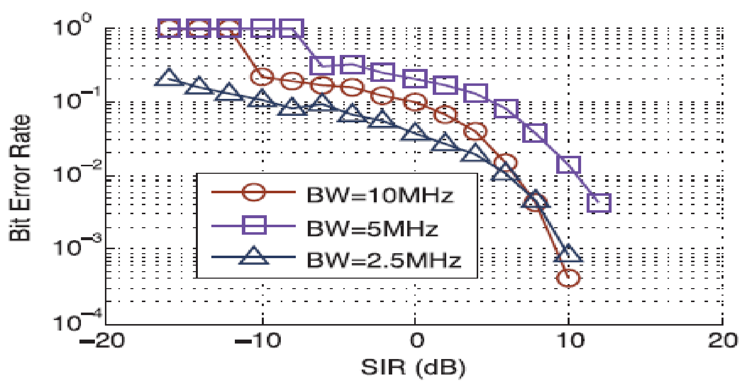


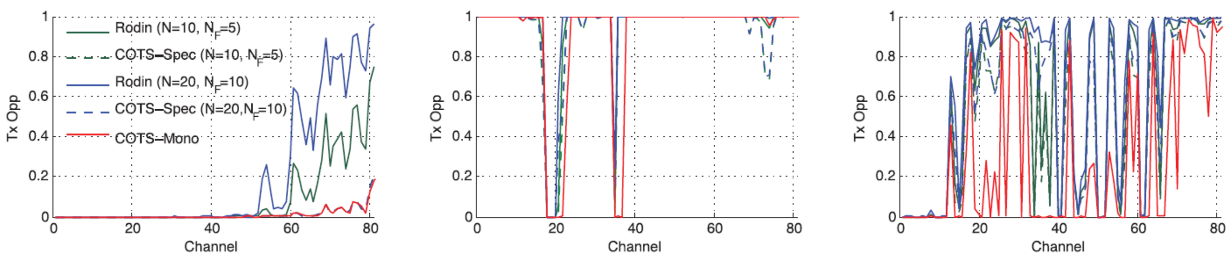
Figure 6. BER of OFDM frames measured at COTS 2 without shaping.

No errors are encountered when spectrum shaping is used. A radio is effectively given instructions on which frequency to "listen to," and therefore which stream of data to convert to audio output, when we tune it to the channel of our choice. If two radio stations are broadcasting simultaneously, on the same frequency, in the same region, interference and distortion will result. As a result, no two radio stations broadcast simultaneously, on the same frequency, or in the same location. All services that use radio waves to transmit or receive data fall under this category.

IV.SPECTRUM MANAGEMENT

The pseudocode that describes how the Spectrum Manager works. Until frames from the COTS device are identified, RODIN is in the receive state. The RX spectrum-shaping filters are set up in this state to span the occupied spectrum that each received I-FOP indicates. Upon the COTS device transmitting a frame, RODIN first sets up the TX spectrum-shaping filters and TX I-FOP to cover the subbands of the transmit spectrum. Following the filtering and modulation of the COTS device samples, the preamble is broadcast. Following the completion of I-FOP transmission, the spectrally shaped samples are communicated. shows how the configuration for assessing each RODIN device's performance is done. Every RODIN spectrum shaper operates on the FPGA of a WARP platform with four radios and is built in Verilog/VHDL.

The Tx or Rx mode is always selected on each radio. A circulator, which is linked to a COTS device, receives a pair of Tx/Rx radios from each WARP device. Coaxial cables are used to make these connections. Between the COTS device and the two radios on the WARP, passband signals are routed via a circulator. Analogue signals from the COTS device are delivered only to the Rx radio on the WARP, and signals from the Tx radio on the WARP are routed solely to the COTS device. The circulator blocks signals between the Rx and Tx radios.In this case, the circulator is utilised to allow RODIN to receive frames from the COTS device without experiencing the Tx-Rx switching delay that would otherwise be caused by the radio hardware when connecting the COTS device to a single radio. Each WARP device has a direct connection to an antenna for its other two Tx/Rx radios. There are around two metres between the two RODIN devices. For COTS 1 and 2, the Ralink 802.11a Wi-Fi card has been used with success. For the remaining tests, however, we employ WARP for COTS 1 and 2 in order to get more precise control over the sent signal for experimental reasons.



(a) 5250MHz. (b) 2250MHz. (c) 770MHz.

Figure 7. Proportion of time slots that each of the devices, RODIN, COTS-Spec, and COTS-Mono, can transmit in.

Between the two COTS devices, we transmit uncoded OFDM frames with a bandwidth of 10 MHz. Within the 20 MHz maximum bandwidth that each radio may handle, the OFDM frames' spectrum can be tailored to cover any 10 MHz of spectrum. We divided the 10-MHz OFDM frame into two subbands, each measuring 5 MHz, for all of the tests in this section. There is a 10-MHz gap between these subbands when they are sent. By monitoring the RSSI of the Rx radio that is directly linked to the circulator, each RODIN device detects signals from the COTS device that is attached to it. It is presumed that the COTS device is transmitting if the RSSI rises beyond a certain threshold. The high signal-to-noise ratio (SNR) of transmissions over coaxial cable makes this task simple. The COTS device receives and processes incoming signals constantly from the Tx radio at all other times. As a result, the COTS device may continue to overhear communications from other devices using the same contiguous spectrum. Bit error rate (BER), which is the proportion of bits received incorrectly, and error vector magnitude (EVM), which is shown as a percentage, are the two measures we use to assess the spectrum shaper's performance.

```
while True do
    while No frame from COTS device detected do
        ŷ[n] ← next sample from RF frontend;
        if Preamble detected at ŷ[n] then
            Configure Rx Spectrum Shaper to span
            subbands of next frame;
        end
        Send ŷ[n] to Rx Spectrum Shaper;
        Send output of Rx Spectrum Shaper to COTS
        wireless device;
    end
    while Frame from COTS device detected do
        Configure filters in Tx Spectrum Shaper to
        appropriate subbands, if necessary;
        Configure Tx Preamble to tag occupied
        subbands;
        Transmit preamble from Tx Preamble;
        x[n] ← next sample from COTS device;
        Send x[n] to Tx Spectrum Shaper;
        Send output of Tx Spectrum Shaper to RF
        frontend;
    end
end
```

V. RESUTLS AND DISCUSSION

Using the configuration shown in Figure 7, we send 2,000 OFDM frames with QPSK symbols from COTS 1 to COTS 2. We then calculate the mean EVM of the frames between each pair of devices that are directly linked. Spectrum shaping is used in this experiment twice, once with and once without it. Figure 8 displays the measured EVM's CDF. A significant inference drawn from this outcome is that the signal is not distorted by spectrum shaping. With and without the transmitted OFDM frame's spectrum shaping, the EVM's CDF across each OFDM frame is the same. Thus, without sacrificing signal quality, real-time spectrum shaping may be accomplished in the FPGA.

There is some distortion added to a signal when it is directly manipulated from a COTS device with an associated RODIN platform. In Fig. 7, the frames transmitted over Link A have a median EVM of 7%, but the frames shaped spectrally and delivered over Link B have a median EVM of 9%. Ultimately, the median EVM rises to 11% as a result of the transfer over Link C to COTS 2. These extra distortions are produced by two processes: 1) time and frequency offsets between the COTS device and its associated WARP, and 2) up and down signal modulation by the AD/DA converters at both COTS devices and the radios on the WARP. Greater integration between RODIN and the COTS device can eliminate both of these sources of distortion: distortion from up/down converters can be minimised by directly passing the baseband signal between RODIN and the COTS device; distortion from time and frequency offsets can be reduced by synchronising RODIN with the COTS device's clock.

The OFDM transmission is greatly affected by narrowband interference in the absence of spectrum shaping. The larger the interference power per subcarrier for a given interference power, the narrower the interference bandwidth.The result of this is that the distortion of the OFDM frames resulting from the 5-MHz interference is larger than that of the 10-MHz frames; this is because there is enough increased interference power on fewer subcarriers to offset the decrease in the number of subcarriers that experience interference. The minimal number of impacted subcarriers at 2.5 MHz enables the EVM to drop below that of a 10-MHz interference when that bandwidth is used.

In order to cover the 2.4- and 5-GHz ISM bands used by Wi-Fi equipment, each channel measurement of [9] covers a 1.6-GHz bandwidth that is centred at three separate frequencies: 770, 2,250, and 5,250 MHz. Three separate sites were used for measurements over the course of many days; for the sake of simplicity, we only provide findings using the data set collected from the school's rooftop. It takes around 1.8 seconds to cover the whole 1.6 GHz bandwidth in one sweep, capturing 8,192 samples, each covering 200 kHz. Channel statistics have been shown to be constant at shorter time scales, despite the measurement data not capturing channel use patterns longer than 1.8 s [15]. This strongly implies that such statistics should be expected to exist at short enough time scales for RODIN to be meaningful. Therefore, our research based on this data remains relevant even when taking into account more detailed channel use patterns.

In our simulations, we represent three distinct kinds of wireless devices: two that allow spectrum shaping and one that doesn't. Every gadget has a maximum radio frequency bandwidth of 20 MHz. The transmitted signal has a bandwidth of 10 MHz, while the remaining 10 MHz is allocated for spectrum reallocation. The gain from per-frame spectrum shaping is dependent on the temporal variability; the higher the frequency of channel interference level changes, the higher the need for quick spectrum shaping. The correlation coefficient of the RSSI for each trace set across time is shown in Fig. 13. Channels with a median correlation value of around 0.3 and significant temporal variability are seen in the 5,250 MHz data set. The strong correlation values, on the other hand, indicate that the channels in the 770- and 2,250-MHz data sets have little temporal fluctuation. Thus, we anticipate that in the 5,250-MHz channels as opposed to other frequencies, the benefit from per-frame spectrum shaping will be higher.

VI.CONCLUSION

This study offers an overview of how rapidly spectrum shaping methods are developing for next-generation wireless networks. Fast spectrum shaping promises to transform spectrum management and allow more effective use of frequency resources by leveraging developments in cognitive radio, machine learning, and software-defined networking. This research presents the advantages and disadvantages of implementing quick spectrum shaping in future wireless communication systems using a thorough architecture and performance assessment. .For dynamic spectrum access (DSA) networks, device coordination and spectrum management have drawn a lot of research interest. But because of the challenges in implementing spectrum-agile communications, modern wireless devices have not yet completely embraced DSA networks. We respond to the crucial issue, "What is a simple practical extension to current wireless devices that makes them spectrum-agile?" by addressing the real-world challenges and offering methods for putting DSA devices into practice. Our proposal, RODIN, is a general per-frame spectrum-shaping protocol that supports DSA in commercial off-the-shelf (COTS) wireless devices. Its features include fast FPGA-based spectrum shaping, direct manipulation of passband signals from COTS devices, and a unique preamble design for spectrum agreement. To accomplish per-frame spectrum shaping with a latency of less than 10 μs, RODIN combines a preamble I-FOP with an FPGA-based spectrum shaper.

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