Responses to NTIA-2023-0003-0001
Responses by Aditya Dhananjay, Pi-Radio (aditya.dhananjay@pi-rad.io)

Pillar 1, Question 1

As the wireless ecosystem hurtled toward 6G, it is increasingly clear that more spectrum will be required to meet the projected data demands. The sub-6 GHz bands are severely congested, and the 5G mmWave bands (24 GHz and above) have not had the kind of commercial success that was envisioned. The reason for this is that the propagation at the mmWave bands is challenging; the signals are easily blocked. Maintaining connectivity requires a dense deployment of base stations, which in reality, are expensive to build and deploy. Further, a majority of users are indoors, and the indoor-to-outdoor propagation in the mmWave bands is poor. Therefore, to enable 6G, we have to look at spectrum sharing in the mid-bands (roughly, in the 6-24 GHz range). The goal of identifying 1500 MHz of spectrum is a good target. This will be a game changer in the communications world.

It is my opinion that trying to repurpose 2G/3G spectrum will not be a real game changer, since the amount of spectrum allocated to these services is not very large. This spectrum is also very fragmented.

In terms of allowable transmit power, there is no one-size-fits-all answer. The reality is that it depends on the usage scenario (urban, semi-urban, or rural), as well as on the frequency of operation. But in terms of link budgets, gunning for 10dB SNR over a 1-2 km distance would be a good target.

Pillar 1, Question 2

I will skip this question since it is outside of my area of expertise.

Pillar 1, Question 3

I cannot speak to which spectrum bands in particular should be opened up for sharing. However, irrespective of which spectrum bands are chosen for sharing, it is absolutely important to experimentally demonstrate coexistence and spectrum sharing. There are a wide variety of incumbents with vastly different characteristics. For example, one incumbent could be a ground station receiver of a satellite transmission, trying to detect a very weak signal from a far-off satellite. Another incumbent could be a RADAR transmitter blasting away massive amounts of power. Clearly, the way that spectrum sharing and coexistence work should depend on the kind of incumbent that we're trying to share with.

Given this heterogeneity, it is imperative that experimental validation of spectrum sharing and coexistence be done in a replicable and reproducible manner. This means that researchers (academia, governmental laboratories, private sector companies) should have access to affordable prototyping platforms based on software-defined radios (SDRs) to run such experiments. It is only after such demonstrations are done, can rule makers have confidence that new technologies can work, without harming incumbents. Such experimental efforts, including the development of the underlying prototyping platforms like SDRs, needs to be supported.

It is only through such experimentation that rule-makers can decide which bands to open up, and which kinds of incumbents are safe to coexist with.

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Pillar 1, Question 4

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Pillar 1, Question 5

The government's spectrum management processes should be decided through replicable and reproducible experiments that demonstrate the following: 1) can the new users derive benefit from the spectrum; and 2) are any incumbents harmed?

Not all incumbents are equal from a technology standpoint. Not all incumbents are equal from a national security or national interest standpoint. We believe that it is only through spectrum sharing and coexistence experiments/demonstrations that decisions should be made to operate in this band or that band.

Pillar 1, Question 6

It is my belief that incumbent users of spectrum should not have to change or be modified in any significant way. The only possible change would be for incumbent users to signal their use of spectrum through a database. Other than that, we believe that the changes made to incumbent users would be very significant and expensive. Let technology innovation drive the new users of the spectrum to share with incumbents, without harming them.

The key technical challenge is to build experiments and demonstrations that have the following two aspects: 1) an incumbent spectrum user like a RADAR system or a satellite communication link; and 2) a new user of the spectrum who is trying to opportunistically use the same spectrum. The demonstrations should show that the new users are able to use the spectrum and derive significant benefit, while the incumbent user does not have its key performance indicators (KPIs) affected in any meaningful or negative way.

It is clear that such systems require a significant R&D effort to design and build. It is important that the NTIA funds such experimental works. For example, funding the creation/deployment of software-defined radio (SDR) based testbeds where such spectrum sharing or coexistence experiments can be run. As far as we know, there are no commercially available SDRs that operate in the 6-24 GHz bands. This is stymieing the development of technologies related to spectrum sharing. At Pi-Radio, we have started the development of such an SDR that can be used for such experimentation. Testbeds should be built using such SDRs, and these testbeds can be used to build and demonstrate spectrum sharing.

We believe that there are two ways that such a testbed can be built. In the first way, a shared testbed can be co-located with an existing NSF funded wireless testbed like any of the PAWR deployments (COSMOS, POWDER, AERPAW) or at Colosseum at Northeastern University. Such a testbed makes the hardware accessible to users in-person or remotely. The second method is for various universities to have their own (albeit, smaller scale) testbeds in their own laboratories. This has advantages related to flexibility and control of experimental scenarios.

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The critical goal should be to build wireless SDR-based testbeds that operate in the required bands (6-24 GHz), while supporting experiments related to coexistence and spectrum sharing. From the vendor side, Pi-Radio is working on an effort to build 6-24 GHz SDRs with 8-channel fully-digital (i.e., MIMO) beamformers, and keep these SDRs plainly affordable.

Pillar 1, Question 7

The right way to do spectrum sharing is an open research question. The answer depends on the characteristics of the incumbents, as well as that of the new users of the spectrum. There is no one-size-fits-all approach. What's needed is experimental demonstration of a variety of spectrum sharing and coexistence techniques. This is why SDR-based testbeds are critical.

Pillar 1, Question 8

I will skip this question since it is outside of my area of expertise.

Pillar 1, Question 9

I will skip this question since it is outside of my area of expertise.

Pillar 2, Question 1

I will skip this question since it is outside of my area of expertise.

Pillar 2, Question 2

We do need data on the current spectrum users along three dimensions: space (i.e., location), time, and frequency. Who is using the spectrum, where, when, and which frequencies? The burden should not rest solely on the incumbents to declare their spectrum use. They have the license to the spectrum, and additional burdens on them are unfair, because that's not what they signed off on. The burden should be on the new users who want to use what's already been licensed to someone else.

As a result, a key challenge is performing spectrum sensing. We need to build sensing tools that can sense the wireless medium to see who's using what and when. Once such tools are demonstrated, it should be the responsibility of the new users of the spectrum to deploy a network of such sensors in their area of operation, to make sure that they don't interfere with incumbent users. More R&D is required on such sensing tools. We believe that such prototypes should be built using SDRs.

Pillar 2, Question 3

I will skip this question since it is outside of my area of expertise.

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Pillar 2, Question 4

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Pillar 2, Question 5

I will skip this question since it is outside of my area of expertise.

Pillar 2, Question 6

I will skip this question since it is outside of my area of expertise.

Pillar 2, Question 7

Workforce development is a key area of national interest. The US does not produce enough wireless engineers who have real-world practical skills. A vast majority of wireless engineers (from EE programs) graduate with advanced degrees without ever having transmitted or received a real wireless signal ever. Wireless education is dominated by theory and simulations. As important as theory and simulations are, this is not sufficient to produce engineers who know how to build real-world systems.

To solve the spectrum problems of the future, Universities need to do a better job of making experimentation in wireless more common. For a regular academic research group, getting funding to build a small-scale testbed in their laboratory remains very hard. Shared wireless testbeds solve this problem to some degree, but in-person experimentation remains the gold standard.

As an analogy, consider the system that produces musicians like pianists. Suppose a vast majority of students did not have access to a piano. Further, suppose that some pianos were kept in a central location, and students could log on and remotely control the piano in a time-shared manner over a MIDI interface. Would this system produce concert pianists of any caliber? Most certainly not. But somehow, in wireless, we seem to be content with doing things this way. SDRs need to be made affordable such that every lab can afford a few, just like how every CS department has computers. Reference software implementations need to be free and open-source; (Open Air Interface) is one such effort. Efforts that produce affordable but advanced SDRs in the relevant bands (6-24 GHz) need to be supported. Testbeds need to be supported, even if the scale of testbeds at various labs remains modest. This is the only way that, in the long term, the US produces enough engineers of high caliber who can build real-world wireless systems.

Pillar 3, All questions:

I will skip these questions since they are outside of my area of expertise.

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Summary

Solving complex problems (like spectrum sharing) requires experimentation. We can perform simulations and theoretical analyses until the cows come home, but until systems are demonstrated in the real-world, we have nothing.

Right now, performing experiments in the candidate spectrum sharing bands (6-24 GHz) remains difficult to do because of the lack of prototyping hardware (i.e., SDRs) that operate in these bands. A few giants in the industry certainly have the capability to build their own, but this is hardly a democratic process. We need to make experimentation accessible to the wireless research community at large, and do so in a way that is plainly affordable.

To contribute to the solution, Pi-Radio has embarked on an effort to build 6-24 GHz SDRs with an 8-channel fully-digital (i.e., MIMO) beamformer. This SDR can be used to implement systems that consist of incumbent spectrum users, as well as new users who desire to use the same spectrum. Pi-Radio's goal is to make this SDR plainly affordable, while remaining powerful from a technical standpoint. We are looking to contribute toward this effort to solve the spectrum challenges of the future.