Achieving National Scale Infrastructure for Spectrum Monitoring

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***Abstract*—Achieving national scale infrastructure for spectrum monitoring will require virtualization of spectrum sensors, a cloud-based architecture using open interfaces, and transparency in the modules that perform signal processing and data analysis.**

Keywords—spectrum monitoring, virtualized spectrum monitors, cloud-based processing, open interfaces

I. Abstract

Efficient use of the RF spectrum relies on sharing, which requires effective spectrum monitoring and interference management. Spectrum monitoring is a fundamental capability that provides the data needed to make real-time, dynamic decisions regarding the use of spectrum, as well as historical data used for policy making and regulatory enforcement. A **nationwide** spectrum monitoring infrastructure is needed to fully realize the potential of dynamic spectrum sharing. We believe that the future nationwide spectrum monitoring system should be built off the following building blocks: 1) virtualized spectrum monitors/sensors 2) scalable, nationwide cloud-based infrastructure 3) open interfaces and 4) open-source modules for signal processing and data analysis.

There are still many questions to be answered regarding what the future of dynamic spectrum sharing will look like, which means the infrastructure built now should be flexible and support a variety of wireless technologies and signal processing techniques, including those that do not yet exist. Using **virtualized spectrum monitors**, in place of traditional sensors that perform the RF collection and signal processing in one box, we can provide the flexibility needed for the future, as well as divide the challenges of spectrum monitoring into more manageable pieces. A virtualized spectrum monitor consists of a hardware and software component, that are most likely **not** collocated (i.e., not in one box on a pole). On the hardware side, a frequency-agile RF frontend and digitizer offload RF samples to a data processing center, representing an edge sensing device. While a certain level of energy detection may be desired at the edge, in order to reduce data backhaul requirements, the core signal detection, classification, and identification should be performed in reconfigurable software. This software could be located at the edge and/or within a central data center, but it should not be tied to the specific hardware vendor. The software side of the virtualized spectrum monitor should consist of a series of **modules** that process the RF data or the results from other upstream modules. Not all modules will be signal processing modules, some could be data fusion/analysis and would run in the cloud, in order to have access to as much spectrum data as possible.

Using a virtualized spectrum monitoring approach will require a scalable and nationwide **cloud-based infrastructure**. In addition to the signal processing side, the process of determining when and where spectrum can be occupied will require substantial computational resources. It is quite possible that the future of spectrum sharing will involve system-level simulation, essentially a "digital twin" of the spectrum, to run interference analysis and determine whether certain communications can coexist. The scalability and elasticity of the cloud should be leveraged for these efforts. Novel cloud-based services are being released every year, and while there is no way to know exactly what will exist in 5-10 years from now, using a cloud-native architecture from the start will allow us to best leverage future technology.

The operation of a nationwide network of virtualized spectrum monitors will of course be complex task. Likely, there would not be a single entity that operates it in its entirety, but instead multiple organizations and companies working in coordination. To operate at hyperscale, cloud providers have had to tackle similar problems, and have come up with **standardized approaches for orchestration and management**, such as Kubernetes. The Cloud Native Computing Foundation (CNCF) serves as a cross industry forum for collaboratively developing these standards. Much of CNCF's work can be extended to serve as building blocks for this infrastructure. Using widely adopted commercial standards would allow for this infrastructure to keep pace in a rapidly advancing market and ensure that the development focus is kept on the aspects that are truly unique.

Virtualized spectrum monitors can only be realized if the supporting **interfaces** exist, to allow for multi-vendor RF hardware, processing modules, and compute infrastructure. We believe these interfaces should be as open as possible, to allow for maximum innovation and transparency. Luckily there are ongoing efforts related to open interfaces, including the IEEE Standard for Spectrum Characterization and Occupancy Sensing (IEEE 802.15.22.3-2020) which provides a standard architecture and messaging for spectrum sensors, as well as the Digital Intermediate Frequency Interoperability (DIFI) standard for streaming digital IF. Combining existing standards with additional open interfaces for processing modules should provide a great foundation for the future nationwide spectrum monitoring system. Most importantly, these interfaces should support ability for processing to be collocated at the edge and in the cloud, and support heterogeneous computing so that FPGAs, GPUs, and other processors (both at the edge and within the cloud) can be leveraged. Lastly, the open interfaces should not only support virtualized spectrum monitors, but also input from telemetry from communications systems operating in shared spectrum.

The arguably most complex part of dynamic spectrum sharing is acquiring useful occupancy and emitter information. This information must be reliable, as it will be used for high-valued decisions. We believe that a **large set of modules that perform signal processing and data analysis** will form the heart of the future nationwide spectrum monitoring system. It is critical that these modules are implemented in a **transparent** manner, in the form of **open-source software**, so that third parties can independently verify that the information being gathered through signal processing does not invade privacy or go against regulations. Proper regulatory enforcement of spectrum misuse will require trusted details about how the malicious emitters were acting, and it's important that this information is gathered in a trusted manner. Creation of these modules should not be limited to any specific groups; a grad student should be able to create one as a thesis project. An open interface, combined with an SDK, will be needed to facilitate cross-platform compatibility. We believe that while this SDK should be created from scratch, the existing **GNU Radio** tools and ecosystem can be heavily leveraged for the design, prototyping, and testing of any modules that perform signal processing. It may also be possible for GNU Radio to act as a temporary framework for performing the virtualized signal processing live, until the proper SDK is created and refined. This will lead to a smoother transition between prototyping and fielding of modules.

Virtualizing spectrum monitors will allow for rapidly evolvable and waveform-specific signal processing, with the transparency needed for use in regulatory decision making. While dynamic spectrum sharing has come a long way over the past decade, there are still many challenges blocking the realization of a nationwide and vendor/operator agnostic spectrum monitoring system.

References

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