Before the
DEPARTMENT OF COMMERCE
National Telecommunications and Information Administration
Washington, D.C. 20230

In the Matter of	)	
	)	Docket Number: 230308–0068
Development of a National Spectrum Strategy	)	
	)	

COMMENTS OF THE NSF AERIAL EXPERIMENTATION AND RESEARCH PLATFORM ON ADVANCED WIRELESS (AERPAW)

The NSF Aerial Experimentation and Research Platform on Advanced Wireless (AERPAW) project appreciates the opportunity to respond to National Telecommunications and Information Administration (NTIA)'s request for comment ("RFC") on the Development of a National Spectrum Strategy.

I. INTRODUCTION

The NSF AERPAW Platform is one of the four PAWR platforms that are funded by the National Science Foundation. AERPAW is the first wireless research platform to study the convergence of 5G technology and autonomous drones. Awarded by over $11M of cash funding through the PAWR Project Office (PPO), and over $6M of additional in kind contributions from wireless industry, AERPAW is led by North Carolina State University, in partnership with Wireless Research Center of North Carolina, Mississippi State University, and Renaissance Computing Institute (RENCI) at the University of North Carolina at Chapel Hill; additional partners include Purdue University, University of South Carolina, and several other academic, industry and municipal partners. AERPAW offers its users an experimentation environment with programmable radio access network (RAN) technologies based on open-source software, commercial off-the-shelf hardware, and programmable unmanned aerial and ground vehicles (UAVs/UGVs) with 5G and beyond technologies.

To that end, AERPAW is providing comments to the NTIA in the following two sections: 1) Overview of AERPAW and related capabilities, and 2) AERPAW's views on the questions presented in NTIA's request for comments (RFC) on the national spectrum strategy.

II. AERPAW OVERVIEW

AERPAW is a multi-year, multi-phase project that started in September 2019 and its development is expected to be finalized in 2025. AERPAW experimentation capabilities became generally available with an initial set of resources and features in November 2021. These capabilities include channel propagation studies in sub-6 GHz bands, LTE experimentation, and spectrum monitoring at fixed ground nodes as well as UAVs. Additional platform resources, sample experiments, and experimentation capabilities are expected to be released at the end of Phase-2 (by August 2023) and Phase-3 (by August 2024). AERPAW is primarily and essentially a testbed of physical resources, not computing resources. The crucial part of these physical resources are: (i) the RF environment and the airspace that the AERPAW operating areas represent; (ii) the physical equipment (SDRs, commercial RF equipment, fixed towers, UAVs, UGVs, and helikite) that AERPAW provides to leverage those environments for experimental studies; and (iii) the expertise (and consequent exemptions) in conducting such studies in compliance with FCC and FAA regulations that AERPAW represents.

Physically, the testbed is hosted at sites in and around the NC State campus in Raleigh, NC. Central to AERPAW's unique characteristic is the availability of UAVs and UGVs in the testbed that can be placed under the direct programmatic control (of trajectories) of the researcher. In conjunction with the programmable USRPs that are also available for direct programming by the researchers, as well as other real-world, commercial radio equipment, this provides the NextG wireless researcher a facility for research experiments not practicable in any other facility at this time.

Fixed Nodes, Portable Nodes, and Vehicles: At a very high level, the facility includes a number of tower locations (fixed nodes), at each of which some combination of AERPAW programmable software defined radios (SDRs) and commercial radio equipment (such as an Ericsson 4G/5G base station, multiple Keysight RF sensors with spectrum monitoring and signal decoding capabilities up to 6 GHz, and LoRa gateways) are permanently installed. The SDRs are controlled by servers, or companion computers (CCs), installed in each location that also offer edge-computing capabilities. These fixed node locations are distributed over the extensive Lake Wheeler Agricultural Fields of NC State University, and some nodes are also installed in the Centennial Campus of NC State University. The complement of these fixed nodes are AERPAW's portable nodes, also consisting of a computer and SDR(s), but smaller ones so that an AERPAW portable node can be mounted on a UAV/UGV. The CC on a portable node, an Intel NUC, also controls the UAV/UGV itself. A smaller version of the portable node that can get carried at the smaller UAV is also available, to do experiments with mobile phones and LoRa sensors that are connected to a LattePanda as the CC. More information on AERPAW is available at the AERPAW Facility website (aerpaw.org) and the User Manual linked therefrom, and previous publications including [5]. A list of representative recent references related to AERPAW and our recent research related to wireless connectivity and spectrum management with aerial platforms are also included at the end of this document [1-38].

III. AERPAW'S VIEWS ON THE ISSUES IDENTIFIED IN THE NTIA RFC ON THE NATIONAL SPECTRUM STRATEGY

There have been several important questions raised in the NTIA RFC on the National Spectrum Strategy. Our comments below are generally centered around the view that there needs to be dedicated spectrum bands to support command, control, and payload communications with non-terrestrial networks and unmanned aerial systems, due to significant demand for such systems in the future and increasing utilization of those networks. Moreover, our view is that the national spectrum strategy should be shaped significantly by real-world data that consists of detailed and accurate spectrum measurements collected in different environments, time scales, and network configurations.

Pillar #1—A Spectrum Pipeline To Ensure U.S. Leadership in Spectrum-Based Technologies

1. What are projected future spectrum requirements of the services or missions of concern to you in the short (less than 3 years), medium (3–6 years) and long (7–10 years) term? What are the spectrum requirements for next-generation networks and emerging technologies and standards under development (e.g., 5G Advanced, 6G, Wi-Fi 8)? Are there additional or different requirements you can identify as needed to support future government capabilities? What are the use cases and anticipated high-level technical specifications (e.g., power, target data rates) that drive these requirements? How much, if at all, should our strategy by informed by work being performed within recognized standards-setting bodies (e.g., 3GPP, IEEE), international agencies (e.g., ITU), and non-U.S. regulators or policymakers (e.g., the European Union)? What relationship (if any) should our strategy have to the work of these entities? Are there spectrum bands supporting legacy technology (e.g., 3G, GSM, CDMA, etc.) that can be repurposed to support newer technologies for federal or non-federal use?

The increasing popularity of UAVs has resulted in a significant rise in the number of commercial UAVs in the skies. According to a report by the Federal Aviation Administration (FAA), the number of registered commercial UAVs in the US reached over 450,000 in 2020. Furthermore, a study by Drone Industry Insights estimated that there were approximately 580,000 commercial drones in operation in the US in 2020, with this number expected to increase to 1.55 million by 2025. Based on the same report, the energy sector is the largest industry that uses drones, while the transport sector has been growing rapidly. NASA and FAA have been developing concepts for Unmanned Aircraft System Traffic Management (UTM) and Advanced Aerial Mobility (AAM), which will allow the integration of drones and air taxis into the national airspace. Technology, standards, and regulations in this area have been advancing rapidly. As the UAV technology continues to advance and becomes more accessible, the number of commercial drones in the skies is expected to rise significantly in the next 5 to 10 years. The drone technology is also critical for national defense, as it has been more apparent based on the ongoing war in Ukraine.

Drones require the use of wireless spectrum in all the services and missions identified in page 16245 (second page) of the NTIA's RFC on the Development of a National Spectrum Strategy: Fixed and mobile wireless broadband services; next-generation satellite communications and other space-based systems; advanced transportation technologies; industrial and commercial applications, (i.e., manufacturing, agriculture, and utilities); wireless medical devices and telemedicine; Internet of Things (IoT) and smart cities; national defense and homeland security; safeguarding the national airspace and ports; securing the Nation's critical infrastructure; earth and space exploration and research; climate monitoring and forecasting, and other scientific endeavors. As these different services and missions are adopted by communities and organizations, and the density of drones keeps increasing in the future, the existing spectrum resources will not be sufficient to service these vehicles that rely on continuous wireless communications for their safe operation. Such spectrum for drones may use a variety of wireless technologies, ranging from WiFi, Bluetooth, 4G LTE, 5G NR, and LoRa, among others, including radio frequency (RF) based radar and sensing technologies at sub-6 GHz and millimeter wave bands.

Currently, the 5030-5091 MHz band is being considered by the FCC to serve as a dedicated band for safety-critical UAS command-and-control communications. However, use cases of drones may require high data rate communications, e.g. for real-time video streaming for situational awareness purposes. Existing 4G and 5G cellular networks may be used to support broadband communications with drones. However, since the existing networks are not designed to serve aerial users, connectivity with drones at higher altitudes can be spotty – see e.g. research studies [3,4,10,13,34] from the AERPAW team, among other studies in literature. One of the reasons for this is the base station antennas typically being down-tilted to serve ground users, and aerial users being served by antenna side-lobes or ground reflections.

Drones, when operating as user equipment, may also have a very high uplink interference footprint even at modest altitudes, interfering to even very distant base stations due to line-of-sight propagation conditions. Operators can deploy antennas directed to the skies to improve wireless coverage for drones, especially when the drones are allowed to fly only within predetermined drone corridors (see e.g. [2,7,23,32,36]). These problems will increase exponentially as the number of small drones and other aerial vehicles (such as air taxis and mid-range delivery drones) keep increasing in the future.

2. Describe why the amount of spectrum now available will be insufficient to deliver current or future services or capabilities of concern to stakeholders. We are particularly interested in any information on the utilization of existing spectrum resources (including in historically underserved or disconnected communities such as rural areas and Tribal lands) or technical specifications for minimum bandwidths for future services or capabilities. As discussed in greater detail in Pillar #3, are there options available for increasing spectrum access in addition to or instead of repurposing spectrum (*i.e.,* improving the technological capabilities of deployed systems, increasing or improving infrastructure build outs)?

It may be possible to improve utilization of existing terrestrial spectrum bands for simultaneous use with aerial wireless devices, if there are additional investments for adding extra set of antennas at cellular towers pointed to the skies, dedicated for serving the drones and other aerial vehicles. In other words, spectrum can be reused in spatial domain. There may still be coupling between transmissions to users on the ground and aerial users. However, there can be ways to mitigate such interference. For example, inter-cell interference coordination with almost blank subframes in the 4G LTE technology can be utilized to manage high interference to/from UAVs [13]. Similar mitigation approaches based on time-domain blanking can also be utilized for 5G NR technology, for example, by using flexible symbol periods that can be silenced when interference scenario is detected. All these likely require additional investments (both OPEX and CAPEX) from operators to accommodate drone users.

3. What spectrum bands should be studied for potential repurposing for the services or missions of interest or concern to you over the short, medium, and long term? Why should opening or expanding access to those bands be a national priority. For each band identified, what are some anticipated concerns? Are there spectrum access models (*e.g.,* low-power unlicensed, dynamic sharing) that would either expedite the timeline or streamline the process for repurposing the band?

Some of the existing spectrum bands can be reused to serve drones. For example, there are works that illustrate coexistence of terrestrial cellular users and drones when they are served through separate sets of antennas – terrestrial users on the ground can be served by antennas at cellular towers that are tilted towards the ground, while drones can be served by a separate set of antennas that are tilted towards the sky. This of course requires additional infrastructure investments for cellular operators that serve drones, or other 3rd parties who serve the drones while sharing the spectrum with other terrestrial users. Considering the significant cost of the spectrum, alternative approaches for “spatial” sharing of the available spectrum with directional antennas may offer significant advantages.

4. What factors should be considered in identifying spectrum for the pipeline? Should the Strategy promote diverse spectrum access opportunities including widespread, intensive, and low-cost access to spectrum-based services for consumers? Should the Strategy promote next-generation products and services in historically underserved or disconnected communities such as rural areas and Tribal lands? Should the Strategy prioritize for repurposing spectrum bands that are internationally harmonized and that can lead to economies of scale in network equipment and devices? How should the Strategy balance these goals with factors such as potential transition costs for a given band or the availability of alternative spectrum resources for incumbent users? How should the Strategy balance these goals against critical government missions? How should the Strategy assess efficient spectrum use and the potential for sharing? What is an ideal timeline framework suitable for identifying and repurposing spectrum in order to be responsive to rapid changes in technology, from introduction of a pipeline to actual deployment of systems?

Allocation of experimental spectrum for testing and experimentation by outdoor testbeds is important for collecting data in real-world scenarios, which then can be used for making future decisions on how to use the spectrum. This is especially critical for 3D sharing of the wireless spectrum, such as for the case of use cases that involve drones and satellites. To better identify the scope of permissible services in spectrum bands of interest, there is a need for measurement data, propagation studies, and data-driven research, especially for non-traditional use case scenarios that involve drones and satellites.

5. Spectrum access underpins cutting-edge technology that serves important national purposes and government missions. Are there changes the government should make to its current spectrum management processes to better promote important national goals in the short, medium, and long term without jeopardizing current government missions?

No comments.

6. For purposes of the Strategy, we propose to define ''spectrum sharing'' as optimized utilization of a band of spectrum by two or more users that includes shared use in frequency, time, and/or location domains, which can be static or dynamic. To implement the most effective sharing arrangement, in some situations incumbent users may need to vacate, compress or repack some portion of their systems or current use to enable optimum utilization while ensuring no harmful interference is caused among the spectrum users. Is this how spectrum sharing would be defined? If not, please provide a definition or principles that define spectrum sharing. What technologies, innovations or processes are currently available to facilitate spectrum sharing as it should be defined? What additional research

and development may be required to advance potential new spectrum sharing models or regimes, who should conduct such research and development, and how should it be funded?

Spectrum sharing can be in time, frequency, space, and code domains, and to take best advantage of sharing opportunities, all four dimensions should be exploited. Programmable software-defined radios can be used to test spectrum sharing approaches in all these domains. PAWR platforms and test sites that study National Radio Dynamic Zones (NRDZs) are well-suited to deploy and test spectrum sharing technologies in real-world outdoor environments. Government can facilitate collaborations between industry, academia, and government labs, for joint development and testing activities to study different spectrum sharing mechanisms. Instead of grants, contracts with well defined deliverables that require testing of fundamental sharing mechanisms in real-world environments can help move fundamental academic research into practice. Digital twins of the radio environment can be used to develop and mature spectrum sharing concepts in a cloud environment, before moving the developed software into outdoor testbeds for real-world testing. Platforms such as Colosseum at Northeastern University and AERPAW at North Carolina State University allow software development and testing in virtual environments, and containers developed in the virtual environment can subsequently be moved to for testbed experimentation.

7. What are the use cases, benefits, and hinderances of each of the following spectrum access approaches: exclusive-use licensing; predefined sharing (static or predefined sharing of locations, frequency, time); and dynamic sharing (real-time or near real-time access, often with secondary use rights)? Are these approaches mutually exclusive (*i.e.,* under what circumstances could a non-federal, exclusive-use licensee in a band share with government users, from a nonfederal user point of view)? Have previous efforts to facilitate sharing, whether statically or dynamically, proven successful in promoting more intensive spectrum use while protecting incumbents? Please provide ideas or techniques for how to identify the potential for and protect against interference that incumbents in adjacent bands may experience when repurposing spectrum.

No comments.

8. What incentives or policies may encourage or facilitate the pursuit of more robust federal and non-federal spectrum sharing arrangements, including in mid-band and other high priority/demand spectrum? For example, does the current process for reimbursement of relocation or sharing costs adequately incentivize the study or analysis of spectrum frequencies for potential repurposing? Are there market-based, system-performance based or other approaches that would make it easier for federal agencies to share or make spectrum available while maintaining federal missions? At the same time, what mechanisms should be considered to meet some of the current and future federal mission requirements by enabling new spectrum access opportunities in non-federal bands, including on an ''as needed'' or opportunistic basis?

No comments.

9. How do allocations and varying spectrum access and governance models in the U.S. compare with actions in other nations, especially those vying to lead in terrestrial and space-based communications and technologies? How should the U.S. think about international harmonization and allocation disparities in developing the National Spectrum Strategy?

No comments.

Pillar #2—Long-Term Spectrum Planning

1. Who are the groups or categories of affected stakeholders with interests in the development of the National Spectrum Strategy and participating in a long-term spectrum-planning process? How do we best ensure that all stakeholders can participate in a long-term spectrum planning process in order to facilitate transparency to the greatest extent possible, ensure efficient and effective use of the nation's spectrum resources?

There are different ways that industry, academia, and government entities can contribute into a long-term spectrum planning process by bringing diverse perspectives. A multi stakeholder group can be instrumental in developing a robust, data-driven, research-based national strategy. Any stakeholder who can contribute meaningful spectrum and propagation measurements and data can add value to the process (see e.g. [6,18,19,22,24] from the AERPAW platform for representative propagation studies).

2. What type of timeline would be defined as a ''long-term'' process? What are key factors to consider and what are the key inputs to a long-term planning process? What data are

required for planning purposes? Do we need data on spectrum utilization by incumbent users, including adjacent band users, and, if so, how should we collect such data and what metrics should we use in assessing utilization? Do we need information from standards-setting bodies and, if so, what information would be helpful and how should we obtain such information? What is the appropriate time horizon for long-term spectrum planning and how often should we revisit or reassess our prior findings and determinations? How do we balance periodic review and reassessment of our spectrum priorities with providing regulatory certainty to protect investment-backed expectations of existing spectrum users? How can federal and non-federal stakeholders best work together?

The use of historical spectrum occupancy collected at diverse geographical environments, locations, and measurement altitudes, is of paramount importance for making spectrum planning decisions, such as which bands may be more suitable for sharing, at what geographical areas, and under what network configurations (e.g. antenna tilts, transmit powers, etc). At the very minimum, the mean and variance of observed spectrum power at different bands should be observed at short, medium, and long-term time scales. Short-term observations, such as at milli-second level, can reveal information on spectrum sharing opportunities. Medium- and long-term spectrum observations (over hours, days, months, and years) can reveal long term trends on the use of spectrum in a certain bands, and also reveal temporal opportunities. Raw I/Q samples can help extract additional information that cannot be obtained solely from spectrum power measurements. NSF AERPAW platform has been collecting spectrum data at bands up to 6 GHz, at altitudes up to 180 meters, see e.g. [19, 24] for spectrum measurements in many commercial 4G and 5G bands. Based on the measurements in [19,24], as soon as a UAV rises above a critical altitude, the aggregate spectrum power from all cellular towers is seen to increase significantly. This effect is more abrupt for an urban scenario when compared with a rural scenario. There is a need for more detailed studies to understand interference patterns and statistics for different bands, altitudes, and scenarios. Such studies may for example reveal that spectrum sharing may be allowed in certain geographical areas up to certain altitudes, but not at higher altitudes without additional measures.

AERPAW has also been collecting I/Q data samples from its 4G and 5G base stations in the C-band spectrum, which can be used for studying time, frequency, and spatial domain correlation of spectrum occupancy at different UAV altitudes, see e.g. [22].

3. How can federal and non-federal stakeholders best engage in productive and ongoing dialogue regarding spectrum allocation and authorization, repurposing, sharing, and coordination? Learning from prior experiences, what can be done to improve federal/nonfederal spectrum coordination, compatibility, and interference protection assessments to avoid unnecessary delays resulting from non-consensus?

Spectrum data driven mechanisms by trusted third parties can help accelerate decision making and resolve conflicts.

4. What technical and policy-focused activities can the U.S. Government implement that will foster trust among spectrum stakeholders and help drive consensus among all parties regarding spectrum allocation decisions?

No comments.

5. Are additional spectrum-focused engagements beyond those already established today (e.g., FCC's Technical Advisory Committee (TAC), NTIA's Commerce Spectrum Management Advisory Committee (CSMAC), and NTIA's annual Spectrum Policy Symposium) needed to improve trust, transparency, and communication among the federal government, industry, and other stakeholders (including Tribal Nations) and why? What would be the scope of such engagements, how would they be structured, and why would establishing new engagements be preferable to expanding the use of existing models? If existing models are sufficient, how (if needed) should FCC and NTIA maximize their usefulness or leverage their contributions to enhance and improve coordination?

No comments.

6. In considering spectrum authorization broadly (i.e., to include both licensed and unlicensed models as well as federal frequency assignments), what approaches (e.g., rationalization of spectrum bands or so-called ''neighborhoods'') may optimize the effectiveness of U.S. spectrum allocations? Are there any specific spectrum bands or ranges to be looked at that have high potential for expanding and optimizing access? Which, if any, of these spectrum bands or ranges should be prioritized for study and potential repurposing? Conversely, are there any bands or ranges that would not be appropriate for access expansion? What, if any, metrics are ideal for measuring the intensity of spectrum utilization by incumbents in candidate bands?

Spectrum utilization in a spectrum band can be measured over time (how often the band used), space (where and in which directions in a 3D volume the band used), and frequency (what portion of the band is used). It is also measured in terms of received power in all these dimensions. The metric for measuring the intensity of spectrum utilization should take into account all these metrics. Moreover, the receiver sensitivity for incumbent users is also critical. For some bands, very low received powers may still cause high interference to some sensitive receivers such as radioastronomy radars, while there can be other bands that may not be as sensitive.

7. What is needed to develop, strengthen, and diversify the spectrum workforce to ensure an enduring, capable and inclusive workforce to carry out the long-term plans (including specifically in rural and Tribal communities)?

Spectrum technology has both fundamental/theoretical aspects as well as experimental aspects. In many universities, experimental educational infrastructure is not available or they fall short of training the next generation spectrum workforce. Remotely accessible large-scale wireless testbeds such as the NSF PAWR platforms can be taken advantage of by the broader spectrum education community for providing hands-on and real-world training opportunities to graduate, under-graduate, and high-school students.

Pillar #3—Unprecedented Spectrum Access and Management Through Technology Development

1. What innovations and next-generation capabilities for spectrum management models (including both licensed and unlicensed) are being explored today and are expected in the future to expand and improve spectrum access (and what are the anticipated timelines for delivery)?

No comments.

2. What policies should the National Spectrum Strategy identify to enable development of new and innovative uses of spectrum?

There are various features of 4G and 5G systems that can facilitate spectrum sharing. For example, for 5G, different numerologies on subcarrier spacing (hence slot duration) can allow different granularities in time and frequency domains for spectrum coexistence and sharing. Advanced beamforming capabilities of 5G allows spectrum sharing in the spatial domain. These should be studied in experimental platforms to better understand spectrum sharing performance in real-world environments. National Spectrum Strategy policy, when possible, can allow expedited allocation of FCC experimental licenses in and innovation zones for facilitating such real-world testing.

3. What role, if any, should the government play in promoting research into, investment in, and development of technological advancements in spectrum management, spectrum-dependent technologies, and infrastructure? What role, if any, should the government play in participating in standards development, supporting the use of network architectures, and promoting tools such as artificial intelligence and machine learning for spectrum coordination or interference protections? What technologies are available to ensure appropriate interference protection for incumbents in adjacent bands? What spectrum management capabilities/tools would enable advanced modeling and more robust and quicker implementation of spectrum sharing that satisfies the needs of non-federal interests while maintaining the spectrum access necessary to satisfy current and future mission requirements and operations of federal entities? How can data-collection capabilities or other resources, such as testbeds, be leveraged (including those on Tribal lands and with Tribal governments)?

Large scale outdoor wireless testbeds such as the NSF PAWR platforms have related capabilities for monitoring and logging wireless spectrum occupancy up to 6 GHz, at various time scales and various altitudes. National Radio Dynamic Zones (NRDZs) are recently being investigated by projects funded by the NSF, including supplementary projects to PAWR platforms. For example, AERPAW platform focuses on NRDZs that involve aerial vehicles, representative references from the AERPAW team are available at [6,22,29,31] in a wide range of bands and monitoring altitudes up to 180 meters. Coordinated efforts across all these testbed platforms can help aggregate extensive spectrum data in a variety of propagation environments for more informed decisions.

4. NTIA is pursuing a time-based spectrum sharing solution called the incumbent informing capability (IIC) to support spectrum sharing between federal and non-federal users. What are some recommendations for developing an enduring, scalable mechanism for managing shared spectrum access using the IIC or other similar mechanism, with the goal of increasing the efficiency of spectrum use? What challenges do nonfederal users foresee with potentially having limited access to classified or other sensitive data on federal spectrum uses and operations as part of the IIC or similar capabilities, and what recommendations do users have for ways to mitigate these challenges? What are the costs and complexities associated with automating information on spectrum use?

No comments.

5. What other technologies and methodologies are currently being, or should be, researched and pursued that innovate in real-time dynamic spectrum sharing, particularly technologies that may not rely on databases?

Spectrum monitoring at aerial platforms (such as drones and helikites) can help significantly expand the spectrum monitoring range due to higher likelihood of line-of-sight to primary users, see e.g. [19]. This therefore improves the detection probability of primary users of the band (e.g., aerial radars at the 3.1-3.45 GHz), and therefore, reduces the risk of interference to such primary users. It may be possible to crowdsource spectrum monitoring for mandating low-cost spectrum sensors attached to drones in the future, which can report spectrum occupancy measurements e.g. along with remote ID and GPS information that they report. Such information can then be aggregated and combined at the edge processing servers for making spectrum sharing decisions. While the complexity and cost of such an approach may be very high, if there are incentives that convince even a small fraction of drones to report spectrum observations, that may add significant value for rela-time spectrum monitoring and facilitate new spectrum sharing mechanisms.

Respectfully submitted,
NSF AERPAW TEAM
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