Before the
DEPARTMENT OF COMMERCE
National Telecommunications and Information Administration
Washington, DC 20230

In the Matter of	)	
	)	
Public Wireless Supply Chain Innovation Fund Implementation	)	Docket No. 221202-0260
	)	RIN 0693-XC05
	)	

COMMENTS OF THE NSF PAWR COSMOS PROJECT

Introductory Comments:

This response to the NTIA RFC on implementation of the Public Wireless Supply Chain Innovation Fund is on behalf of the COSMOS project at Rutgers/Columbia/NYU which is intended to support 5G/6G testbed services to both academia and industry. The COSMOS ("**C**loud enhanced **O**pen **S**oftware defined **MO**bile wireless testbed for city-**S**cale deployment") project is aimed at design, development, and deployment of an advanced wireless city-scale testbed in order to support real-world experimentation on next-generation wireless technologies and applications. COSMOS is a joint project involving Rutgers, Columbia, and NYU along with several partner organizations, including New York City, City College of New York, Silicon Harlem, and IBM, **with the first phase being built with support from the NSF Platforms for Advanced Wireless Research (PAWR) program**. The COSMOS testbed (a NY/NJ partnership) is being deployed in West Harlem, New York City (NYC) with technical focus on ultra-high-bandwidth and low-latency wireless communications with tightly coupled edge computing, and emphasis on the millimeter-wave (mmWave) radio communications and dynamic optical switching.

The COSMOS testbed Phase 1 outdoor deployment and sandboxes already support at-scale experimentation of novel advanced wireless broadband and communication technologies in both sub-6 GHz and mmWave frequency bands in a dense urban environment. The COSMOS testbed provides a mix of programmable software-defined radio (SDR) nodes for flexible wireless experimentation. It also includes novel WDM fiber and mmWave backhaul technologies interconnected with a software-defined network (SDN) switching fabric for minimum latency and flexibility in setting up experimental network topologies. For more information about COSMOS, please see the ACM MobiCom 2020 overview paper[1] and www.cosmos-lab.org.

The COSMOS testbed was specifically developed as an open programmable, software-defined platform that enables researchers from both academia and industry to evaluate architectures and technologies for current and future wireless systems including 5G, beyond-5G, and 6G. In addition to serving the academic community as a research testbed for 5G/6G, **COSMOS has been used in the last few years by industry for O-RAN interoperability trials, including successfully hosting several O-RAN plugests**. More recently, COSMOS **has been designated by the O-RAN Alliance as one of two O-RAN testing and**

[1] D. Raychaudhuri, I. Seskar, G. Zussman, T. Korakis, D. Kilper, T. Chen, J. Kolodziejski, M. Sherman, Z. Kostic, X. Gu, H. Krishnaswamy, S. Maheshwari, P. Skrimponis, and C. Gutterman, "Challenge: COSMOS: A city-scale programmable testbed for experimentation with advanced wireless," in *Proc. ACM MOBICOM* 2020.

integration centers in North America (officially called "North American OTIC in NYC Metro Area/East (COSMOS)").[2] Moreover, the COSMOS testbed area (West Harlem in NYC) has been designated as one of first two FCC Innovation Zones[3], thereby allowing extensive experimentation on spectrum and radio interference aspects.

Numerous academic and industry users have been relying on the testbed for their experiments. These include ORAN alliance members (e.g., AT&T and Dish), Nokia Bell Labs, NEC, NTT, and startups (e.g., Spectral DSP and Kentyou). Research conducted on the testbed has been supported by various funding agencies, including NSF, DoD, DOT, and the European Commission. In particular, the recently awarded NSF $26M Engineering Research Center (ERC) for Smart Streetscapes (CS3) relies on the testbed. Finally, various international partnerships (with for example, with Ireland, Brazil, Japan, and India) have been supported by the NSF, the European Commission, and the Indian Department of Science and Technology.

Due to the deployment in an area that is impacted by the digital divide, the COSMOS testbed team has also been engaged in workforce development and outreach activities and in activities focusing on bridging the digital divide. Among other things, these include an extensive program for middle and high school teachers exposing them and their students to next generation wireless technologies. More details are available in a paper published in ACM SIGCOMM Computer Communication Review.[4]

We believe that the NTIA initiative on wireless supply chain innovation will benefit as a whole from access to the COSMOS testbed. A major benefit would be reducing technology risk via experimental validation of the open RAN architecture and its enabling key technology components in terms of performance and interoperability across a wide variety of use cases and test scenarios. Therefore, we believe that support for community testbeds such as COSMOS is of utmost importance. Specifically, we believe that the industry and wireless community will greatly benefit from (i) extended deployment covering the full geographical potential in West Harlem, (ii) development/upgrades of testbed components as technology develops, (iii) maintenance, operation, and experimentation support.

Moreover, we believe that additional core R&D investments (vs. technology transfer or product development) may be considered on the following topics:

1. Architectural principles and performance aspects of large-scale distributed software/network systems such as ORAN. While a software-based cloud native implementation has many advantages, additional work is needed to ensure manageable complexity and competitive cost performance when compared with single vendor solutions with custom hardware.
2. New applications and use cases to be supported on emerging 5G/6G networks, including those involving augmented reality (AR), virtual reality (VR), real-time control or machine learning. In-depth understanding of emerging applications will ensure a common set of use cases which can be used to validate O-RAN designs and interoperability aspects.
3. Distributed algorithms for end-to-end performance management and service virtualization across heterogeneous multi-vendor implementations of O-RAN. This is a potentially challenging problem that may require critical enhancements to the O-RAN specification in future releases.

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[2] see https://www.o-ran.org/otics/north-american-otic-in-nyc-metro-area-east-cosmos

[3] See https://www.engineering.columbia.edu/news/fcc-announces-major-expansion-of-cosmos-innovation-zone

[4] P. Skrimponis, N. Makris, S. Borges Rajguru, K. Cheng, J. Ostrometzky, E. Ford, Z. Kostic, G. Zussman, and T. Korakis, "COSMOS Educational Toolkit: Using Experimental Wireless Networking to Enhance Middle/High School STEM Education," *ACM SIGCOMM Computer Communication Review*, vol. 50, no. 4, Oct. 2020.

4. Fundamental solutions for security and privacy in O-RAN systems. Privacy and security tends to be an add-on and the movement towards open software/standards presents an opportunity to develop an integrated zero-trust solution for 5G/6G systems.
5. Open-source software development communities to develop accessible code that can serve as a baseline for O-RAN implementation across industry, government and academia.

Finally, we believe that partnering with institutions such as those involved it the COSMOS testbed deployment and leveraging existing programs (e.g., the COSMOS program for teachers) will allow designing training programs that promote the generalized skills, competencies, and attitudes required by the new wireless workforce. These programs can span the full range from middle school students/teachers to postdoctoral researchers and also address the needs of seasoned engineers.

In the following, we briefly respond to some of the specific questions in the NTIA RFC based on our experience with development of the COSMOS testbed and subsequent work with industry partners on O-RAN testing and evaluation.

Questions on the State of the Industry

Understanding the current state of the telecommunications industry is important to determining how any topics should be prioritized in the Innovation Fund, and what level of funding a topic should receive.

1. What are the chief challenges to the adoption and deployment of open and interoperable, standards-based RAN, such as Open RAN? Are those challenges different for public vs. private networks?

- Public: interoperability, security, QoE/QoS and e2e management
- Private: Management issued with MNO vs MVNO

a. What are the challenges for brownfield deployments, in which existing networks are upgraded to incorporate open, interoperable, and standards-based equipment?

- Full openness (i.e., a lot of proprietary code)
- Lack of (proven) interoperable
- Standards based (a number of standards are not fully established yet)

2. What ongoing public and private sector initiatives may be relevant to the Innovation Fund?

- Public – fix supply chain, realizing DoD zero-trust roadmap
- Private – cost-effectiveness, energy savings/consumption, lifecycle management (LCM),

a. What gaps exist from an R&D, commercialization, and standards perspective?

- R&D gaps: There is a lack of R&D funding and resources dedicated to developing and maturing O-RAN technologies since most of the effort is left to the vendors who are focused on very specific products and not necessarily on technology development. Creating additional lines of funding and RFPs especially focusing on performance acceleration and energy efficiency could significantly improve this situation.
- Commercialization gaps: There is a lack of commercial O-RAN deployments, which can make it difficult for vendors to gain experience and develop a track record of success. Additionally, there is a lack of standardization in the O-RAN ecosystem, which can make it difficult for vendors to develop and market their products.

- Standards gaps: There are currently no universally accepted full standards for end-to-end O-RAN based system, which can make it difficult for vendors to develop and market their products.
- Interoperability gaps: O-RAN is based on open interfaces, but still there is a lack of interoperability between different vendors. This can make it difficult for operators to deploy O-RAN solutions and to ensure that they work seamlessly with other parts of the network.
- Security gaps: There are concerns around the security of O-RAN solutions as it is based on open interfaces and can be more vulnerable to cyber attacks.
- Skilled workforce gaps: As O-RAN is a new technology, there is a lack of skilled workforce to manage and maintain O-RAN solutions.
- Regulation gaps: There are currently no regulations in place that mandate/encourage the use of O-RAN solutions, which can make it difficult for operators to justify the costs of deploying O-RAN solutions.

b. How might NTIA best ensure funding is used in a way that complements existing public and private sector initiatives?

- Carefully crafted problem statements – focusing on addressing gaps in current initiatives
- Panel of experts to determine awardees based on feasibility
- Checks and balances

3. What kind of workforce constraints impact the development and deployment of open and interoperable, standards-based RAN, such as Open RAN? How (if at all) can the Innovation Fund help alleviate some of these workforce challenges?

One way to alleviate some of the technological workforce challenges related to Open RAN is to provide training and education opportunities through courses at various existing educational institutions. Some specific strategies can include:

1. Developing specialized courses: Universities can develop specialized courses that focus on the technologies and applications related to Open RAN. These courses can include topics such as O-RAN, 5G, 6G, NextG network architectures, radio access technologies, and use cases in various industries.
2. Providing hands-on training and experience: In addition to support for traditional classroom instruction, support student hands-on training and experience through lab-based courses, internships, and research opportunities at various experimental platforms (like PAWR testbeds), university and industrial laboratories can provide. This can help students develop practical skills and knowledge that they can apply in the workplace.
3. Partnering with industry: Support coordination with industry organizations to provide training and education that is directly relevant to the needs of the workforce. This can include developing customized training programs, hosting workshops and seminars, and providing opportunities for students to work on real-world projects.
4. Encouraging interdisciplinary studies: Provide funding and support that will encourage students to pursue interdisciplinary studies that combine technology, business, and other disciplines. This can help students develop a broader understanding of the implications and applications of 5G and 6G technologies for different industries.

5. Create “Staying updated with the technology” programs: make sure that all participants' courses are updated with the latest developments and advancements of Open RAN technology. This can be done by programs/seminars by experts in the field and also by having targeted workshops with the key industry players.
6. Support establishment of a common (core) curriculum.
7. Funding for students and workers for training.

4. What is the current climate for private investment in Open RAN, and how can the Innovation Fund help increase and accelerate the pace of investment by public and private entities?

N/A

5. How do global supply chains impact the open, interoperable, and standards-based RAN market, particularly in terms of procuring equipment for trials or deployments?

N/A

Questions on Technology Development and Standards

6. What open and interoperable, standards-based network elements, including RAN and core network elements, would most benefit from additional research and development (R&D) supported by the Innovation Fund?

- Specialized and non-specialized accelerators for development and deployment
- SMO

A number of production-ready core network elements that are compliant with open standards should be made available for end-to-end experimentation so that researchers could focus on experimentation and development of various other components and applications.

7. Are the 5G and open and interoperable RAN standards environments sufficiently mature to produce stable, interoperable, costeffective, and market-ready RAN products?

No

If not:

a. What barriers are faced in the standards environment for open and interoperable RAN?

- Ecosystem fractures, players not required yet to interoperate
- Lack of full (end-to-end) specifications/standards

b. What is required, from a standards perspective, to improve stability, interoperability, cost effectiveness, and market readiness?

- Fully developed core standards
- More frequent (and truly interoperable) testing
- Testing and certification
- Reluctance to make pre-market equipment available for development and testing

c. What criteria should be used to define equipment as compliant with open standards for multivendor network equipment interoperability?

- Performance and interoperability certification and testing (badging)
- Development of end to end testing capability
- Process of validating new (individual) components in the fully functional e2e system

8. What kinds of projects would help ensure 6G and future generation standards are built on a foundation of open and interoperable, standards-based RAN elements?

- Proof of concept evaluations and prototypes
- Hackathons / integration events
- Meetings targeting policy development
- Workshops/seminars/education events
- International cooperation/adoption meetings on standards
- Workforce certifications on open RAN standards and technologies

Questions on Integration, Interoperability, and Certification

9. How can projects funded through the Innovation Fund most effectively support promoting and deploying compatibility of new 5G equipment with future open, interoperable, and standards-based equipment?

a. Are interoperability testing and debugging events (e.g., ''plugfests'') an effective mechanism to support this goal? Are there other models that work better?

- Additional thematic plugfests focused on interoperability, E2E, etc.
- Availability of pre-market equipment for continuous integration

10. How can projects funded through the program most effectively support the ''integration of multi-vendor network environments''?

- Require interoperability testing for funded projects
- Require pre-market equipment/etc. developed through funding for continuous integration testing

11. How do certification programs impact commercial adoption and deployment?

a. Is certification of open, interoperable, standards-based equipment necessary for a successful marketplace?

Yes

b. What bodies or fora would be appropriate to host such a certification process?

- PAWR platform sites
- Government participation in overseeing of certification
- Additional government ribbon certification processes

12. What existing gaps or barriers are presented in the current RAN and open and interoperable, standards-based RAN certification regimes?

A number of Standards/certifications are not yet defined

a. Are there alternative processes to certification that may prove more agile, economical, or effective than certification?

- Continuous integration and testing rather than snapshot based certification (i.e. semi-annual PlugFest) .

b. What role, if any, should NTIA take in addressing gaps and barriers in open and interoperable, standards-based RAN certification regimes?

- Organize thematic Plugfests in addition to those organized by O-RAN.
- Support deployment of pre-market equipment for continuous integration in publicly accessible testbeds.

Questions on Trials, Pilots, Use Cases, and Market Development

13. What are the foreseeable use cases for open and interoperable, standards based networks, such as Open RAN, including for public and private 5G networks? What kinds of use cases, if any, should be prioritized?

- ORAN use case document
- 3GPP use case document
- Spectrum sharing use case
- Hostile operation use case
- Multi-operator resource pooling and slicing use cases

14. What kinds of trials, use cases, feasibility studies, or proofs of concept will help achieve the goals identified in 47 U.S.C. 906(a)(1)(C), including accelerating commercial deployments? a. What kinds of testbeds, trials, and pilots, if any, should be prioritized?

We believe that core R&D investments (vs. technology transfer or product development) need to be considered on the following topics:

1. Architectural principles and performance aspects of large-scale distributed software/network systems such as ORAN. While a software-based cloud native implementation has many advantages, additional work is needed to ensure manageable complexity and competitive cost performance when compared with single vendor solutions with custom hardware.
2. New applications and use cases to be supported on emerging 5G/6G networks, including those involving augmented reality (AR), virtual reality (VR), real-time control or machine learning. In-depth understanding of emerging applications will ensure a common set of use cases which can be used to validate O-RAN designs and interoperability aspects.
3. Distributed algorithms for end-to-end performance management and service virtualization across heterogeneous multi-vendor implementations of O-RAN. This is a potentially challenging problem that may require critical enhancements to the O-RAN specification in future releases.
4. Fundamental solutions for security and privacy in O-RAN systems. Privacy and security tend to be an add-on and the movement towards open software/standards presents an opportunity to develop an integrated zero-trust solution for 5G/6G systems.
5. Open-source software development communities to develop accessible code that can serve as a baseline for O-RAN implementation across industry, government and academia.

To support such efforts as well as efforts described in the response to Q. 15, below, there is a definite need for testbeds that **will be available for a variety of external user**s. However, we would like to highlight that as far as we know, among the existing US-based labs and testbeds that make themselves available to external users (i.e., are not vendor-sponsored or internal to mobile network operators), there is a need for additional hardware and software, including Open RAN-specific testing equipment. No facility currently has the necessary volume and diversity of hardware and software to support wide-scale testing and experimentation, including meaningful Open RAN trials and proof-of-concept pilots. The labs that participate in trials and plugfests often have to resort to renting fairly expensive test equipment for the trials only (and are otherwise unable to perform advanced tests outside of those short periods of time).

15. How might existing testbeds be utilized to accelerate adoption and deployment?

Existing NSF PAWR platforms (COSMOS and POWDER) have already been successfully used by both equipment vendors and operators for evaluation of various O-RAN components in the last three PlugFests and have shown that public testbeds can be utilized in several ways to accelerate the O-RAN adoption and deployment:

1. Interoperability testing: Testbeds can be used to test the interoperability of O-RAN components and software from different vendors, which is crucial for ensuring that the system works seamlessly.
2. Performance testing: Testbeds can be used to test the performance of O-RAN systems under different conditions and configurations.
3. Integration testing: Testbeds can be used to test the integration of O-RAN systems with existing network infrastructure, such as backhaul and core networks.
4. Field testing: Testbeds can be used to conduct field testing of O-RAN systems in a controlled environment that simulates real-world conditions. This can help identify any issues that may arise in a real-world deployment and can also provide valuable insights into how the O-RAN system behaves in a real-world deployment.
5. Experimentation: Testbeds can be used for experimentation, which can help accelerate the adoption of O-RAN by providing a platform for researchers, developers, and industry players to test and validate new ideas, technologies, and use cases for O-RAN.
6. Certification: Testbeds can also be used to certify vendors and their products, which can help ensure that O-RAN systems are deployed with the highest level of quality and reliability. The process is envisioned as fully automated and can lead to a very fast field deployment. The fact that public testbeds like PAWR platforms tend to be completely vendor and operator neutral were especially emphasized as an important attribute in the certification process.
7. Collaboration: Testbeds can foster collaboration between different stakeholders such as vendors, telecom operators, researchers and regulators. This can accelerate the adoption and deployment of O-RAN by providing a platform for stakeholders to work together to address common challenges and share best practices.

By utilizing existing testbeds in these ways, organizations can more effectively and efficiently evaluate and validate O-RAN systems, identify and resolve any issues that may arise, and gain valuable insights into how O-RAN systems behave in a real-world deployment. This can ultimately accelerate the adoption and deployment of O-RAN. The fact that a research testbed (such as the NSF PAWR testbeds) tends to be designed for field experimentation with highly modular capabilities is a perfect example of an environment that is designed for fast E2E/functional/vertical verification.

Due to the potential impact of the items above, we believe that support for community testbeds such as COSMOS is of utmost importance. Specifically, we believe that the industry and wireless community will greatly benefit from the following:

(i) extended deployment covering the full geographical potential of COSMOS in West Harlem: it should be noted that the COSMOS testbed FCC Innovation Zone footprint covers much larger geographical area allowing for significant expansion of the testbed which would greatly expand the versatility and the number of different experiments that could be performed.

(ii) development/upgrades of testbed components as technology develops: O-RAN technology and especially the R&D aspects of it are rapidly evolving requiring constant upgrades and the funding model for NSF testbeds is based on a single funding cycle which significantly limits the upgradability and ability to introduce new components and technologies as they become available.

(iii) maintenance, operation, and experimentation support: the pay for Lab-as-a-service (LaaS) model for a testbed platform in the context of O-RAN works well but only for a subset of players (i.e., for large vendors and operators) which very quickly become almost exclusive users of the platform. In order to prevent that, it is necessary to provide basic funding for core support personnel and core equipment maintenance which would ensure testbed independence and neutrality.

16. What sort of outcomes would be required from proof-of-concept pilots and trials to enable widespread adoption and deployment of open and interoperable, standards-based RAN, such as Open RAN?

- Functional verification of new capabilities in a functioning E2E system

Questions on Security

17. ‘‘Promoting and deploying security features enhancing the integrity and availability of equipment in multivendor networks,’’ is a key aim of the Innovation Fund (47 U.S.C 906(a)(1)(C)(vi)). How can the projects and initiatives funded through the program best address this goal and alleviate some of the ongoing concerns relating to the security of open and interoperable, standards-based RAN?

a. What role should security reporting play in the program’s criteria?

N/A

b. What role should security elements or requirements, such as industry standards, best practices, and frameworks, play in the program’s criteria?

N/A

18. What steps are companies already taking to address security concerns?

N/A

19. What role can the Innovation Fund play in strengthening the security of open and interoperable, standards based RAN?

Support “red” and “blue” projects/hackathons/competitions (attack and defense)

20. How is the ''zero-trust model'' currently applied to 5G network deployment, for both traditional and open and interoperable, standards-based RAN? What work remains in this space?

N/A

Questions on Program Execution and Monitoring

21. Transparency and accountability are critical to programs such as the Innovation Fund. What kind of metrics and data should NTIA collect from awardees to evaluate the impact of the projects being funded?

- Periodic site visits and reports
- Deliverables monitoring
- Timely certification and badging of equipment

22. How can NTIA ensure that a diverse array of stakeholders can compete for funding through the program? Are there any types of stakeholders NTIA should ensure are represented?

- Making sure small equipment vendors are supported

23. How (if at all) should NTIA promote teaming and/or encourage industry consortiums to apply for grants?

- Program promotion in appropriate venues

24. How can NTIA maximize matching contributions by entities seeking grants from the Innovation Fund without adversely discouraging participation? Matching requirements can include monetary contributions and/or third-party in-kind contributions (as defined in 2 CFR 200.1).

N.A

25. How can the fund ensure that programs promote U.S. competitiveness in the 5G market?

a. Should NTIA require that grantee projects take place in the U.S.?

- Yes (with exceptions when required by the manufacturing processes)

b. How should NTIA address potential grantees based in the U.S. with significant overseas operations and potential grantees not based in the U.S. (i.e., parent companies headquartered overseas) with significant U.S.-based operations?

N/A

c. What requirements, if any, should NTIA take to ensure ''American-made'' network components are used? What criteria (if any) should be used to consider whether a component is ''American-made''?

N/A

26. How, if at all, should NTIA collaborate with like-minded governments to achieve Innovation Fund goals?

- Joint RFPs, joint funding opportunities with foreign governments
- Joint workshops and consortiums

- Interoperability events in collaboration with foreign governments

Additional Questions

27. Are there specific kinds of initiatives or projects that should be considered for funding that fall outside of the questions outlined above?

N/A

28. In addition to the listening session mentioned above and forthcoming NOFOs, are there other outreach actions NTIA should take to support the goals of the Innovation Fund?

- Organizing topical workshops
- Incentives for US companies to perform R&D

Respectfully submitted,

NSF PAWR COSMOS Project

January 27, 2023