Federated Broadband Performance Measurement: The Key to America's Continued Global Internet Leadership

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ASSIA

Key Points and Executive Summary

- America's broadband network is as vital to our nation's infrastructure as our airways, railways, highways, and the electric grid, specifically impacting all American citizens' prosperity and security. Significant public funds have been appropriated to enhance equitable broadband access. Timely and accurate measurements and analysis of broadband services' actual quality can ensure these funds achieve their goals.
- Present broadband performance measurement, however, is based on infrequently collected data that is often inaccurate or incomplete. Further this data may come from biased sources, both intentional and systemic. Indeed, there are currently no consistent standards for broadband performance data's definition, collection, and presentation. The present environment is incapable of an accurate and unbiased broadband performance assessment.
- Collection and analysis of pervasive, accurate, statistically valid, and anonymized data stored in federated databases addresses these shortcomings. These data and their corresponding analysis are key to sound broadband policy decisions, thereby enabling broadband networks to serve all American stakeholders' interests.
- Systems can be deployed today that meet these requirements. Much data is already available and, in many cases, also already collected by Internet Service Providers (ISPs), carriers, and others in their ongoing network management. With appropriate policies standardizing collection interfaces, cost effective systems can be deployed that will vastly improve broadband networks' oversight.
- Four federal policy initiatives can accelerate the benefits of pervasive, continuous, accurate, and anonymized broadband data collection and analysis using federated databases.
    1. **Enact appropriate regulations** that ensure standardized Application Programing Interfaces (APIs), data definitions, and procedures for the collection and exchange of broadband performance information. These API's enable the analysis and presentation federated databases' data.
    2. **Allocate up to 1% of federal funds already appropriated** for broadband infrastructure to support the development and deployment of broadband data analysis and presentation systems based on these federated databases.
    3. As a condition for receiving federal broadband funding **require all entities that receive subsidies to provide data** using the APIs to the federated databases.
    4. Encourage timely financial support from entities such as the National Science Foundation (NSF) and the Defense Advanced Research Projects Agency (DARPA) to **fund research and development of the most efficient and cost-effective** methods for collecting, analyzing, and presenting salient broadband data.

1. Background and Overview of the Problem

Ensuring widespread and equitable broadband connectivity to US citizens is a significant public policy issue. Over the past several years, Congress has appropriated nearly $80 billion to enhance equitable broadband access to underserved communities[1]. Governments, Non-Governmental Organizations (NGOs), and the private sector all have an interest in broadband access' oversight and regulation. Regardless of funding source, regulatory oversight and enforcement should support mandated requirements' verification, using meaningful, measurable, and accurate metrics. Such support enables government and industry cooperate and to deliver competitive and continually improving broadband services to all American citizens.

Governmental use of public networks, such as the Emergency Preparedness Communications Services (EPCS) and Department of Defense's (DoD's) use of shared public infrastructure, also generate concern over shared network resources' stability and security. Coordination between private stakeholders and governmental agencies to support public safety and national security is clearly crucial. Analysis facilitated by measurements and monitoring can ensure that the broadband network also provides the needed functions during emergency situations.

To support sound policy decisions, all metrics should be based on pervasive and continuously collected data that assesses the Quality of Service (QoS) actually delivered to users. Such collection must also be secure, anonymous, non-interfering, and statistically valid. When based on common requirements and processes, a federated database containing information from such collection can become a common resource for use by the government, industry, and others. This use enhances all our understanding of our broadband infrastructure's performance and, in turn, helps us guide its future evolution. However, current public broadband measurements are neither pervasive nor always accurate, and the resulting analysis is thus incomplete and often misleading. Typically, measurements today only include infrequent snapshots of the downstream and upstream data rates. This simple characterization does not account for many salient aspects that directly contribute to the overall service quality, including latency, congestion, interference, service availability, etc.

The Federal Communications Commission's (FCC's) March 2022 report, entitled *Broadband Data Collection – Data Specifications for Biannual Submission of Subscription, Availability, and Supporting Data*[2], makes it clear that the current system is entirely dependent on self-reporting of broadband services by the carriers. Moreover, FCC's Measuring Broadband America webpage[3] clarifies that the data for fixed broadband are:

> "Tests conducted used automated, direct measurements of service delivered to the homes of ***thousands*** of ***volunteers*** across the United States". [emphasis added]

[1] Fierce Telecom: "Finding the money: A US broadband funding guide" (September 13, 2021, last updated August 15, 2022) https://www.fiercetelecom.com/special-report/u-s-government-funding-sources-for-broadband
[2] https://www.fcc.gov/sites/default/files/bdc-availability-data-specifications-03042022.pdf
[3] https://www.fcc.gov/general/measuring-broadband-america

These two fundamental flaws, i.e., self-reporting by carriers on services provided and using only a small number of volunteer-based data collections, lead to systemic bias in the quality and validity of the collected data. These problems have been independently verified by the BroadbandNow Research.

> "In May 2022, BroadbandNow Research manually checked internet accessibility for more than 11,000 addresses. Based on that study, it was estimated that 42 million Americans, or 13 percent of the population, have no access to an internet provider at their home address. That was nearly double the amount of the 21.3 million Americans that the FCC identified as lacking internet service in their 2019 Broadband Deployment Report."[4]

The use of only 'thousands of volunteers', random requests by users for speed tests run for unknown reasons, and unaudited reports from ISPs and carriers to regulators on the quality of their own services cannot provide meaningful insight into the true quality of broadband services in America. In fact, the present methods cannot even provide insight on broadband at the crudest level of whether access is even provided, much less provide any meaningful insight into the actual quality of service delivered to Americans.

"Broadband service's" definition itself is also an evolving target that must be clarified in terms of meaningful criteria based on various applications' actual requirements. The users' needs in terms of performance and stability evolve over time as new applications emerge and are widely adopted. Performance requirements and measurements needed to determine broadband quality must therefore be flexible and comprehensive to enable a coherent view for future needs, as well as current situations. For example, the FCC's recent Notice of Inquiry (NOI) entitled "*Inquiry Concerning Deployment of Advanced Telecommunications Capability to All Americans in a Reasonable and Timely Fashion"*[5] agrees. This NOI's introduction observes a fundamental question that needs addressing is whether broadband is actually being provided to subscribers. Furthermore, the FCC acknowledges that the current broadband-quality measures are insufficient.

ASSIA observes that if the present operation cannot even reliably answer the basic question of 'mere availability', then better evaluations of broadband performance require a fundamentally different approach to data collection, exchange, analysis, and presentation.

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[4] BroadbandNow: "Lawmakers Complain FCC's New Broadband Maps Are Still Inaccurate Post-Form 477" (January 27, 2023) https://www.msn.com/en-us/news/technology/lawmakers-complain-fcc-s-new-broadband-maps-are-still-inaccurate-post-form-477/ar-AA16ORHm

[5] FCC, *Inquiry Concerning Deployment of Advanced Telecommunications Capability to All Americans in a Reasonable and Timely Fashion,* GN Docket No. 22-270, Nov 1, 2023, https://docs.fcc.gov/public/attachments/FCC-23-89A1.pdf

2. Overview of Requirements for Pervasive, Accurate, and Anonymized Data Collection

ASSIA has previously responded to Notices of Inquiries, Requests for Comment, and Notices of Rule Making issued in the last two years by various governmental agencies.[6,7,8,9] ASSIA's comments centered on the requirements for broadband performance data collection and analysis. Of special interest is ASSIA's response to the mandates required by the FCC, National Telecommunications and Infrastructure Administration (NTIA), and the Department of Agriculture under The Broadband Interagency Coordination Act of 2020 (BICA)[10]. While BICA requires procedures for interagency broadband data exchange, ASSIA's recommendations to the FCC Request for Comments[11] on BICA also apply to broadband-access regulation and oversight in general. ASSIA's recommendations appear below:

- **Consistent understood data:** Data model and parameter definitions should be consistent across agencies and funding programs, where the definitions should also be aligned with the industry's consensus understandings.
- **Verifiable Accuracy:** The accuracy of the data shared across agencies should be independently verifiable and should not depend solely upon network operators' self-reporting.
- **Sufficient Data:** The values of parameters shared among agencies should be based on statistically valid sample sizes.
- **Subsidization Compliance:** The shared data should align with measurements made for any governmental purposes, including but not limited to broadband mapping, verification of conformance with grant terms, and required reporting by network operators.
- **All broadband links:** Data collection should include all broadband-performance-affecting network segments, as experienced by the end internet consumer, including the Wi-Fi link, the access link, the internet backbone, and the performance of a content provider's network and servers.

Extending points made in ASSIA's BICA comments above, the following basic characteristics help address these issues.

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[6] FCC*'s* Request for Comments on *Empowering Broadband Consumers Through Transparency* – CG Docket No. 22-2 – *FCC 22*-7. Comment from Adaptive Spectrum and Signal Alignment, Incorporated (ASSIA®)
[7] ASSIA and Wireless Institute, University of Notre Dame, joint response to FCC RFI-OET2022-MBA
[8] FCC*'s* Notice of Inquiry on *Advancing Understanding of Non-Federal Spectrum Usage* - WT Docket No. 23-232. Comment from Adaptive Spectrum and Signal Alignment, Incorporated (ASSIA®)
[9] NTIA – Request for Comments on Broadband Programs in Bipartisan Infrastructure Law – [Docket No. 220105–0002]. Comment from Adaptive Spectrum and Signal Alignment, Incorporated (ASSIA®)
[10] *The Broadband Interagency Coordination Act of 2020, Pub.L. 116-260, 134 Stat. 3214, Div. FF, tit. IX, § 904 (2020), codified at 47 U.S.C §1308 (BICA)*
[11] *FCC's Request for Comments on the Interagency Broadband Coordination Agreement [WC Docket No. 22-251].* Comment from Adaptive Spectrum and Signal Alignment, Incorporated (ASSIA®)

- **Pervasive** – A wide range of data should be collected frequently from the entire broadband community so as to support a broad range of possible data uses. Pervasive collection also ensures a statistically valid network view.
- **Automatic** – Data collection should not require volunteers, opt-in, nor installation of specialized equipment. Data collection should be automatic in the background.
- **Non-invasive** – Data collection must not harm users' quality of service, nor negatively affect service providers' operation. More specifically, the data collection process should have no effect on broadband performance as perceived by the internet consumer.
- **Uniform** – Data collection, analysis, and presentation are based on consistent and well-defined schema and interfaces.
- **Accurate** – The collected data must provide a statistically valid and complete view of broadband services' performance..
- **Cost Effective** – Data collection's incremental cost must be minimal and appropriate. It should add only a negligible amount to broadband deployments' overall cost.
- **Sectionalized** – The data-collection process should enable location of a bottleneck or issue within the end-to-end connection. Not all impediments to a user's Quality of Service or Quality of Experience are caused by the broadband access link.
- **Stakeholder Independent** – The data quality and its resulting analysis should be bias free, whether bias was intentionally introduced due to vested interests or systematically introduced by the organization providing the data.
- **Privacy** – Only aggregated data be publicly distributed and analyzed to preserve user anonymity, to protect personally identifiable information, and to safeguard the proprietary interests of all data sources.

3. Proposed System Architecture for Data Collection and Analysis

ASSIA, with its *ASSIA Reports* platform, addresses the problems cited above. Systems using ASSIA's methods are deployed today that enable pervasive data collection, analysis, and presentation on overall end-to-end, as well as sectionalized, performance of a broadband network. This collection and analysis platform has been anonymized to protect both users' personal identifiable information as well as the proprietary interests of carriers and content providers. It is also fully automated, avoiding opt-ins, volunteering, or specific actions by the users of the network. This data today, however, is largely restricted within the confines of internet service providers who use the ASSIA Reports technology - ***this is not a technical restriction, but one born of the service providers' initial disposition to control this data.***

3.1. Schematic View of the Proposed Architecture

Figure 1 provides a schematic architectural overview for pervasive broadband data collection. This architecture has some customer premises served by wireline ISPs (fiber, cable, or DSL-based services), while other customer premises may be served by fixed-wireless-access technologies.

Most broadband households today have a gateway that provides both the modem functionality as well as the Local Area Network (LAN) functionality. This gateway connects devices to the

broadband link, be that link wired or wireless. The gateways in the proposed system architecture include an Integrated Performance Agent (IPA) that collects performance information on both the in-home LAN and on the broadband access link. Some IPA embodiments are already deployed widely in many existing broadband gateways. For example, ASSIA has developed a software IPA that is used by roughly 40 major internet service providers to monitor nearly 100 million operational lines worldwide. Similar IPAs have been developed and deployed by other vendors as well.

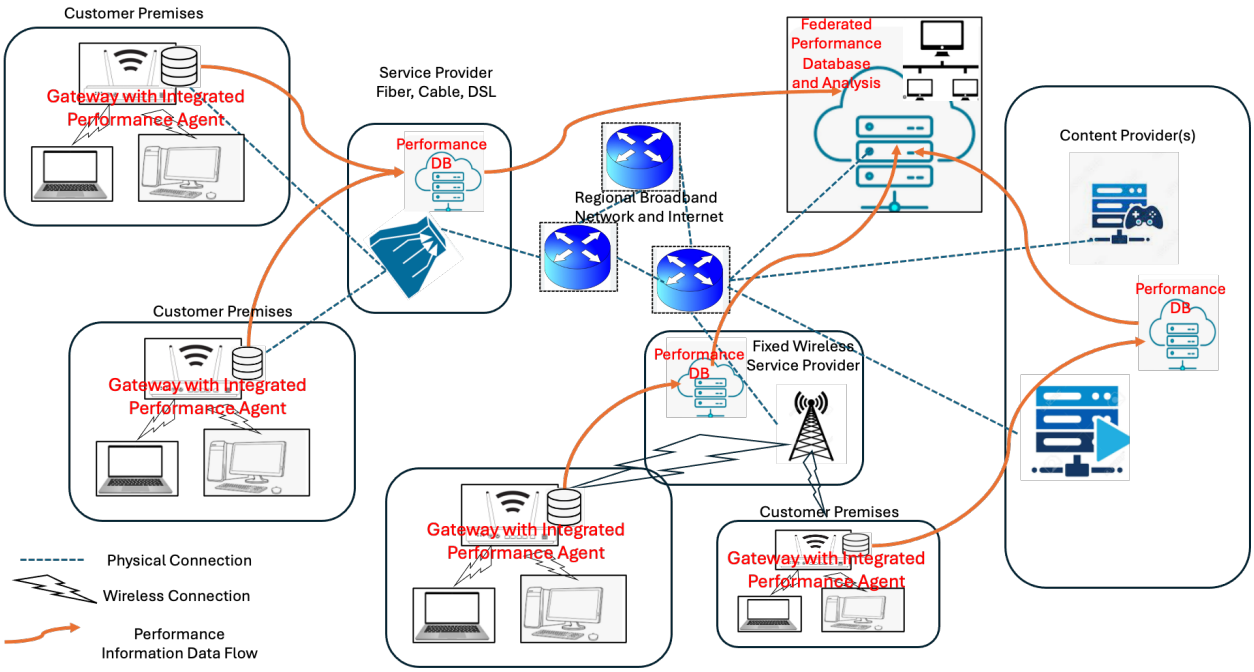

Figure 1 Schematic View of the Pervasive Data Collection Architecture

Furthermore, standards such as the Broadband Forum TR-069 and TR-369 provide standardized methods for nearly 1 billion subscribers worldwide[12] to send performance information to servers and databases that are maintained by carriers, ISPs, and content providers.

Much of the raw performance data described in this paper is already widely collected by the service providers to manage their own networks and serve their internet-consumer customers. However, different service providers do not necessarily use the same data model or the same interfaces to their management systems. A goal in developing a mature architecture for federated data collection and analysis is data-model standardization for the collected performance information collected and for the interfaces and APIs between the gateways and the carriers' servers and databases.

[12] Per the Broadband Forum at https://www.broadband-forum.org/projects/connected-home/resources-research-analysis

Standardized interfaces then can support a requirement that federal, state, or municipal funds' recipients must provide the data, over the standardized interfaces, as a condition for funds' receipt. This will help enable the overall system's development as a public resource.

As anonymized data is collected, it becomes available for presentation and analysis by any number of systems. This federated-database data becomes a public resource available to all stakeholders. Data access and its ultimate use can be decoupled by API definition and by data schemas required to access these federated databases.

3.2. Data Collection and Analysis Framework

Underlying this system architecture and providing a basis for the standardization explored above is a common Broadband Data Collection and Analysis Framework developed by ASSIA for *ASSIA Reports*. This framework defines various data collection and analysis phases, and it also stratifies broadband parameters into different levels, as detailed in this paper's next sub-sections. When implemented to support a pervasive and anonymous data collection process, this framework can provide the basis for a common national repository of broadband performance data.

3.3. Data Collection and Analysis Phases

To enable the use of commonly collected and comparable data that can support disparate analyses, ASSIA recommends four processing 'phases,' as in Figure 2.

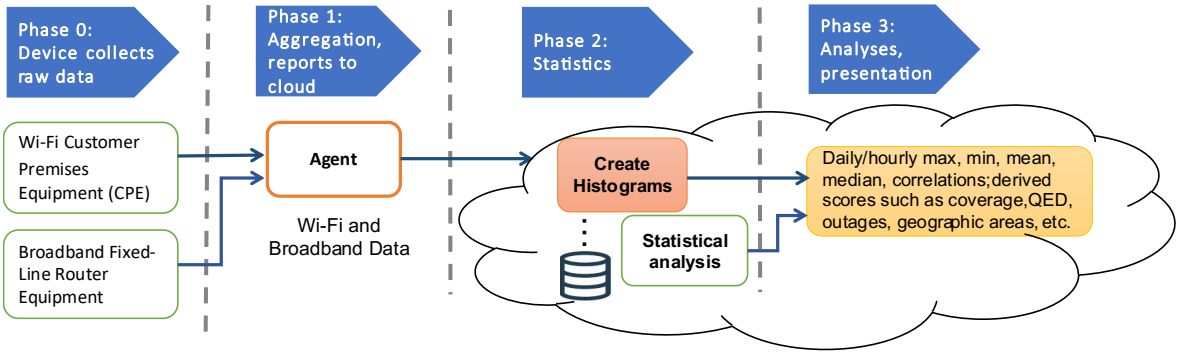

Figure 2 – Overview of the Phases of Analysis of Broadband QoS and Reliability Data

Phase 0: Raw data and measurements are collected from network and user devices. Installation of a software agent on the devices is an effective way to run tests and gather measurements.

Phase 1: Devices send data to a remote server or a cloud database. An agent aggregates raw data, averaging many 5-second measurements and then reporting every 15 minutes. This limits telemetry traffic. A standardized protocol such as Broadband Forum's TR-069 or TR-369 is recommended for such data transmission.

Phase 2: An analysis engine determines statistical performance across the population. Histograms, maximums, minimums, averages, and other statistics are effective outputs of this phase.

Phase 3: Evaluation is performed where metrics are produced and presentations generated, e.g. plots, trends, and overall scores such as the Quality of Experience Delivered (QED) metric as defined in Broadband Forum BBF MR 452.2.

Table 1 lists a minimal example collected-parameter set that supports broadband-performance measurement. Table 1's last column provides the raw data's assigned level.

Table 1 – Minimal Broadband Access Parameters and Levels

Parameter	Direction	Recording Frequency	Unit	Level
Offered Speeds	Downstream and upstream	N/A	Mbps	0
Throughput	Downstream and upstream	Daily (hourly also optional)	Mbps	1
Latency	Roundtrip	Daily (hourly also optional)	Milliseconds	1
Traffic	Downstream and upstream	Daily (hourly also optional)	GBytes/day MBytes/hour	2
Packet Loss Rate	Downstream and upstream	Daily	Percent	2
Internet Down Count		Daily	Number of occurrences/day	2
Internet Down Duration		Daily	Seconds/day	2

While not specific to broadband access, Wi-Fi link performance is highly useful for sectionalization and identification of Wi-Fi bottlenecks versus other bottlenecks. Salient Wi-Fi performance parameters are throughput, latency, traffic, frame loss rate, retransmission rate, interference, congestion, channel utilization (airtime), Wi-Fi coverage, transmit rate, surrounding BSS density, and received signal strength, to name just a few. A useful subset of these parameters can be collected easily that will provide Wi-Fi link visibility. Table 2 below lists some example Wi-Fi parameters for collection.

Table 2 – Example Wi-Fi Parameters

Parameter	**Frequency of Collection**
Wi-Fi Throughput (Speed)	Daily, 2.4 and 5 GHz bands
Wi-Fi Transmit Rate	Daily, 2.4 and 5 GHz bands
Wi-Fi Throughput to Transmit Rate Ratio	Daily, 2.4 and 5 GHz bands
Wi-Fi Congestion	Daily and max hour, 2.4 and 5 GHz bands
Wi-Fi Interference	Daily and hourly, 2.4 and 5 GHz bands
Wi-Fi Traffic	Daily and hourly, upstream and downstream, 2.4 and 5 GHz bands
Wi-Fi Latency	Daily, 2.4 and 5 GHz bands

4. Proposed Policy Directions

To enable the opportunities and benefits provided by a flexible yet simple system architecture supporting pervasive, statistically valid, and anonymous broadband data collection and analysis, several policy re-directions, and minor reallocations of federal funding is recommended. More specifically:

- **Encourage API use:** Appropriate regulations should be enacted to encourage the development and adoption of standardized APIs, date schemas, protocols, and procedures for the collection, exchange, analysis, and presentation of broadband performance information. Standardization efforts should be supported and stakeholders in the private sector should be encouraged to embrace them. Special attention should be given to issues related to maintaining privacy and anonymity of data, as well as efficiency and system cost.

- **Support Data Collection:** Funds should be sub-allocated from various appropriated federal funds (currently totaling nearly $80 billion over 10 years) for deploying broadband infrastructure. If just 1% of the already appropriated funds were sub-allocated to support the measurement, analysis, and presentation of the current state of America's broadband infrastructure, the remaining funds can be used much more effectively, focused on addressing those problems that really matter. The likely benefit on the use of the other 99% of funds will greatly exceed the 1%. Furthermore, the USA will benefit from the development of a better broadband regulatory environment, more efficient deployment of next generation network architectures, more effective private expenditures to benefit more Americans, and a focused public policy that is based on the actual quality of service received (and perceived) by users of America's broadband networks.

- **Motivational Regulation:** Regulation should encourage, and where necessary require, the stakeholders, private or public, to provide access to broadband performance data

that is needed to better serve the rapidly growing demands of American broadband. One obvious regulatory avenue would require public-funding recipients to provide public access to pervasive, accurate, and anonymized data as a condition for receiving grants. Many ISP's already collect the data necessary to support such analysis for their own network management. Similarly, existing (and future) network and customer equipment are also designed to collect this salient broadband performance data. These data can be collected without disrupting normal operation as perceived by the user, at a low cost, and with anonymity. However, public and unbiased access to those data can occur only if motivated by appropriate regulations.

- **Federal Agencies' Support:** Specific support by NSF, NIST, and DARPA to fund research and development into methods for collecting, analyzing, and presenting broadband data should become a priority. Some such areas may include a better understanding of existing standardized data schemas and protocols and how they may be used to enable pervasive and anonymous data collection. Other areas may include the identification and possible new development of data-analysis techniques that can be adapted for use in determining broadband quality of service and quality of experience. With commonly understood and accepted analytical definitions and criteria (objective and social), the determination of whether equity of access among affected groups and/or geographic regions has been achieved can be accurately assessed. Further use of artificial intelligence for the analysis of massive amounts of broadband performance data will almost certainly lead to innovation and improved services that would sustain and maintain America's leadership in the Internet Age.

5. About Adaptive Spectrum and Signal Alignment, Inc. (ASSIA)

ASSIA is a small business with an exemplary history. Founded in 2003, we have developed software and systems that currently manage the performance of nearly 100 million broadband access lines worldwide. These products were successfully sold to a public company in 2022, which currently manages field deployments under a nonexclusive license from ASSIA. ASSIA retains a global patent portfolio with over 80 patent families in the areas of broadband monitoring and management. A number of these families directly apply to use cases detailed in this white paper. ASSIA, as an enterprise, endeavors to promote and enable further success for global, widescale use of broadband access monitoring. As stated previously, this technology area has presently and will increasingly be of crucial public importance, and it is one where ASSIA can uniquely contribute.

ASSIA's team is headed by Dr. John Cioffi, Recalled Emeritus Professor of Electrical Engineering at Stanford University. Dr. Cioffi is listed as an inventor on over 200 patents, some of which are foundational to broadband access, and he is a recipient of numerous awards, including the National Medal of Technology and Innovation. He heads a seasoned technical team that includes multiple IEEE Fellows and leaders in standards development.