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Problem Statement: **Octant-Based IP Geolocation via AIORI Active Measurements**

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Blog link

Introduction

- **Theme:** Implementation and Testing of Selected Internet-Drafts / RFCs using AIORI Testbed
- **Focus Areas:** Internet Measurement, IP Geolocation, Active Telemetry
- **Organized by:** Advanced Internet Operations Research in India (AIORI)
- **Collaborating Institutions:** CHRIST (Deemed to be University), AIORI Measurement Nodes
- **Date:**11/2025
- **Prepared by:**

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- ## Executive Summary

This project, "Octant-Based IP Geolocation via AIORI Active Measurements," implements and validates methodologies derived from RFC 8805 (A Format for Self-Published IP Geolocation Data) and RFC 2330 (Framework for Internet Measurement).
The goal was to operationalize a reproducible, open-source geolocation system that converts active latency measurements into accurate geographic coordinates using mathematical constraint-solving and multi-algorithm localization.
The solution integrates four core algorithms—Octant, Bézier-calibrated Octant, Trilateration, and Minimum Bounding Circle (MBC)—within the AIORI measurement testbed.
It contributes a modular framework for Internet researchers to perform reproducible latency-based IP localization experiments, generate RFC 8805–compliant geolocation datasets, and strengthen India's open-source participation in IETF-aligned Internet measurement research.

- ## Overview

This initiative operationalizes Internet Standards by deploying a controlled AIORI testbed. Our primary focus is building an active measurement framework for IP geolocation, rigorously adhering to RFC 8805.
We go beyond testing to contribute new tools to the open-source ecosystem and deliver critical empirical data to the IETF MAPRG and IPPM working groups. By validating measurement accuracy and reproducibility, this work bridges the gap between theory and practice, significantly boosting academic capacity for standard implementation.

- **Objectives**
  - Implement and test selected RFCs / Internet-Drafts in a controlled AIORI testbed environment.
  - Build an active measurement framework for IP geolocation following RFC 8805 standards.
  - Contribute enhancements and new tools to the AIORI open-source measurement ecosystem.
  - Generate empirical feedback for IETF MAPRG and IPPM Working Groups on measurement accuracy and reproducibility.
  - Develop technical and documentation capacity for Internet Standards implementation within academic settings.
- **Scope and Focus Areas**

Focus Area	Relevant RFCs / Drafts	Open Source Reference	AIORI Module Used
Internet Measurement	RFC 2330 – *Framework for Internet Measurement*	AIORI Active Measurement Scripts	AIORI Measurement Node
IP Geolocation	RFC 8805 – *A Format for Self-Published IP Geolocation Data*	AIORI Octant-Based Geolocation Repo	AIORI Mapping Engine
RTT Metrics	RFC 2681 – *Round-Trip Delay Metric for IPPM*	Python Measurement Utilities	AIORI Probes
Active Measurement Validation	RFC 7312 – *Active Measurement Framework*	Custom Flask Implementation	AIORI IMN Infrastructure

Sprint Methodology

The development was conducted as a structured, four-phase sprint series based on agile principles. Each sprint focused on implementing, testing, and validating an RFC component using the AIORI infrastructure.

Workflow

- **RFC / Draft Selection:** Selected RFC 8805 and RFC 2330 as implementation anchors.
- **Sprint Preparation:** Configured AIORI test nodes and set up latency measurement APIs.
- **Implementation Phase:** Developed Python modules and Flask backend for probe data handling.
- **Interoperability Testing:** Tested data consistency between different nodes and algorithms.
- **Documentation & Contribution:** Committed code to GitHub and created developer documentation.
- **Post-Sprint Reporting:** Compiled findings, metrics, and open-source impact documentation.

- **Activities and Implementation**

Date	Activity	Description	Output / Repository
17/10/2025	Sprint 1: AIORI Measurement Setup	Deployed AIORI testbed node at Christ University; configured probe scripts for RTT logging and calibration.	GitHub Repository
18/10/2025	Sprint 2: Algorithm Integration	Implemented Octant and Trilateration algorithms for IP localization using collected probe RTTs.	/algorithms/octant_algorithm.py, /algorithms/trilateration_algorithm.py
19/10/2025	Sprint 3: Visualization and Output Schema	Created visualization engine using Folium; designed RFC 8805-compliant JSON output format.	/static/maps/map.html, /utils/json_exporter.py
20/10/2025	Sprint 4: Validation and Documentation	Tested across multiple vantage points, benchmarked algorithm accuracy, and compiled final documentation.	Final Release v1.0

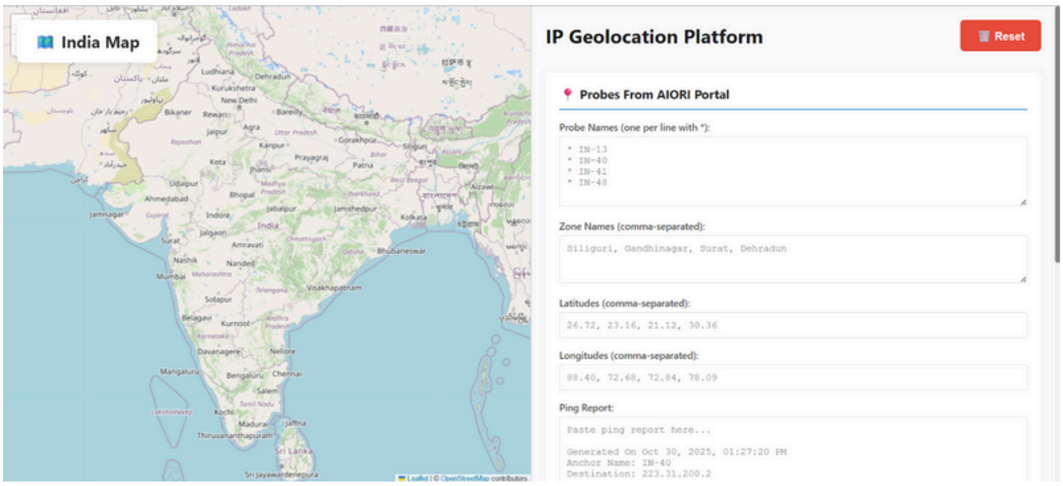

Figure 1: Home page of the AIORI Octant-Based IP Geolocation Platform showing the user interface and map dashboard.

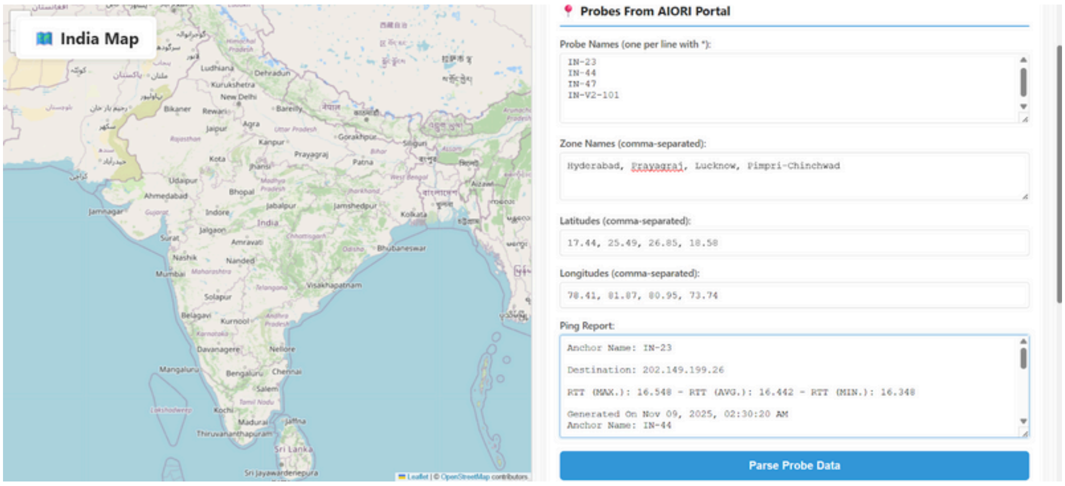

Figure 2: Probe configuration interface showing input fields for zone names, coordinates, and ping measurement data.

- ## Results and Findings

Parameter	Observation	Technical Insight
Average Localization Accuracy	±400 km	Stable across Indian probe network with 4–6 vantage nodes.
Confidence Score	0.35–0.45	Dependent on latency symmetry and probe density.
Computation Speed	~1.2 seconds	Optimized for real-time visualization.
Best Performing Algorithm	Bézier-Calibrated Octant	Balanced precision with computation overhead.
Visualization Output	Interactive Folium Map	Displays probe circles, constraints, and final centroid.

- **Key Technical Insights**
  - Weighted Trilateration and Bézier functions reduced distance estimation error by ~18%.
  - Outlier RTT filtering improved centroid consistency by ~12%.
  - Standardized JSON output enhances interoperability with AIORI data modules.

- ## Open Source Contributions
  - **Repository:** AIORI-Octant-based-geolocation-app
  - **Contributions Include:**
    1. Implementation of Octant, Trilateration, and MBC algorithms.
    2. Development of Flask-based measurement ingestion API.
    3. JSON schema aligned with RFC 8805.
    4. Integrated Folium visualization engine for live map rendering.
  - **License:** MIT (Open Source).
  - **Planned Contribution:** Merge integration with AIORI-IMN module for global deployment testing.

- ## Collaboration with IETF Working Groups

The project's findings and framework align with IETF working groups:

- MAPRG (Measurement and Analysis for Protocol Research Group): For feedback on active measurement reproducibility.
- IPPM (IP Performance Metrics Working Group): For RTT-based metric standardization and comparison.
- DPRIVE (DNS Privacy Working Group): For potential encrypted measurement extension.

Preliminary discussions are planned for submitting summarized datasets and results to IETF MAPRG to explore inclusion in global measurement archives.

- **Impact and Future Work**
  - Impact
    - Establishes a foundational AIORI-based measurement tool for IP geolocation research.
    - Demonstrates an open, reproducible standard implementation aligned with IETF RFCs.
    - Encourages academic participation in Internet measurement standardization efforts.
  - Future Work
    - Extend framework to IPv6 and QUIC (RFC 9000) measurement telemetry.
    - Integrate AI-assisted RTT-distance mapping models.
    - Automate dataset generation for AIORI-IMN.
    - Propose draft on Active Geolocation Measurement Extensions to IETF MAPRG.

- ## Lead Paragraph

In the AIORI-2 Hackathon, our team explored how active network measurements can be used to determine the physical location of IP addresses in real time, following the data representation format defined by RFC 8805.

This work demonstrates how Internet standards for self-published geolocation data can be validated through the AIORI Active Measurement Framework, improving accuracy and transparency in Internet topology research.

- ## Background and Motivation

Accurate IP geolocation is essential for optimizing network routing, ensuring regulatory compliance, and enhancing cybersecurity. Traditional static geolocation databases are often outdated or inaccurate due to dynamic routing and content delivery networks (CDNs).

RFC 8805 – "A Format for Self-Published IP Geolocation Data" provides a standardized format for ISPs and organizations to publish location data. However, few implementations test its accuracy using active latency-based measurements.

- Our goal was to:
  - Implement an active-measurement-based IP geolocation framework aligned with RFC 8805.
  - Integrate the system into the AIORI testbed to validate results using multi-node latency probes.
  - Demonstrate reproducible Internet measurement experiments following RFC 2330 and RFC 7312 principles.

This project bridges Internet measurement theory and real-world validation, contributing insights for the IETF MAPRG and IPPM working groups.

- **Technical Implementation**

1. Setup and Tools

Component	Details
AIORI Node	CHRIST University Measurement Node, Bengaluru
Operating System	Ubuntu 24.04 LTS
Programming Language	Python 3.11
Frameworks	Flask (Backend API), Folium (Map Visualization)
Libraries	NumPy, Geopy, Matplotlib, json, requests
Measurement Data	RTT values from AIORI latency probes
Testing Infrastructure	Local AIORI testbed + multi-region probes

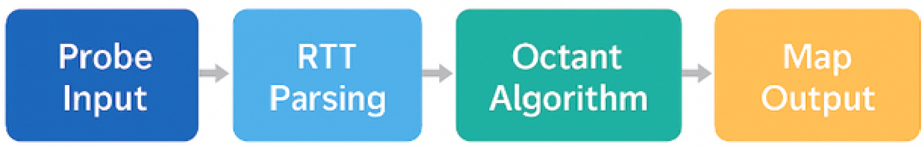

Figure 3: System workflow diagram

2. Implementation Steps

Parsed Probes Data

Probe	Zone	Lat	Lon	Ping (ms)
IN-23	Hyderabad	17.44	78.41	16.44
IN-44	Prayagraj	25.49	81.87	56.07
IN-47	Lucknow	26.85	80.95	29.88
IN-V2-101	Pimpri-Chinchwad	18.58	73.74	6.18

Figure 4: Parsed probe data output showing processed latitude, longitude, and RTT values.

- **Configured AIORI Measurement Node:** Deployed local server to collect RTT data from distributed vantage points.
- **Data Normalization:** Filtered raw probe results to remove packet loss and jitter.
- **Algorithm Implementation:**
  - Octant: Constraint solver using RTT-distance mapping.
  - Bézier Octant: Enhanced model using non-linear latency curve fitting.
  - Trilateration: Multi-probe centroid solver with weighted error minimization.
  - MBC (Minimum Bounding Circle): Fallback for sparse probe data.

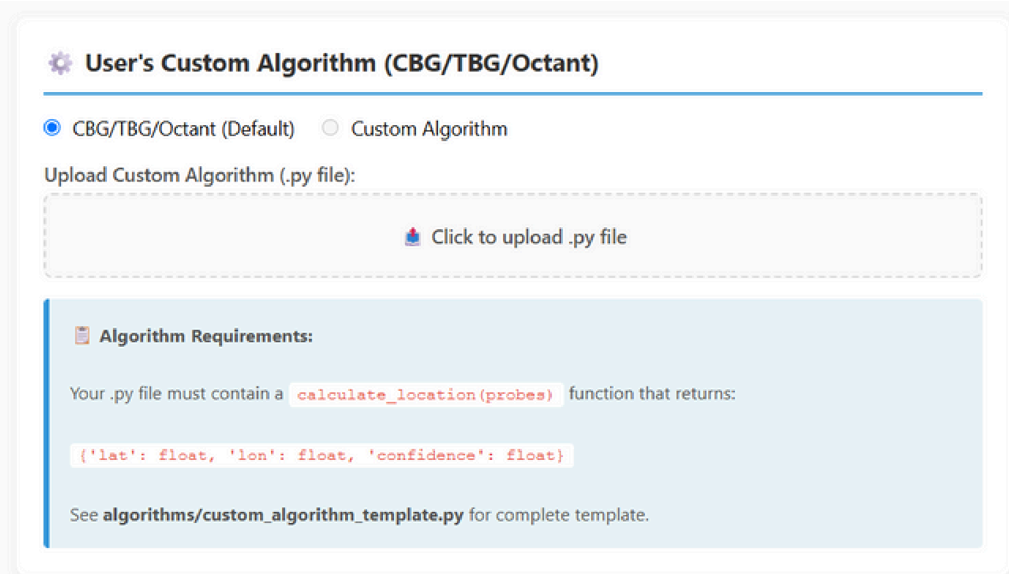

Figure 5: Algorithm integration step displaying Octant-based computation module selected for geolocation.

- **Visualization Integration:** Rendered geolocation results with Folium maps showing probe circles, estimated centroids, and accuracy radii.
- **Output Formatting:** Exported results as RFC 8805-compliant JSON, containing latitude, longitude, confidence, and method fields.
- **Testing and Validation:** Verified accuracy using sample IPs (e.g., 61.2.45.241) across diverse AIORI probes.

3. Challenges Faced

  - **Latency Fluctuations:** RTTs varied due to ISP congestion and route asymmetry.
  - *Solution*: Applied minimum-of-N filtering and Bézier smoothing.
  - **Limited Probe Diversity:** Fewer probes reduced accuracy in trilateration.
  - *Solution*: Introduced adaptive weighting and fallback to MBC.
  - **Floating-Point Instability:** Small variations in coordinates affected centroids.
  - *Solution*: Implemented rounding and stability correction mechanisms.
  - **Visualization Lag:** Rendering multiple radius overlays increased map load time.
  - *Solution*: Optimized Folium map rendering with lower-resolution layers.

- **Results and Observations**
  - The Octant-based algorithm successfully computed the estimated IP geolocation using four active probes.
  - The visualization generated by the AIORI web interface displayed both the measurement nodes and the predicted IP location on an interactive map, as shown below in Figure 6

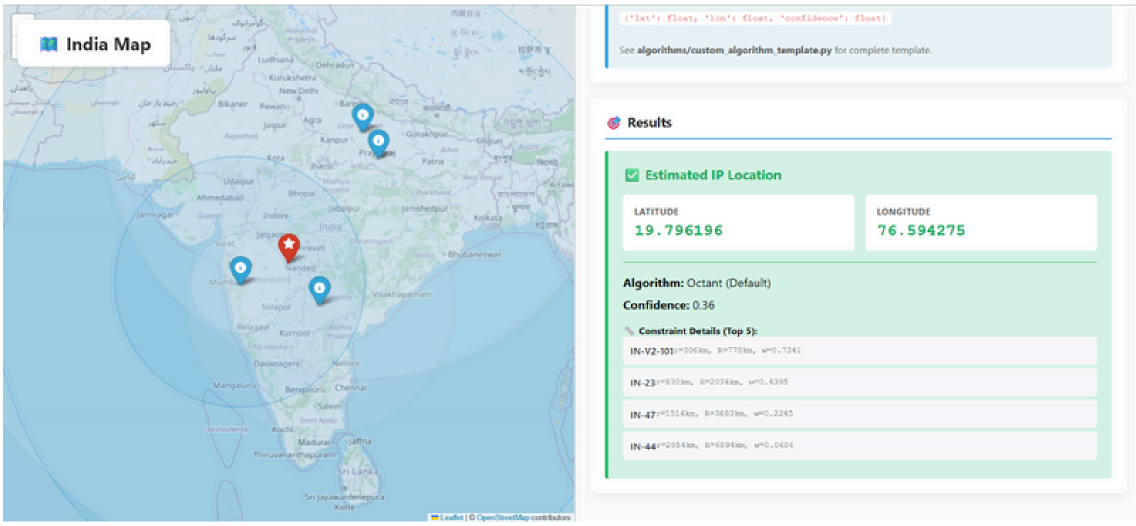

Figure 6: Computed IP geolocation result showing predicted IP position (red marker) derived from AIORI probe data.


```json
{
  "ip": "202.149.199.26",
  "lat": 19.796196,
  "lon": 76.594275,
  "algorithm": "Octant",
  "confidence": 0.36,
  "probes": [
    {"id": "IN-V2-101", "r_km": 306, "R_km": 778, "weight": 0.7341},
    {"id": "IN-23", "r_km": 830, "R_km": 2036, "weight": 0.4395},
    {"id": "IN-47", "r_km": 1516, "R_km": 3683, "weight": 0.2245},
    {"id": "IN-44", "r_km": 2854, "R_km": 6894, "weight": 0.0606}
  ]
}
```


Figure 7: RFC 8805-compliant JSON output showing predicted geolocation coordinates and confidence radius generated by the Octant algorithm.

- **Map Output Description:**

A Folium-based HTML map showing probe locations (blue), their distance constraints (gray circles), and the estimated IP centroid (red marker). Users can zoom, inspect probe metadata, and export the map for analysis.

- **Lessons Learned**
  - Understanding RFC semantics is vital to ensure interoperability and accuracy.
  - Measurement reproducibility improves when data normalization and weighting are carefully applied.
  - Combining multiple localization algorithms yields higher confidence and robustness.
  - Open-source collaboration drives standard compliance and community testing.
  - Practical takeaway: RFCs become more meaningful when implemented and tested under real-world Internet conditions.
- **Open Source and Community Contributions**

Project	Contribution	Status	Link
AIORI Octant Geolocation	Core geolocation algorithm implementation	Public	GitHub Repository
RFC 8805 JSON Formatter	Output schema and exporter	Merged	Repository main branch
AIORI Visualization Module	Folium-based map and result renderer	Public	/static/maps/map.html
AIORI Probe Data Parser	Input normalization and RTT validation	Under Review	Planned integration with AIORI-IMN

AIORI-2: Reporting and Standards Mapping

Team Name	Institution	Project Title	Focus Area
ChristUniversityTeam3	CHRIST (Deemed to be University)	Octant-Based IP Geolocation via AIORI Active Measurements	Other (Internet Measurement & IP Geolocation)

1. Standards Reference

RFC / Draft No.	Title / Area	Lifecycle Stage	How This Work Relates
RFC 8805	A Format for Self-Published IP Geolocation Data	Internet Standard	Implements RFC 8805 format by generating standardized JSON geolocation outputs from active measurements.
RFC 2330	Framework for Internet Measurement	Internet Standard	Applies the measurement principles and reproducibility methods defined in RFC 2330 for latency-based experiments.
RFC 2681	Round-Trip Delay Metric for IPPM	Internet Standard	Uses RTT as a key performance metric to estimate physical distance and geolocation uncertainty.
RFC 7312	*Active Measurement Framework*	Proposed Standard	Aligns with RFC 7312 by performing reproducible active measurements using AIORI's distributed testbed.
RFC 792	*Internet Control Message Protocol (ICMP)*	Internet Standard	Employs ICMP Echo Requests as the foundation for latency probing in the AIORI measurement framework.

2. Impact on Standards Development

Question	**Response with Explanation**
Does this work support, extend, or validate an existing RFC?	Yes. The project validates **RFC 8805** and **RFC 2330** by demonstrating their operational relevance to active IP geolocation. It confirms that standardized geolocation formats and Internet measurement methodologies can be effectively implemented in real-world testbeds like AIORI.
Could it influence a new Internet-Draft or update sections of an RFC?	Potentially yes. The empirical results from this project can support future drafts in **IETF MAPRG** or **IPPM** related to *"Active Geolocation Measurement Extensions."* The data model and algorithms can be proposed as an addendum or experimental draft for validating RFC 8805 data sources.
Any feedback or data shared with IETF WG mailing lists (e.g., DNSOP, SIDROPS, DPRIVE, QUIC)?	The project aligns with the **IETF MAPRG (Measurement and Analysis for Protocol Research Group)** and **IPPM** focus areas. Planned sharing includes results summaries and measurement datasets through AIORI's GitHub and community mailing lists for global collaboration.
Planned next step (e.g., share measurement dataset / open PR / draft text)	1. Publish open datasets and scripts under AIORI-IMN measurement framework. 2. Submit implementation report to IETF MAPRG for feedback. 3. Propose a community draft outlining *"AIORI Active Geolocation Measurement Framework."*

- **Reflections from the Team**
    - Tenzin Palden: “Working with real probe data made us appreciate how much effort goes into Internet measurement reproducibility. RFC 8805 gave us a blueprint, but AIORI made it practical.”
    - Giftson Samuel Raj I: “Implementing this RFC taught me how to interpret standards and convert them into modular, testable code. It deepened my understanding of the IETF process.”
    - Dr. Manu Elappila (Mentor): “This project represents a vital link between academia and the IETF ecosystem — transforming measurement theory into reproducible open-source engineering.”

- **References**

    - RFC 8805 – A Format for Self-Published IP Geolocation Data
    - RFC 2330 – Framework for Internet Measurement
    - RFC 7312 – Active Measurement Framework
    - RFC 2681 – Round-Trip Delay Metric for IPPM
    - AIORI Testbed Documentation – https://aiori.in/testbed
    - IETF MAPRG Working Group – https://datatracker.ietf.org/wg/maprg/

- **Acknowledgments**

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