Characterizing traffic destinations and temporal trends for adaptive resource management in 5G/6G networks

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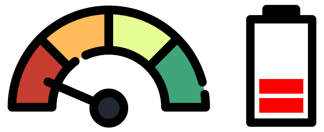
CSE3000 Research Project

1. Introduction

Problem:
Traditional networks are often designed to handle peak demand, leading to inefficient resource utilization and unnecessary energy consumption during off-peak periods.



>>> This rigid approach is increasingly unsustainable as network traffic continues to grow unpredictably, driven by applications such as immersive augmented reality (AR) and virtual reality (VR), remote healthcare, autonomous vehicles, and large-scale IoT deployments.

Estimations:

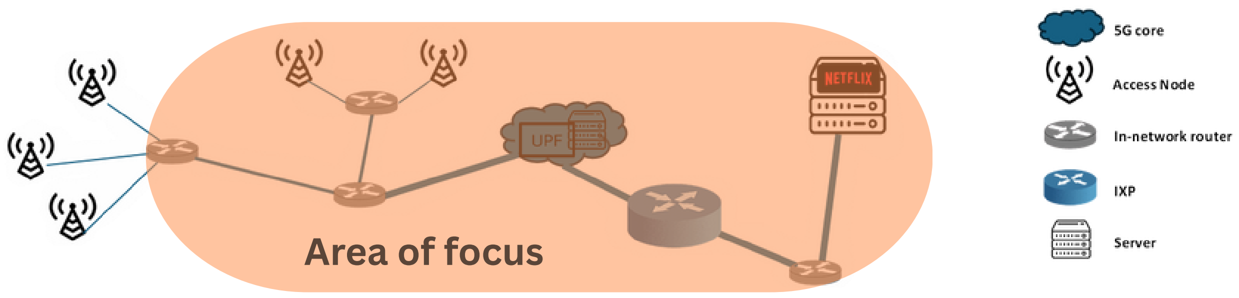
- International Telecommunication Union:
  - 📊 Global mobile network data traffic to reach 1,110 EB/month by 2029
  - 📈 25% CAGR from 2023–2029
- Cisco Internet Report:
  - 📱 Mobile = 30% of IP traffic by 2027
- GSMA Mobile Economy:
  - 🌐 5G > 50% of connections by 2030

Solution:
The transition from 5G to 6G networks is expected to fundamentally reshape network resource management, moving from static capacity provisioning toward dynamic, adaptive, and predictive orchestration.

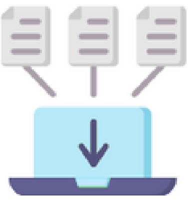
- **Previous work:** Current research often treats spatial or temporal patterns in isolation, neglects destination-level analysis, or lacks relevance to dynamic network control.
- **Approach:** This work proposes MANTA: a passive, reproducible framework that combines traffic destination analysis with performance metrics (latency, BGP churn) to support adaptive resource management in 5G/6G networks.

2. Research question

How can we characterize where user traffic is terminating across various infrastructures and analyze temporal patterns in traffic flows?

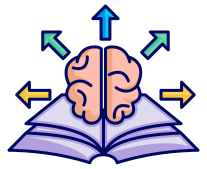


3. Methodology



Data collection & ingestion

- Collect passive traffic traces (MAWI, CAIDA)
- Extract flow-level metadata (IP addresses, ports, protocols)
- Preprocess packet data into flow records



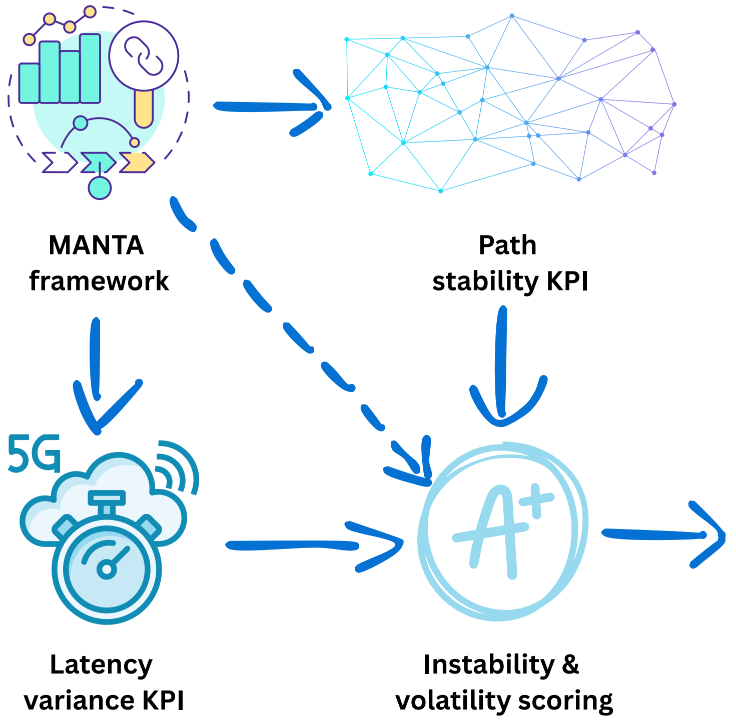
Enrichment & classification

- Geolocate IPs (IPInfo, GeoLite2) → country, city, coordinates, org
- Map IPs to prefixes and ASNs (CAIDA RouteViews)
- Classify ASes by role using PeeringDB (e.g., Content, ISP, Enterprise)
- Label flows by destination category (locality, ASN type, organization)

Metric computation & analysis

- Estimate RTT passively via TCP Timestamps
- Measure BGP instability (AS path churn, announcements) from RIPE RIS
- Compute composite volatility scores per prefix
- Analyze trends over different time windows and across regions/orgs

4. Contributions



- **Traffic steering:** Route interactive or real-time traffic to low-volatility destinations to reduce jitter and delay.
- **Slice placement:** Deploy latency-critical services on infrastructure with stable RTT and BGP profiles.
- **Cache replication:** Mirror content to destinations with low volatility scores to improve delivery reliability.
- **SLA enforcement:** Monitor passive metrics to ensure compliance for priority traffic without active probes.

$$I(p) = \frac{\sigma_{\mathrm{RTT}}}{\mu_{\mathrm{RTT}}}$$

$$\mathrm{BGP\_Churn}(p) = \#\ of\ path\ updates\ to\ p$$

$$V(p) = \alpha \cdot I(p) + \beta \cdot \mathrm{BGP\_Churn}(p)$$

🔧 **Use Case: Slice Placement**
A telecom operator plans to deploy AR services in Southeast Asia. MANTA identifies regional ASes with high volatility. Based on composite scores, the operator selects alternate prefixes in Singapore and Bangkok with lower instability for consistent user experience.

5. Results

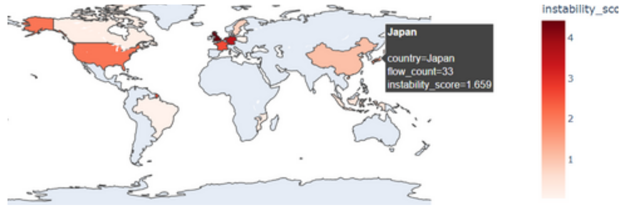


Figure 1: Geographical RTT instability by country (Content ASNs, 2015-03-30–2015-04-05, 14:00 JST)

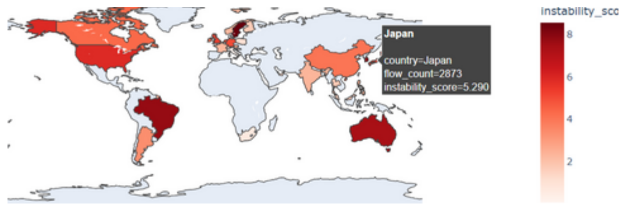


Figure 2: Geographical RTT instability by country (Content ASNs, 2025-03-31–2025-04-06, 14:00 JST)

📌 **Insights (2015 → 2025)**

- 🌐 **Broader flow coverage:** More countries appear over time, reflecting greater global reach and routing diversity.
- 📈 **More traffic, more volatility:** Heavier flow regions tend to show higher instability, likely due to load-sensitive paths.
- 📍 **Distance ≠ instability:** Geographic proximity doesn't guarantee low volatility, peering and infrastructure matter more.
- ⚠️ **Emerging hotspots:** Persistent high-instability regions highlight targets for edge cache and interconnect deployment.
- 🧩 **Content ASNs stay stable:** CDNs maintain low volatility, benefiting from redundant, well-placed infrastructure.

📌 **Insights (Jan → Jun 2025)**

- 🔺 **Enterprise ASNs show spikes:** Volatility peaks in March and May, likely due to reconfigurations or workload shifts.
- 📦 **Content ASNs remain stable:** Low, stable scores reflect CDN redundancy and resilient routing strategies.
- — **Other networks (e.g., ISPs, NSPs)** maintain low volatility with minimal month-to-month variation.
- 📉 **Volatility levels converge by June**, hinting at seasonal balancing or network stabilization efforts.

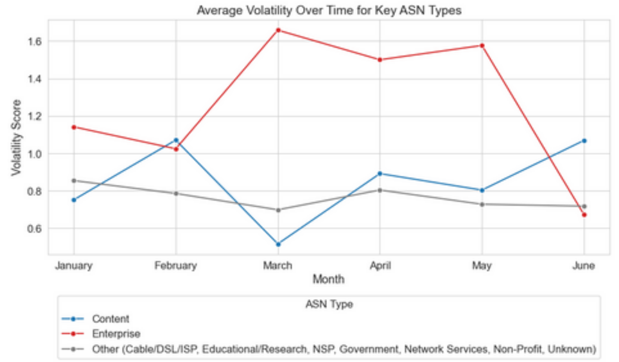


Figure 3: Monthly prefix volatility by ASN type (Jan–Jun 2025)

6. Discussion & conclusions

- 🔍 **Volatility is not evenly distributed across AS types or geographies**: some networks experience chronic instability, while others remain predictably stable.
- 🧪 **Passive measurements are operationally viable**: RTT estimation and BGP churn can offer actionable insights without active probing.
- 🚧 **Incomplete visibility remains a challenge**: Backbone traces miss access/RAN layers and often lack metadata for uncategorized traffic.
- 📊 **Composite volatility scoring enables infrastructure benchmarking**, allowing operators to prioritize stable prefixes for routing and resource planning.