Ripe Atlas
Internet communication analysis tool

Project in Computer Networks
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1. Project overview

The RIPE Atlas Network Analysis Tool is a project aimed at harnessing the power of the RIPE Atlas global network of probes to uncover and analyze significant internet anomalies that occurred during the Covid-19 crisis or other significant world events. In a world increasingly reliant on digital connectivity, understanding the impact of global events on internet behavior is of paramount importance. This project seeks to contribute to this understanding by developing a comprehensive tool capable of extracting, processing, and interpreting publicly available statistics from RIPE Atlas.

1.1 Abstract

The Internet is a dynamic and intricate ecosystem susceptible to the influence of diverse factors, including cyber threats, political dynamics, and unforeseen events. Measuring and analyzing internet performance provides insights into its health, behavior, and response to external influences. RIPE Atlas, a worldwide network of probes, offers a wealth of real-time data on network connectivity, security, and stability. This project's aim is to leverage RIPE Atlas to create an analysis tool capable of identifying anomalies in internet behavior during the Covid-19 crisis.

1.2 Project Objectives

The primary goals of the RIPE Atlas Network Analysis Tool are as follows:

Phenomena Identification: Define and categorize significant internet phenomena during the Covid-19 crisis that can be detected and analyzed using RIPE Atlas data.

Capability Assessment: Evaluate existing tools in the field and specify the unique capabilities of the tool under development.

High-Level Design: Develop a comprehensive High-Level Design document that outlines the software architecture. Define the required modules and their interactions to ensure seamless data extraction, processing, and anomaly detection.

Implementation and Testing: Code and test the developed tool to ensure accuracy, reliability, and robust anomaly detection capabilities.

Anomaly Discovery: Deploy the tool to extract and analyze publicly available RIPE Atlas statistics. Uncover and interpret unusual internet phenomena that emerged during the Covid-19 crisis.

1.3 Prerequisites

A foundational understanding of computer networks (course number 236334) is essential to comprehending the intricacies of the RIPE Atlas Network Analysis Tool and its implications for understanding internet anomalies.

1.4 Expected Outcomes

This project's outcomes encompass not only the development of a powerful analysis tool but also potential avenues for academic research and exploration. The long-term trajectory of this project includes the production of an academic paper, contributing valuable insights into the field of internet behavior analysis. Moreover, this project can lay the foundation for future research proposals, potentially culminating in an MSc research endeavor.

In essence, the RIPE Atlas Network Analysis Tool embodies a quest to decipher the internet's responses to global events, specifically shedding light on the Covid-19 crisis. By undertaking this project, we endeavor to enhance our understanding of internet dynamics and their broader societal implications.

2. Ripe Atlas overview

RIPE Atlas [1], an integral project of the Réseaux IP Européens Network Coordination Centre (RIPE NCC), is a pioneering and globally distributed measurement network designed to monitor and analyze the Internet's infrastructure and behavior. Through a dense network of geographically dispersed probes, RIPE Atlas provides data, insights, and tools that empower researchers, network operators, and stakeholders to comprehend the intricate workings of the digital landscape.

2.1 Key Components

2.1.1 Probes

At the core of the RIPE Atlas network are the probes, small hardware devices strategically placed around the world. These probes actively conduct a diverse range of measurements, such as latency, packet loss, DNS performance, and traceroutes, capturing the nuances of internet connectivity and behavior from various vantage points.

2.1.2 Anchors

Anchors serve as stationary, high-capacity measurement devices, enhancing the measurement capabilities of the network. By providing consistent and reliable data points, anchors contribute to comprehensive internet performance analysis.

2.1.3 Measurements

RIPE Atlas enables the creation and execution of a wide array of measurements, each tailored to specific aspects of internet analysis. These measurements encompass critical dimensions, including connectivity, performance, security, and infrastructure analysis. Researchers and operators can initiate measurements to gather insights into the behavior of specific networks, services, or websites, enabling them to troubleshoot issues, identify vulnerabilities, and optimize their online presence.

2.2 Data Visualization and Analysis

RIPE Atlas offers a suite of data visualization and analysis tools that transform raw measurements into actionable insights, although these tools have inherent limitations in capturing the full spectrum of results that can be derived from raw data. While the platform provides intuitive interfaces to explore and interpret collected data, empowering users to detect patterns, anomalies, and trends, these predefined tools might not encapsulate all the nuanced intricacies present in the raw measurements. The complexity of the digital landscape, coupled with the unique challenges posed by different network scenarios, underscores the need for a flexible and adaptable approach.

2.2.1 Data Sharing and Collaboration

Embracing the principles of open data, RIPE Atlas encourages collaboration and knowledge-sharing within the global community. The collected data is made accessible through APIs and data sharing mechanisms, fostering an ecosystem where researchers, developers, and enthusiasts can leverage the data to advance their understanding of internet phenomena.

2.2.2 Significance and Impact

RIPE Atlas plays a pivotal role in shaping the digital landscape by offering an unprecedented level of transparency and insight. Its contributions extend across various domains:

Network Monitoring and Troubleshooting: Network operators rely on RIPE Atlas to detect, diagnose, and rectify network anomalies promptly. The real-time measurements provided by the probes empower operators to maintain optimal network performance and address emerging issues swiftly. [2]

Security Enhancement: RIPE Atlas aids in enhancing cybersecurity by detecting DDoS attacks. By analyzing traffic patterns and identifying abnormal behavior, the network assists in safeguarding digital infrastructure from malicious activities. [3]

Research and Analysis: The wealth of data offered by RIPE Atlas fuels groundbreaking research in fields ranging from internet topology and routing to the impact of global events on network behavior. Researchers gain a comprehensive view of internet trends, enabling them to make informed conclusions and contribute to the advancement of networking knowledge.

Policy Formulation: Policymakers and regulators may use RIPE Atlas insights to understand the implications of network policies and regulatory changes. The platform provides empirical evidence that informs decision-making and contributes to the formulation of effective internet governance strategies. [4]

2.3 Conclusion

RIPE Atlas stands as a testament to the power of global collaboration and data-driven insights. Its distributed infrastructure, diverse measurement capabilities, and open approach to data sharing have revolutionized our understanding of the internet's inner workings. As we navigate the ever-evolving digital landscape, RIPE Atlas continues to illuminate the path forward, empowering stakeholders to make informed decisions, optimize network performance, and ensure the robustness and security of the global digital ecosystem.

3. World Events affecting the Internet

The internet, as a dynamic and interconnected ecosystem, is profoundly influenced by a myriad of world events that span from global crises to technological advancements. Understanding how these events impact the internet's behavior, stability, and performance is crucial for comprehending the network's intricate dynamics. One significant event that has had a profound impact on the internet's landscape is the COVID-19 pandemic, along with several other noteworthy occurrences that have left their mark.

3.1 COVID-19 Pandemic

A Paradigm Shift in Internet Usage The emergence of the COVID-19 pandemic in early 2020 marked a turning point in global history, altering the way societies functioned and interacted. This monumental event brought about an unprecedented surge in internet usage worldwide. As nations implemented lockdowns and restrictions, remote work, online learning, and virtual socialization became the norm. The resulting surge in internet traffic placed immense strain on networks, forcing them to accommodate an influx of users, applications, and data demands. [5]
During the pandemic, internet service providers faced the challenge of maintaining the quality and reliability of their services under increased demand. The strain on bandwidth and the need to support a variety of online activities underscored the importance of robust and resilient network infrastructure. The pandemic also accelerated the adoption of cloud services and online platforms, further reshaping the digital landscape. [6]

3.2 Geopolitical Events

Beyond the pandemic, geopolitical events have demonstrated their capacity to shape the internet's behavior. These events encompass a range of incidents that reflect the intricate interplay between global politics and digital connectivity. One illustrative example is the geopolitical tensions between countries that can manifest in localized internet disruptions. [7] For instance, during times of political unrest or diplomatic standoffs, governments may impose internet shutdowns or restrict access to specific online services.

Cybersecurity incidents, another facet of geopolitical events, can have far-reaching consequences on network behavior. Large-scale cyber attacks, often attributed to nation-state actors, can lead to widespread outages, data breaches, and disruptions in online services. These incidents highlight the vulnerability of the digital landscape to cyber threats arising from geopolitical motivations. [8]

Furthermore, diplomatic tensions between nations can impact the routing of internet traffic. Countries may implement measures such as rerouting data flows, affecting the efficiency and stability of internet connections. These actions underscore the intricate relationship between technological infrastructure and international relations. [9]

Geopolitical events can also prompt shifts in user behavior and the types of online services accessed. Fearing surveillance or censorship, individuals may alter their online activities, contributing to changes in traffic patterns. Additionally, restrictions imposed on content or communication platforms can influence the adoption of alternative tools and services, resulting in shifts in user engagement. [10]

The delicate balance between global politics and technological infrastructure is evident in the manifold ways geopolitical events can influence network behavior. As societies become increasingly reliant on digital communication, commerce, and information dissemination, understanding the impact of geopolitical dynamics on the internet is crucial for maintaining a resilient and accessible online ecosystem.

3.3 Conclusion

The internet's response to world events showcases its adaptive nature and its integral role in modern society. From the unprecedented challenges posed by the COVID-19 pandemic to the influence of geopolitical dynamics, each event has left an indelible imprint on the internet's evolution. Understanding the interplay between world events and the internet's behavior provides valuable insights into the network's resilience, vulnerabilities, and potential areas for improvement. As the digital realm continues to intertwine with global events, the ability to analyze and anticipate the impact of these occurrences on the internet becomes increasingly critical for network operators, researchers, and stakeholders alike.

4. Potential Use Cases

RIPE Atlas offers a diverse range of potential use cases that leverage its extensive data collection and analysis capabilities. This section showcases pivotal use cases that prominently feature RIPE Atlas data, illuminating its pivotal role in deepening insights into network dynamics and infrastructure. These use cases are realized through the implementation of the RIPE Atlas REST API, a tool that empowers access and integration of RIPE Atlas data into various analytical frameworks. Further details on the API can be explored in the official documentation. [11]

4.1 Latency Analysis

RIPE Atlas enables researchers and network operators to study latency across the Internet. By conducting active measurements like ping and traceroute, it becomes possible to monitor and analyze latency and packet loss between probes and various network targets. This capability is invaluable for identifying network congestion, diagnosing routing issues, and optimizing overall network performance.

4.2 DNS Reachability Analysis

With RIPE Atlas probes performing DNS queries, we can gain insights into DNS reachability. This functionality aids in assessing the health and efficiency of DNS resolvers and root servers. Furthermore, the analysis of DNS reachability can provide valuable historical context, helping us understand periods when the internet's reachability might have been impacted by various global events. By studying changes in DNS reachability, we can gain insights into moments when the internet may have been less accessible due to external factors or disruptions, contributing to a deeper comprehension of the broader influences on network behavior.

4.3 Routing Stability and BGP Analysis

RIPE Atlas anchors provide data on Border Gateway Protocol (BGP) dynamics, offering insights into routing stability and potential issues such as route leaks and hijacks. Researchers can analyze BGP data to identify changes in network paths and assess routing efficiency.

4.4 IPv6 Deployment and Performance

RIPE Atlas offers a comprehensive platform for studying IPv6 adoption, connectivity, and performance. The comparison of measurements over both IPv4 and IPv6 offers a unique lens through which researchers can assess the direction and effectiveness of governance investment in the digital realm.

4.5 Network Topology and Bottleneck Identification

The traceroute data collected by RIPE Atlas probes allows researchers to map the topology of the Internet (through investigation of BGP), identifying critical nodes and potential bottlenecks. This information aids in optimizing routing algorithms, enhancing network efficiency, and identifying areas for infrastructure improvement.

4.6 Time Synchronization and NTP Performance

Through the monitoring of Network Time Protocol (NTP) servers, RIPE Atlas enables the study of time synchronization issues within the Internet. This capability is crucial for maintaining accurate and consistent time across global networks. [19]

In summary, RIPE Atlas provides a versatile toolkit for exploring and understanding various aspects of the Internet's infrastructure and behavior. The platform's data collection and analysis capabilities empower researchers, network operators, and policymakers to make informed decisions, optimize network performance, and contribute to the evolution of a resilient and efficient global network.

5. Analysis tool overview

5.1 System Architecture

The system builded from 3 main parts:

Ripe Atlas - measurements database.

Django - web server that will serve the GUI as API , and will encapsulate the ripe atlas API calls for the frontend.

React - frontend that will show the GUI to the user.

All the system runs on localhost , no need for any external infrastructure. User only need to run a server and open the web page.

5.2 Functional requirements

- Modern web browser:
  - Chrome 60+
  - Firefox ESR +
  - Safari 10.1+/iOS 10.1+
  - Edge 12+
  - Opera 47+
- Internet connection
- Installed python ≥ 3.11
- Node ≥ 14

5.3 System Components and Modules Design

Ripe Atlas Cousteau - python library that encapsulate the Ripe Atlas API requests. [12]

Ripe Atlas Sagan - python library ,that encapsulate the Ripe Atlas API responses parcing and aggregation. [13]

Django - python web server that serve the GUI as API , and encapsulate the ripe atlas API calls for the frontend. Also will serve the frontend.

React - frontend that will show the GUI to the user.

React-router - routing library for react.

Redux - state management library for react.

Redux Toolkit Query - powerful data fetching and caching library for react.

5.4 Setup development stages

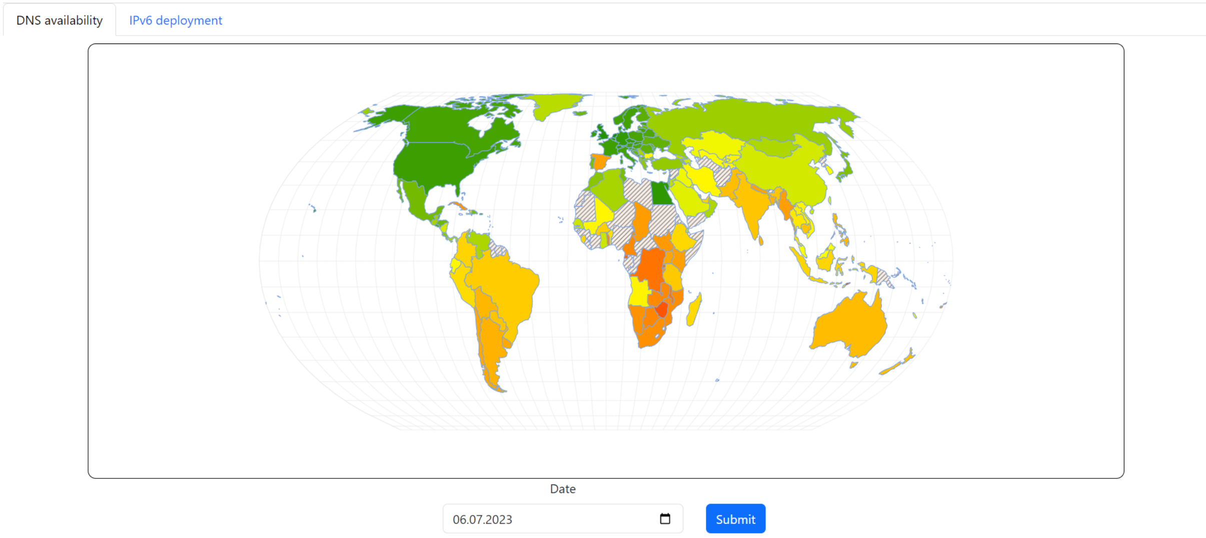
1. Create initial setup
    i. Create django initial project
    ii. Create react initial project using create-react-app
    iii. Connect them together using django-cra-helper
2. UI setup
    i. Setup Redux
    ii. Setup React-router
    iii. Setup Redux Toolkit Query.
    iv. Create basic UI for the main page , that will include choosing the use case and showing the results of use case.

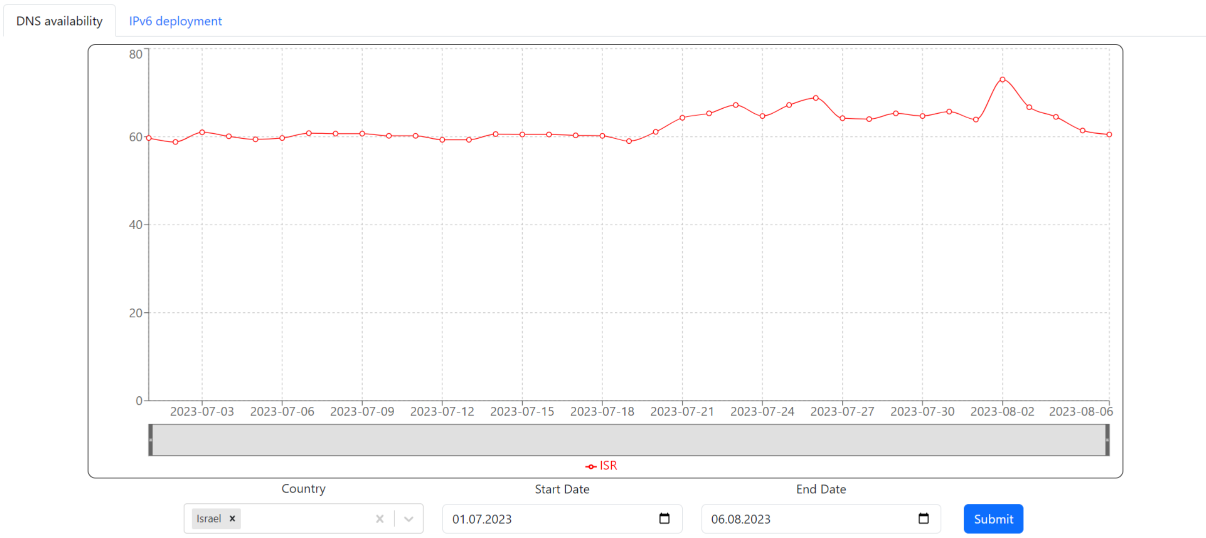
5.5 DNS stability check

5.5.1 Introduction and Objective

The primary aim of this part of the tool is to provide users with an intuitive GUI interface that facilitates the assessment of global DNS stability. This interface empowers users to comprehensively analyze and monitor the robustness of DNS services on a global scale.

5.5.2 User interface design





5.5.3 Algorithms and System Logic

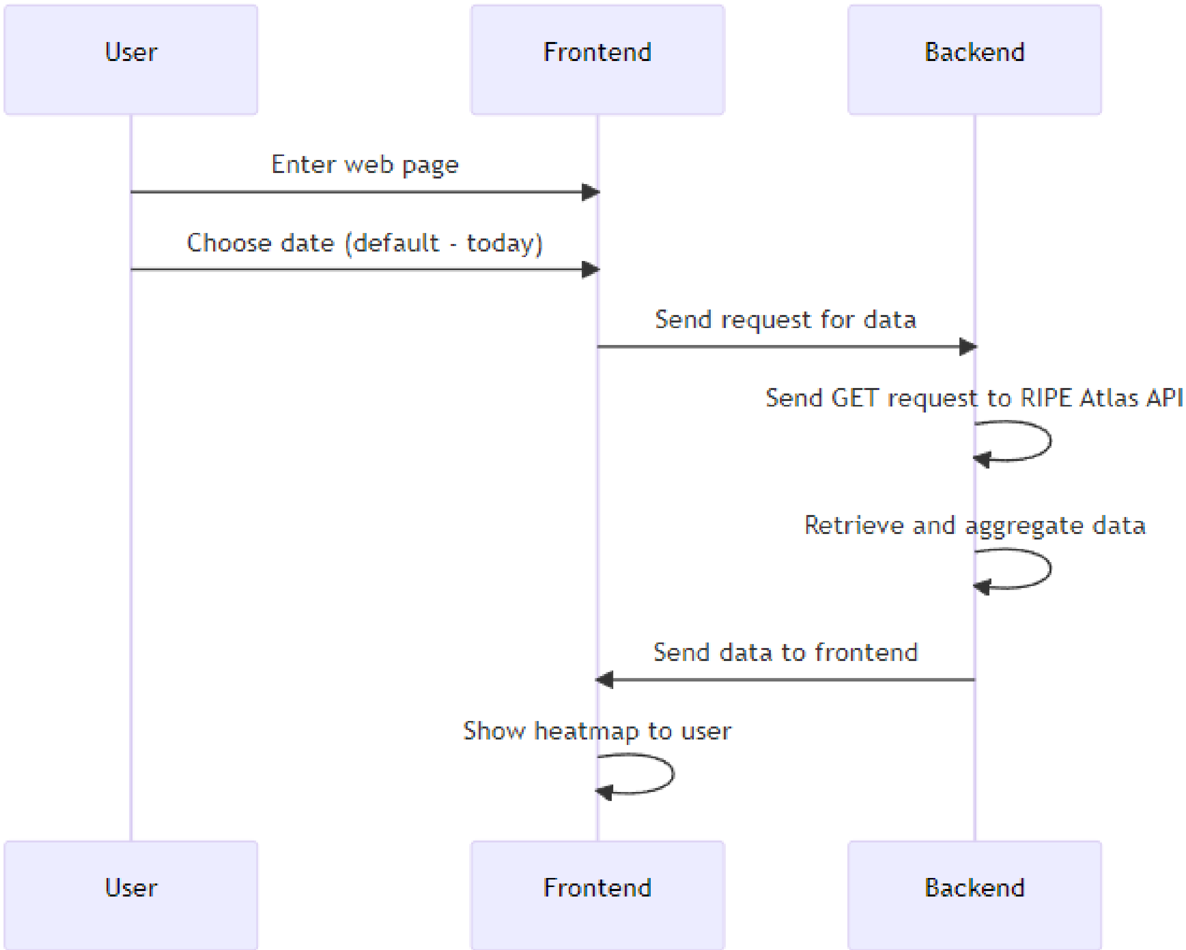
5.5.3.1 User Interaction Scenario

1. User chooses the date he want to compare (default is set today).
2. User push “Submit” button.
3. The user is presented with a world map display, where each country is shaded in accordance with its DNS stability. This shading is determined by the Real-Time Transfer Time (RTT) data extracted from DNS measurements collected by RIPE Atlas. Countries with good DNS stability are represented in green, while those with poor DNS stability are highlighted in red. This visual

distinction offers an intuitive representation of DNS performance across various regions.

4. Users can click on any country to access the DNS stability graph specific to that country. They are required to select two dates and have the option to include additional countries for comparison if desired.
5. The user is presented with a graph displaying the changes in RTT to DNS for each day within the selected date range. He has the option to focus on a specific period within the graph using the bar located at the bottom.
6. The user can tap on any of the dots representing a specific day, and upon doing so, he will be directed back to the DNS map for the chosen day.

5.5.3.2 System logic



5.5.4 Development stages

Backend Development: Challenges and Solutions

1. **Initial Algorithm Design**: The fundamental objective was to calculate the average RTT for all countries on specific dates. The algorithm had to fetch DNS measurements and associate them with geographical locations. However, we confronted significant bottlenecks. With the probes API returning at most 100 results and thousands of probes possibly operating on a given day, the latency could surge to 15 seconds per country.

2. **Optimization of Geolocation Fetches**: Recognizing the inefficiency in obtaining probe geolocations due to the limited API response, an optimization strategy was employed. Precaching tuples of (probe_id, probe_geolocation) locally cut down computation time by 3 seconds per country, although the 12-second latency remained a concern.

3. **Leveraging Recurrent Measurements**: Collaboration with the RIPE Atlas development team unveiled the existence of recurrent DNS measurements. By focusing on these recurrent measurements, particularly from regions with high probe densities such as Europe and America, the computation time was further reduced to 3 seconds per country.

4. **Framed Caching Implementation**: Given the project's focus on anomaly detection in networks, framed caching was introduced. Data was precomputed in a specified range, and dynamic user requests leveraged this cached data. This methodology leaned heavily on the Ripe Atlas Sagan for parsing responses and Ripe Atlas Cousteau for API requests.

5. **Testing and Visualization**: To validate our algorithms and get preliminary visual representations, we employed Jupiter notebook, harnessing the power of matplotlib for visual insights.

Frontend Development: Structuring and Connectivity

1. **DOM Planning**: A meticulous logical plan of the Document Object Tree was formulated, laying the foundation for a responsive frontend.

2. **Finite State Machine Design**: To ensure predictable and efficient frontend behavior, an FSM was crafted, delineating the various possible states of the system.

3. **Component Hierarchy and React Implementation**: The calling hierarchy for React components was mapped out to ensure efficient data flow and state management.

4. **Routing and Data Fetching** : Routing between components was streamlined, and a robust data fetching functionality was developed to bridge the frontend and backend seamlessly.

5. **Visualization with D3 and Recharts** : The frontend was enriched with graphical representations using the d3 charts library. Moreover, Recharts enabled the creation of trend lines, enhancing the visual interpretability of data.

6. **Dynamic Data Fetching** : As user preferences evolved, the frontend was equipped to dynamically adjust its data fetch requests based on mode changes.

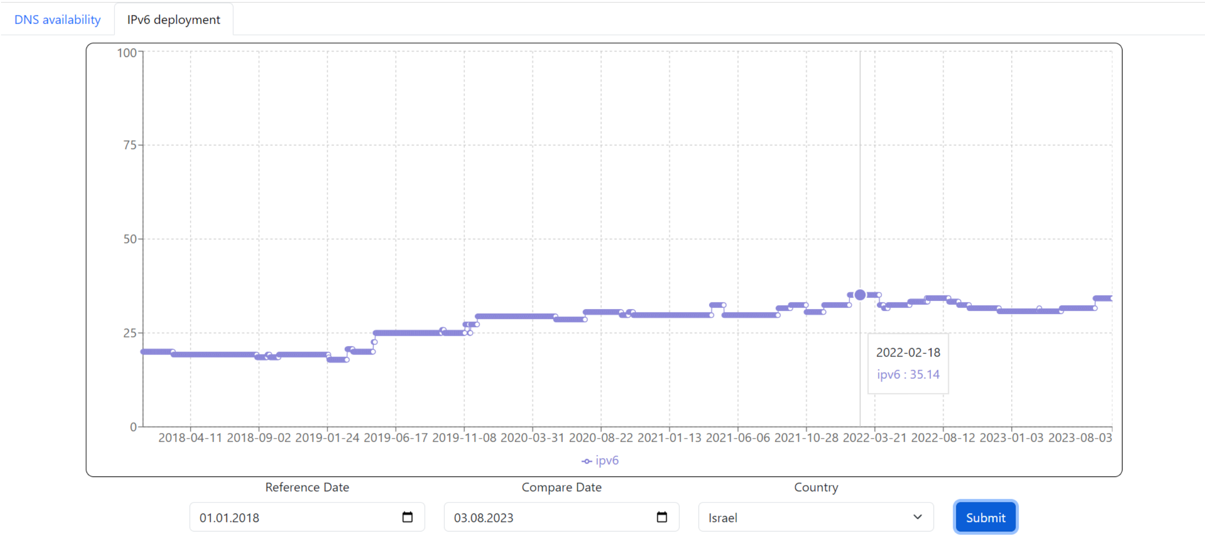
7. **Backend-Frontend Integration** : The final stage involved synchronizing the backend and frontend, ensuring real-time data flow and rendering.

5.6 IPv6 Deployment

5.6.1 Introduction and Objective

The IPv6 Deployment use case endeavors to provide users with a dynamic representation of global IPv6 deployment status. Through this feature, users will have the ability to visualize the extent of IPv6 routing across various countries, all depicted on the map. This visualization will be based on the selected dates, allowing users to gain insights into the progression of IPv6 adoption worldwide.

5.6.2 User interface design

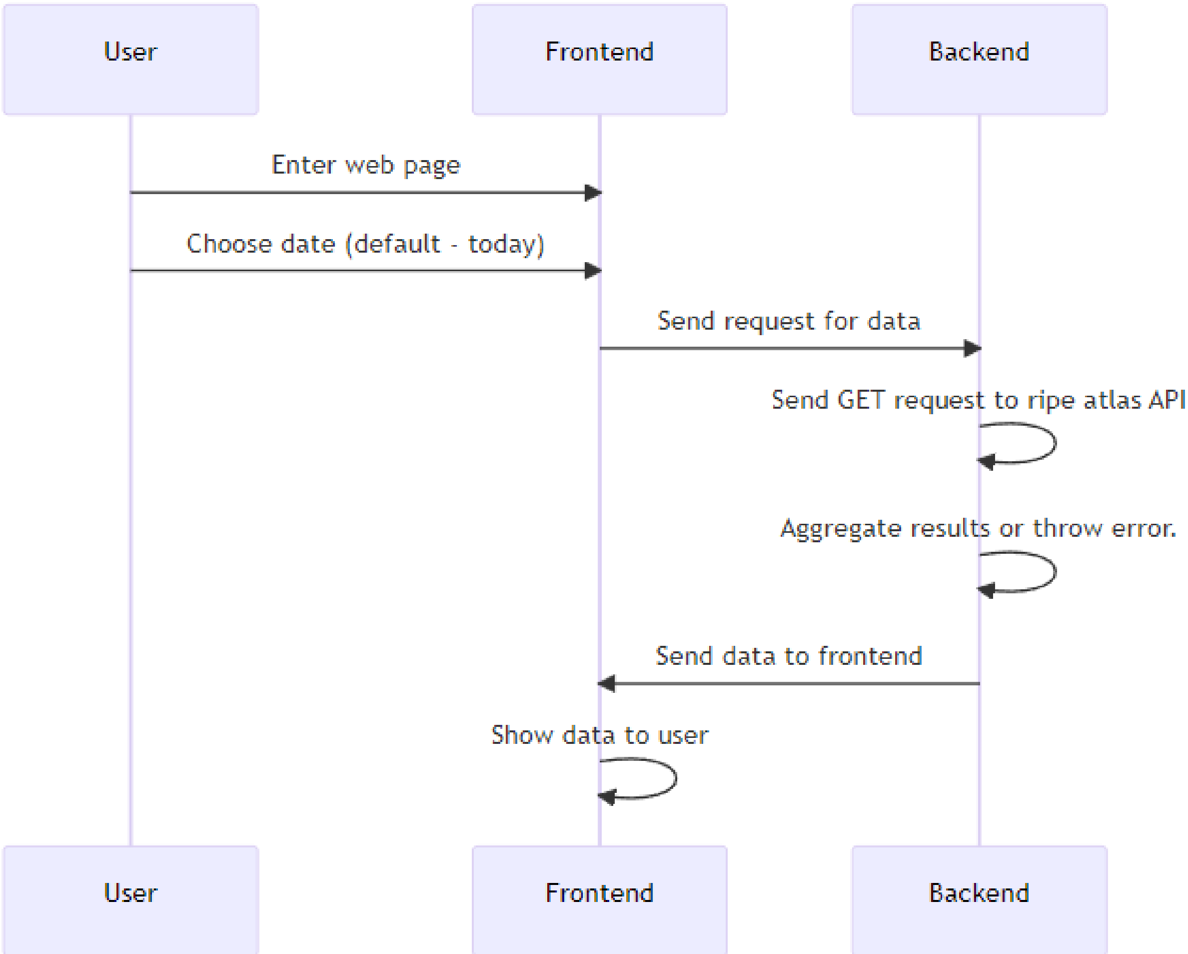


5.6.3 Algorithms and System Logic

5.6.3.1 User Interaction Scenario

1. User choose the country.
2. User enters the date range to observe the dynamic changes over time.
3. The user is presented with a graph that shows the percentage of IPv6 routing related to all routings per day. This graph will display a dot for each day within the specified time range, allowing users to track the progression of IPv6 deployment over time. Hovering the mouse over any of the dots will reveal detailed information, including the exact percentage value and the corresponding date.

5.6.3.2 System logic



5.6.4 Development stages

1. Develop a Python function within a Jupyter notebook to efficiently compute the IPv6 percentage for a specified country within a given start and finish date range.
2. Test the function and study the output wanted to be received. Make necessary adjustments as needed to achieve accurate calculations.
3. Integrate the thoroughly tested function, named "check_as_for_probes," into the existing "utils.py" file, ensuring clean and well-documented code.
4. Create a function named "ipv6_data" in the "views.py" file. This function should utilize the "check_as_for_probes" function to fetch the calculated results and format them as JSON data.
5. In the "urls.py" file, define a new URL path that corresponds to the "ipv6_data" function, enabling access to the IPv6 deployment data through the specified URL.

6. Develop a JavaScript component named "IPv6component.js" in the frontend. Utilize the recharts library for creating visually appealing graphs and leverage the react-select-country-list library to offer users a convenient selection of countries. This component should display the received IPv6 deployment data effectively.
7. Enhance the existing "MainPage.js" file by adding a dedicated tab labeled "IPv6 deployment." This tab should seamlessly integrate the developed "IPv6component.js" to provide users with easy access to IPv6 deployment statistics.

6. Challenges and Resolutions in the Project

6.1 Rest API limitations

Throughout the course of this project, several challenges emerged that required innovative solutions to ensure the successful development and functionality of the platform. One notable challenge arose from the empirical approach we undertook to gather data through the REST API. It came to light that the API response was limited to a maximum of 100 objects, presenting a potential roadblock to comprehensive data retrieval. In response, we devised a strategy to overcome this limitation. We proactively cached probe data along with their associated country information, enabling us to circumvent data loss during user queries and providing a more holistic dataset for analysis.

6.2 Request Time Optimization

Another significant challenge revolved around the time taken for each request to yield results. The extended duration of each request translated to prolonged waiting times for users, impeding the platform's overall responsiveness. To address this concern, we embarked on a multifaceted optimization approach.
Firstly, we reevaluated the number of queries required for each tool's functionality, streamlining the process to minimize redundant requests.
Additionally, we implemented a strategic enhancement by deferring the execution of requests until the user explicitly initiated the "submit" action. This optimization not only reduced waiting times but also contributed to a more seamless and efficient user experience.

By tackling these challenges and devising effective resolutions, we were able to enhance the project's usability, responsiveness, and data completeness.

6.3 Django and React integration challenges

While Django serves as a solid backend framework and React excels on the frontend, integrating the two was not without its challenges. Issues arose around serving static files, especially when it came to the Webpack-built React components being served by Django's static files system. The default configurations were not seamless.

We overcame this by setting up Django to serve only the API endpoints using the Django Rest Framework (DRF) while letting React handle all the frontend routes and views. This separation ensured that both frameworks operated within their strengths without much overlap. Furthermore, tools like `django-webpack-loader` proved invaluable, as they allowed Django to recognize and serve the latest Webpack bundles.

6.4 React state management complexity

As our frontend grew in complexity with more features and interactions, managing the application state became a challenge. We initially used local component states, but as components began to share and require more interrelated data, our states became dispersed, leading to convoluted prop-drilling and unexpected behaviors.

The solution came in the form of integrating state management libraries like React-Hooks instead of React class-based design . With React-Hooks, we centralized our application's state, making it more predictable and manageable. This not only made the data flow more transparent but also reduced the occurrence of unexpected behaviors and made debugging easier.

7. Build and run project instructions

7.1 Initial Setup Guide

7.1.1 Setup of Backend

1. Install the latest version of Python. [14] (tested with Python 3.10 and 3.11)
2. Install the latest version of Git. [15]
3. Install the latest version of Visual Studio Code. [16]
4. Install the latest version of the Python extension for Visual Studio Code. [17]
5. Clone code from github repo
6. Create venv in project root Using and activate it.

```
python3.10 -m venv ./venv


# activating of venv in bash an zsh


source ./venv/bin/activate
```

7. Install python libraries using the following command:

```
pip install -r ./src/Backend/requirements.txt
```

7.1.2 Setup of Frontend

1. Install the latest version of Node.js. [18]
2. Install node dependences

```
cd src/frontend


npm install
```

7.2 Guide to Running the Project

7.2.1 Prerequisites

These steps must be done each time frontend or backend packages are updated.

1.
```
cd src/frontend
npm install
```

2.
```
... # entrer venv setup
cd src/Backend
pip install -r requirements.txt
```

7.2.2 Running The project

1.
```
cd src/frontend
npm start
```

2.
```
... # entrer venv setup
cd src/Backend
python manage.py runserver
```

8. Investigation of COVID-19 Impact on the Internet

The COVID-19 pandemic brought about unprecedented global changes that extended beyond public health. As society adapted to lockdowns and remote work, the digital landscape experienced shifts in behavior, connectivity, and usage patterns. This section delves into two distinct investigations: "Countries with Significant IPv6 Growth Due to COVID-19" and "DNS Stability Changes Due to COVID-19." These investigations explore the pandemic's influence on the intricate dynamics of the internet and uncover its implications for network behavior and infrastructure.

8.1 IPv6 Growth Due to COVID-19

We anticipate revealing countries that experienced accelerated adoption of IPv6 during the pandemic. By analyzing the percentage of ASes using IPv6 and correlating these rates with pandemic-related events, we aim to identify the factors that contributed to increased adoption.

8.1.1 Methodology

1. Get all differences between ASNs with IPv6 between dates 07/07/2023 and 01/01/2020. For this purpose we used python function in Jupyter notebook that gave us a list with all countries and percentage of ASes with IPv6 in both dates.

2. Identify countries with IPv6 growth of at least 4% between the dates.

3. Build a graph using a graphical user interface (GUI) to visualize the IPv6 growth trend between dates 01/01/2018 and 01/01/2023. This graph will help to understand if the same growth trend was observed before the COVID-19 pandemic (e.g., similar growth patterns in countries like China before the pandemic).

4. Define countries that witnessed a significant surge in IPv6 Autonomous Systems during the latter half of 2020 and the initial half of 2021.

By implementing these steps, we aim to comprehensively explore the IPv6 growth landscape, considering both pre-pandemic and pandemic periods. This investigation promises to shed light on the influence of COVID-19 on internet infrastructure and offers valuable insights into network behavior.

8.1.2 Steps to Achieve the Objective

1. Implement a GUI for data visualization, allowing users to interactively explore the IPv6 growth trends for different countries.
2. Collect data on ASNs with IPv6 for the dates "2023-07-07" and "2020-01-01".
3. Group ASNs by country and calculate the overall IPv6 growth percentage for each country.
4. Identify countries with an IPv6 growth rate of at least 4%.
5. Plot the graph using the GUI, showing the growth trend for each country between 01/01/2018 and 01/01/2023.

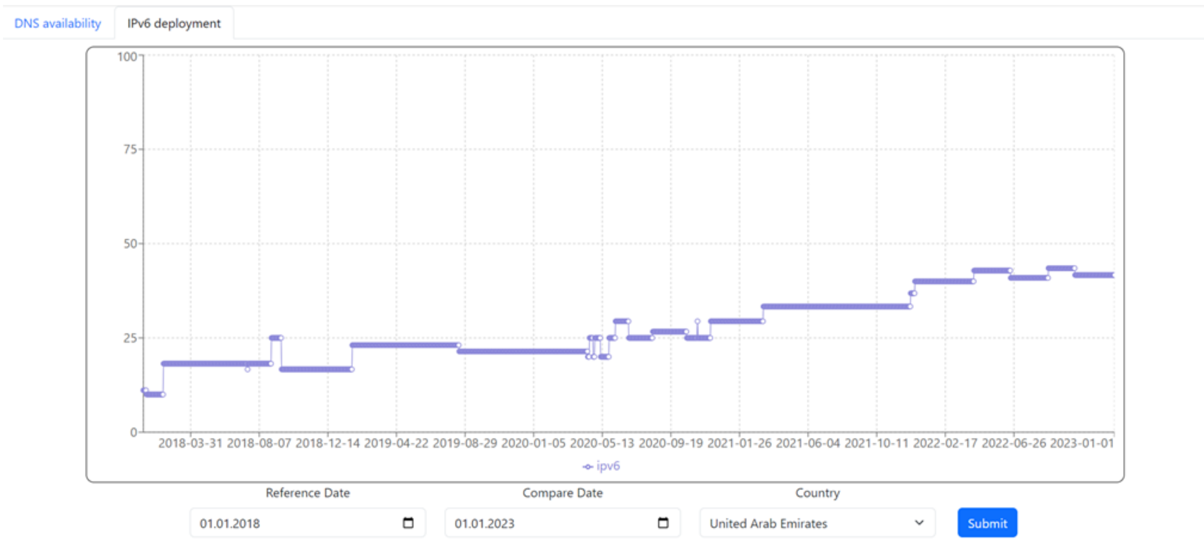
8.1.3 Expected Outcome

The project will provide insights into countries with significant IPv6 growth during and after the COVID-19 pandemic. The graph generated through the GUI will help to compare the growth trend during the pandemic with the trend before the pandemic, helping to identify any patterns and similarities in IPv6 adoption across different countries.

8.1.4 Results

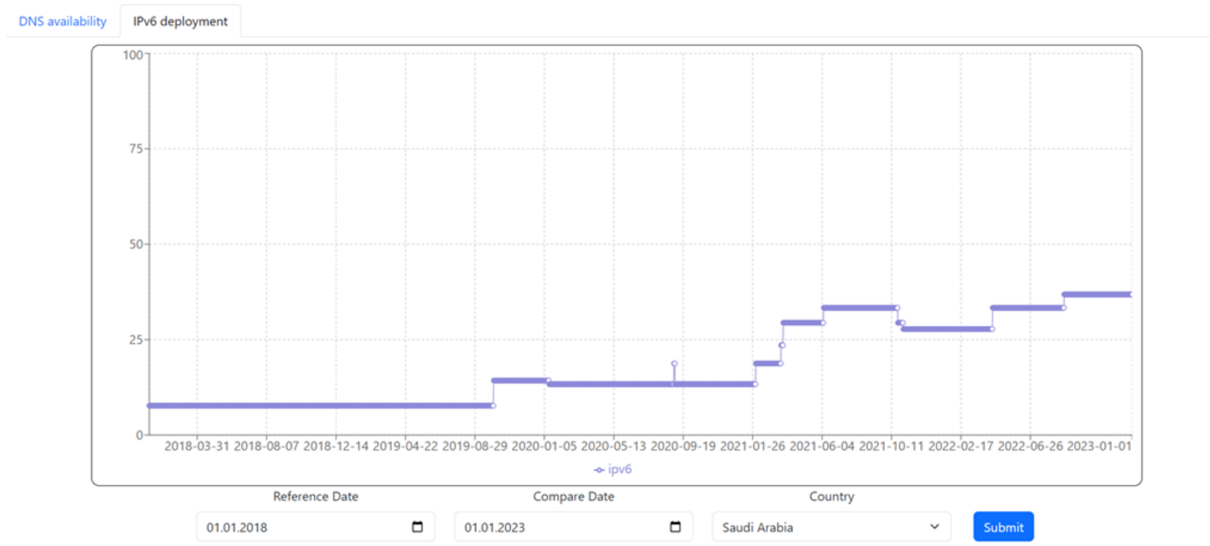
The most significant growth of IPv6 Ases was in United Arab Emirates and Saudi Arabia. There are more interesting results of the research:

<u>United Arab Emirates</u>



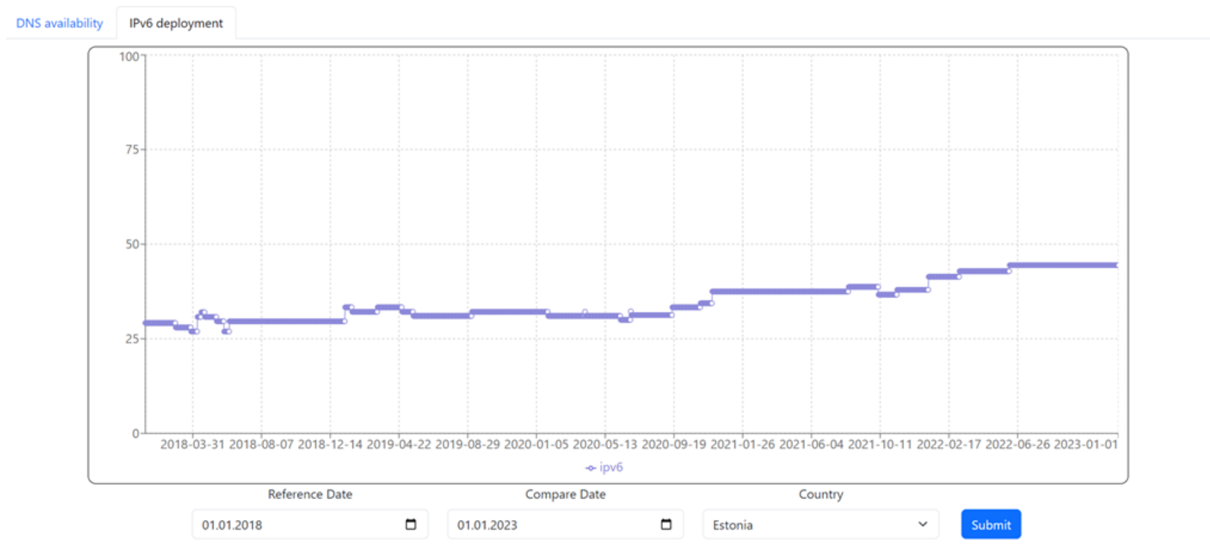
01/01/2018 – 11.11%
01/01/2023 – 41.67%

Saudi Arabia



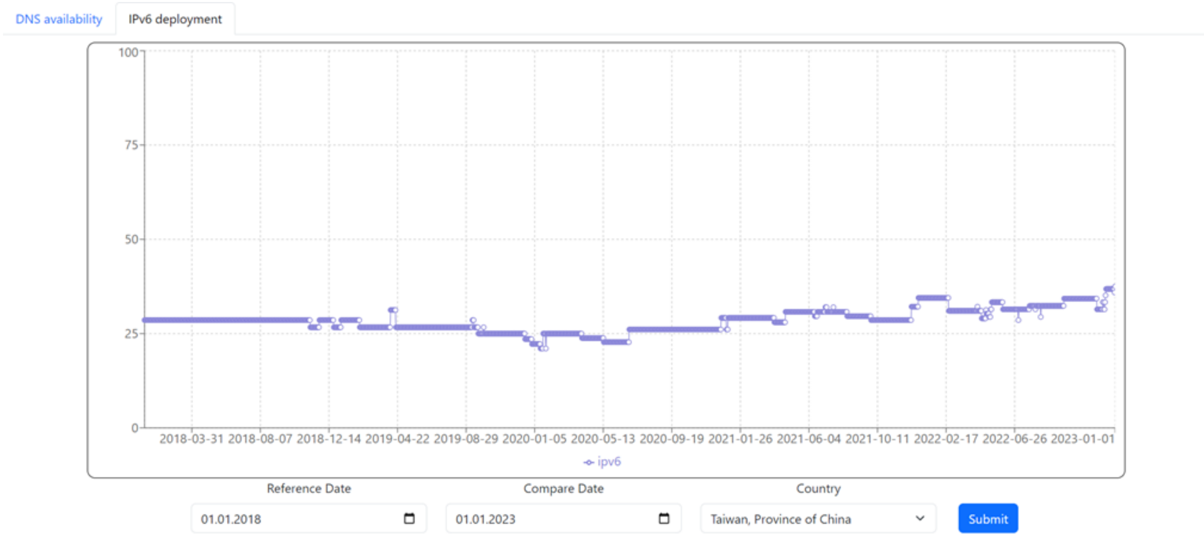
01/01/2018 – 7.69%
01/01/2023 – 36.84%

Estonia



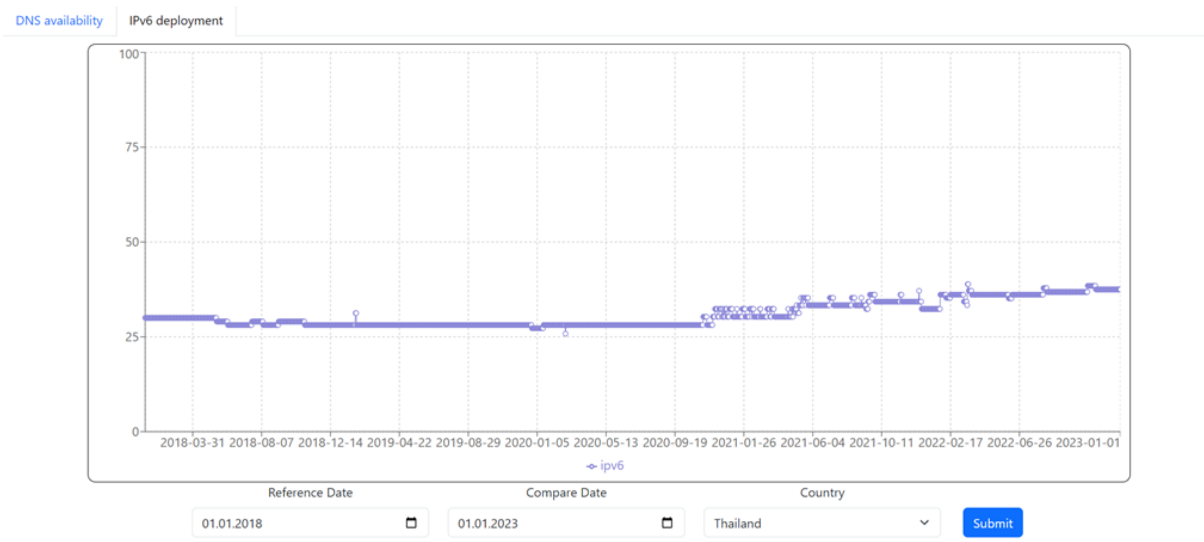
01/01/2018 – 29.17%
01/01/2023 – 44.44%

Taiwan



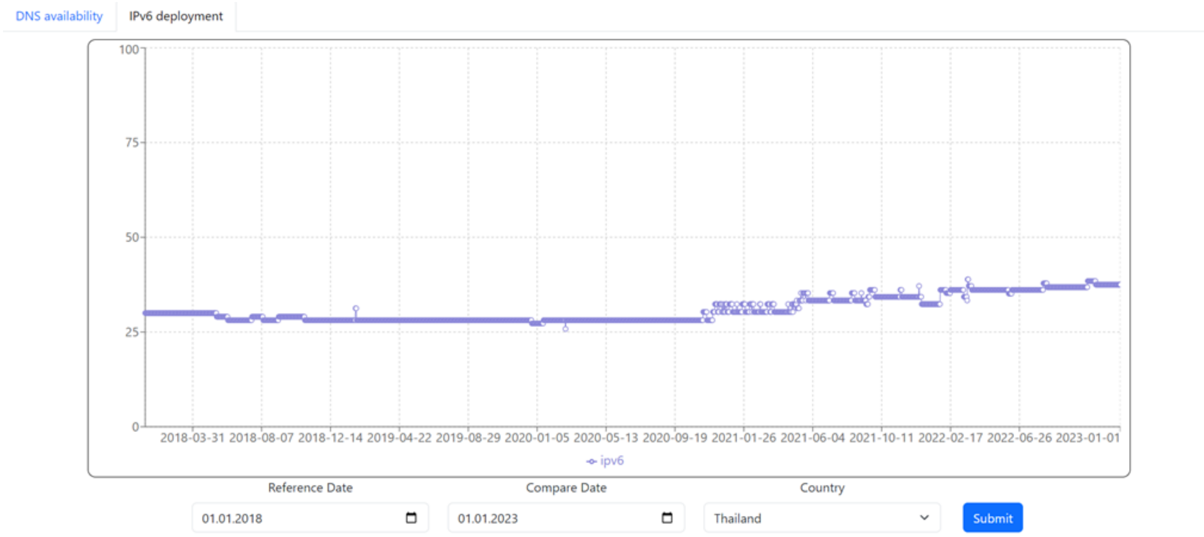
01/01/2018 – 28.57%
01/01/2023 – 36.84%

Thailand



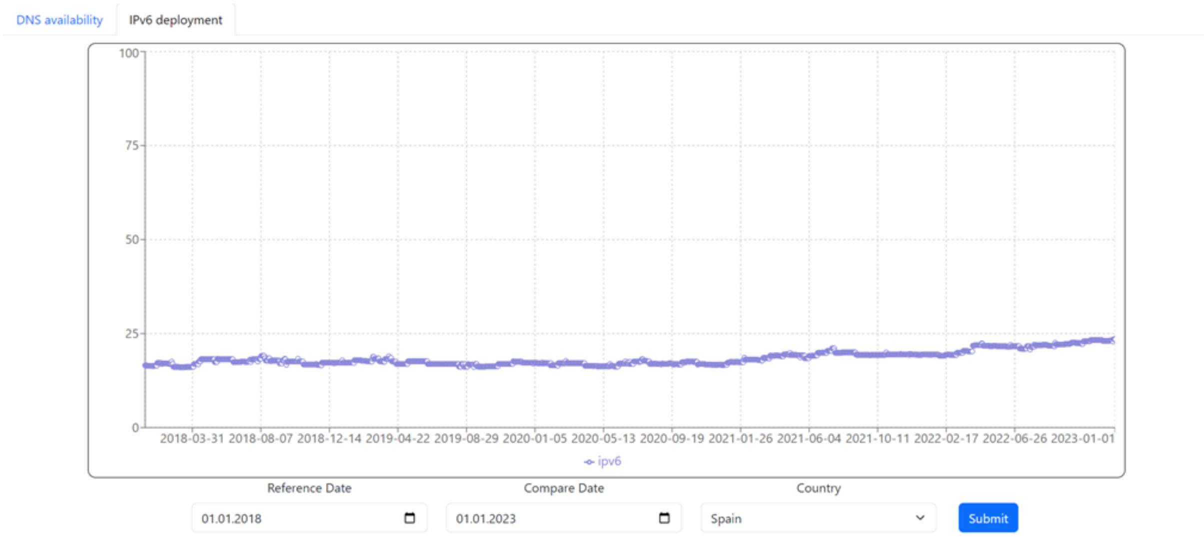
01/01/2018 – 30%
01/01/2023 – 37.50%

<u>Chile</u>



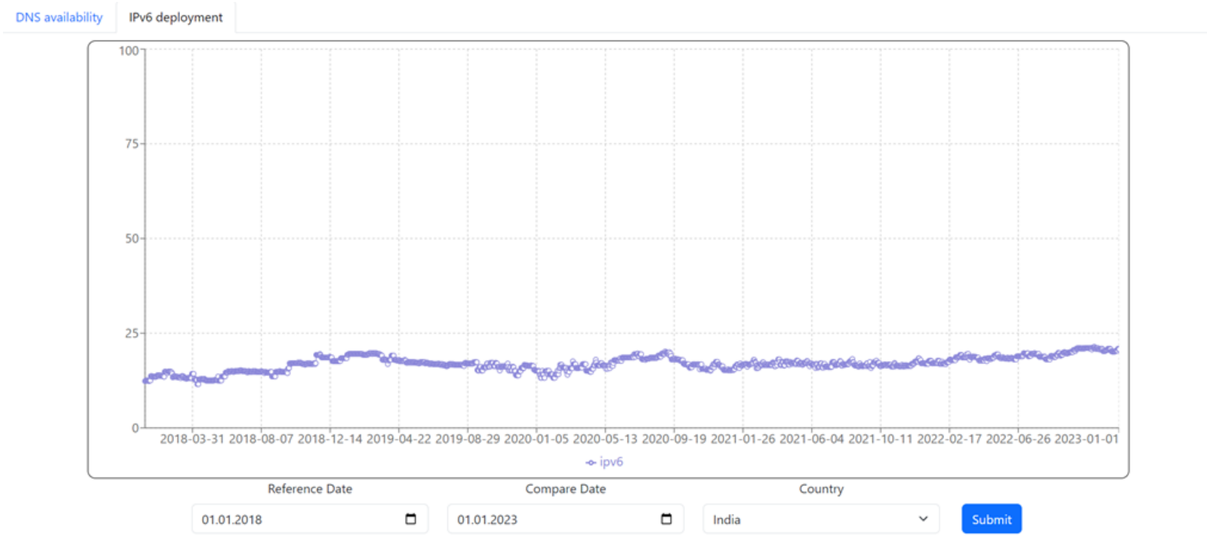
01/01/2018 – 13.64%
01/01/2023 – 30.23%
But real interesting result:
01/03/2020 – 20%
01/09/2020 – 28.12%

<u>Spain</u>



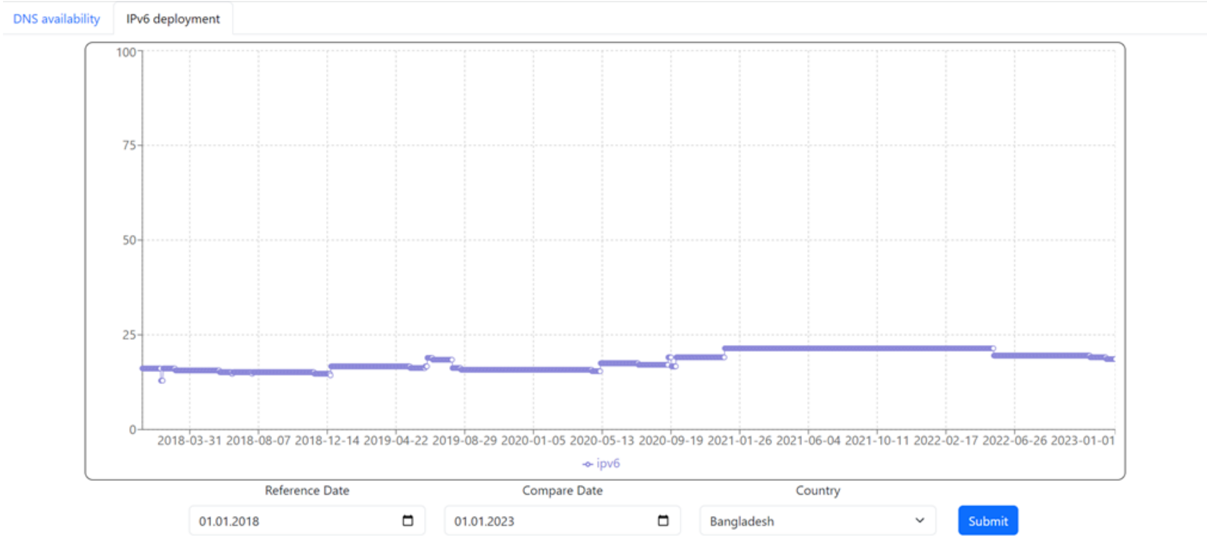
01/01/2018 – 16.54%
01/01/2023 – 23.49%
The significant growth occurred between 25/12/2020 and 19/07/2021, increasing from 16.67% to 21.05%.

India



01/01/2018 – 12.33%
01/01/2023 – 20.78%
The significant growth occurred between 13/04/2020 and 02/09/2020, increasing from 14.95% to 20.17%.

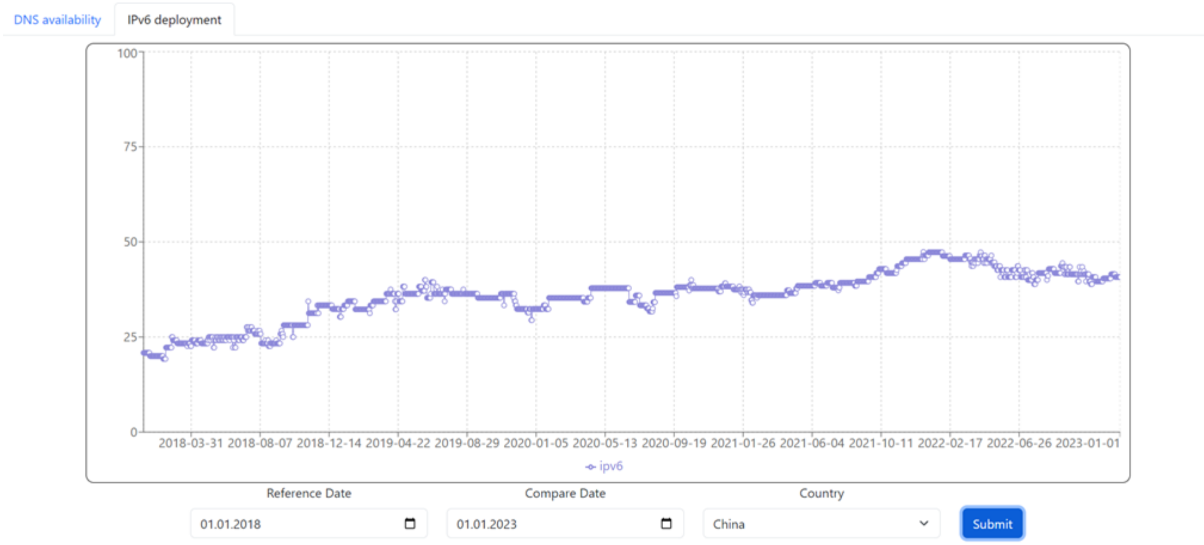
Bangladesh



01/01/2018 – 16.13%
01/01/2023 – 18.60%
The significant growth occurred between 04/05/2020 and 01/01/2021, increasing from 15.38% to 21.43%.

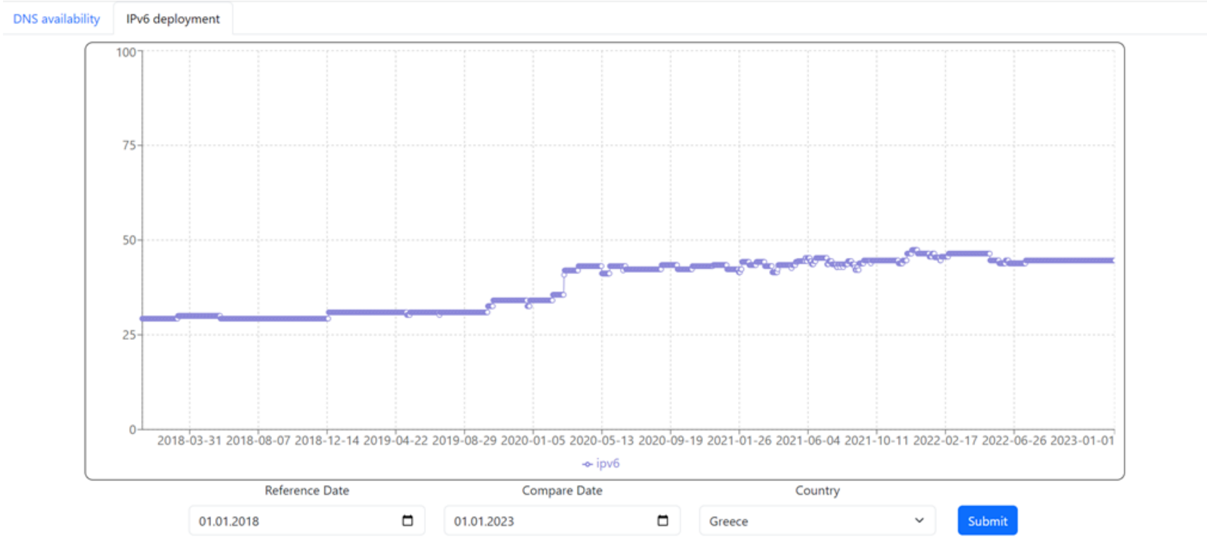
Post-commencement of the COVID-19 pandemic, a substantial number of developing countries have displayed noteworthy expansions in their IPv6 adoption rates. This phenomenon invites careful scrutiny, as it is plausible that these developments are not mere coincidences. Rather, they could signify the presence of underlying imperatives driving increased investments in internet infrastructure within these nations. However, it is pertinent to acknowledge that certain countries eluded accurate assessment due to a scarcity of RIPE Atlas probes within their territories, thereby limiting the precision of our calculations. Furthermore, our exploration revealed intriguing variations in results for select countries.

<u>China</u> – example of growth that was also before COVID



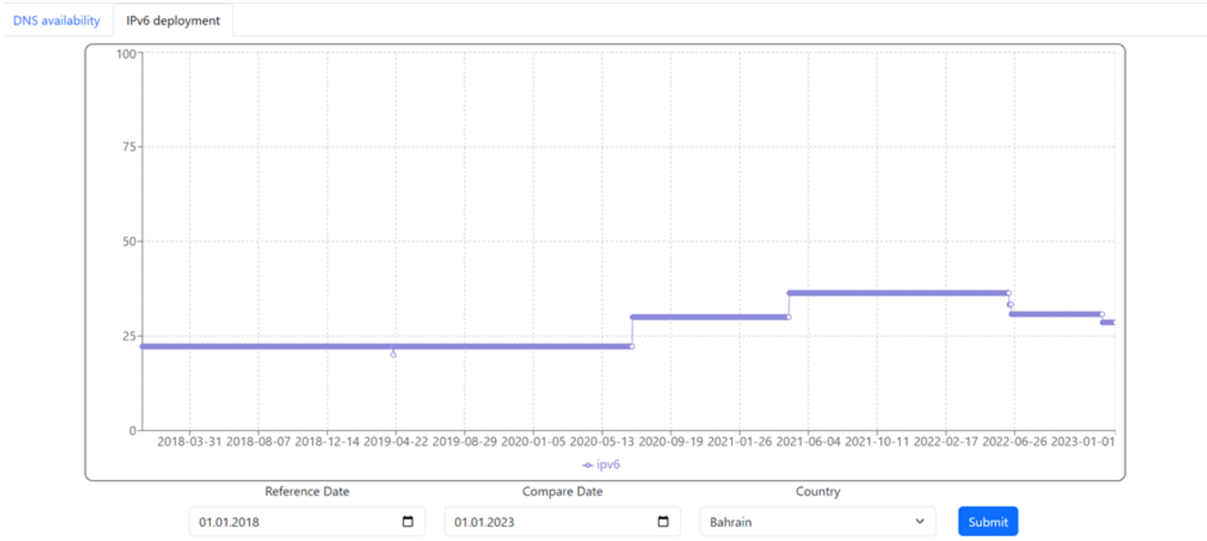
01/01/2018 – 20.83%
01/01/2023 – 40.74%
The investigation did not encompass countries exhibiting a growth pattern akin to that observed in China, as our analysis did not reveal a marked acceleration in their IPv6 adoption rates.

Greece – example of too early growth



01/01/2018 – 29.27%
01/01/2023 – 44.64%
The substantial surge witnessed on 02/03/2020, escalating from 35.56% to 42%, seems to predate the pandemic's onset, making it unlikely that the pandemic directly caused this growth.

Bahrain - regression after the pandemia finished



01/01/2018 – 22.22%
01/05/2021 – 36.36%
01/01/2023 – 28.57%

The commencement of the expansion in IPv6 usage was observed on 08/07/2020. The subsequent decrease in IPv6 adoption may imply a phase of recovery post-pandemic, potentially indicating a reduced demand for internet technologies or a decrease in the availability of RIPE Atlas probes within the country. Furthermore, this phenomenon may arise from factors beyond the scope of this investigation.

8.2 Changes in DNS stability Due to COVID-19

8.2.1 Methodology

To investigate the impact of the COVID-19 pandemic on DNS stability, the following methodology was employed:

1. Selection of Top 30 Countries with COVID-19 Quarantine Measures.
The selection was on base striction of quarantine measures, based on information from International Monetary Fund. [20]

2. Measurement of Average Round Trip Time (RTT) to DNS Servers
For each of the selected countries, the average Round Trip Time (RTT) to DNS servers was measured. This involved querying DNS servers from diverse geographic locations using RIPE Atlas probes. The measurements were got for each day within the time frame of January 1, 2020, to June 30, 2020.

3. Comparative Analysis of DNS RTT
The RTT data collected during the quarantine period was compared with the RTT data from the days when quarantine measures were initiated and when they were lifted. This comparison aimed to identify any significant variations in DNS stability during the quarantine period and assess the impact of quarantine measures on DNS performance.

8.2.2 Steps to Achieve the Objective

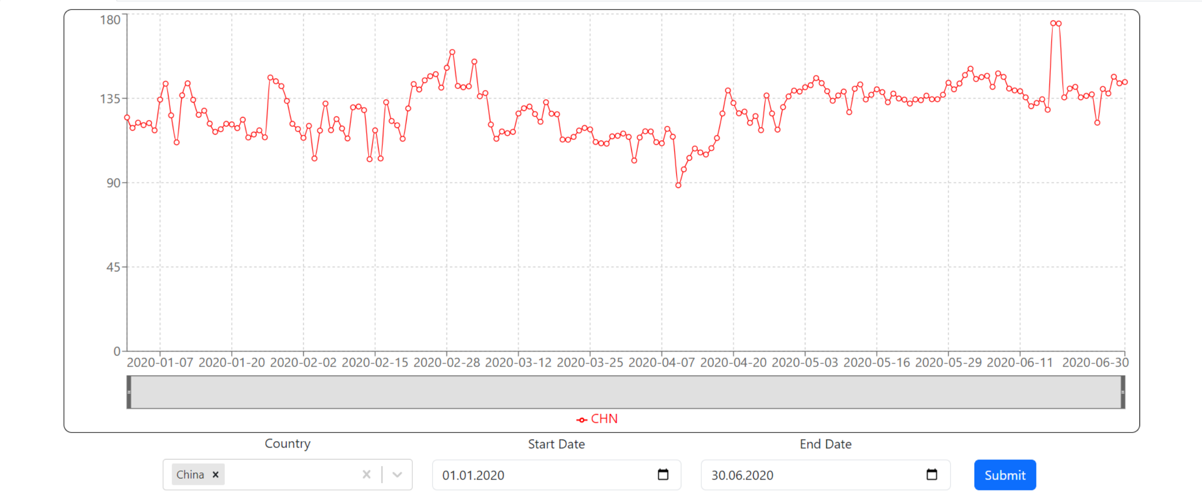
1. Implement a GUI for data visualization, enabling users to interactively explore DNS stability for different countries within the specified dates.
2. Collect data regarding the average Round Trip Time (RTT) to DNS servers for the dates "2020-01-01" and "2020-06-30."
3. Plot the graph using the GUI, displaying the RTT to DNS for each country between "2020-01-01" and "2020-06-30."
4. Check when quarantine started and finished and compare to Graph for every country. [21]
5. Formulate conclusions based on the analysis and findings.

8.2.3 Expected Outcome

The anticipated outcome of this analysis involves the identification of potential increases in Round Trip Time (RTT) to DNS, which may signify higher-than-expected Internet usage within the selected countries during the specified time frame. Such findings can provide insights into the level of Internet activity and may also serve as an indicator of the extent to which individuals adhered to quarantine regulations. By examining RTT trends in DNS stability, this investigation seeks to shed light on the relationship between changes in Internet usage and adherence to quarantine measures.

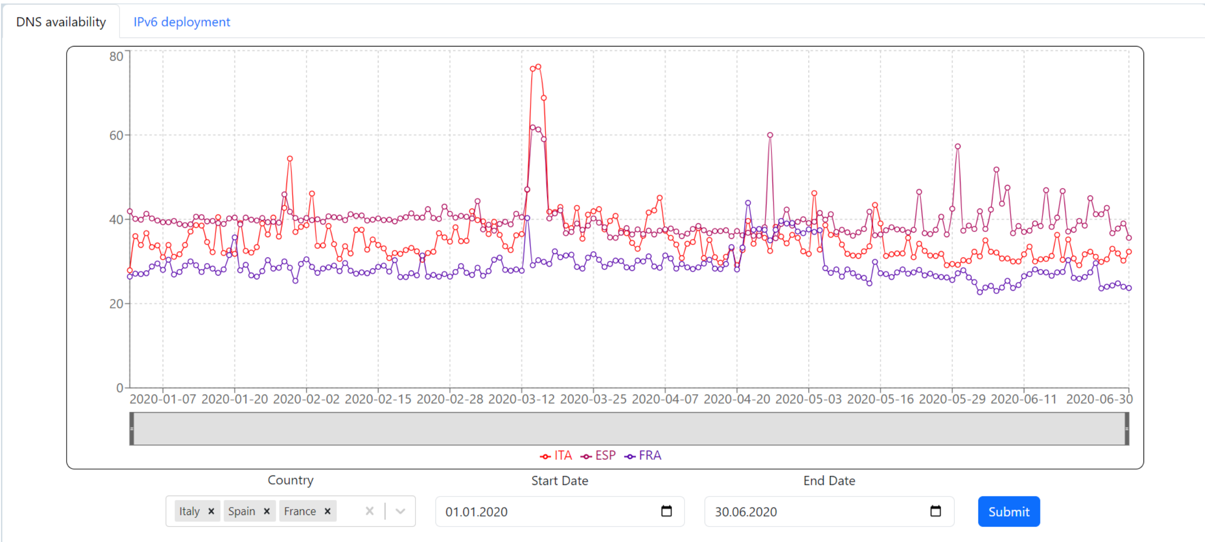
8.2.4 Results

China



The lockdown in China started on 23/01/2020 in Wuhan and several cities in Hubey. [22] A consistent and stable increase is evident in the graph around this date. Subsequently, over the next few months, the Chinese government implemented lockdown measures in several additional regions. On 08/04/2020, Wuhan lifted its lockdown, resulting in an unusual drop in RTT. Notably, other regions, such as Shanghai, continued to enforce quarantine measures, contributing to sustained high RTT even after the conclusion of the lockdown in Wuhan.

<u>Italy, Spain, France</u>



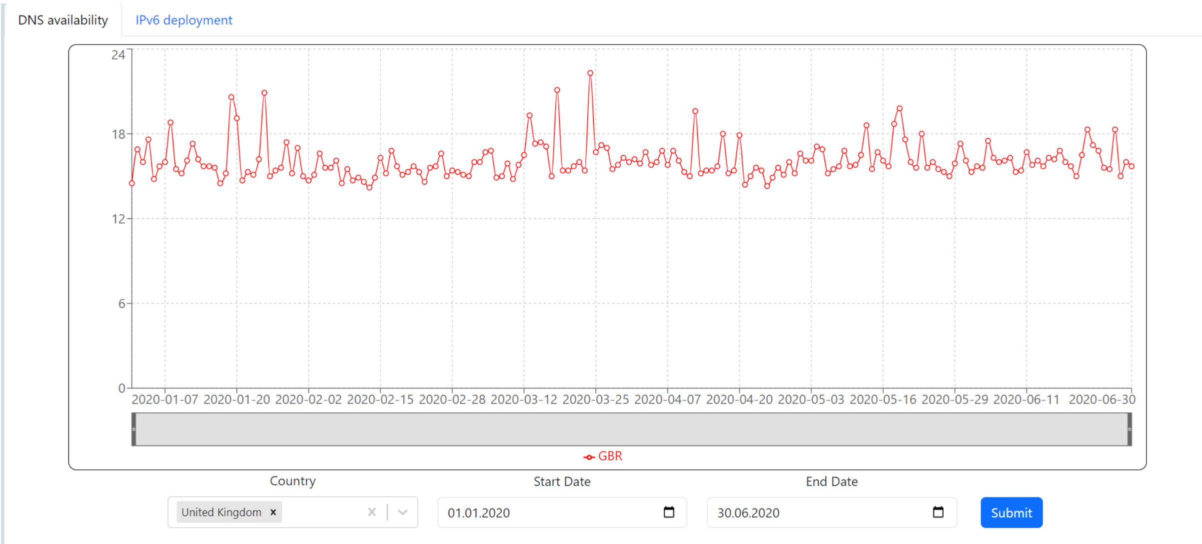
Italy: The stringent quarantine commenced on March 10, 2020, and concluded on May 4, 2020. An unusual increase in RTT is observable on the day when the quarantine was initiated, accompanied by a spike in RTT throughout the entire quarantine period, albeit significantly less pronounced than on the first day. Subsequent to May 4, 2020, a decline in RTT is evident, indicating a return to lower values.

Spain: The advisory to stay at home was issued on March 12, 2020, followed by official Stay-at-home orders for the general population, which were in effect from March 14, 2020, to April 23, 2020. In our analysis, we observe an unusual spike in RTT on the day when the quarantine measures commenced. However, during the quarantine period, the RTT to DNS displayed an unexpectedly low trend. Subsequently, after the conclusion of the lockdown, the RTT returned to higher and more volatile levels.

France: Stay at home order was between 17/03/2020 and 11/05/2020

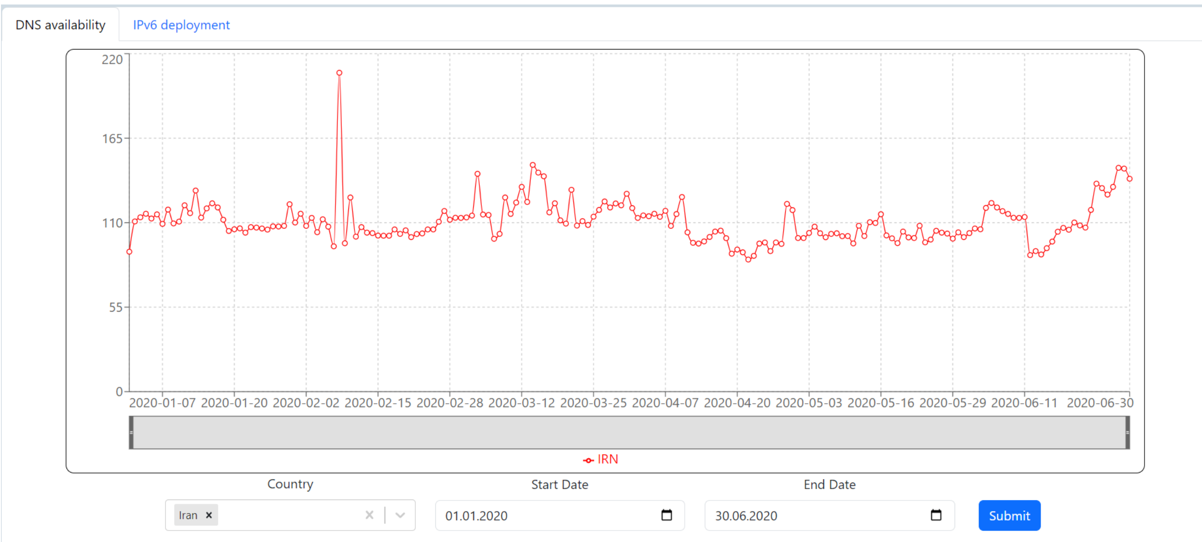
We can see significant increasing in RTT at the first part of March.

United Kingdom



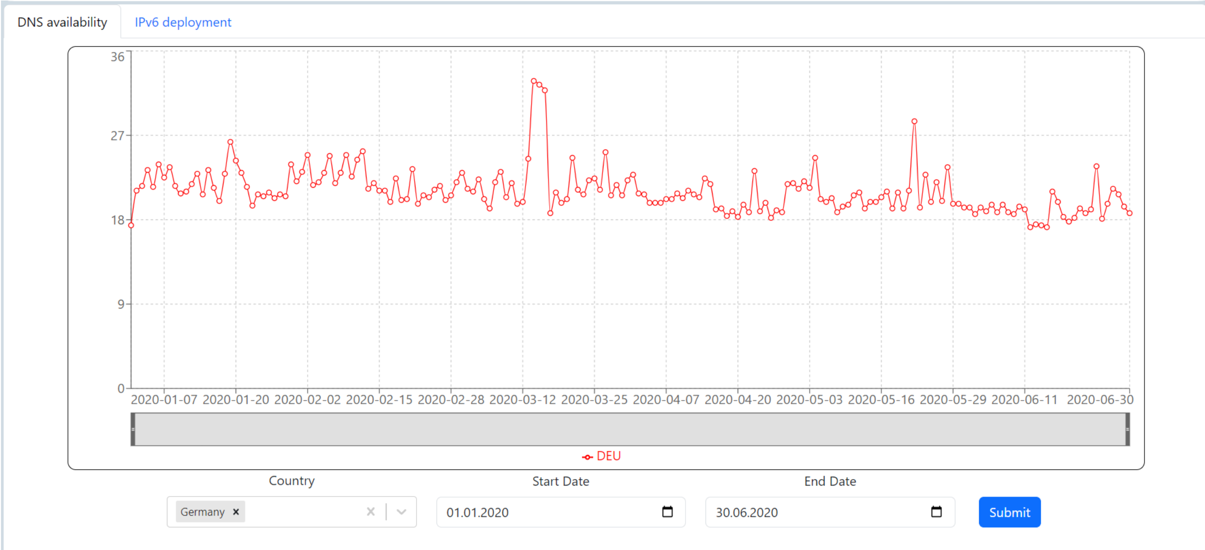
Similar to other countries, a spike can be observed between March 11, 2020, and March 30, 2020. Notably, the lockdown in this country spanned from March 26, 2020, to May 10, 2020, and interestingly, it does not exhibit a direct correlation with the RTT patterns. [23]

Iran



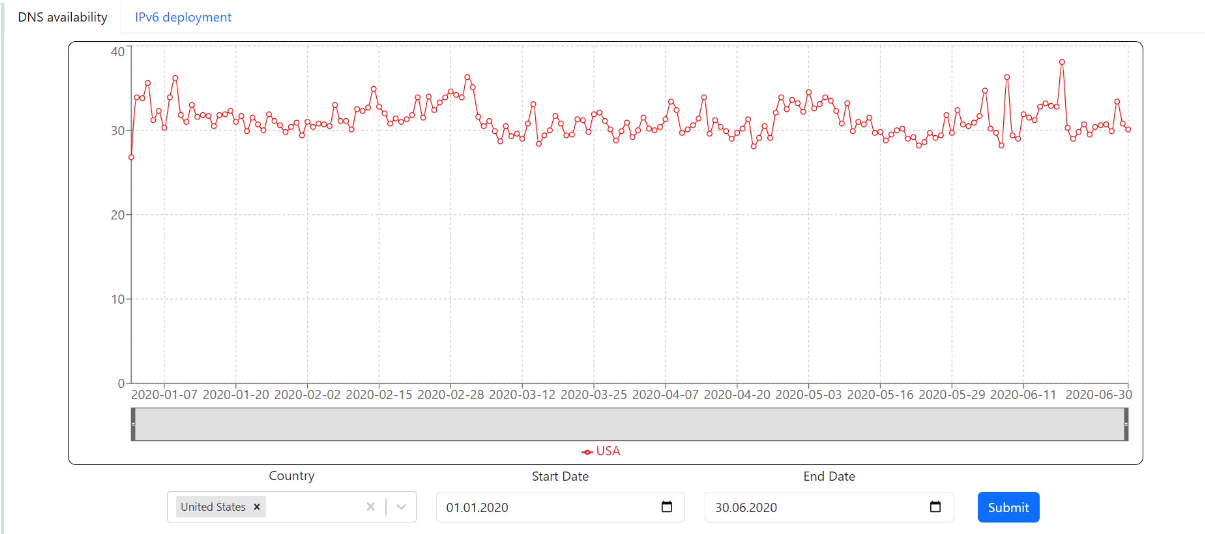
The strict lockdown was initiated on March 25, 2020, and concluded on April 8, 2020. Interestingly, an increase in RTT is noticeable between these dates, albeit commencing prior to the actual lockdown initiation. [24]

Germany



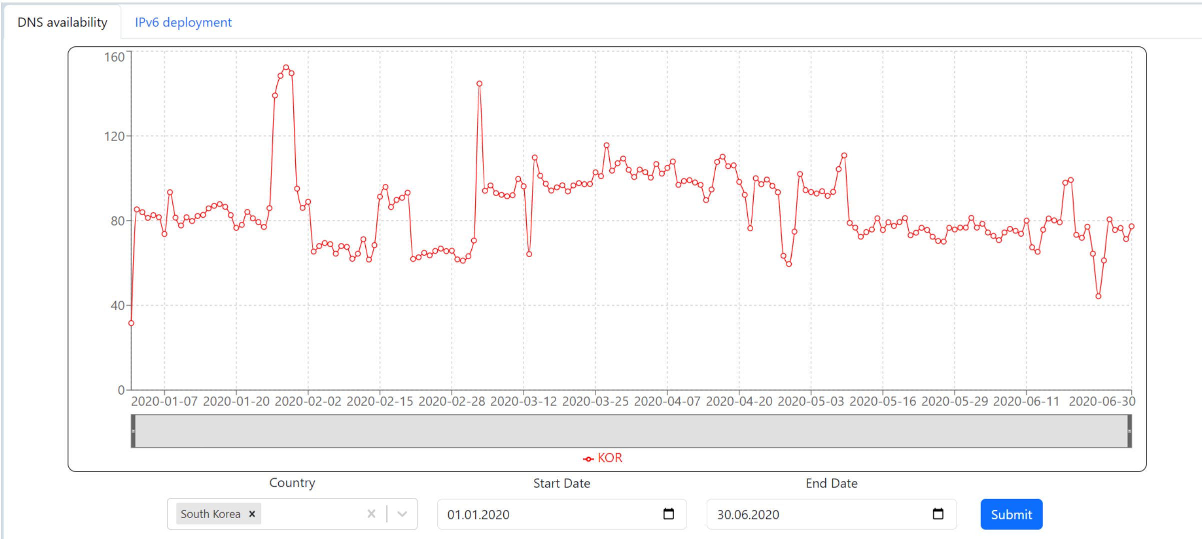
In Germany, there was no nationwide quarantine order; however, partial quarantine measures were implemented in certain regions, alongside a general recommendation to stay at home (from March 9, 2020, to May 5, 2020). Interestingly, we do not observe any significant spike in RTT in Germany during the quarantine period, only at the first and the last day.

United States



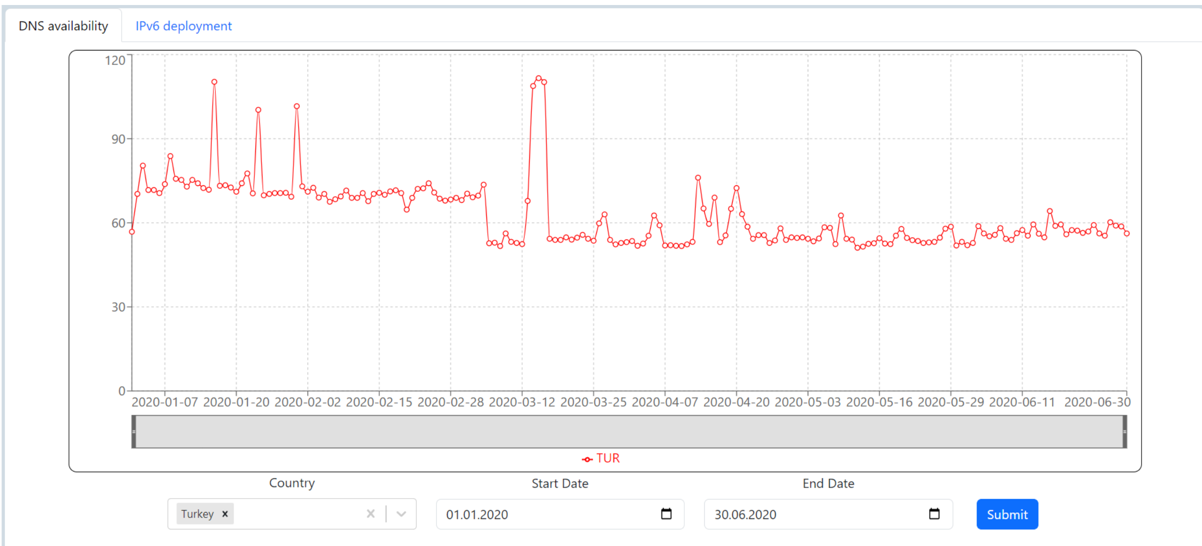
Lockdown measures in various regions of the USA were implemented between March 19, 2020, and March 24, 2020, and concluded between April 13, 2020, and May 15, 2020. [26]
Notably, there is a decrease in RTT from the commencement of March until the latter half of April. This trend might suggest that individuals in the USA began staying at home even before official government quarantine directives were enforced. Interestingly, in contrast to patterns observed in other countries, a decline in RTT is evident during the quarantine period in the USA. This could indicate that internet usage was more concentrated in workplaces rather than homes, and a portion of the population was less active online during the quarantine phase.

South Korea



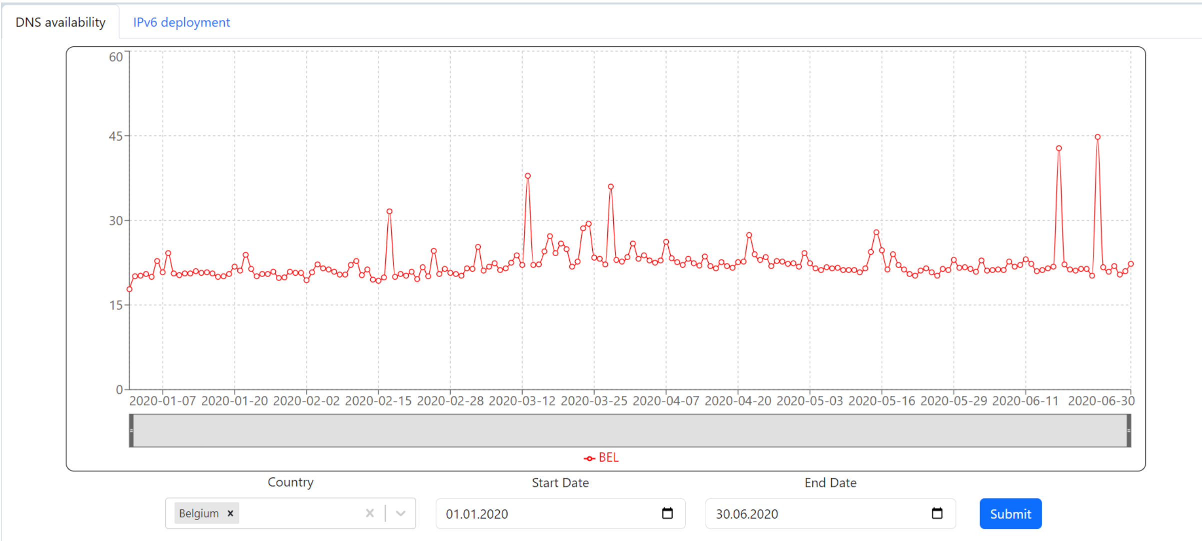
The first case in South Korea was announced on 20 January 2020. We can see here a huge spike in RTT.
There wasn't a strick lock down in whole South Korea. South Korea introduced what was considered one of the largest and best-organised epidemic control programs in the world. [27]
South Korea began relaxing social distancing rules on 4 March 2022 and announced a shift toward endemic living on 18 March.

Turkey



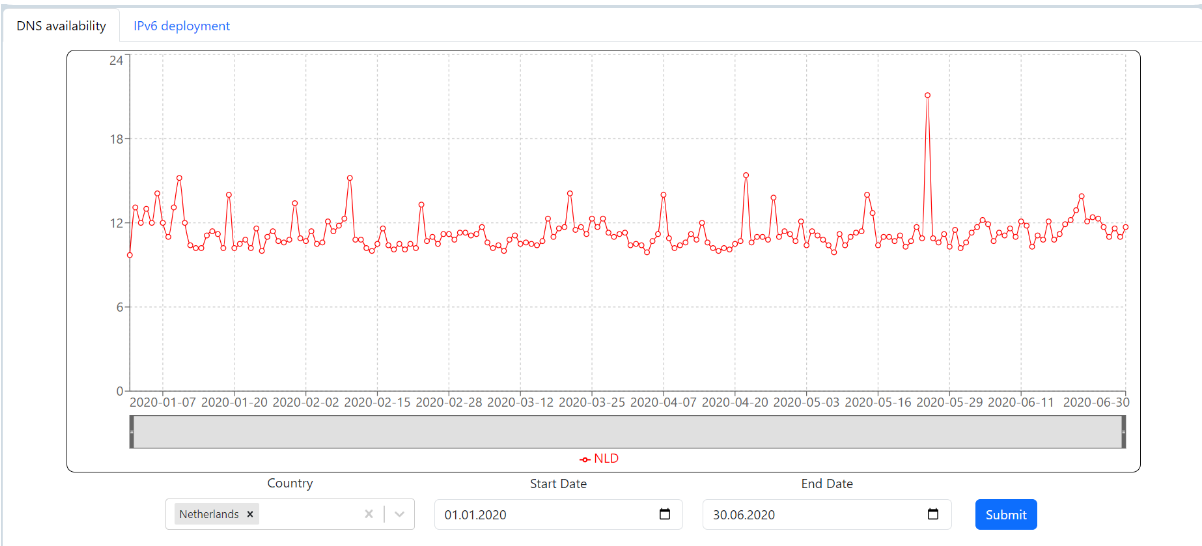
The lockdown in Turkey was between 2021-04-29 and 2021-05-17.
We can't see an abnormal spiked during these days. We see a high spike at March like in a lot of other countries.

Belgium



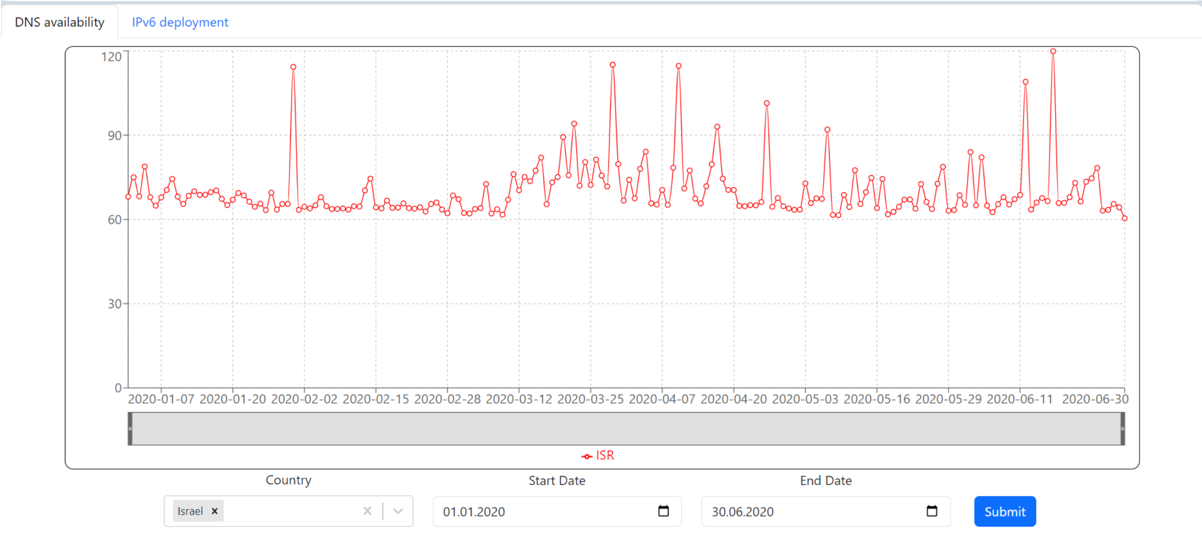
The stay-at-home order was in effect from March 18, 2020, to May 9, 2020. However, the closure of public spaces, which occurred between March 13, 2020, and April 2, 2020, is noteworthy for the unusual spikes observed in the RTT. These spikes may indicate an increased usage of the Internet when various public places were closed. Interestingly, despite the stay-at-home order, there is no corresponding significant increase in RTT, suggesting that the order might not have directly influenced increased internet usage.

Netherlands



General instruction to stay at home was between 18/03/2020 and 10/05/2020. We can’t see a special spikes at these days

Israel



The lockdown in Israel was between 14/03/2020 and 30/04/2020. We can see increasing in RTT from the lockdown started, but it left high after lockdown finished due other limitations.

8.2.5 Conclusion

The exploration into changes in DNS stability due to the COVID-19 pandemic has yielded intriguing observations across various countries. While some nations experienced a significant increase in Round-Trip Time (RTT) to DNS servers during the lockdown period, others displayed a contrasting trend, with a notable decrease in RTT. These divergent dynamics underscore the complexity of network behavior and its interaction with global events.

The observed RTT patterns cannot be solely attributed to lockdown measures; they reflect a confluence of societal, political, and contextual factors. In-depth investigations into each country's unique circumstances are imperative to unveil the underlying reasons behind the observed RTT behavior.

It is evident that the relationship between network behavior and real-world events, such as the COVID-19 pandemic, is intricate and multifarious. A comprehensive understanding necessitates an interdisciplinary approach, considering not only technical metrics but also societal dynamics, policies, and a spectrum of influences. As the Internet continues to evolve in tandem with global events, ongoing research remains vital to unravel the intricate connections that shape its performance and accessibility.

9. Proposal for project continuation

Building upon the foundational framework developed in this project, there is a promising avenue for extending the tools and capabilities of the system to further investigate and visualize network changes in response to significant world events or localized incidents. This proposal outlines potential areas of expansion that can enhance the project's utility and relevance:

9.1 Multi-Dimensional Analysis

Expand the analytical capabilities of the platform to accommodate multi-dimensional analysis. Incorporate additional network parameters beyond latency, packet loss, and IPv6 adoption, such as BGP data, DNS performance, and traffic patterns. This will provide a more comprehensive understanding of network behavior during various events.

9.2 Predictive Modeling

Integrate machine learning and predictive modeling algorithms to forecast potential network disruptions or changes based on historical data patterns. This feature could provide valuable insights for proactive network management and response planning.

9.3 Event Correlation

Develop tools to correlate network behavior changes with specific world events, such as major geopolitical developments, natural disasters, or infrastructure upgrades. By overlaying event timelines with network data, users can gain a deeper understanding of causal relationships.

9.4 Integration with Other Data Sources

Explore opportunities to integrate RIPE Atlas data with other data sources, such as social media trends, economic indicators, or environmental factors. This integration could reveal intriguing correlations between non-network events and network behavior.

9.5 The Potential Value of Continuing Project Development

By incorporating these enhancements, the project can evolve into a comprehensive network analysis platform that not only captures the impact of world events on network behavior but also provides advanced analytical and predictive capabilities. This expanded toolkit will be a valuable resource for researchers, network operators, policymakers, and other stakeholders seeking to understand the dynamics of the global digital landscape.

9.6 Graph Comparison Using User's Data

A valuable enhancement to the analysis involves comparing the DNS stability graph with user-provided data. This comparison could extend to various aspects, such as correlating the DNS stability graph with the graph depicting the number of new COVID-19 cases in a specific country. This inclusion not only enriches the research but also enhances the utility of the tool, enabling users to gain deeper insights and draw more comprehensive conclusions from the interplay between network behavior and real-world events.

10. Additional project

In the pursuit of enhancing the capabilities of the RIPE Atlas Network Analysis Tool, we embarked on an additional project aimed at introducing several critical features to enrich user experience, streamline data processing, and facilitate further research endeavors. The objectives of this endeavor were meticulously planned to address existing limitations and unlock new avenues for exploration. Here is an overview of the successfully implemented enhancements:

10.1 Multiselect and Interactive Timeline for IPv6 Analysis

Building upon the success of the DNS feature, we extended the IPv6 tool's capability to allow users to visualize graphs of multiple countries simultaneously within a given timeline. This feature empowers users to explore correlations between different countries, providing a comprehensive view of IPv6 adoption trends.

10.2 Pre-Caching Algorithm for IPv6 Data

To expedite data processing and fetching, we devised and implemented a pre-caching algorithm for IPv6 data. By proactively computing IPv6 percentages per country per date and storing them in advance, we significantly accelerated the data retrieval process. This improvement enables users to interactively research events using the user interface, eliminating the need to spend time on dynamic data processing.

10.3 Unit Testing of Core Algorithms.

Ensuring the reliability and maintainability of our core algorithms was very important concern. To this end, we implemented thorough unit testing for the business logic underpinning data processing and fetching. This practice not only aids new project participants in understanding the intricate workings of the system but also provides the freedom to refactor code without the fear of introducing unintended consequences.

10.4. Jupyter Notebooks for Programmable API Usage

We created Jupyter Notebooks that facilitate the programmatic usage of functions to fetch raw data. This feature enables users to access and process raw data in alternative systems such as R, Excel, or the pandas library. The notebooks empower users with greater flexibility in data manipulation and analysis.

10.5 User Interface Enhancements

In line with our commitment to a user-centric approach, we addressed various user interface inconsistencies and usability issues. These enhancements contribute to a more coherent and user-friendly experience across different features. The graphs were refined for improved comprehension, ensuring a seamless and efficient interaction.

Through dedicated efforts, we have successfully brought these additional features to life, enriching the RIPE Atlas Network Analysis Tool with expanded capabilities. These advancements not only enhance the tool's existing utility but also pave the way for more intricate research projects, streamlined data analysis, and insightful network behavior exploration.

11. Conclusion

In conclusion, this project has provided valuable insights into the dynamic and intricate nature of the global Internet landscape, particularly during the unprecedented times of the COVID-19 pandemic. Through the utilization of RIPE Atlas data, we have successfully discerned notable shifts in network behavior that were catalyzed by this global crisis.

Our analysis unveiled a significant surge in IPv6 Adoption and ASes in developing countries, indicating a strategic investment in Internet infrastructure. Concurrently, the observed decline in DNS availability during periods of lockdowns shed light on the fragile interplay between global events and digital accessibility.

Additionally, the success of this project extends beyond its immediate findings. The platform we have developed for intuitive data visualization and analysis lays a strong foundation for future endeavors. This framework can serve as a base for creating new tools that allow researchers, network operators, and policymakers to further explore the ever-changing dynamics of the Internet. It provides a solid starting point for integrating additional tools into the existing platform, enhancing its impact and enabling ongoing in-depth investigations.

In sum, the project's findings underscore the profound impact of global events on the digital sphere, while the platform's capabilities offer a gateway to a wealth of insights that can guide informed decisions and actions in the realm of network management and development. We extend our gratitude to the RIPE Atlas project for furnishing us with a powerful instrument for understanding and navigating the complexities of the modern digital age.

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