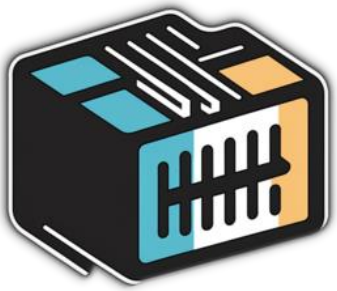
Cairo University
Faculty of Computers and Artificial intelligence
Department of Computer Science

Ethernet Traffic Jam (E-Jam)



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Chapter 1: Introduction

1.1 Abstract

Networking industry is evolving very fast, trying to achieve higher bandwidth and speeds to fulfil today's needs in every aspect of our life. E-Jam (Ethernet traffic jam) is a software solution that aims to support the electronic design life cycle of networking devices and switches by providing tools that enables industry leaders to verify and qualify network switches through software that provides high performance network streaming over distributed systems connected to a manufactured switch with the ability to develop different and custom streaming scenarios. It also provides monitors and debugging mechanisms that allow users to perform testing scenarios and automate regressions over a connected switch. E-Jam will provide subsystems responsible for processes management, analytics, benchmarking and visualization.

1.2 Acknowledgment

We would like to thank Dr. El Ramly and our mentors from Siemens EDA (Eng. Mohamed Shaaban, Eng. Momen Adel, Eng. Ehab Fawzy, Eng. Belal Hamdy), for their helpful advice, direction, and monitoring in all the phases.

1.3 Problem definition

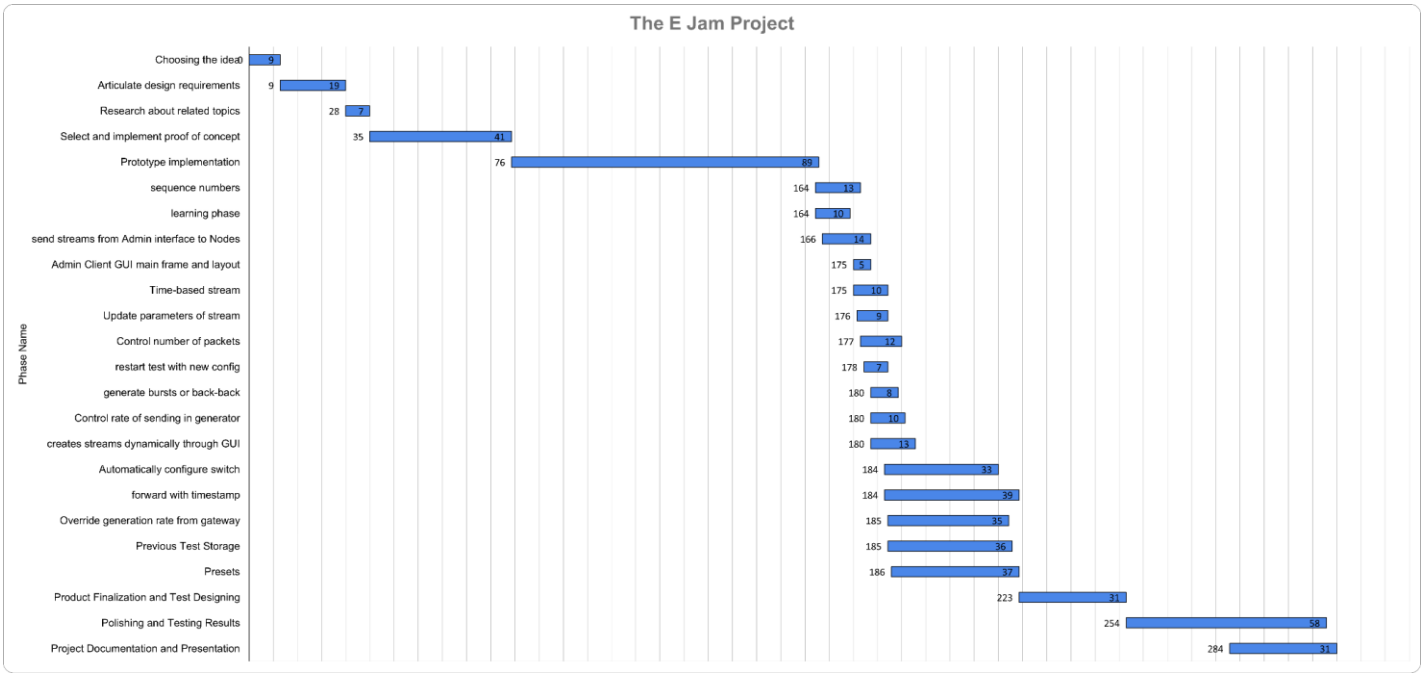
With many factors affecting switch performance, it is very useful for network vendors and network administrators to be able to test the performance of their switches constantly. It is critical to make sure the switch is running as intended, as it might be very expensive. Many products exist to test entire network topologies and measures of switch performance under certain protocols, but few provide the flexibility to test multiple protocols under customizable testing conditions.

1.4 Project Objective

A viable strategy to deal with problems mentioned earlier is to decipher the black box enveloping the switching process, so our project aims to provide the maximum flexibility in switch benchmarking in all its aspects. We have monitoring, visualization, testing, statistical and debugging features to make sure the switch is functionally correct. In collaboration with Siemens EDA company which sees advantages in such a solution, we aim to implement a high-performance software tool which uses low-level frame generation to generate highly customizable frames which allows us to implement a set of well-defined tests mentioned in RFC2544, RFC2889 to benchmark the switch. Also, SNMP is used to passively monitor the performance of the switch at any non-testing time.

A simple user interface will be used to visualise the data resulting from the test to the user and control the system for admin in an admin-Client User Interface.

1.5 Gantt chart of project time plan



1.6 Technical background

Setting up the DUT

- Before starting to perform the tests, the DUT must be configured following the instructions provided to the user (if any).

- Before starting the test, all traffic of supported protocols must be allowed through the switch and no further tuning should be done regarding protocols.

- No vendor-specific filter functions should be used to ensure that there is a basis for comparison between vendors.

- The routing update intervals, keep alive frequency, and buffer sizes should be set once and kept with the same values while performing any tests later.

Inter-process communication

1- Pipes:

Definition: Pipes are special files managed by the OS, they act as FIFO queue with two ends (read and write). Both reading and writing processes need to open the file at the same time to communicate. Communication happens this way: the writing end puts the bytes on the FIFO, it can put more than one item. Meanwhile, the reading process is blocked, once the reading process detects something was written on the pipe it unblocks, reads it, then deletes it from the pipe.

There are two types, unnamed pipes and named pipes. Unnamed pipes are in-memory files created by the processes and deleted at the end of execution. Named pipes reside in a filesystem and exist outside the scope of the execution, as its life cycle is independent of the processes.

Advantages: Quick, somewhat easy to use, reliable.

Limitations: Both reading and writing processes must be using it simultaneously all the time, or it will block the other one. This issue can be worked around using a slave process that just detects the change thus the slave will be blocked instead of the master process. This issue still requires using another non-blocking communication method to deliver data to the master process. Also sends data as raw bytes.

2- POSIX Shared Memory:

*Definition: P*OSIX shared memory is organized using memory-mapped files, which associate the region of shared memory with a file.

Advantages: Skips the part where we must ensure the FIFO file exists, accessible, non-corrupted, etc…

The read and writing processes are not blocked.

3- Sockets

Definition: Sockets are a method of communication using IP and ports ex. 127.0.0.0:80. It is said to be lower level than pipes.

Advantages: In Java they are very easy to use. Sockets are bidirectional. Allows communication with other machines easily.

Limitations: Using Java imposes a challenge related to the use of multiple programming languages at the same time thus forcing us to use multiple executables. The other alternative of using sockets with C++, is unnecessarily a bit more complex than other IPC methods. Also, still only able to send raw bytes.

Cyclic Redundancy Check

CRC or Cyclic Redundancy Check is a method of detecting accidental changes/errors in the communication channel. CRC uses Generator Polynomial which is available on both sender and receiver side.

An example generator polynomial is of the form like x3 + x + 1. This generator polynomial represents key 1011.

Sender side (Generation of Encoded Data from Data and Generator Polynomial (or Key)):

1. The binary data is first augmented by adding k-1 zeros in the end of the data

2. Use modulo-2 binary division to divide binary data by the key and store the remainder of the division.

3. Append the remainder at the end of the data to form the encoded data and send the same

Receiver Side (Check if there are errors introduced in transmission)

Perform modulo-2 division again and if the remainder is 0, then there are no errors.

Where:

n: Number of bits of data to be sent from the sender side.

K: Number of bits in the key obtained from the generator polynomial.

RESTful APIs

A RESTful API is a specific type of API that follows certain guidelines. REST stands for Representational State Transfer. This means that when a client requests a resource using a REST API, the server transfers back the current state of the resource in a standardized representation.

To make the API service RESTful, six guiding constraints must be satisfied. These are:

- Use of a uniform interface (UI): To have a uniform interface, multiple architectural constraints are required to guide the behaviour of components. Additionally, resources should be unique, so they are identifiable through a single URL.

- Client-server architecture: The client and server must be separate from each other and communicate through HTTP requests and responses.

- Stateless: The server should not store any client context between requests. Each request should contain all the information necessary for the server to understand it.

- Cacheable: The server should indicate whether a response can be cached by the client.

- Layered system: The client should not be able to tell whether it is communicating directly with the server or with an intermediary.

- Code on demand (optional): Servers can temporarily extend or customize the functionality of a client by transferring executable code.

Test Setup

The user is recommended to consult this section in order to be able to produce tests which measure certain performance attributes correctly.

It is highly recommended to consult RFC1242, RFC2285, RFC2544, RFC2889 when reading this section.

Our primary test setup will consist of several sender/receiver pairs with multiple ports.

All frames generated will have a sequence number which will help in identification of dropped frames, duplicated frames, and out of order frames. There will be a learning period for the switch in which all the devices involved in the current test send pings to the switch so that the switch learns the mac addresses of all packets involved.

The parameters to be automated during the setup are protocol filters and maximum allowed frame size on the switch. The parameters to be input by the user are frame size(s), whether to include broadcast frames, and interframe gap (IFG), and protocol(s) to use.

The frame sizes of all packets will be the same under the normal test. There is an option for the user to choose a multi-frame size test. In which case, the user will specify which frame sizes to be included, and in which ratio. There is an option for the user to include broadcasting frames in the test to test the ability of the switch to handle flooding frames. If chosen, the user will specify the percentage of broadcast frames (this percentage cannot exceed 2%). The broadcast frames will be evenly distributed across the streams. There is an option for the user to include certain protocols. In a multiprotocol environment, there will be an even distribution of frames with the different protocols. The recommended ratio is even distribution among the frames. The sizes available are 64, 128, 256, 512, 1024, 1280, 1518.

There will be a facility to control the Interframe gap. There will be a facility to control the type of traffic which is either bursty or back-to-back. A flow control facility between the gateway and the generators will be available. Some test presets will not allow the modification of traffic types or frame sizes. Presets included are throughput, latency, frame loss rate, packet integrity.

Preset for measuring throughput:(theoretical frame rate provided)

This preset will use fully meshed traffic.

Each trial will last at least 30 seconds, but the final determination trail will last at least 60 seconds.

We will binary search for the rate to send packets: Count the total number of packets sent and total number of packets received. If no packets are dropped, then we have found a lower bound on the throughput, and we continue the binary search.

Preset for measuring Latency: (frame size, OPTIONAL throughput)

Before performing this test, it is required to have an exact measurement of the maximum throughput for the frame size used. There will be a stream that lasts 60 seconds, followed by a single tagged frame, followed by another stream which lasts 60 seconds. The switch will be configured so that when it receives any frame with that tag, it records the timestamp at which that frame enters, and the timestamp

where that frame exists in the switch and appends them to the frame. The latency will be the difference in these timestamps, which will be calculated at the destination device. This test must have at least 20 trials.

Frame loss rate: (frame rate)

At each frame size specified above, there will be multiple trials (at least 10), each trial will send packets at a certain frame rate (the first trial will send 100% of the maximum rate allowed for the frame size), then we decrement the frame rate and do another trial. We record the frame loss percentage calculated at every trial as (number of received frames - number of transmitted frames)/ number of transmitted frames * 100.

Packet integrity test:

Devices will be all included in one stream, divided into two equal-sized groups of generators and verifiers. The stream should be executed, and every out-of-order packet or wrong payload will be noted and included in the calculation of error percentage. The test will be repeated five times with different frame sizes, as previously mentioned.

There are many topics that are needed to understand how the software operates fully. However, due to space constraints, we cannot include them in this document. They can be located here.

1.7 Project development methodology

Introduction

Scrum is an agile project management framework that helps teams' structure and manage their work through a set of values, principles, and practices. Scrum is widely used by software development teams because it encourages them to learn through experiences, self-organize while working on a problem, and reflect on their wins and losses to continuously improve. In this section, we will describe how we developed our project using scrum methodology and what benefits and challenges we encountered along the way.

Scrum Roles

Scrum defines three main roles for the team members: the product owner, the scrum master, and the development team. The product owner is responsible for defining and prioritizing the product backlog, which is a list of features and requirements that the team needs to deliver. The product owner represents the voice of the customer and ensures that the team delivers value to the stakeholders. The product owner in our case was the team of Siemens EDA.

The scrum master is responsible for facilitating the scrum process and coaching the team on how to apply scrum principles and practices.

The development team is responsible for designing, developing, testing, and delivering the product in increments according to the product backlog. The development team is self-organizing and cross-functional, meaning that they have all the skills and expertise needed to complete the work without relying on external resources.

In our project, we had one product owner, one scrum master, and five developers. The product owner was also the client who contacted us to develop this application for verifying, debugging, and monitoring switching devices.

Scrum Events

In our project, we followed a two-week sprint cycle. We had sprint planning meetings every Saturday night for two hours. We had daily scrum meetings every evening for 15 minutes. Furthermore, we had sprint review meetings every Friday afternoon for one hour. We had sprint retrospective meetings right after each sprint review for 30 minutes.

Scrum Artifacts

Scrum defines three main artifacts for the team to track and manage their work: product backlog, sprint backlog, and product increment.
The product backlog is a dynamic list of features and requirements that represent what the customer wants from the product. The product backlog is never complete, as new items can be added, modified, or removed at any time based on customer feedback or market changes.

The sprint backlog is a subset of the product backlog that represents what the team commits to deliver in one sprint. The sprint backlog is owned and maintained by us, the development team, who breaks down the items into smaller and more manageable tasks. It is updated daily during the sprint, as the team completes the tasks and monitors their progress.
In our project, we used Trello Software as a tool to manage our scrum artifacts. We used the product backlog to store and prioritize our user stories, which were descriptions of features and functionalities from the user's perspective. We used the sprint backlog to assign and track our tasks, which were subtasks of user stories with specific details and acceptance criteria.

Benefits

Using scrum methodology for our project brought us many benefits and challenges. Some of the benefits were:

- Improved customer satisfaction: By delivering frequent and valuable product increments, we were able to meet the customer's expectations and needs more effectively. We also received regular feedback from the product owner, which helped us improve our product quality and functionality.
- Increased team collaboration: By working as a self-organizing and cross-functional team, we were able to leverage our diverse skills and expertise to

solve problems creatively. We also communicated more frequently and transparently with each other, which helped us coordinate our work and resolve any issues quickly.

- Enhanced team learning: By following scrum principles and practices, we were able to learn from our experiences and experiments. We also reflected on our performance and improvement opportunities during each sprint retrospective, which helped us grow as a team and as individuals.

Challenges

As with every experience, along the benefits, comes the challenges. Some of the challenges we faced were:

- Managing changing requirements: As we developed our project, we faced many changes in customer requirements that affected our product backlog. We had to adapt our plans and priorities accordingly, which sometimes caused delays or rework.
- Estimating work accurately: As we planned our sprints, we had to estimate how much work we could do in one sprint and how long each task would take. We often faced difficulties in estimating work accurately, especially for complex or unfamiliar tasks. We had to adjust our estimates based on our actual progress and the circumstances the team members are facing at the sprint planning period.
- Maintaining quality standards: As we delivered our work each sprint, we had to ensure that they met the definition of done and satisfied the customer's expectations. We sometimes faced challenges in testing, debugging, or integrating our software components, especially when we had dependencies or technical issues such as changes in the execution environment.

1.8 Tools Used

E-Jam leverages a powerful and versatile tech stack to deliver its robust network testing capabilities. Let's explore the key technologies and tools used:

Wireshark

Wireshark is a free and open-source packet analyser used for network troubleshooting, analysis, software and communications protocol development, and education. It listens to a network connection in real-time and then grabs entire streams of traffic - quite possibly tens of thousands of packets at a time. We used it to debug many issues and make sure packets are sent correctly.

CLion

CLion is an Integrated Development Environment (IDE), used for developing the C++ part of our system including the Generators and Verifiers and Gateway of the low-level network packet controller.

IntelliJ IDEA

IntelliJ IDEA is an integrated development environment (IDE) written in Java for developing computer software. We used it mainly to develop the System API component. It was useful especially when dealing with packaging and maven dependency management.

Make and Cmake

CMake is an extensible, open-source system that manages the build process in an operating system and in a compiler-independent manner. Unlike many cross-platform systems, CMake is designed to be used in conjunction with the native build environment. It is cross-platform free and open-source software for build automation, testing, packaging and installation of software by using a compiler-independent method. We used it in the development process of many components in our system.

Visual Paradigm

Visual Paradigm is a tool used for modelling software systems. It has been used in as a means of creating UML diagrams, ER diagrams, and other types of diagrams that help to visualise a system's architecture. These diagrams can then be used as a reference to build out the system's components.

Draw.io

Draw.io is an online diagramming tool that can be used to create flowcharts, network diagrams, and other types of diagrams. It has been used to create diagrams that help to explain complex systems or workflows. These diagrams can be shared with stakeholders, which helps to ensure that everyone is on the same page.

Figma

Figma is a design tool that allows teams to collaborate on designs. In the project, it has been used to create mock-ups of user interfaces, which can then be shared with

developers. This helps to ensure that the user interface is designed in a way that is intuitive and easy to use.

GitHub Actions

GitHub Actions is a tool used for automating tasks in a project's development workflow. It has been used to automate tasks such as building and testing code and notifying team members of changes to the codebase. This helps to ensure that the development process is streamlined and efficient.

Flutter

Flutter is used to develop the cross-platform User Interface (UI) component of E-Jam. Flutter enables the creation of visually appealing and responsive interfaces that can run on various operating systems.

Linux

Linux is an operating system that is used in many big projects. It is known for its stability, security, and flexibility. It has been used as a server operating system, as well as a development environment for developers. Its open-source nature also allows for customization and optimization for our specific use cases.

Docker

Docker is a tool used for containerization. It has been used to ensure that code can be run in a consistent environment, regardless of the underlying infrastructure. This helps to ensure that code runs the same way across different environments, which can save time and reduce errors.

Qemu

Qemu is a virtualization tool that allows for the creation and management of virtual machines. In our project, it has been used to create virtual environments for testing and development. This allows developers to test code in a controlled environment, on multiple platforms like macOS, windows, and different Linux distros like Fedora and Ubuntu, before deploying it to production.

Kafka

Kafka is a distributed streaming platform that allows for the processing of large volumes of data in real-time. It has been used for tasks such as collecting data from various Nodes, processing that data, and then delivering that data to the Admin Interface. It is known for its scalability and fault-tolerance.

Avro

Avro is a data serialization system that is used in big projects to make it easier to share data between different systems. It allows for the definition of data schemas, which makes it easier to ensure that data is consistent across different systems. It is also designed to be language-agnostic, which means that it can be used with multiple programming languages.

Conduktor

Conduktor is a tool used for managing Apache Kafka clusters. It has been used to manage and monitor The Kafka cluster. It provides a user-friendly interface for managing topics, partitions, and other aspects of a Kafka cluster.

Rust

Rust is a programming language that is known for its performance and memory safety. It has been used to build the centre point of the system. Its memory safety features help to reduce the risk of buffer overflows and other common security vulnerabilities.

Java

Java is a programming language that is widely used in big projects. It is known for its portability and scalability. It has been used to build the system API application. Its large ecosystem of libraries and tools makes it a popular choice for us.

Spring Boot

Spring Boot, a Java-based framework, is used to develop the System API component of E-Jam. Spring Boot provides a robust foundation for building scalable and reliable applications, enhancing the system's performance.

C++

C++ is a programming language that is known for its performance and low-level control. It has been used to build the Low network level that requires high performance. Its low-level control also makes it a popular choice for our components.

1.9 Report Organization

This document is organized into several chapters, each addressing a specific aspect of the project:

Chapter 1: Introduction - Provides a high-level overview of the project.

Chapter 2: Competitors and Related Work - Analyses competitors and explores related tools.

Chapter 3: System Constraints - Discusses functional and non-functional requirements.

Chapter 4: System Design - Presents system diagrams and GUI design.

Chapter 5: Testing and System Life Cycle - Outlines the testing plan and component life cycle.

Chapter 6: Future Work - Identifies potential enhancements for the system.

Chapter 2: Related Work

There are many similar products in the market. However, most of them focus on providing network performance monitoring using SNMP or network traffic analysis using some flow protocols such as NetFlow or others. Most products available aim to troubleshoot the entire network, not a specific network device. Our differentiating factor is that we provide more extensive benchmarking of the switch itself and are not as concerned with the overall network performance.

2.1 SolarWinds Network Bandwidth Analyser Pack

SolarWinds Network Bandwidth Analyzer Pack is a tool for monitoring and analysing the network performance.

Product features

- Real-time network traffic monitoring: SolarWinds Network Bandwidth Analyser Pack provides real-time monitoring of network traffic, allowing you to see where your bandwidth is being used and identify any potential bottlenecks.
- Can detect and resolves network performance issues.
- Detects which nodes are hogging the bandwidth (using most of the bandwidth)
- SolarWinds Network Bandwidth Analyser Pack also allows you to analyse historical network traffic, so you can track trends and identify patterns.
- SolarWinds Network Bandwidth Analyser Pack can forecast your bandwidth needs, so you can make sure you have enough bandwidth to meet your requirements.
- SolarWinds Network Bandwidth Analyser Pack generates detailed reports that you can use to track your network traffic and identify any potential problems.

Pros

- Easy to use: SolarWinds Network Bandwidth Analyser Pack is easy to use, even for users with no prior experience with network monitoring.
- Scalable: SolarWinds Network Bandwidth Analyser Pack can be scaled to meet the needs of small, medium, and large organizations.

Cons

- High cost: SolarWinds Network Bandwidth Analyser Pack is a commercial product, so it can be expensive.
- Complexity: Some of the features of SolarWinds Network Bandwidth Analyser Pack can be complex to configure and use.
- Security: SolarWinds Network Bandwidth Analyser Pack has been the target of security breaches in the past.

2.2 IPerf

IPerf is a tool for measuring the maximum achievable bandwidth in the network.

Product features

- IPerf can be used to measure the bandwidth between two hosts. This can be useful for troubleshooting network performance issues or for simply getting an idea of how much bandwidth is available.
- IPerf can be used to test both TCP and UDP traffic. This is important because different applications use different protocols, and you may need to test both to get a complete picture of your network's performance.
- IPerf has a few configurable settings that allow you to customize the test. For example, you can specify the size of the data packets, the number of packets to send, and the length of the test.
- IPerf measures (practical) bandwidth, MTU, and observed read sizes for TCP and SCTP specifically.
- IPerf measures packet loss, delay jitter for UDP

Pros

- Free and open-source: IPerf is a free and open-source tool, which means that it is available to anyone to use or modify. This makes it a cost-effective option for network performance testing.
- Cross-platform: IPerf is available for a variety of platforms, including Windows, Linux, and macOS. This makes it a versatile tool that can be used on a wide range of systems.
- Easy to use: IPerf is relatively easy to use. The command-line interface is straightforward, and there are a few tutorials available online that can help you get started.
- Versatile: IPerf can be used to test a wide range of network scenarios. This makes it a valuable tool for troubleshooting network performance issues or for simply getting an idea of how much bandwidth is available.

Cons

- Command-line interface: IPerf is a command-line tool, which means that you need to be familiar with the command line to use it. This can be a barrier to entry for some users.

2.3 Spirent TestCenter

Spirent TestCenter is a comprehensive testing solution for network performance, scalability, and functionality.

Product features

- Spirent TestCenter allows users to generate realistic network traffic at various scales, enabling performance testing and analysis.
- It supports a wide range of protocols, allowing users to emulate different network scenarios and test devices' compatibility and functionality.
- The tool can measure and assess QoS parameters such as latency, jitter, and packet loss, helping ensure optimal network performance.
- Spirent TestCenter includes security testing features, allowing users to evaluate the resilience of network devices against various security threats and attacks.
- It provides in-depth analysis capabilities to monitor and analyse network traffic, enabling users to identify bottlenecks, troubleshoot issues, and optimize network performance.
- Multiple users can collaborate and work simultaneously on test scenarios, enhancing productivity in testing environments.

Pros

- Comprehensive Testing Capabilities: Spirent TestCenter offers a wide range of testing capabilities, allowing users to perform thorough testing of network devices and configurations.
- Realistic Traffic Generation: The tool provides the ability to generate realistic network traffic, enabling more accurate testing and evaluation of device performance.
- Protocol Support: Spirent TestCenter supports a broad range of network protocols, making it versatile and suitable for testing a variety of devices and network configurations.
- Advanced Analysis and Reporting: The tool offers robust analysis and reporting features, providing detailed insights into network performance and test results.
- Scalability: Spirent TestCenter can scale to support large-scale network testing scenarios, making it suitable for testing complex network infrastructures.

Cons

- Complexity: Spirent TestCenter can be complex to set up and use, especially for users who are new to network testing tools. It may require a learning curve and training to utilize its full potential effectively.
- Cost: Spirent TestCenter is a commercial tool, and the cost may be a consideration for some organizations, particularly for smaller businesses with limited budgets.

- Resource Intensive: Running extensive tests with Spirent TestCenter may require significant hardware resources, such as powerful servers and high-speed network interfaces.

2.4 Paessler PRTG Network Monitor

PRTG Network Monitor is a comprehensive network monitoring tool that provides real-time monitoring of network devices, bandwidth, and traffic.

Product features

- PRTG can automatically discover all the devices on your network, so you don't have to manually add them.
- PRTG comes with a wide range of preconfigured sensors that can be used to monitor different aspects of your network, such as bandwidth usage, server uptime, and application performance.
- PRTG allows you to create custom dashboards and maps to visualize your network data.
- PRTG can send alerts and notifications when problems are detected on your network.
- PRTG can generate reports that can be used to track the performance of your network over time.
- PRTG monitors SNMP-enabled network devices.
- PRTG analyses network traffic.

Pros

- Easy to use: PRTG is easy to use, even for beginners.
- Scalable: PRTG can be scaled to monitor large networks.
- Cost-effective: PRTG is a cost-effective solution for network monitoring.

Cons

- Not open source: PRTG is not an open-source solution.
- Can be complex: PRTG can be complex to configure for complex networks.
- Requires a paid subscription: PRTG requires a paid subscription to use.

2.5 Wireshark

Wireshark is a popular open-source network protocol analyser that allows you to capture, analyse, and troubleshoot network traffic.

Product features:

- Wireshark captures network packets and provides detailed information about each packet, including source and destination addresses, protocols, and payload.
- Wireshark offers robust filtering capabilities to focus on specific network traffic based on various criteria such as source/destination IP, protocol, port, and more.
- Wireshark supports a wide range of protocols, including Ethernet, IP, TCP, UDP, HTTP, DNS, SSL/TLS, and many others.
- It allows real-time packet analysis while capturing network traffic, helping you identify and diagnose network issues as they occur.
- Wireshark decodes packets and provides detailed analysis of protocols, allowing you to understand network behaviour and identify anomalies.
- Captured packets can be exported in various formats for further analysis or sharing with others.

Pros

- Free and Open Source: Wireshark is free to use and open source, making it accessible to a wide range of users and allowing community contributions.
- Cross-Platform: Wireshark is available for multiple operating systems, including Windows, macOS, and Linux, providing flexibility for users.
- Rich Analysis Capabilities: With its extensive protocol support and powerful filtering and analysis features, Wireshark offers deep insights into network traffic and helps in troubleshooting.
- Active Community: Wireshark has a large and active user community, providing support, documentation, and ongoing development.

Cons

- Resource Intensive: Capturing and analysing network traffic can be resource-intensive, especially for high-traffic networks, which may require sufficient system resources.
- Privacy Considerations: As a packet analyser Wireshark can capture sensitive information if not used responsibly or with appropriate permissions. Users should be cautious about privacy and legal considerations.

2.6 Nagios

Nagios is a widely used open-source monitoring system that allows you to monitor the health and performance of various IT infrastructure components.

Product features

- Nagios provides comprehensive monitoring capabilities for network devices, servers, applications, services, and other IT infrastructure components.
- It offers customizable alerting and notification mechanisms to notify system administrators or designated individuals when issues or anomalies are detected.
- Nagios can generate performance graphs and reports, helping to visualize and analyse historical data for better troubleshooting and capacity planning.
- Nagios supports a wide range of plugins and extensions that enhance its functionality and enable monitoring of specific technologies or platforms.
- Nagios provides a centralized web-based management interface to configure and manage monitoring settings and view real-time status and reports.
- Nagios is designed to scale, allowing you to monitor numerous devices and services distributed across different locations.
- Nagios can integrate with other systems and tools through APIs and plugins, facilitating seamless data exchange and automation.

Pros

- Flexibility: Nagios offers flexibility in terms of customization and configuration, allowing users to tailor monitoring to their specific needs.
- Open Source: Nagios is open-source software, which means it is freely available, extensible, and benefits from a vibrant community of contributors.
- Community Support: Nagios has a large and active user community, providing support, documentation, and a wide range of plugins and extensions.
- Maturity and Stability: Nagios has been around for a long time, making it a mature and stable solution with a proven track record.
- Extensibility: Nagios can be extended with various plugins and add-ons, enabling monitoring of diverse technologies and environments.

Cons

- Complex Setup: The initial setup and configuration of Nagios can be complex, requiring knowledge of system administration, networking, and monitoring concepts.
- User Interface: The Nagios user interface is functional but may not be as modern or user-friendly as some commercial monitoring solutions.

Chapter 3: System Analysis

3.1 Project specifications

3.1.1 Functional Requirements

1. Central admin GUI-based terminal that acts as an interface for configuring the monitoring and testing procedures.
2. Utility to stress test the switch to measure performance and correct sending.
    1. The user will specify nodes for packet generation and others for verification.
    2. The groups of the sending and receiving nodes are flexible and allow for multiple testing scenarios.
        i. Any configuration can be defined by the user. This can include any subset of nodes for generation and any subset for verification. The same node can be a generator and verifier simultaneously (but is highly discouraged). There is the facility to make any set of nodes generators and any set verifiers (a node can be a generator and verifier simultaneously).
        ii. In the beginning of the testing procedure, the user can configure the groups of the sending and receiving nodes using a GUI.
    3. In the beginning of the testing procedure, the user can configure the parameters of the generation of the generating nodes.
        i. Target addresses for each stream (can also be broadcast, multicast addresses)
        ii. Throughput (total number of bytes to send)
        iii. Frame payload size (10-2000)
        iv. Type of traffic, bursty or back-to-back
        v. Interval of burst,
        vi. Inter-frame gap
        vii. Number of packets
        viii. Type of packet content
3. Admin monitors state of system
    1. Shows active nodes and nodes currently involved in a test.
    2. Provide information for currently running tests.
        i. Current rate of transfer of each node
        ii. Error rate (malformed packet rate and packet loss rate)

iii. Number of dropped packets, out of order packets, packets received correctly, packets received containing errors.

4. Admin can accept new nodes after starting up.
5. Admin controls testing procedure.
    1. Starts and stops testing procedure.
    2. Configure test parameters (mentioned in 2)
    3. Collect performance reports after each test.
6. The system supports logging events.
    1. Each node stores logs internally in a database
    2. Logs are retrieved on demand.
    3. Only the admin interface can request logs.
    4. Log events have a certain structure.
        i. Event-ID: identification number related to that event and the origin machine's mac address (ex 434-xx:xx:xx:xx:xx:xx)
        ii. Type: Error / Control event (Test Start / Test Termination / Misc)
        iii. Time Stamp
        iv. Event report: extra details about the event, this report string will include arbitrary but useful information relevant to the event which could be crash logs, traffic lists status error the type, or (aggregated) statistics for a test.
        v. Delivered: A Boolean value used as an indicator
    5. Logs marked with Delivered are deleted at regular intervals.

3.1.2 Non-functional Requirements

The devices in the system must include:

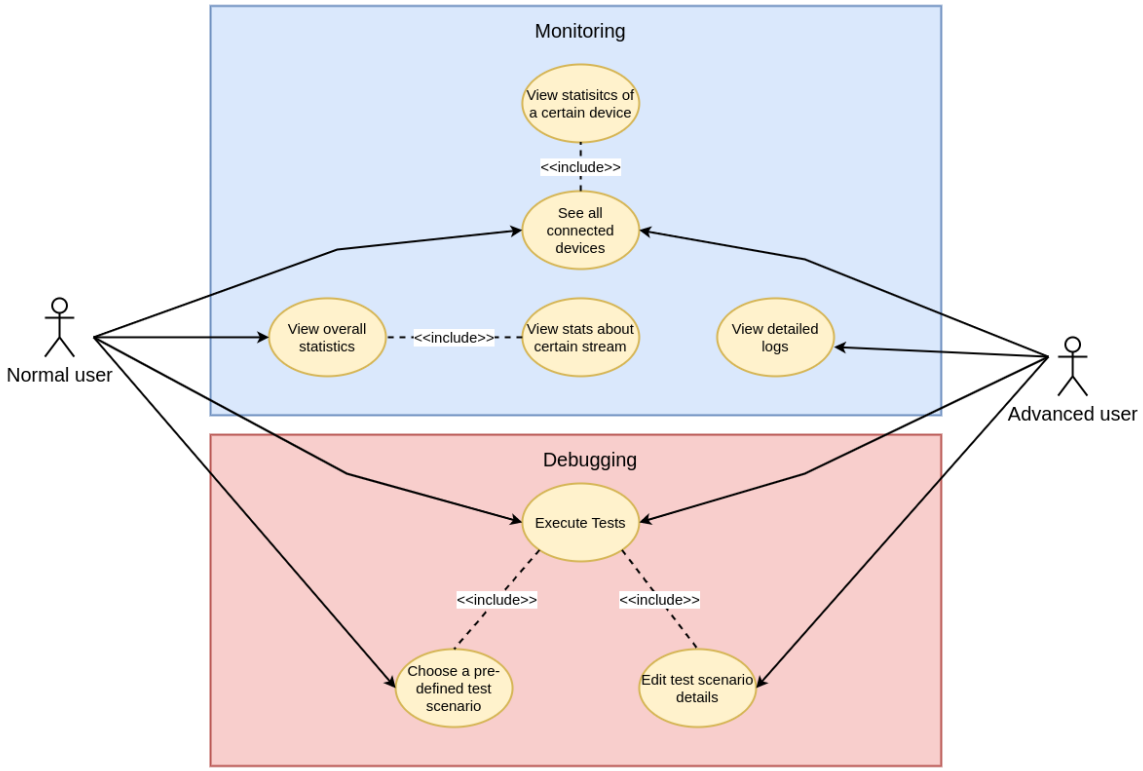
1. The switch to be tested and a different reliable network for the communication of different nodes of the system.
2. A minimum of two testing machines (at least one generator and one verifier the verifier machines should be up before the generator machines) and a maximum of a number equal to the number of Ethernet ports available in the subject.
3. Each test machine involved in the system must:
    a. Have at least two network interfaces (to connect separately to each of the switches) (i.e., Ethernet and Wi-Fi cards)

b. Have minimum requirements of 4 GB of random-access memory and a 2.8 GHz, 4-Core processor.

c. Boot in a Linux/UNIX environment with the following libraries and packages installed along with the default binaries present in common distros ex. Debian, Fedora.

4. Linux system with Apache Kafka on it for the Kafka cluster with Zookeeper and Schema Registry.

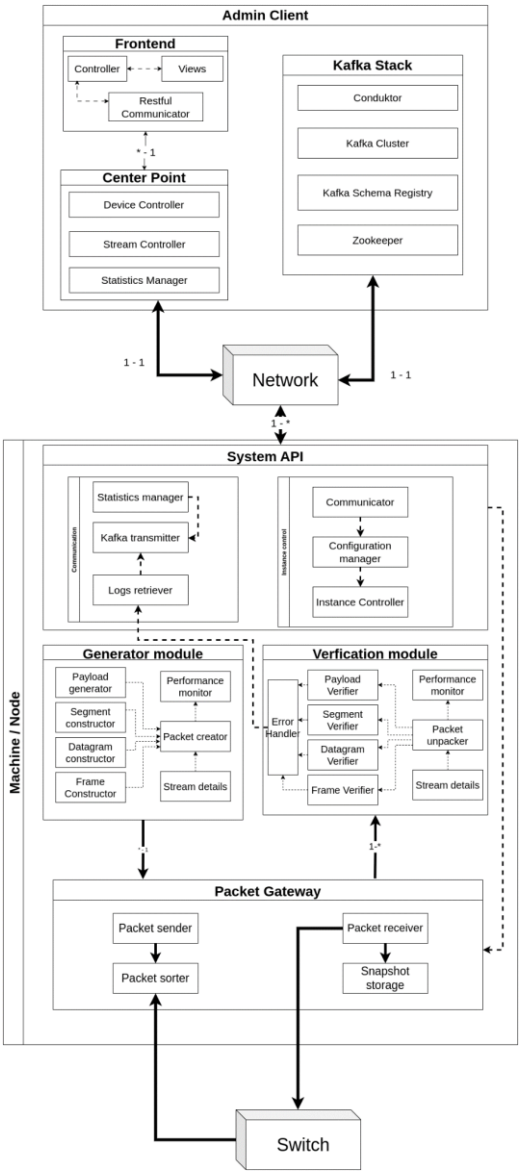
3.2 Use-case Diagram



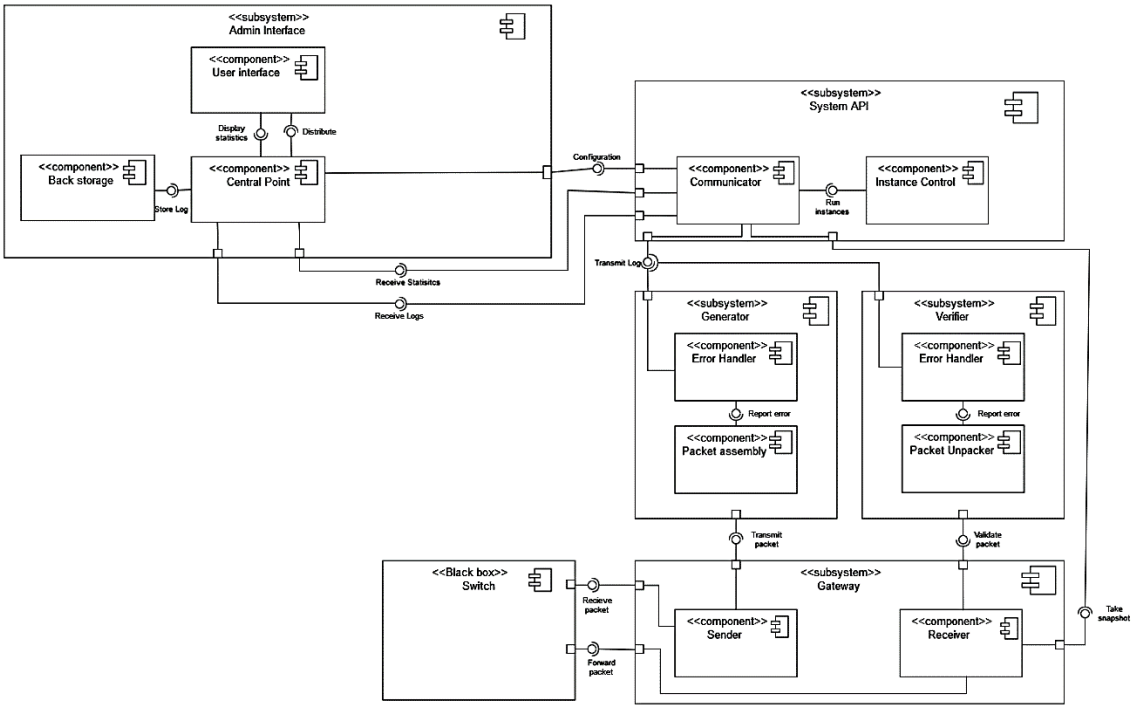
Chapter 4: System Design

4.1 System architecture

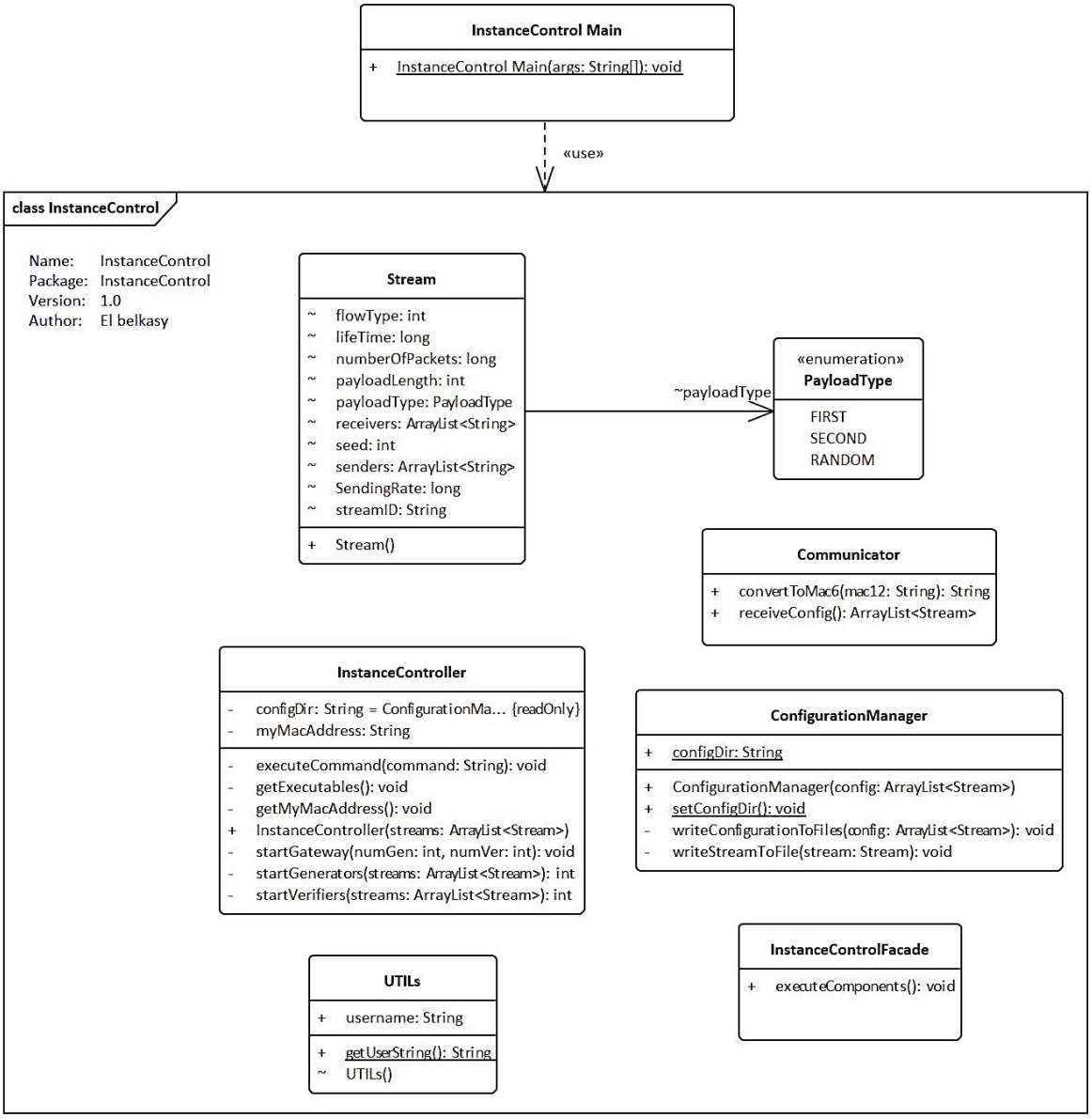
The project consists of eight subsystems that connect with each other via interfaces, the connections are either between processes on the same machine (inter-process communication), or processes on separate machines (network). Four of the main five subsystems will reside on the same machine which are (System API, Generator, Verifier, Gateway), while the other components (Centre Point, Kafka Cluster, Graphical User Interface) will reside on separate machines, the first group of components (System API, Generator, Verifier, Gateway) are designed to be replicated and be deployed in any number of machines across the network to provide the processing power needed for the test, while the rest are deployed anywhere in the system which act as a centralized control system, and a monitoring interface for the users (Admin).

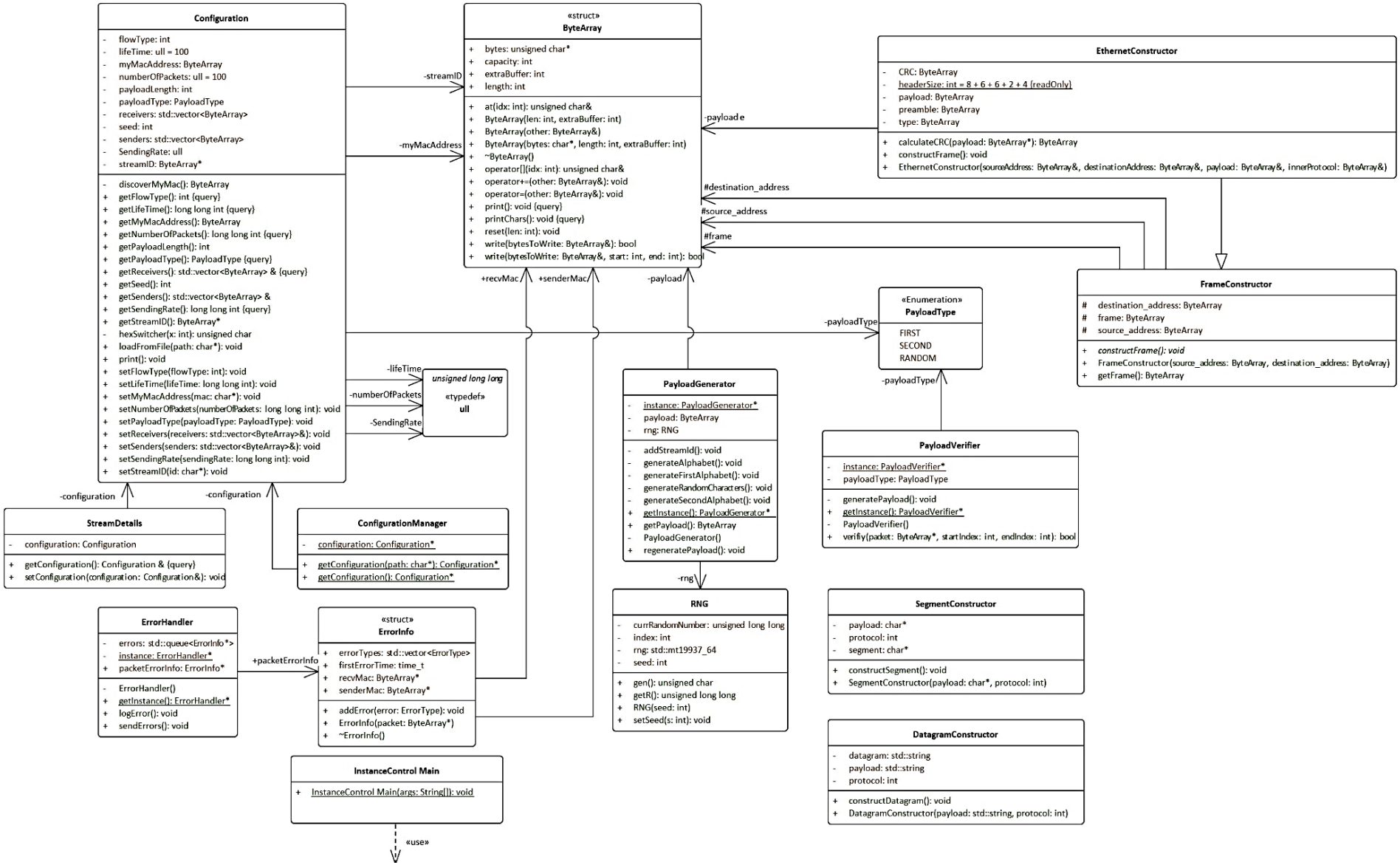


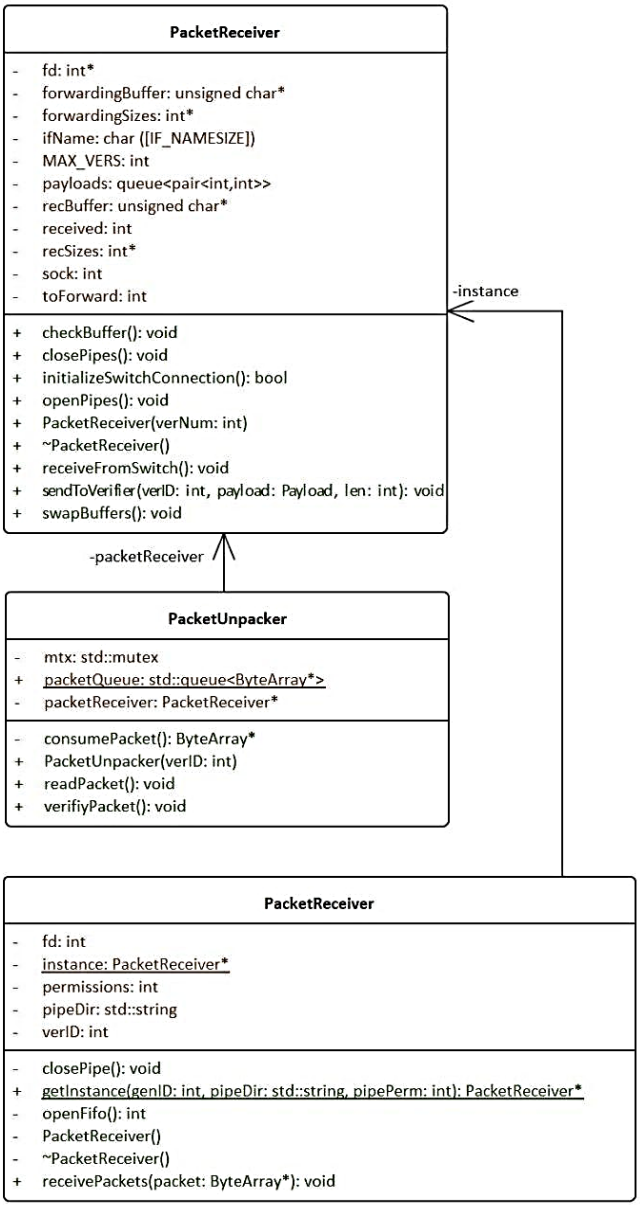
4.2 Component diagram

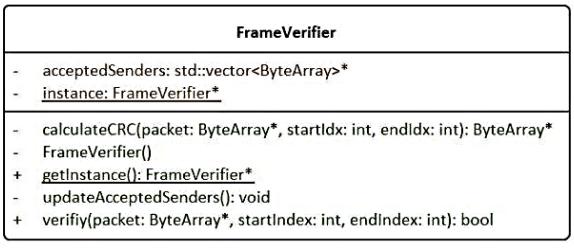


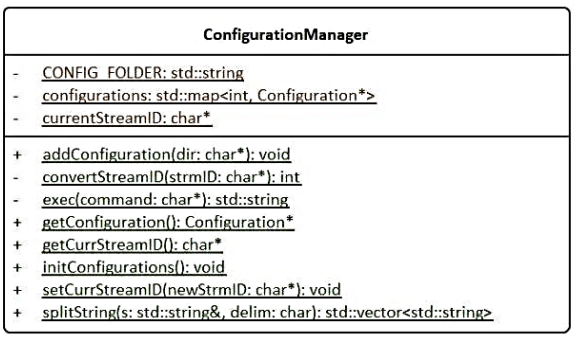
4.3 Class Diagram

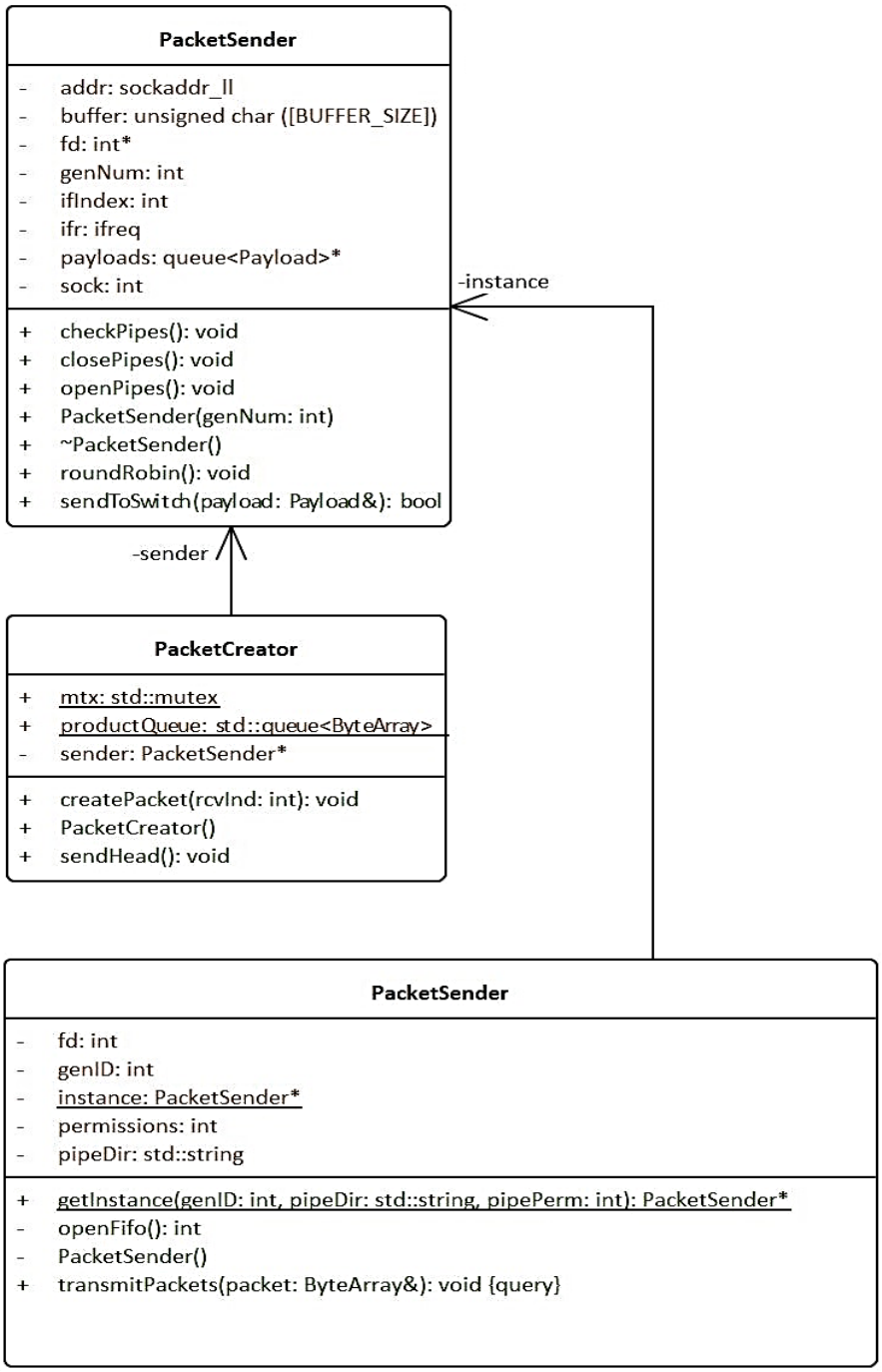


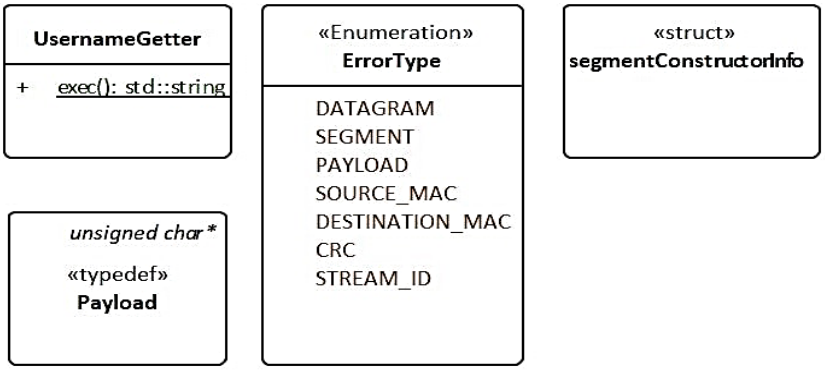

Configuration
- flowType: int
- lifeTime: ull = 100
- myMacAddress: ByteArray
- numberOfPackets: ull = 100
- payloadLength: int
- payloadType: PayloadType
- receivers: std::vector<ByteArray>
- seed: int
- senders: std::vector<ByteArray>
- SendingRate: ull
- streamID: ByteArray*
- discoverMyMac(): ByteArray
+ getFlowType(): int {query}
+ getLifeTime(): long long int {query}
+ getMyMacAddress(): ByteArray
+ getNumberOfPackets(): long long int {query}
+ getPayloadLength(): int
+ getPayloadType(): PayloadType {query}
+ getReceivers(): std::vector<ByteArray> & {query}
+ getSeed(): int
+ getSenders(): std::vector<ByteArray> &
+ getSendingRate(): long long int {query}
+ getStreamID(): ByteArray*
- hexSwitcher(x: int): unsigned char
+ loadFromFile(path: char*): void
+ print(): void
+ setFlowType(flowType: int): void
+ setLifeTime(lifeTime: long long int): void
+ setMyMacAddress(mac: char*): void
+ setNumberOfPackets(numberOfPackets: long long int): void
+ setPayloadType(payloadType: PayloadType): void
+ setReceivers(receivers: std::vector<ByteArray>&): void
+ setSenders(senders: std::vector<ByteArray>&): void
+ setSendingRate(sendingRate: long long int): void
+ setStreamID(id: char*): void
«struct»
ByteArray
+ bytes: unsigned char*
+ capacity: int
+ extraBuffer: int
+ length: int
+ at(idx: int): unsigned char&
+ ByteArray(len: int, extraBuffer: int)
+ ByteArray(other: ByteArray&)
+ ByteArray(bytes: char*, length: int, extraBuffer: int)
+ ~ByteArray()
+ operator[](idx: int): unsigned char&
+ operator+=(other: ByteArray&): void
+ operator=(other: ByteArray&): void
+ print(): void {query}
+ printChars(): void {query}
+ reset(len: int): void
+ write(bytesToWrite: ByteArray&): bool
+ write(bytesToWrite: ByteArray&, start: int, end: int): bool
EthernetConstructor
- CRC: ByteArray
- headerSize: int = 8 + 6 + 6 + 2 + 4 {readOnly}
- payload: ByteArray
- preamble: ByteArray
- type: ByteArray
+ calculateCRC(payload: ByteArray*): ByteArray
+ constructFrame(): void
+ EthernetConstructor(sourceAddress: ByteArray&, destinationAddress: ByteArray&, payload: ByteArray&, innerProtocol: ByteArray&)
FrameConstructor
destination_address: ByteArray
frame: ByteArray
source_address: ByteArray
+ constructFrame(): void
+ FrameConstructor(source_address: ByteArray, destination_address: ByteArray)
+ getFrame(): ByteArray
«Enumeration»
PayloadType
FIRST
SECOND
RANDOM
unsigned long long
«typedef»
ull
PayloadGenerator
- instance: PayloadGenerator*
- payload: ByteArray
- rng: RNG
- addStreamId(): void
- generateAlphabet(): void
- generateFirstAlphabet(): void
- generateRandomCharacters(): void
- generateSecondAlphabet(): void
+ getInstance(): PayloadGenerator*
+ getPayload(): ByteArray
- PayloadGenerator()
+ regeneratePayload(): void
PayloadVerifier
- instance: PayloadVerifier*
- payloadType: PayloadType
- generatePayload(): void
+ getInstance(): PayloadVerifier*
- PayloadVerifier()
+ verify(packet: ByteArray*, startIndex: int, endIndex: int): bool
StreamDetails
- configuration: Configuration
+ getConfiguration(): Configuration & {query}
+ setConfiguration(configuration: Configuration&): void
ConfigurationManager
- configuration: Configuration*
+ getConfiguration(path: char*): Configuration*
+ getConfiguration(): Configuration*
ErrorHandler
- errors: std::queue<ErrorInfo*>
- instance: ErrorHandler*
+ packetErrorInfo: ErrorInfo*
- ErrorHandler()
+ getInstance(): ErrorHandler*
+ logError(): void
+ sendErrors(): void
«struct»
ErrorInfo
+ errorTypes: std::vector<ErrorType>
+ firstErrorTime: time_t
+ recvMac: ByteArray*
+ senderMac: ByteArray*
+ addError(error: ErrorType): void
+ ErrorInfo(packet: ByteArray*)
+ ~ErrorInfo()
RNG
- currRandomNumber: unsigned long long
- index: int
- rng: std::mt19937_64
- seed: int
+ gen(): unsigned char
+ getR(): unsigned long long
+ RNG(seed: int)
+ setSeed(s: int): void
SegmentConstructor
- payload: char*
- protocol: int
- segment: char*
+ constructSegment(): void
+ SegmentConstructor(payload: char*, protocol: int)
DatagramConstructor
- datagram: std::string
- payload: std::string
- protocol: int
+ constructDatagram(): void
+ DatagramConstructor(payload: std::string, protocol: int)
InstanceControl Main
+ InstanceControl Main(args: String[]): void
«use»
-streamID
-myMacAddress
-payload
#destination_address
#source_address
#frame
+recvMac
+senderMac
-payload
-payloadType
-payloadType
-lifeTime
-numberOfPackets
-SendingRate
-configuration
-configuration
-rng
+packetErrorInfo


PacketReceiver
- fd: int*
- forwardingBuffer: unsigned char*
- forwardingSizes: int*
- ifName: char ([IF_NAMESIZE])
- MAX_VERS: int
- payloads: queue<pair<int,int>>
- recBuffer: unsigned char*
- received: int
- recSizes: int*
- sock: int
- toForward: int
+ checkBuffer(): void
+ closePipes(): void
+ initializeSwitchConnection(): bool
+ openPipes(): void
+ PacketReceiver(verNum: int)
+ ~PacketReceiver()
+ receiveFromSwitch(): void
+ sendToVerifier(verID: int, payload: Payload, len: int): void
+ swapBuffers(): void
-instance
-packetReceiver
PacketUnpacker
- mtx: std::mutex
+ packetQueue: std::queue<ByteArray*>
- packetReceiver: PacketReceiver*
- consumePacket(): ByteArray*
+ PacketUnpacker(verID: int)
+ readPacket(): void
+ verifiyPacket(): void
PacketReceiver
- fd: int
- instance: PacketReceiver*
- permissions: int
- pipeDir: std::string
- verID: int
- closePipe(): void
+ getInstance(genID: int, pipeDir: std::string, pipePerm: int): PacketReceiver*
- openFifo(): int
- PacketReceiver()
- ~PacketReceiver()
+ receivePackets(packet: ByteArray*): void


FrameVerifier
- acceptedSenders: std::vector<ByteArray>*
- instance: FrameVerifier*
- calculateCRC(packet: ByteArray*, startIdx: int, endIdx: int): ByteArray*
- FrameVerifier()
+ getInstance(): FrameVerifier*
- updateAcceptedSenders(): void
+ verifiy(packet: ByteArray*, startIndex: int, endIndex: int): bool

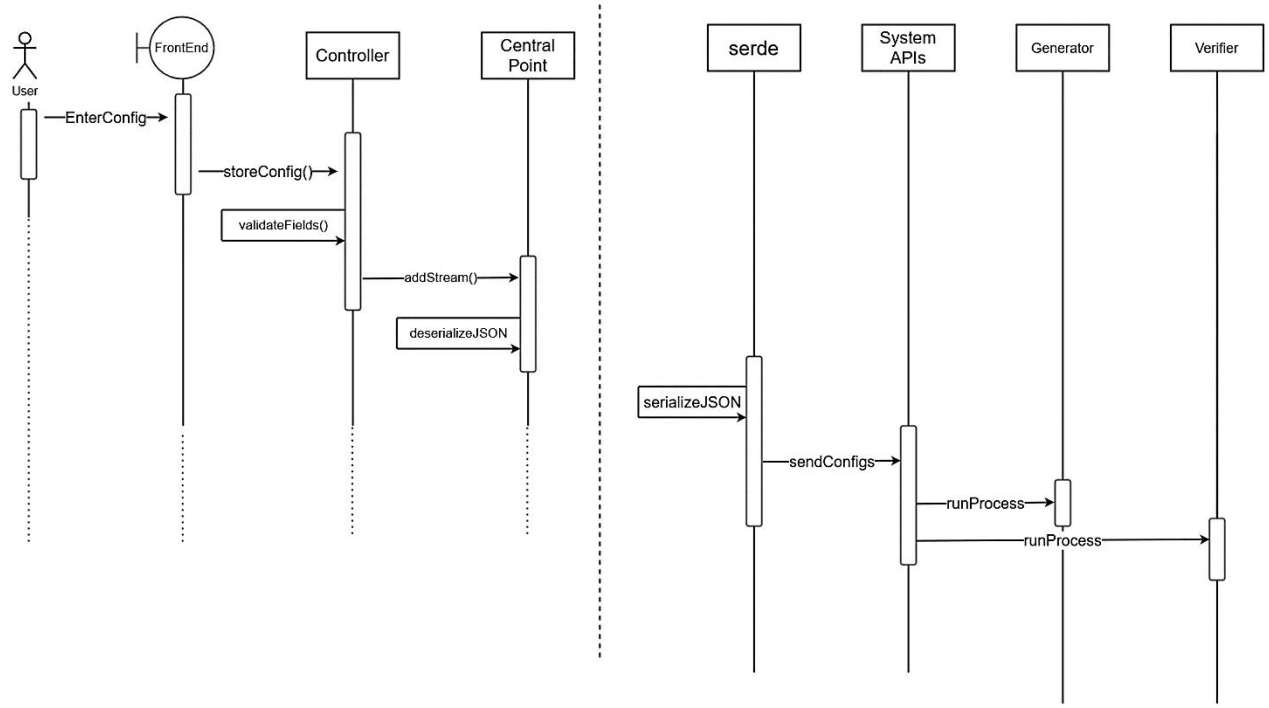

ConfigurationManager
- CONFIG_FOLDER: std::string
- configurations: std::map<int, Configuration*>
- currentStreamID: char*
+ addConfiguration(dir: char*): void
- convertStreamID(strmID: char*): int
- exec(command: char*): std::string
+ getConfiguration(): Configuration*
+ getCurrStreamID(): char*
+ initConfigurations(): void
+ setCurrStreamID(newStrmID: char*): void
+ splitString(s: std::string&, delim: char): std::vector<std::string>


PacketSender
- addr: sockaddr_ll
- buffer: unsigned char ([BUFFER_SIZE])
- fd: int*
- genNum: int
- ifIndex: int
- ifr: ifreq
- payloads: queue<Payload>*
- sock: int
+ checkPipes(): void
+ closePipes(): void
+ openPipes(): void
+ PacketSender(genNum: int)
+ ~PacketSender()
+ roundRobin(): void
+ sendToSwitch(payload: Payload&): bool
-instance
-sender
PacketCreator
+ mtx: std::mutex
+ productQueue: std::queue<ByteArray>
- sender: PacketSender*
+ createPacket(rcvInd: int): void
+ PacketCreator()
+ sendHead(): void
PacketSender
- fd: int
- genID: int
- instance: PacketSender*
- permissions: int
- pipeDir: std::string
+ getInstance(genID: int, pipeDir: std::string, pipePerm: int): PacketSender*
- openFifo(): int
- PacketSender()
+ transmitPackets(packet: ByteArray&): void {query}

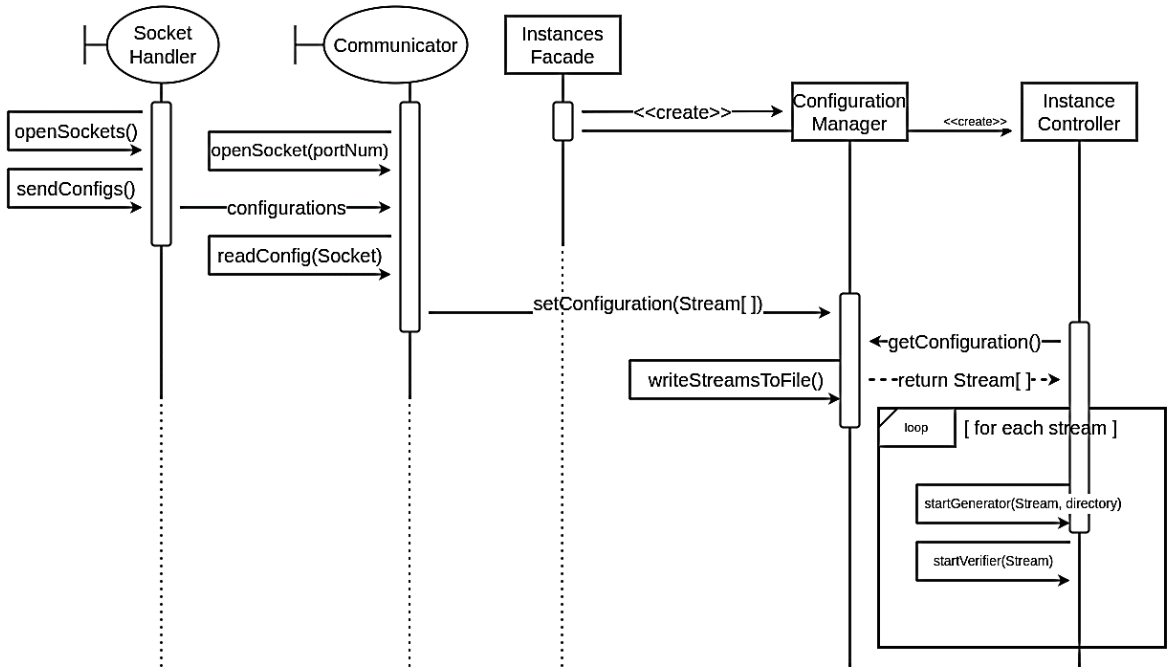

UsernameGetter
+ exec(): std::string
«Enumeration»
ErrorType
DATAGRAM
SEGMENT
PAYLOAD
SOURCE_MAC
DESTINATION_MAC
CRC
STREAM_ID
«struct»
segmentConstructorInfo
unsigned char*
«typedef»
Payload

4.4 Sequence Diagrams

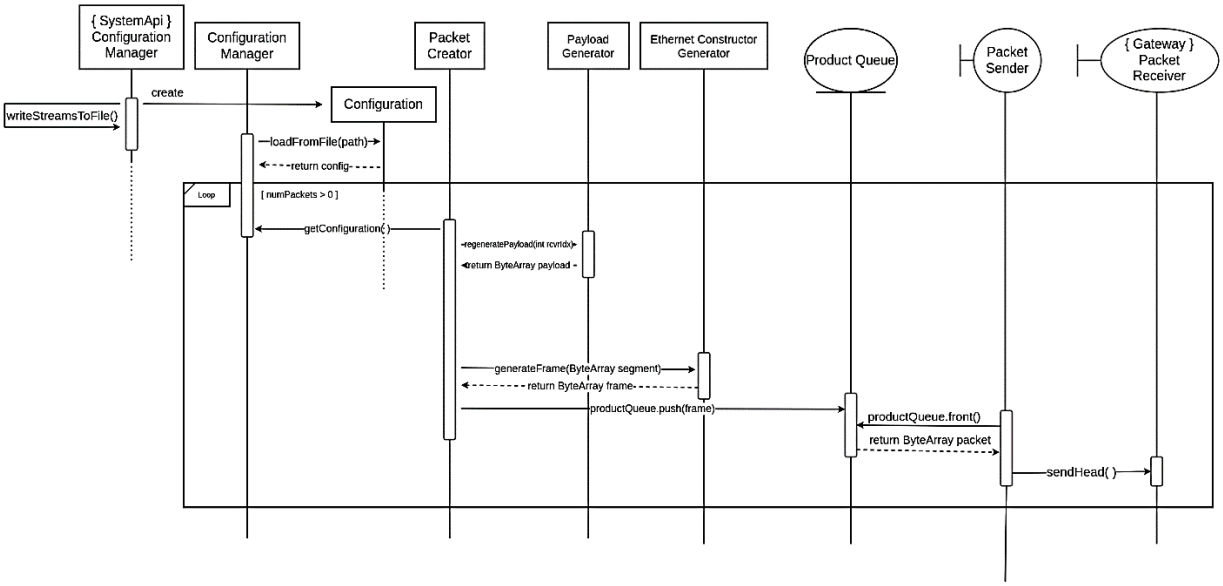
Configuration creation sequence:



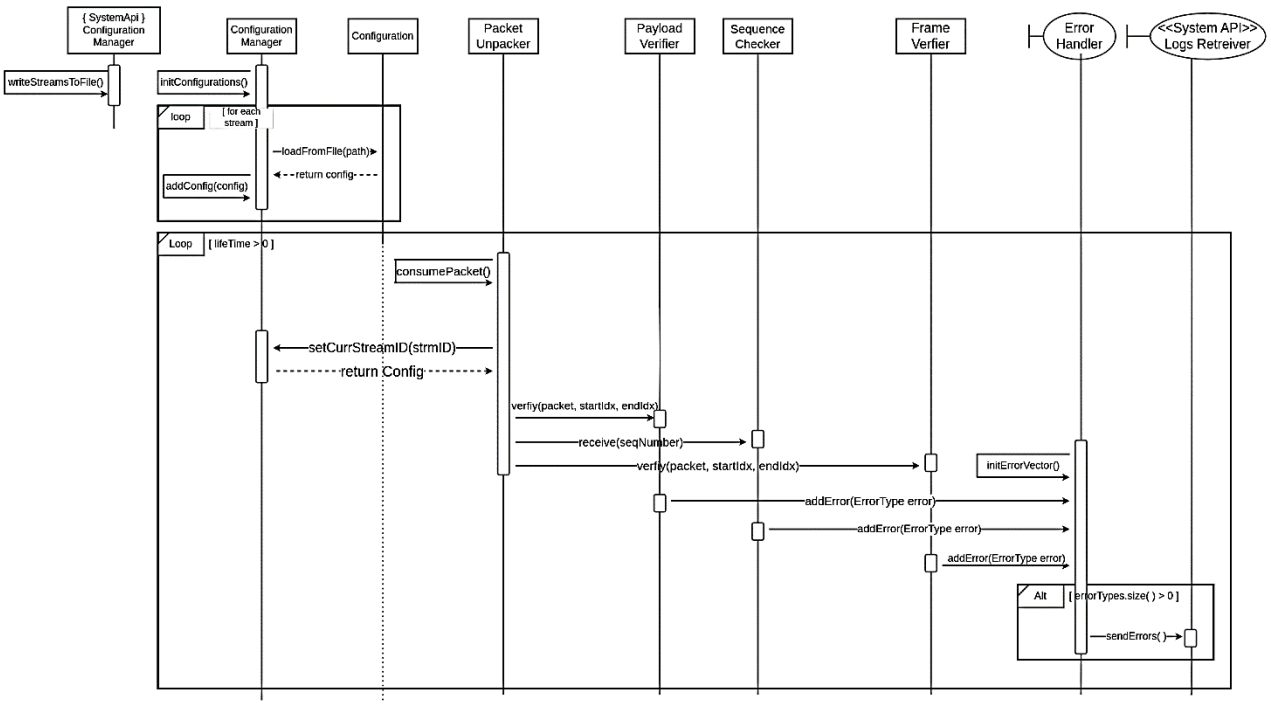
Instances creation sequence:



Generation of a packet sequence:



Verification of a packet sequence:



4.5 GUI Design

Introduction

The purpose of the System GUI Design documentation for the E-Jam project is to provide a concise and comprehensive guide for designers, developers, and stakeholders. It communicates design principles, sets standards, ensures consistency, enhances usability, facilitates collaboration, and supports maintenance and updates. By following this documentation, the goal is to create a visually appealing and user-friendly interface that promotes a positive user experience and aligns with the project's branding and goals.

E-Jam is an enterprise application designed for monitoring, testing, and debugging Network Switches. The project revolves around a user-friendly GUI that enables users to interact with the application. Users can add streams to send and receive data between devices, while also monitoring these streams through interactive charts provided for each one. The GUI also allows for the addition of devices and provides real-time status monitoring of these devices, including the streams running on them. E-Jam provides comprehensive functionality for efficient network management and troubleshooting within an enterprise environment.

GUI Design Principles and Best Practices

GUI Design Principles and Best Practices encompass a set of guidelines and principles that aim to create effective and user-friendly graphical user interfaces.

1. **Consistency**: Maintain a consistent visual style, layout, and interaction patterns across the E-Jam GUI to ensure a cohesive and familiar user experience.
2. **Simplicity**: Keep the interface clean and intuitive, minimizing complexity and unnecessary clutter. Streamline workflows and prioritize essential features to optimize usability.
3. **User-centred Design**: Prioritize the needs and preferences of network administrators and testers when designing the GUI. Conduct user research and gather feedback to create an interface that aligns with their requirements.
4. **Feedback and Responsiveness**: Provide real-time feedback and visual cues to users' actions, such as interactive charts and status indicators. Ensure a responsive interface that promptly reflects changes and updates.
5. **Accessibility**: Design the GUI to be accessible to users with varying abilities. Adhere to accessibility guidelines, including proper colour contrast, keyboard navigation support, and assistive technology compatibility.
6. **Visual Hierarchy**: Use visual cues, such as contrasting colours and font sizes, to establish a clear hierarchy of elements. Highlight important information, such as active streams or device statuses, to facilitate quick comprehension.
7. **Scalability**: Design the GUI to be scalable and responsive, adapting to different screen sizes and devices commonly used in enterprise environments.
8. **Error Handling**: Implement clear and user-friendly error messages and recovery mechanisms to assist users in troubleshooting and resolving issues effectively.

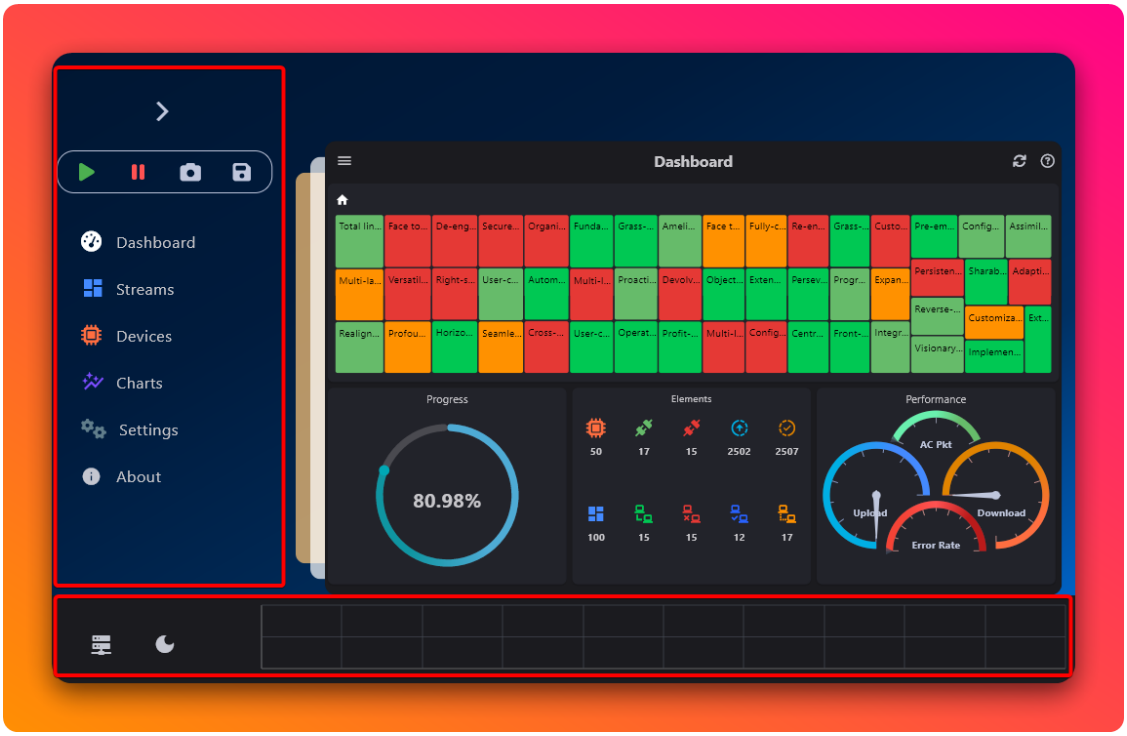
9. **Documentation**: Provide comprehensive documentation, including user guides and tooltips, to assist users in understanding the features and functionalities of E-Jam.
10. **Usability Testing and Iteration**: Conduct usability testing with network administrators and testers to gather feedback on the GUI design. Iterate on the design based on their input to enhance usability and address any identified issues.

By following these principles and best practices, the GUI design for the E-Jam project will aim to deliver an intuitive, efficient, and user-friendly experience for monitoring, testing, and debugging network switches.

GUI Components

Menu Bar

The menu bar provides easy navigation and access to important functionalities within the application.



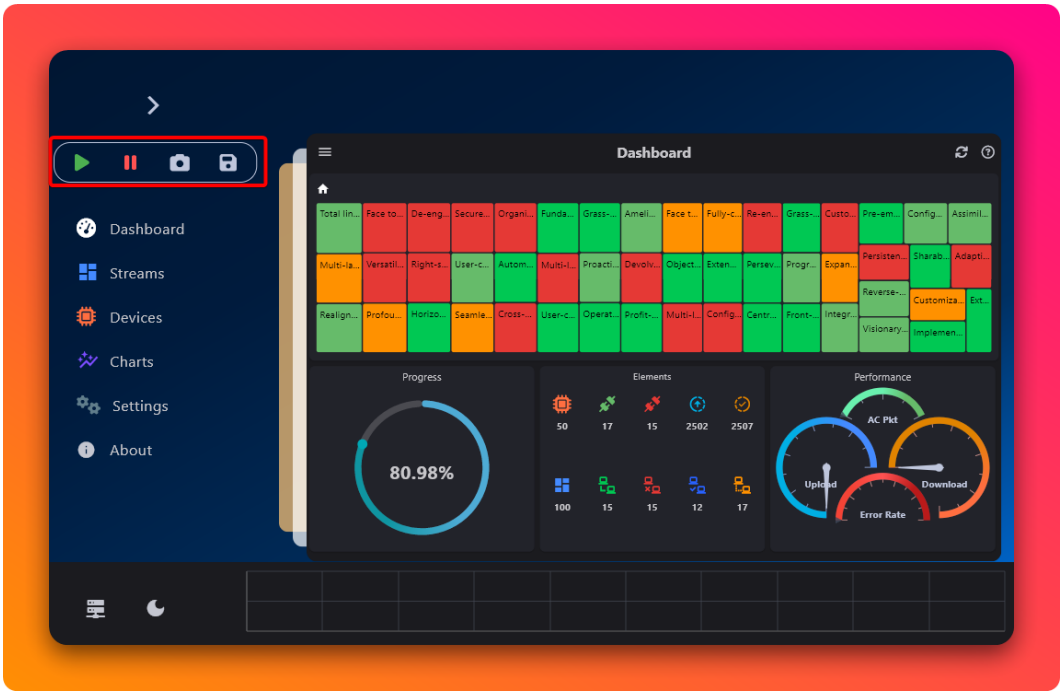
The menu bar is used as a general controller and navigator to the whole system, meaning that you can monitor the whole system using only the menu bar, and you can control all the streams and export data and statics using the menu bar.

The menu bar goes from top to bottom and starting from the left side to the right side of the window, with the control buttons at the top left and the system's total statics chart at the bottom right.

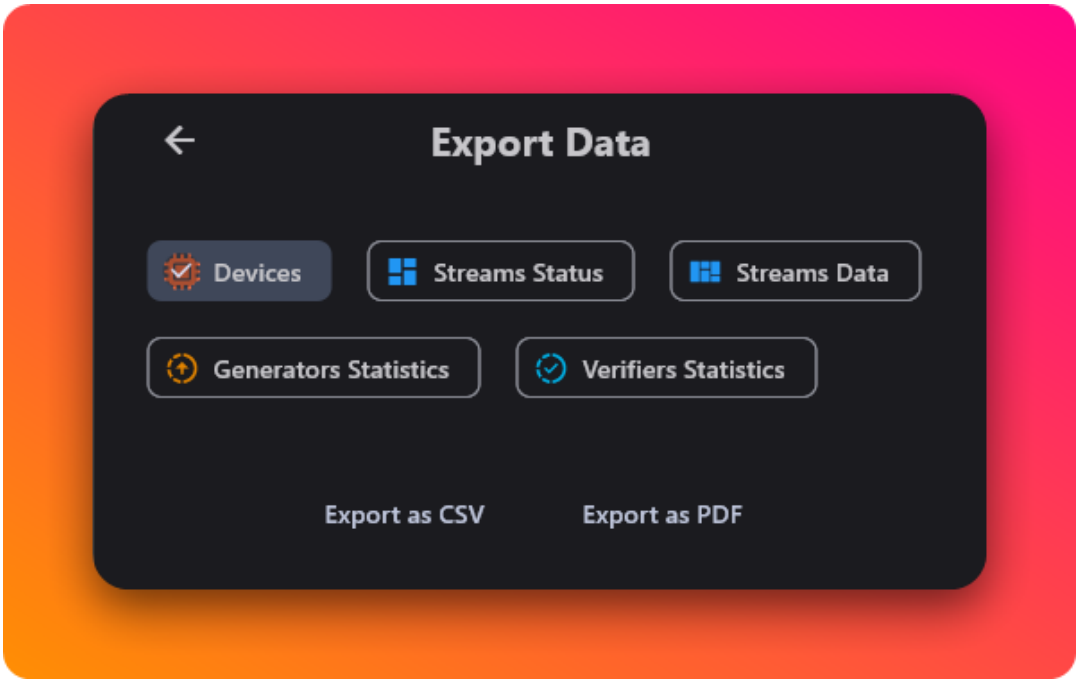
Toolbars

The GUI provides Component specific toolbars with icons or buttons for quick access to frequently used features and actions. Each component has its own toolbar for controlling it.

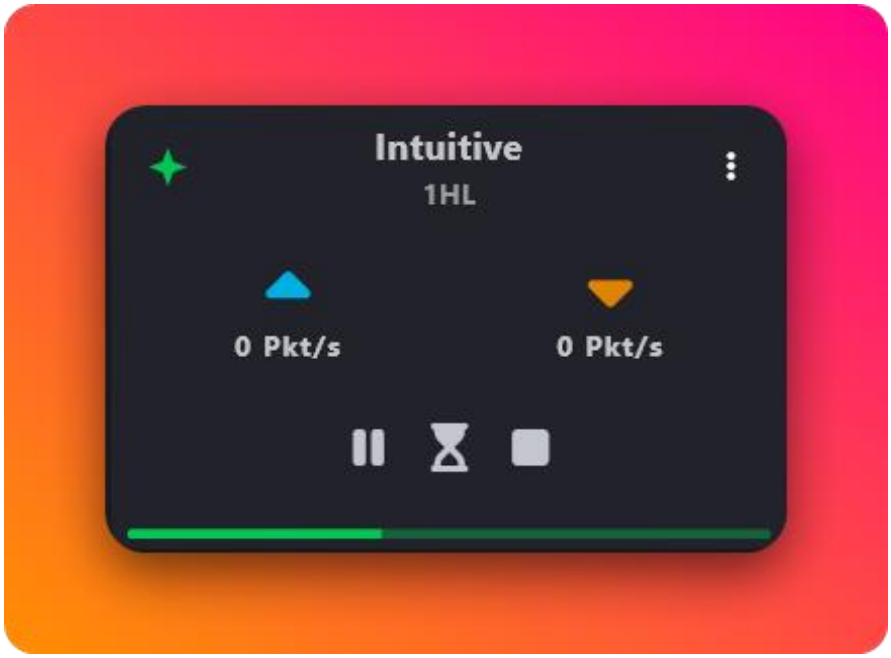
First is the main menu toolbar for controlling the whole system by either running or stopping all the streams and freezing the chart from consuming statics and exporting any kind of data from the system as a PDF or CSV.



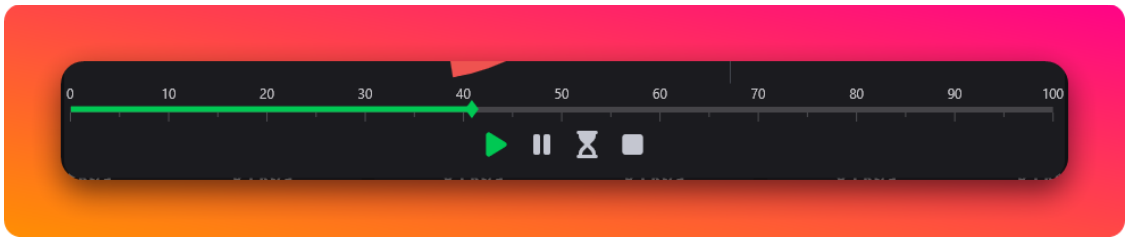
When exporting Component, you can choose any kind of component to export and will be outputted in your desired format.



The Other Toolbars are the stream Cards Mini toolbar:



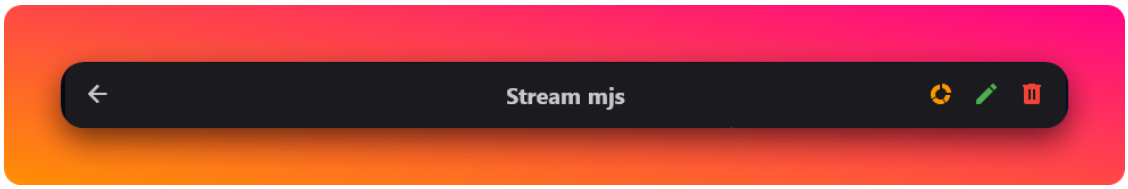
and the Stream's higher details toolbar:



Both have the same functionalities but in different levels of details.

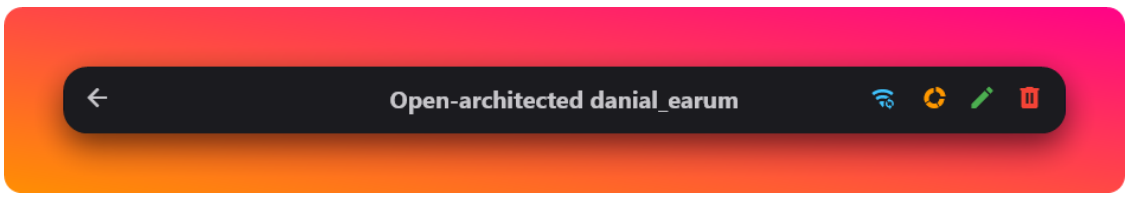
Other toolbars are the top toolbars.

For the stream:

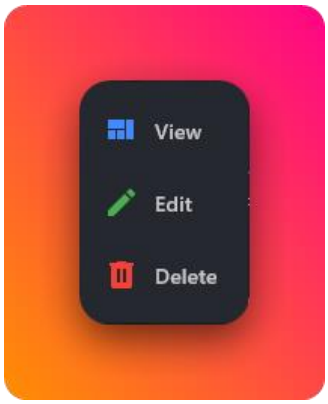


Used for pinning the stream charts to the charts menu and editing the details of the stream and deleting it. Which can also be accessed from the stream card.

For the Device:



The same buttons with an extra button made for pinging the specific device to check the status of it.

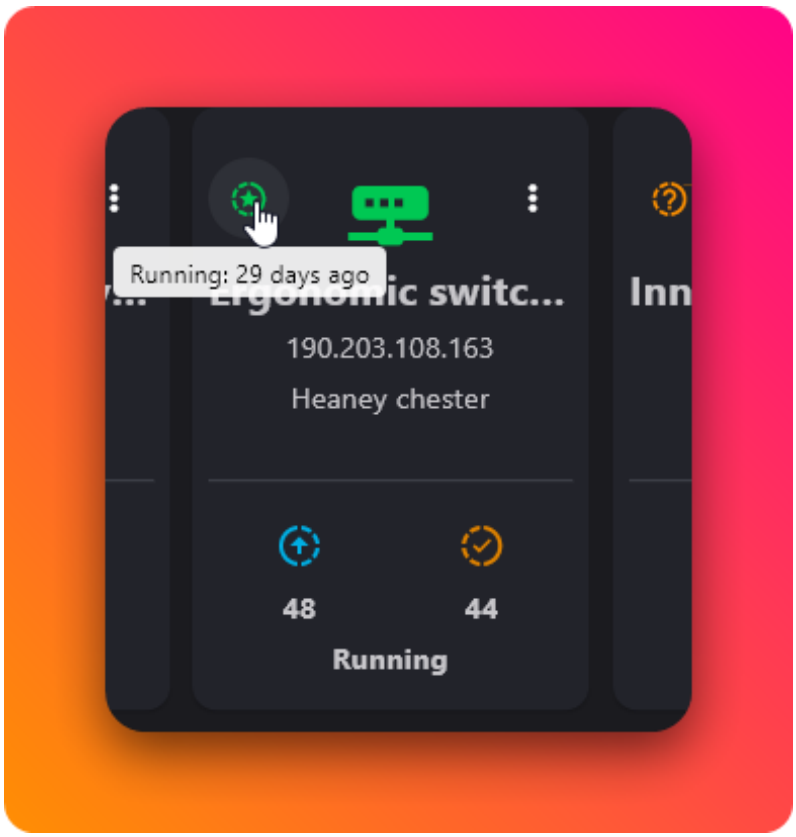


Buttons and Icons and Status Indicators

Each button provides details for it as a tooltip and how to use it, and a specific colour for each status of it.

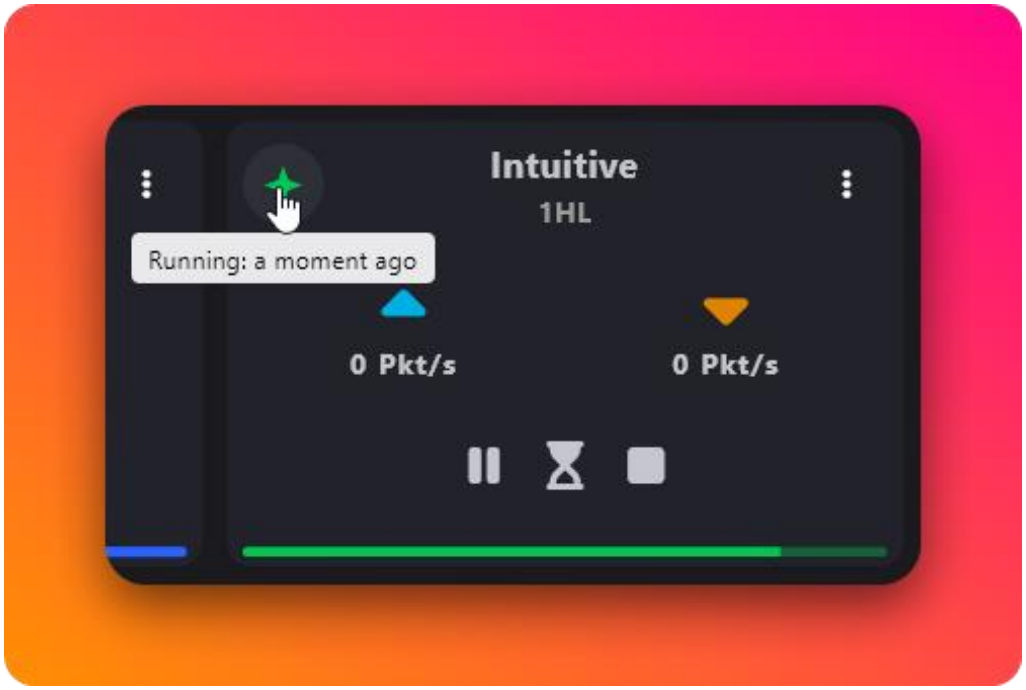
Examples include but not limited to:

The device card:



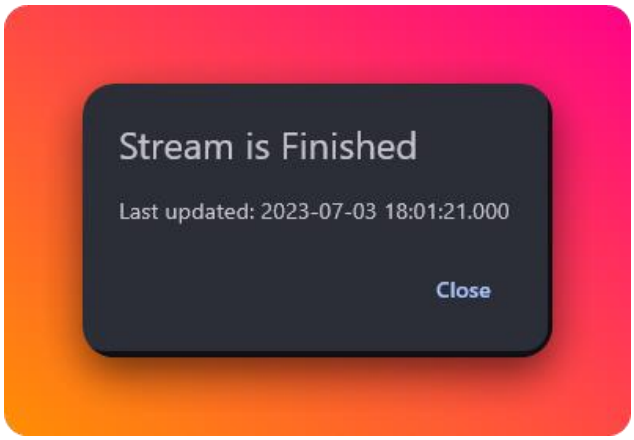
This means that the device has been running for 29 days with the colour green indicating that and the icon “star”.

The Same for the Stream:

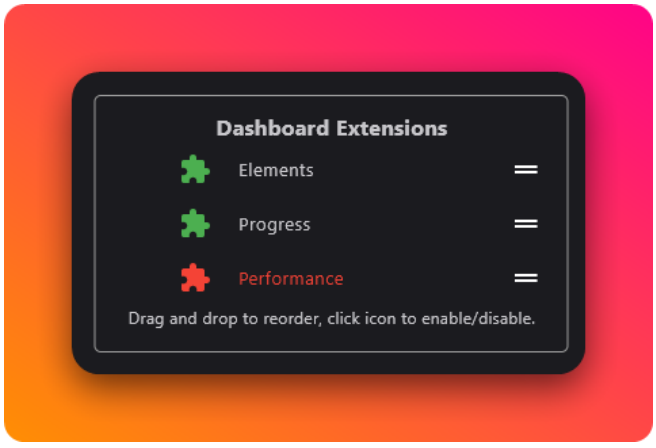


This means that the stream has started running a moment ago, and it almost finished.

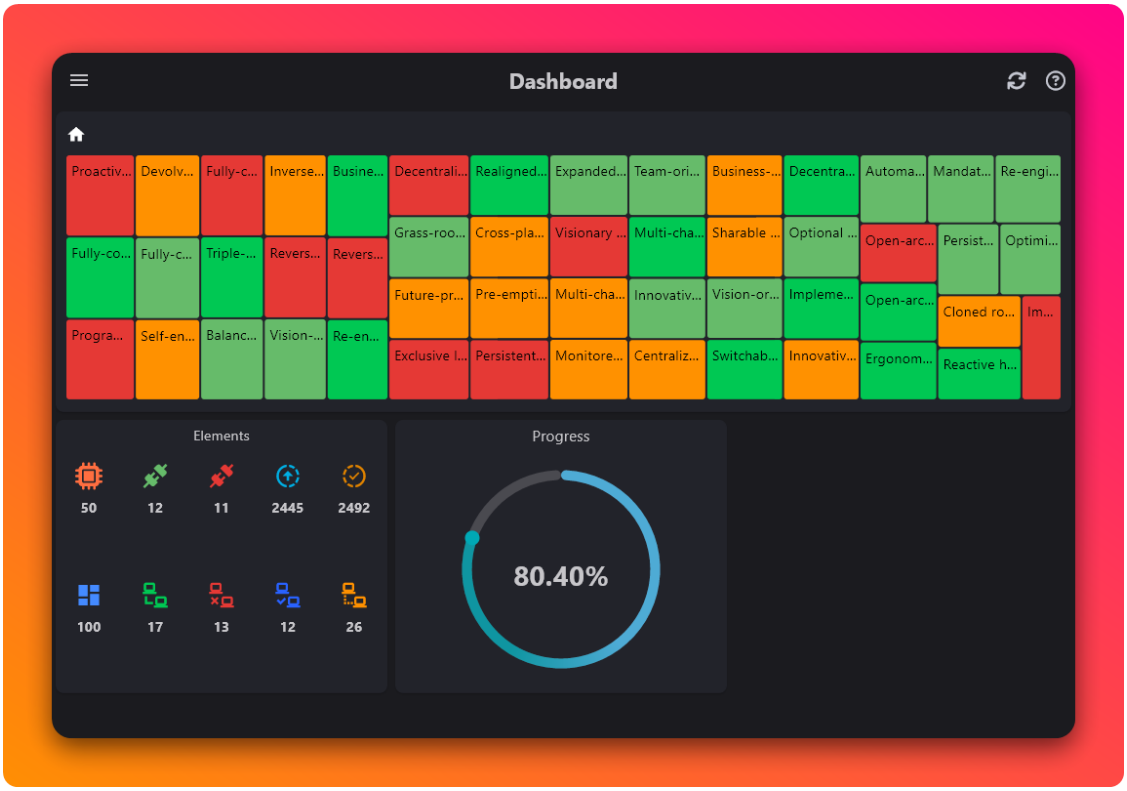
You can check more details about each icon just by simply hovering or clicking on it to show more details.



There are also drag and drop type buttons for reordering and enabling/disabling the dashboard extensions, which you can find in the setting tab.



Here is what the Dashboard look like after.

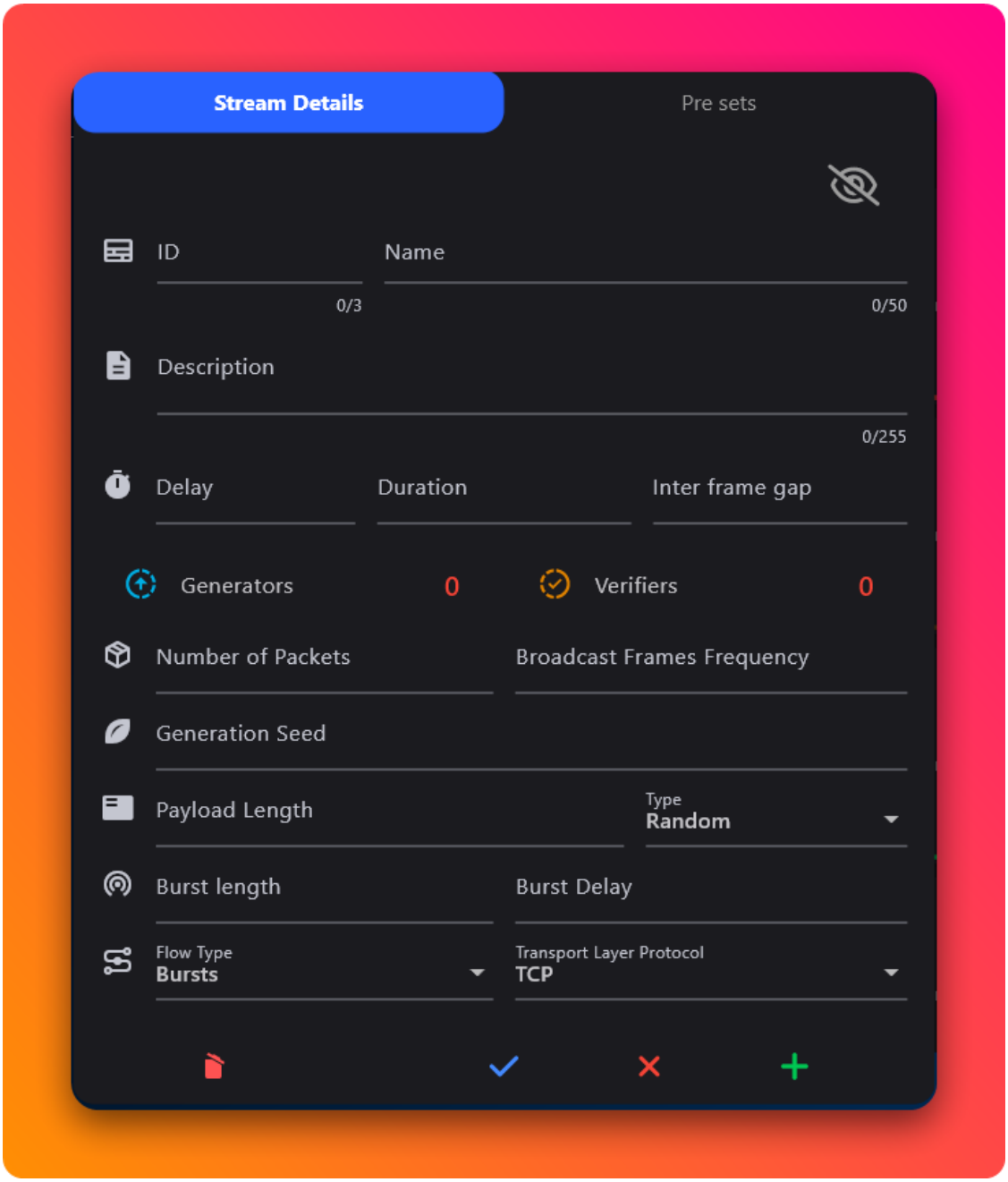


There are more buttons with specific tasks and signifiers for each one which you can easily understand by its location or timing and the tooltip it has or titles for it.

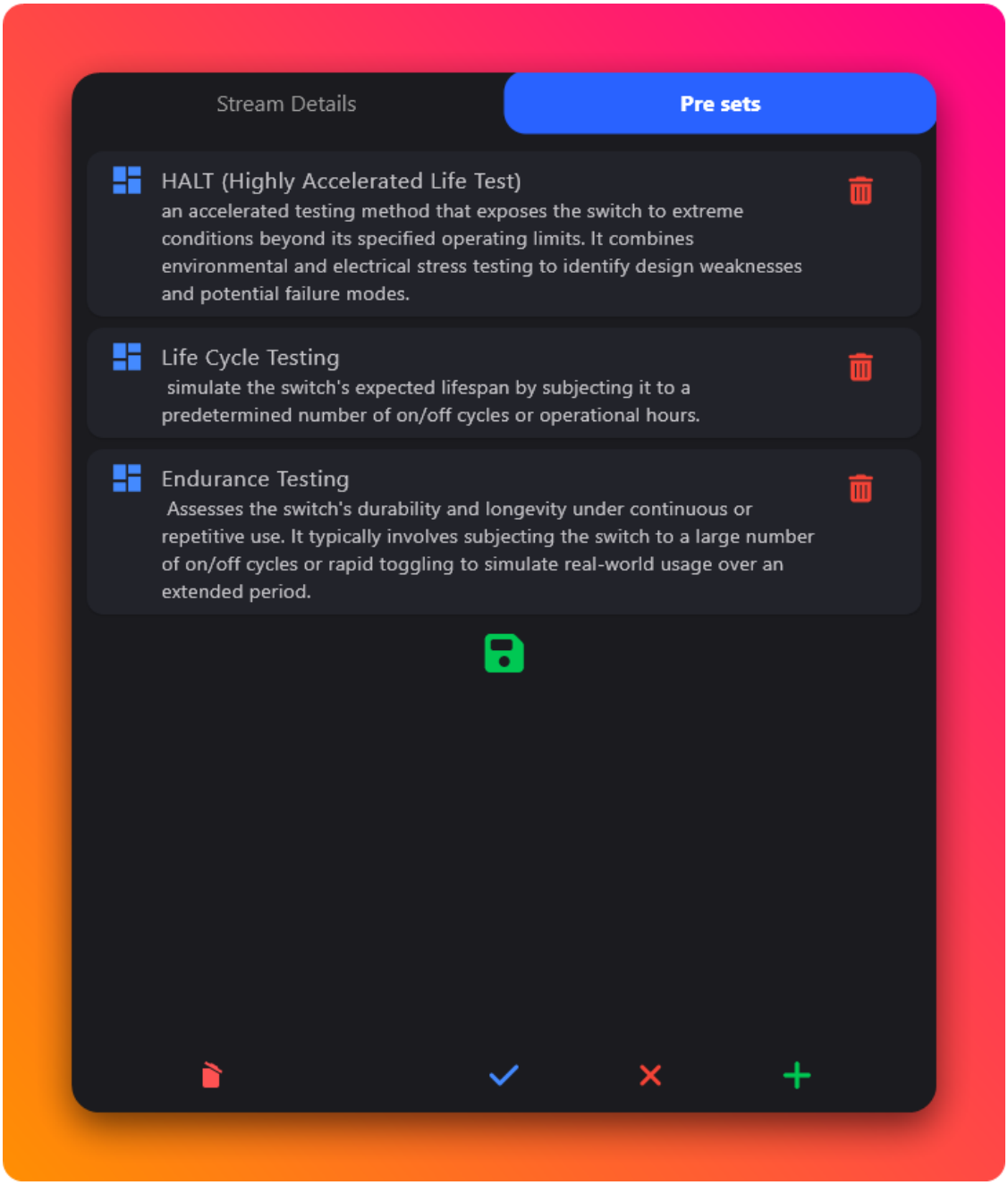
Forms and Input Fields

For the input fields, not only was it made to be simple and easy to understand by having signifiers and details for each section of the input fields, but it can also be saved for later usage to easily fill all fields with specified values provided.

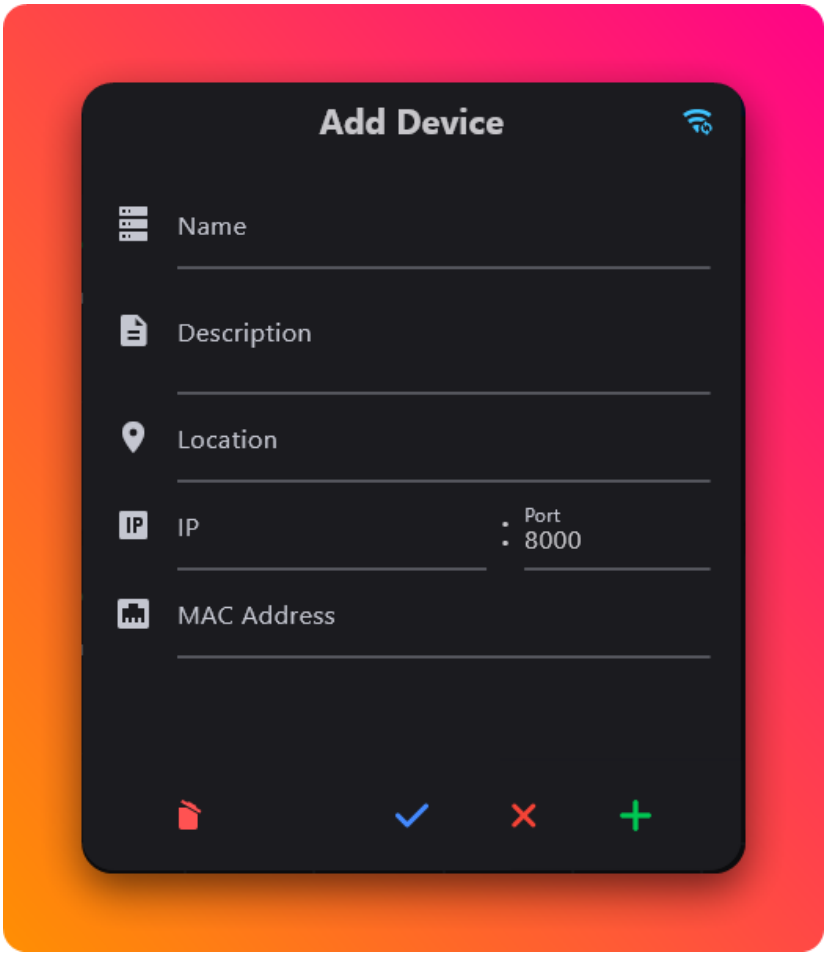
The Stream Details are as follows:



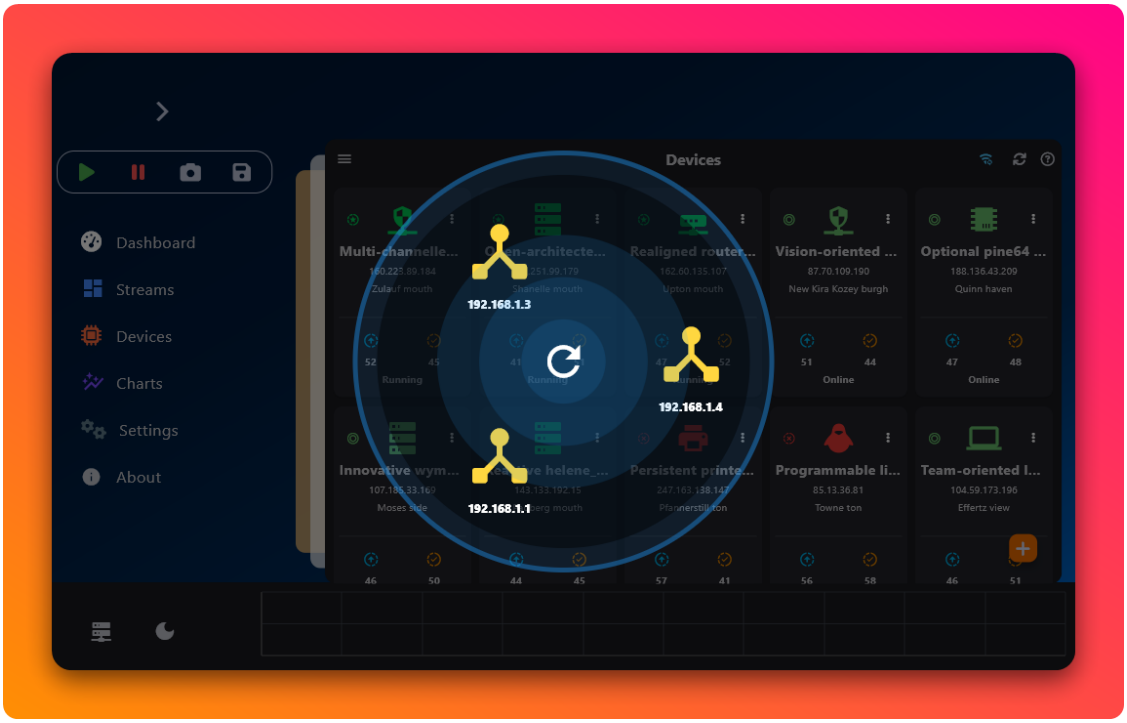
and it can be easily filled from previously save presets in the preset tab:



For the Device, it’s simple, just as follows:

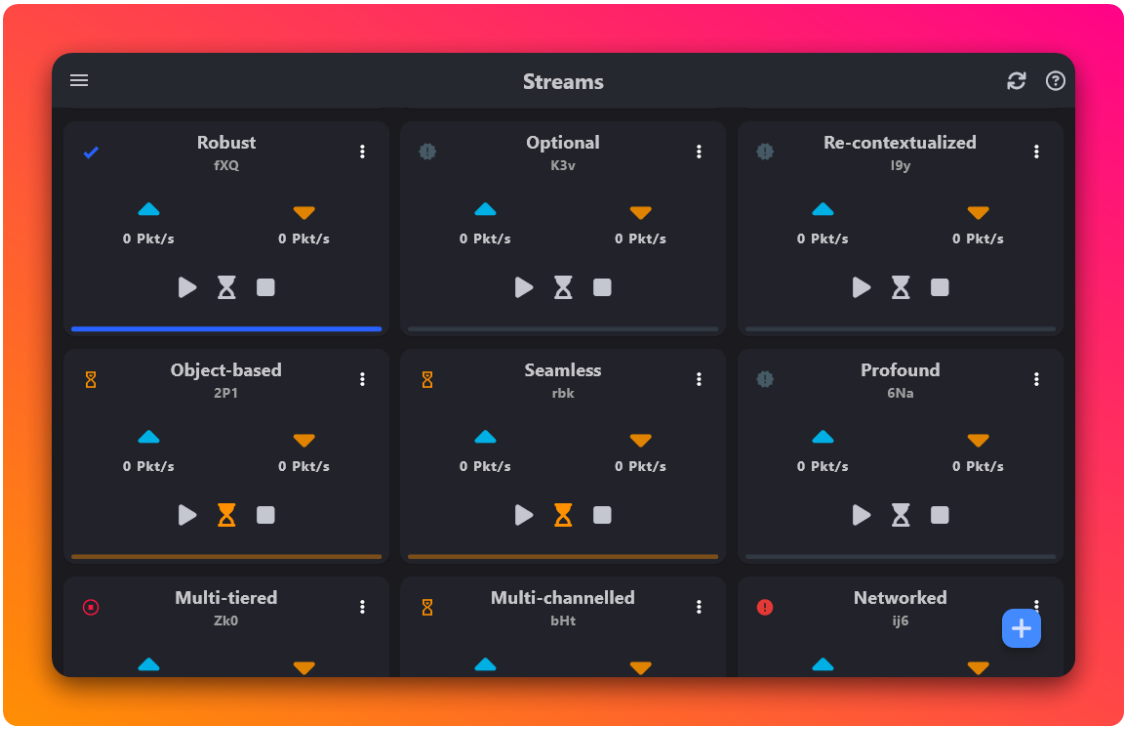


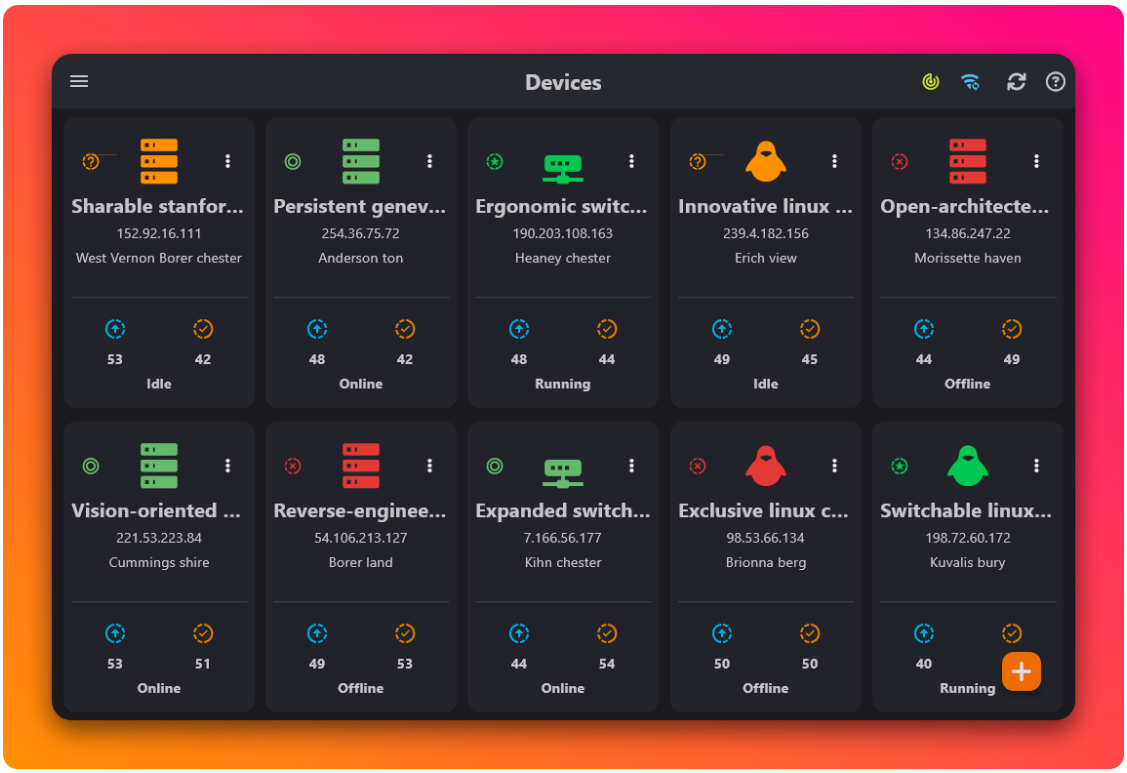
And you can also easily add a device from the device radar tab at the top part of the devices tab.



Lists and Tables

The Three List tabs are the Devices tab, the streams tab, and the chart tabs for pinned charts all were designed with different means and utilities to fit the specified component and be more descriptive for it.



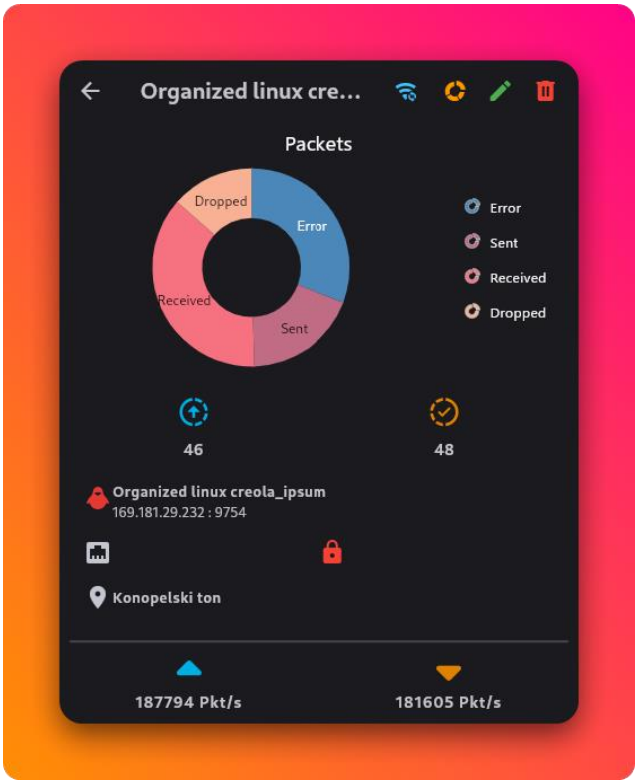


Charts and Graphs

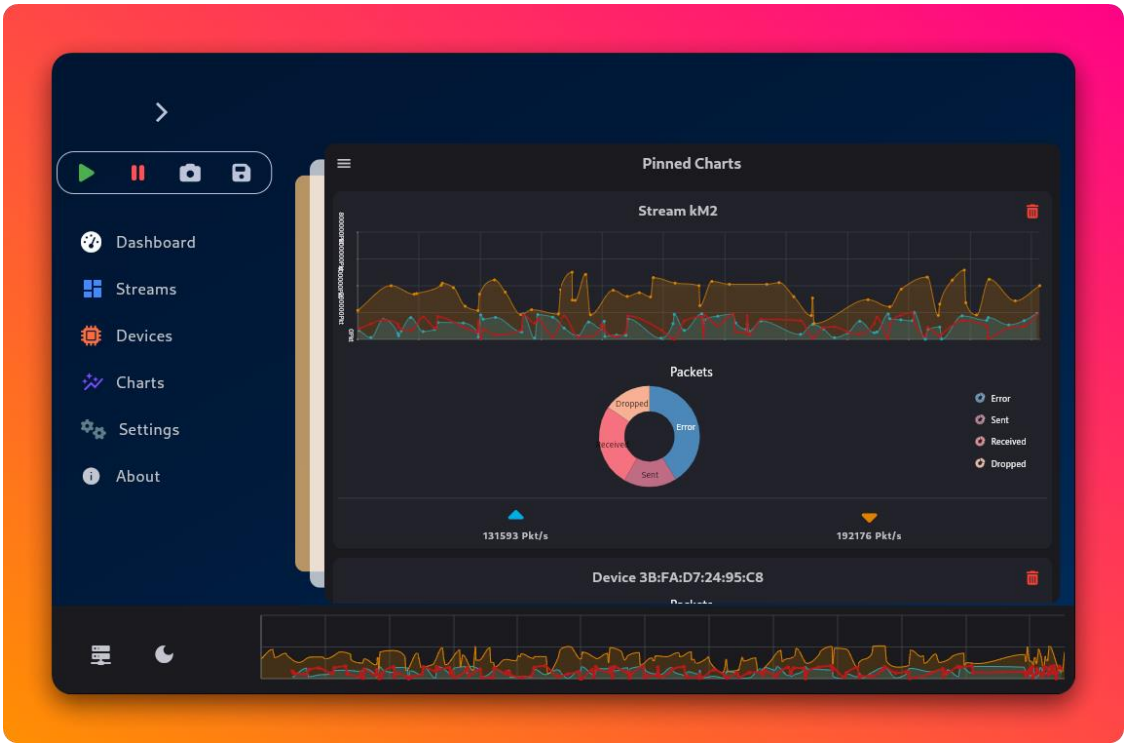
Include interactive charts and graphs to visually represent network statistics, performance metrics, or stream data. Charts are shown for each component on the system, including the total statics on the systems.

For the streams:

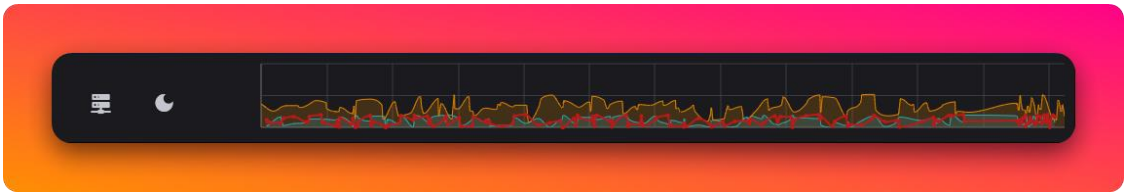
For the Devices:



For the Charts tab:



And as previously mentioned in the menu bar, the total system statics chart:



Navigation Components

For the navigation Components, it includes breadcrumb trails, navigation bars, or hierarchical menus to help users understand their location within the application and navigate efficiently.

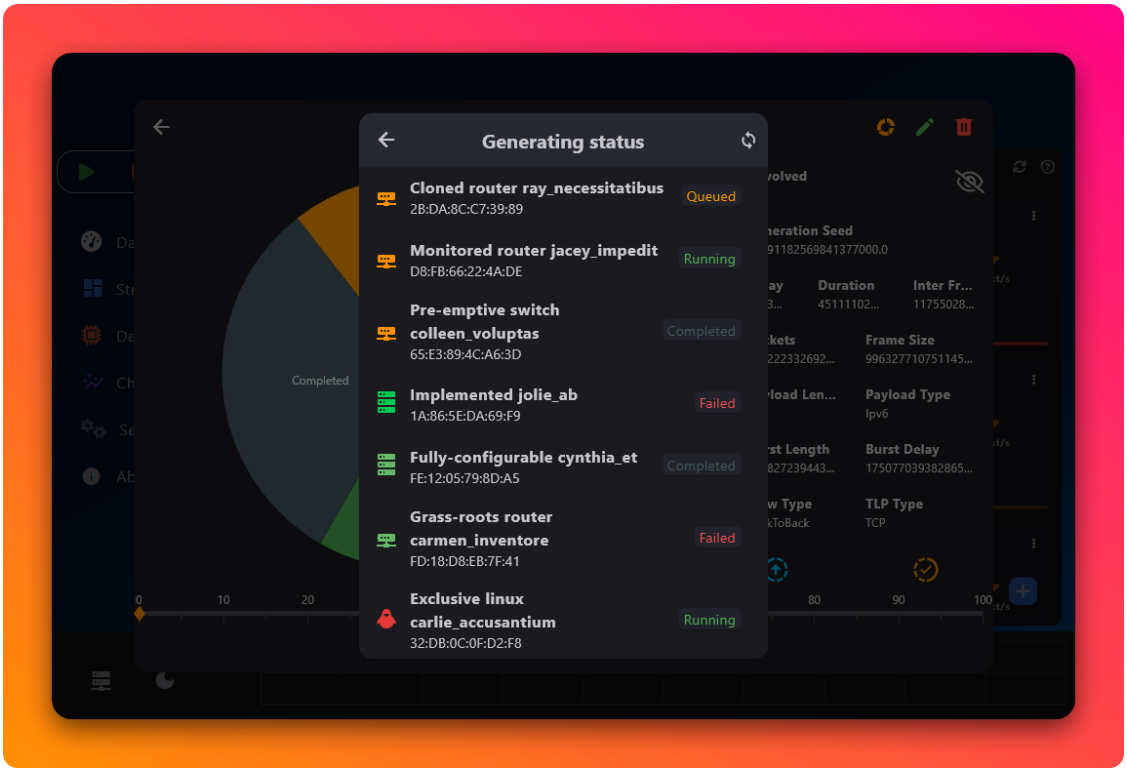
Devices tree map

For example, the devices' tree map in the dashboard tab, which shows at the first level all the devices in the system with the status of each one and at the second level it has all data related to the streams the specified device is running including the status of each process of that device.

Home Level:

Second level when clicking on a device:

Another one is at the stream details of each one to check the status of each process in that specific stream:



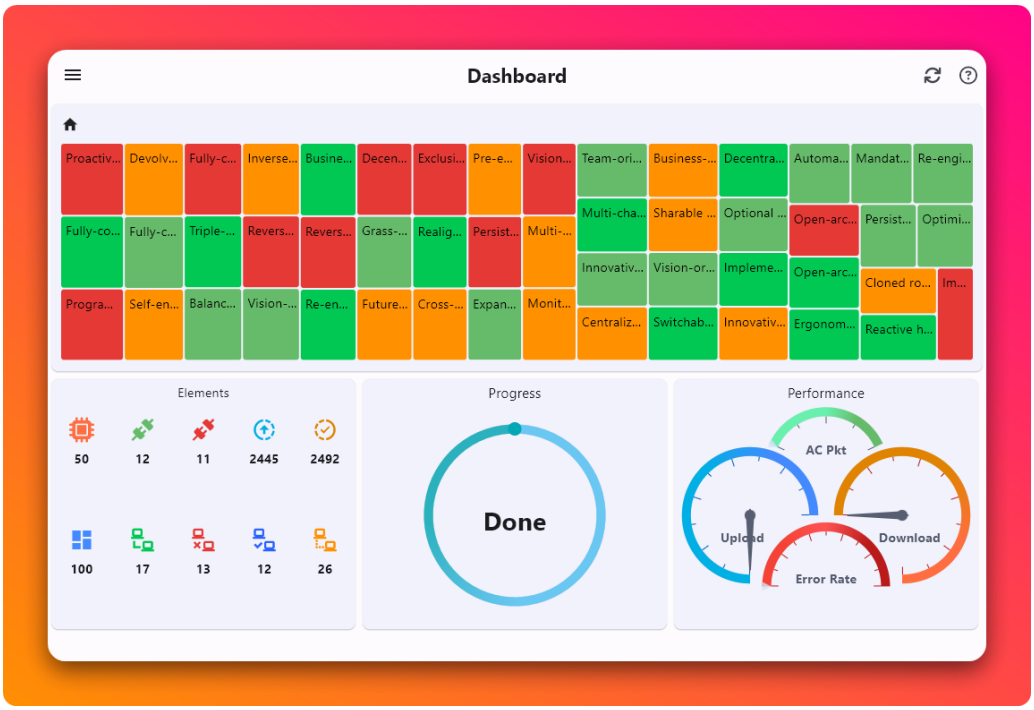
These GUI components play a crucial role in creating an effective and user-friendly interface for the E-Jam project, enabling users to interact with the application's features, manage network switches, and monitor streams and device statuses effectively.

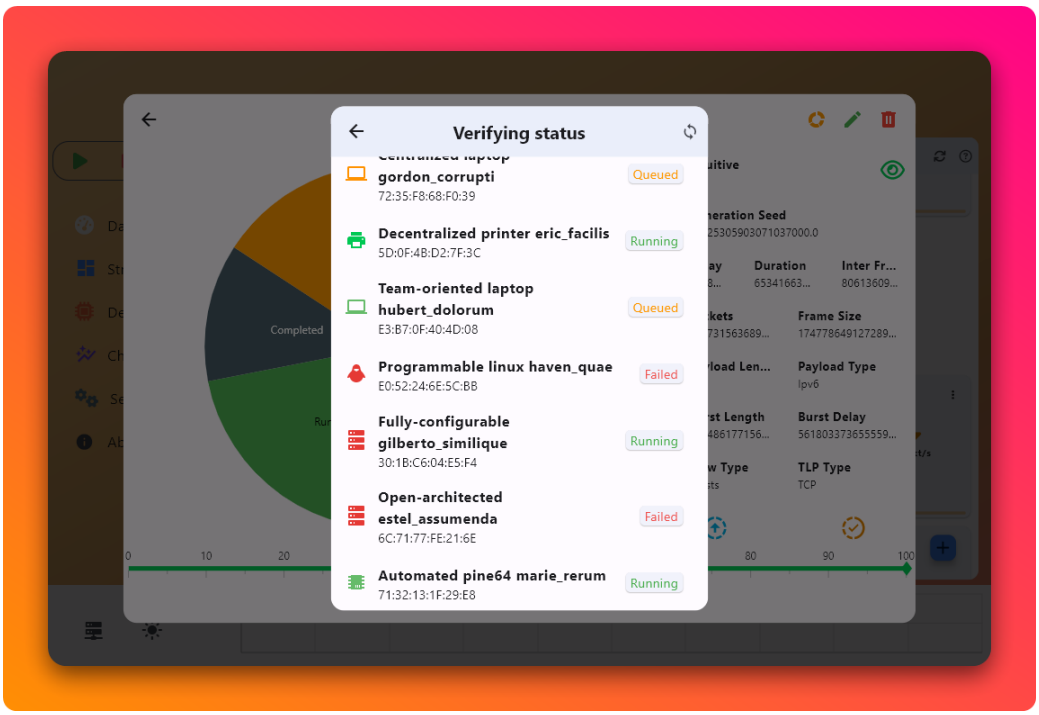
Visual Design Guidelines

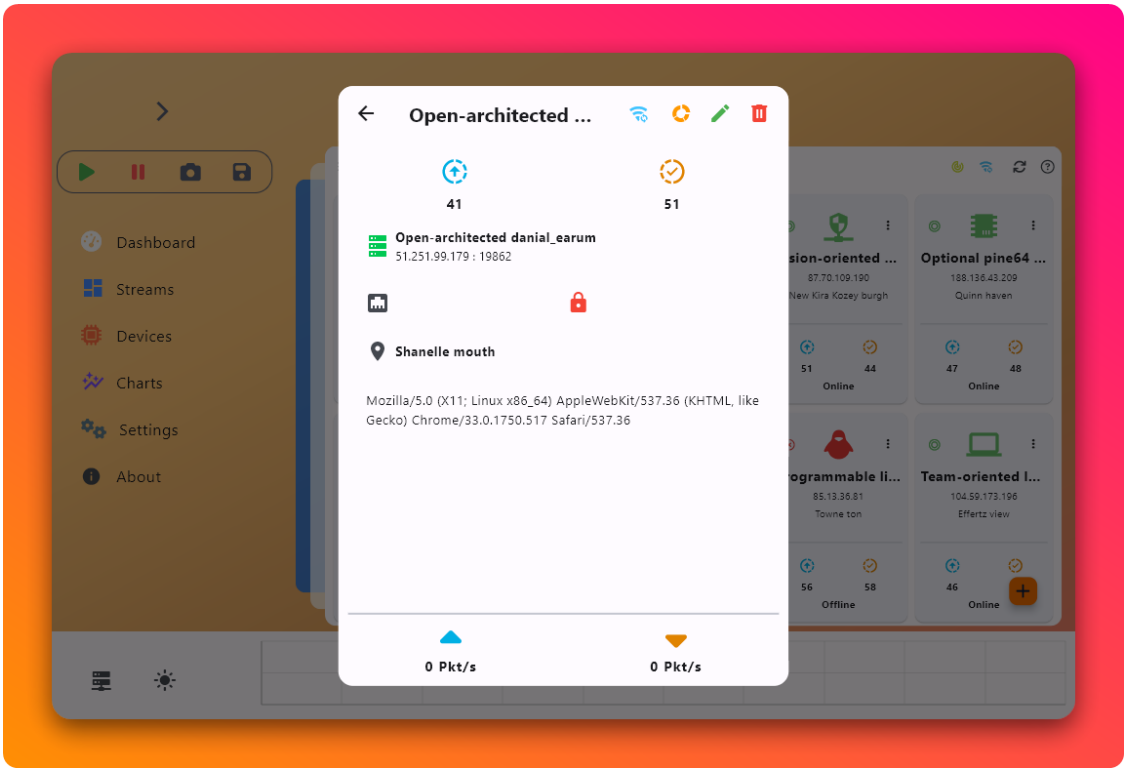
Colour Scheme

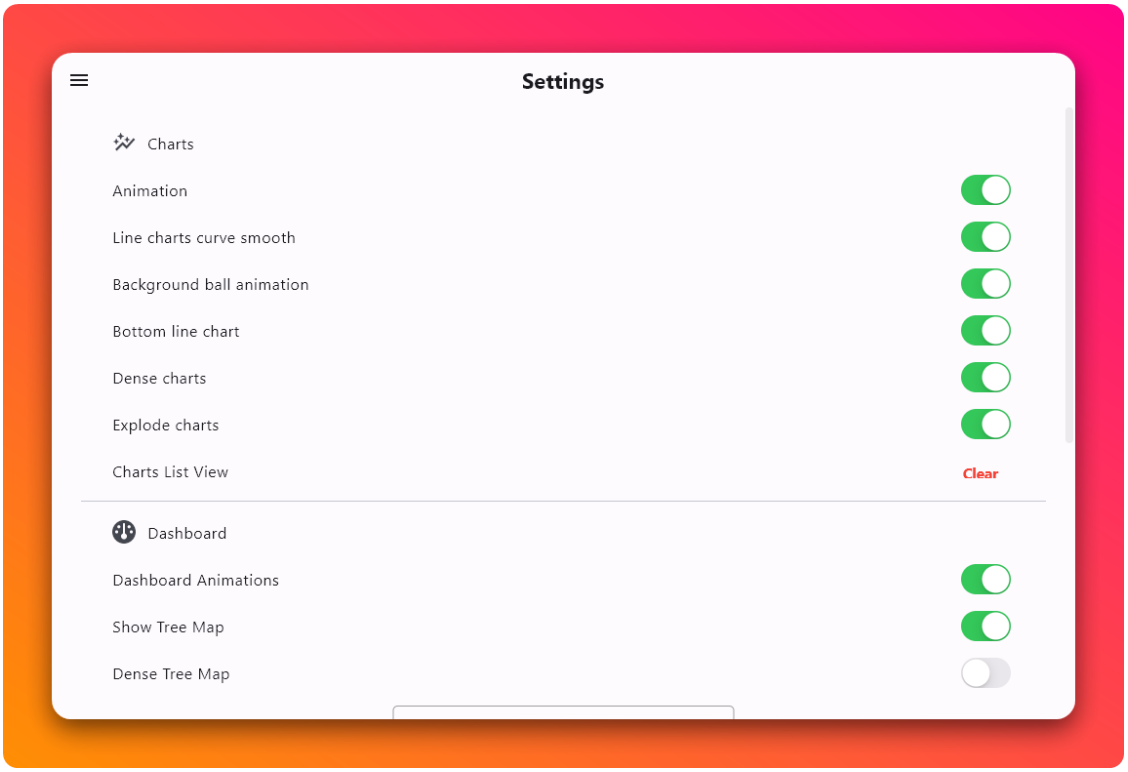
A visually pleasing colour palette that aligns with the E-Jam branding and enhances readability. Using colours strategically to highlight important elements and create visual harmony.

The system can be in either dark or light mode according to the user's liking. The following are examples of the light theme of the system.






Open-architected ...
41
51
Open-architected danial_earum
51.251.99.179 : 19862
Shanelle mouth
Mozilla/5.0 (X11; Linux x86_64) AppleWebKit/537.36 (KHTML, like Gecko) Chrome/33.0.1750.517 Safari/537.36
0 Pkt/s
0 Pkt/s
Dashboard
Streams
Devices
Charts
Settings
About
Optional pine64 ...
188.136.43.209
Quinn haven
Online
Team-oriented l...
104.59.173.196
Effertz view
Online
Offline
Online


Settings
Charts
Animation
Line charts curve smooth
Background ball animation
Bottom line chart
Dense charts
Explode charts
Charts List View
Clear
Dashboard
Dashboard Animations
Show Tree Map
Dense Tree Map

Typography

Selecting the appropriate fonts and font sizes for different UI elements, ensuring readability and consistency. Paying attention to font styles, spacing, and line heights to create a visually appealing and cohesive typographic hierarchy.

Visual Style

The visual style of the E-Jam GUI design embraces a modern aesthetic, incorporating contemporary techniques to create a sleek and visually engaging interface. The design showcases clean lines, minimalist elements, and a harmonious colour palette that aligns with modern design trends. By leveraging modern techniques, such as subtle animations, smooth transitions, and a focus on visual hierarchy, the GUI design of E-Jam delivers a polished and up-to-date user experience that reflects the project's commitment to contemporary design principles.

Iconography

Icons has been used effectively to enhance the visual representation of actions, features, or system status. Ensure that icons are recognizable, clear, and consistent with the overall visual style.

Imagery and Graphics

Appropriate imagery and graphics that are relevant to the E-Jam project, such as network-related visuals or representations of statics and states of components. Ensuring that graphics are of high quality, optimized for different screen resolutions, and contribute to the overall aesthetic appeal.

Visual Feedback

Using visual cues, such as animations, hero, hover effects, or subtle changes in colour, to provide feedback to user interactions. This helps users understand the state of the interface and creates a responsive and engaging experience.

Branding

Maintain consistency with the E-Jam brand identity throughout the GUI, including the use of logos, colours, and typography. Ensure that the GUI design reflects the overall brand image and values.

By adhering to these Visual Design Guidelines, A visually appealing and cohesive GUI design for the E-Jam project that aligns with the project's branding, enhances usability, and provides an engaging user experience has been created.

Usability Testing and Iteration

To ensure the top quality of the system, the E-Jam project has implemented a comprehensive approach to usability testing and iteration. Multiple types of testing have been conducted throughout the design and development process.

User feedback has been provided by our sponsor and other team members for multiple components and colour schemes to ensure optimal view and looks.

Conclusion

The E-Jam GUI design embodies a modern visual style, incorporating contemporary techniques to create a sleek and engaging interface. The use of clean lines, minimalist elements, and a harmonious colour palette contributes to a visually pleasing and cohesive design. The GUI components, such as menu bars, buttons, charts, and navigation elements, have been thoughtfully designed to facilitate seamless interaction and efficient workflow. The emphasis on accessibility ensures that the GUI is inclusive and accessible to users with different abilities. Overall, the E-Jam system GUI design strives to provide a user-friendly and enjoyable experience, enabling IT professionals to monitor, test, and debug systems.

Chapter 5: Implementation and Testing

5.1 Mechanism of statistics generation and transmission

Generator and verifier

The generator and verifier components are the source of the statistics data and are considered the observable part of the system which acts as an indicator of the system behaviour and the result of the tests executed by the admin client.
There is a specific schema for the data produced by the two components.

The generator is concerned about (Number of packets produced, Number of packets sent with errors).

The verifier is concerned about (Number of packets received correctly, Number of erroneous packets, Number of packets not received, Number of packets received out of order).

Along each generator or verifier instance there exists a singleton entity called stats Manager which is responsible for keeping track of the statistics data generated by this specific instance. During the processing of a packet, the packet is classified to be a member of one of the types of packets indicated by the schema (such as valid packet, out of order packet, ... etc), and accordingly the counter of that type is increased showing that the new packet of that type is processed. The counters in the stats Manager are reset after each time the statistics are exported to start a new observing interval, which is one second (1000 Ms) by default, but it can be changed without interfering with other components.
Each generator or verifier instance has a corresponding pipe to write the collected statistics on, which is read later by the Kafka submodule inside the system API. The pipes are named pipes (FIFO) that are stored in a specific directory on the machine running the components.

System API

The system API has an integral role in this process. It is responsible for:

- Locating the statistics data pipes

- Opening the pipes
  preventing indefinite blocking of the statistics worker thread in generators and verifiers.
- Consuming data
  There are two workers in the system API (corresponding to the types of managed instances i.e., generators and verifiers). Each worker opens the pipes of the assigned type and consumes the data and writes what it collected to the main thread of the stats Manager in the system API.
- Transmit the data
  The aggregated data of all generators and all verifiers running on a specific machine is reconfigured and transformed into a data structure called Topic (with the help of Avro) which is then used by the Kafka broker submodule to transmit statistics to the front-end of the application (namely the centre point in the admin client).

5.2 Generation and verification of Packets

Acquisition of stream configuration

Before processing packets, the working module (i.e., generator / verifier) must be aware of the configuration of the stream which acts as the template that will be used to process the packets. The configuration contains information about the fields of the packet, its length, and the instructions to process it, etc… By knowing the configuration, the generators of a certain stream will generate packets with contents and formatting understandable by the verifiers of the same stream. This way, the verifiers will be able to detect errors caused by external factors when the received packets are different from what the verifier has expected.
The configuration of each working module is received in the system API of each node from the centre point. The system API provides the generator/verifier instance with the path to the configuration file on the node. This ensures that each instance can act independently with a different configuration to add more flexibility and functionality to the streams.

Generation process

Each generator instance is responsible for generating the entire configuration of a stream, meaning that there can only be one generator instance per stream per node.

The generation process starts right after the acquisition of the stream configuration when the system API runs the instance. The generation behaviour is selected according to the values stated in the configuration then the packets are produced in that way. The main actor in this stage is the Packet Creator, which needs the configuration and the mac address of the testing interface in order to do its function. Its main driver function createPacket() is used to pace the packet creation according to the intended sending behaviour.

There are two ways to produce packets which are bursty and back-to-back (B2B) production. The bursty method is when packets are produced in bursts separated by a short delay. The B2B method is continuously sending packets without having to wait for a delay.

The Payload Generator is called to generate a payload with a certain payload type and length as instructed in the stream configuration. Then, the sequence number is embedded into the payload to allow tracking out of order packets.

The payload is then encapsulated inside an Ethernet frame after generating the headers for that frame (headers such as source address, destination address, protocol, CRC, ...etc).

Now that the packet is constructed, it is stored in a shared queue managed by a mutex. That queue is used by another worker thread that consumes the packets from it and sends them to the next stage of the pipeline which is the Gateway.

Forwarding process

The gateway module is responsible for forwarding the packets from the generator to the switch and from the switch to the correct verifier instances. It does this by using the unique IDs assigned to the generator instances and verifier instances by the system API.

The system API assigns IDs to the generator and verifier instances before launching them. The ID assigned to the generator is the order of the generator in the list of senders in the stream configuration (after sorting lexicographically); this is done in order to make verification easier and faster on the verifier side.

The ID assigned to the verifier is the order of the stream configuration file in the config folder in /etc/EJam, this is done in order to make the forwarding of the packets from the gateway to the correct verifier instance easier and faster.

Verification process

A single verifier instance is responsible for verifying any packets received from all generators in the current stream, so a single verifier instance is launched for each stream the node is involved in as a verifier.

As with the generation process, this process also starts right after the acquisition of stream configuration. The Verification process was designed to mirror the generation process by having the same steps in reverse order.

A worker thread reads the packets as they are received from the gateway and then stores them in a queue for further processing by the verification components. The Packet Unpacker is the verifier's counterpart of the generator's Packet Creator Its main function is to unpack the headers of the frame and verify their integrity and validity by using the configuration acquired earlier. This verification process involves parsing the packet and is executed the same way the generator acts by comparing the expected values of the headers and the payload with their actual values after passing the network switch (Device under test).

During the process of generation and verification, statistics are collected and transmitted using a worker thread in each component.

5.3 Random Packet Generation and Verification

This section describes how random packets are generated and verified. This is a challenge in this system because we must produce multiple parallel streams of random data (which are random relative to each other). This is done by using an F2-linear pseudo random number generator (RNG). We use this type of generator because it is possible to jump ahead in the RNG state space efficiently with this type of RNG, effectively "partitioning" the RNG state space and allowing for parallel random streams.

In our implementation, we use the xoshiro512++ PRNG as it provides a large state space which allows us to have large partitions and because there are available online implementations of it which already provide two jump ahead functions with different lengths which is exactly what we need. We use the two functions "long jump" and "jump". We use "long jump" in order to partition the RNG state space amongst the different generators in a stream. Likewise, we use "jump" in order to partition that generator partition amongst each packet this generator will create.

5.4 Sub-system communication

In the following section, the communication between various parts (sub-systems) is explained. The communication between subsystems is present for functional purposes such as commands execution, packet preparation, and reporting statistics. The reader is expected to be aware of the system architecture in order to understand the various components mentioned here and their role in the application.

Communication between (Generator/Verifier) and (Gateway)

The gateway is implemented in the system to play the role of the unified interface for receiving and sending packets, as it deals directly with the device's network interface card (NIC). The communication between the Generators/Verifiers and the Gateway occurs mainly in order to collect all packets produced from the generators and forward them to the gateway, and distribute the packets received from other nodes to the correct verifier process.

The mechanism of communication in this case is the usage of named pipes (FIFO) that are provided by the Linux kernel. Each generator and each verifier process communicate with the gateway using its own pipe dedicated to that communication channel. In our implementation, the named pipes are in the /`tmp` directory making the generators' pipes are of this format `/tmp/fifo_pipe_genX`, where X is replaced by a unique ID issued by the System API. The reading and the writing ends of the pipes does not change during the execution, from the perspective of the gateway, data is always read from the generator and sent to the verifier.

Communication between (Generator/Verifier) and (System API for statistics management)

The statistics that the user needs are produced from these two processes. The statistics must be sent to the system API first to aggregate the data from all running

processes on the machine and send them to the admin interface later. The statistical data is written to a named pipe (FIFO) in the form of a tuple that would be parsed by the system API and transmitted as a Kafka topic.

In our implementation, the pipe resides on the file system in `/etc/EJam/stats/genStats` and `/etc/EJam/stats/verStats/`. The pipe itself is named, according to its source, (./ID_sgen_0) and (./ID_sver_0) where the number 0 in this example is replaced with the instance ID and the `ID` is replaced with the three characters denoting the actual unique stream code (ID).

Communication between (Generator/Verifier) and (System API for configuration)

After the user has specified the streams that he wants to be executed on the system, it is transmitted to the System APIs on the nodes in the network, the exact mechanism of the communication in this stage is to be mentioned in another section. The next step is to deliver the configuration to the generators and verifiers to execute it. The communication of the configuration is not done in a direct manner as with the other methods mentioned earlier. The system API stores the configuration as files with a certain format (new line separated values) in the directory `/etc/EJam/`. Each configuration file is named `config_abc.txt`, with the last three characters replaced with the actual stream ID which is unique across the system and issued by the admin interface. When the system API runs the generator and verifier processes, the configuration that this process executes is communicated as arguments to that process.

Communication between (System API) and (Centre point)

The communication in this stage is done using a RESTful API. The default port for the system API is 8000. The following are the endpoints that the System API provide for the centre point:

Get / (index)

will be called to Ping the system API and check if it is Online. (Will be used in the device's Radar)

Post /connect

will be called to connect to the system API and register the device in the system only if the mac address provided is accepted by the system API.

Post /start

Generate or verify the Provided Stream.

Post /stop

Stop a currently running stream.

All endpoints' headers will have mac-address = the mac address of the device that started the stream for verification.

(Centre point) and (Front end)

The communication in this stage is also done using a RESTful API. The following are the endpoints that the centre point provides for any front-end type deployed on any of the operating systems specified earlier:

GET /streams

Returns a list of all streams in the list of streams.

GET /streams/{stream_id}

Returns the stream with the given stream_id.

POST /streams

Adds a new stream to the list.

DELETE /streams/{stream_id}

Deletes the stream with the given stream_id.

PUT /streams/{stream_id}

Updates the stream with the given stream_id.

POST /streams/{stream_id}/start

Starts the stream with the given stream_id in body.

POST /streams/{stream_id}/force_start

Forces the stream with the given stream_id to start.

POST /streams/start_all

Starts all streams in the list of streams.

POST /streams/{stream_id}/stop

Stops the stream with the given stream_id.

POST /streams/{stream_id}/force_stop

Forces the stream with the given stream_id to stop.

POST /streams/stop_all

Stops all streams in the list of streams.

GET /streams/{stream_id}/status

Returns the status of the stream with the given stream_id.

GET /streams/status_all

Returns the status of all streams in the list of streams.

GET /devices

Returns a list of all devices in the list of devices.

GET /devices/{device_mac}

Returns the device with the given device mac address.

POST /devices

Adds a new device to the list.

DELETE /devices/{device_mac}

Deletes the device with the given device_mac.

PUT /devices/{device_mac}

Updates the device with the given device_mac.

/devices/{device_mac}/ping

Pings the device with the given device_mac.

GET /devices/ping_all

Pings all devices in the list of devices.

GET /devices/ping

Pings the device with the given device data.

POST /streams/{stream_id}/started

Notify the system that the stream is started by the device.

POST /streams/{stream_id}/finished

Notify the system that the stream is finished by the device.

5.5 Centralized Control System

The centralized control system is the core component of the overall system, responsible for managing the streams between devices, the devices themselves, and the processes representing the streams running on each device. This section will provide an overview of the implementation details of the centralized control system, emphasizing its role in state verification and management for efficient system control.

Multi-Threaded Architecture:

The centralized control system employs a multithreaded architecture to facilitate concurrent processing and enhance system performance. Multiple threads are utilized to handle different tasks simultaneously, allowing for efficient state verification and management across the streams, devices, and processes. Each thread is dedicated to specific functionalities, ensuring optimal resource utilization and scalability.

State Verification:

The primary function of the centralized control system is to verify the states of the streams, devices, and processes within the system. State verification is achieved through event-driven notifications, and data synchronization techniques, enabling real-time monitoring and assessment of component states.

State Management:

In addition to state verification, the centralized control system manages the states of the streams, devices, and processes. It maintains a comprehensive state database or registry that records the current state of each component, including operational modes, configurations, and relevant metadata.

Communication and Coordination:

To ensure seamless communication and coordination among the components, the centralized control system acts as a mediator, facilitating data exchange and interaction. It provides a standardized interface and communication protocol that enables components to send state updates, receive commands, and exchange relevant information. The control system orchestrates the flow of data and commands, ensuring coherent and synchronized behaviour across the entire system.

Error Handling and Fault Tolerance:

The centralized control system incorporates error handling mechanisms and fault tolerance strategies. It detects, diagnoses, and recovers from errors or failures within the system. In the event of component failures or inconsistencies, the control system initiates appropriate actions such as triggering alarms to maintain system integrity and reliability.

Scalability and Extensibility:

The implementation of the centralized control system supports system scalability and extensibility. It accommodates the addition of new streams, devices, and processes without disrupting overall system operations. The control system architecture allows for easy integration of new threads, state management modules, ensuring future system growth and adaptation to changing requirements.

In summary, the centralized control system is responsible for state verification and management of the streams, devices, and processes within the system. Its multithreaded architecture, state verification mechanisms, state management capabilities, communication and coordination features, error handling and fault tolerance strategies, as well as scalability and extensibility considerations, collectively enable efficient and reliable control over the entire system.

5.6 Test Design

The purpose of this document is to describe the test design of the E-Jam project. This includes the testing strategy, the testing environment, the testing tools, the testing process, and the testing schedule.

Scope

We had multiple constraints during the testing process. Therefore, we focused on testing the core functionalities of the project. The Main scope of this test design is covering the testing strategies such as, the API test, UI test, and performance test of the system, including others that were both essential and critical.

Constraints

Although we faced multiple constraints during the testing process, this document highlights how we overcame these constraints while working on the project.

We had limited resources, which meant that we had to prioritize our testing efforts. Additionally, we encountered time constraints and had to ensure that we completed testing within the given timeframe.

For the Time constraints, we had a limited amount of time allocated for testing, so we focused on testing the most critical functionalities first. To optimize our testing time, we used automation testing for API testing, which saved us a significant amount of time.

Availability of resources: We faced challenges about the availability of devices and tools for testing. However, we used tools such as Docker and virtual machines to simulate different environments and devices, which allowed us to test a variety of scenarios.

Technical constraints: We faced technical challenges in integrating some tools and frameworks, but we were able to overcome them by seeking help from the community and consulting the documentation, and of course our mentors who

helped us a lot. Also reporting bugs on a dependency in the front-end GUI and downgrading until we found a stable version that could work, until the dependency was stable.

We also utilized (CI/CD), just for building the front end on cross platforms, to ensure that it worked properly on different devices and operating systems, and manually testing some of them that were available.

For Risks and prioritization, we had multiple decisions that would help the system significantly, but they were extremely risky.

The first one is that we planned to have the admin client as a single component to ease the development process, but it turned out to be too risky, so we decided to split it into multiple components.

Another risk we faced was changing the front-end framework from electron (A JS framework) to a totally different language and framework, Flutter.

Flutter helped significantly to improve the performance of the UI, but it was a risky decision as it required us to learn a new language and framework, and scrape everything that was done before in JavaScript.

However, it was worth the risk as the result was a much better user experience. As, it offers a wide range of testing tools and widgets designed for UI.

For UI testing, we used Flutter's built-in testing framework, which allowed us to easily write and execute UI tests on cross-platform applications, and then switched to manual testing since the test cases were not strong enough to cover all scenarios.

For API testing, we used postman and Thunder Client to validate the request and response of the API.

In performance testing, we used to build in tools such as Flutter’s Performance Profiler, and cargo bench for rust, and monitoring the output statics for the Low Network Level, and as well monitoring the response time on each request made. Which all seemed to work wonders for helping improve the system’s performance. We also utilized load testing, which helped us identify areas for improvement in the project.

5.7 Test Plan

Throughout the testing process, we maintained regular communication, and standards that follow throughout the system's flow. Our objective was to ensure that the project met the specified requirements and was of high quality, providing a seamless user experience.

The following are example components for standards followed through the system. We will not explain each parameter and how it works, since you will find all of them in the centre point's documentation page.

Stream Entry


```
{
  "name": "Production Stream",
  "description": "This is a stream for production testing.",
  "lastUpdated": 1627902000,
  "startTime": "2023-07-01T08:00:00Z",
  "endTime": "2023-07-01T16:00:00Z",
  "delay": 1000,
  "generatorsIds": ["AA:BB:CC:DD:EE:FF", "11:22:33:44:55:66"],
  "verifiersIds": ["AA:BB:CC:DD:EE:FF", "11:22:33:44:55:66"],
  "payloadType": 1,
  "burstLength": 5,
  "burstDelay": 100,
  "numberOfPackets": 500,
  "payloadLength": 1024,
  "seed": 987654321,
  "broadcastFrames": 100,
  "interFrameGap": 50,
  "timeToLive": 128,
  "transportLayerProtocol": "UDP",
  "flowType": "BackToBack",
  "checkContent": true
}
```


Device


```
{
  "name": "Device 1",
  "description": "This device is used for network monitoring.",
  "location": "Office",
  "lastUpdated": 1627902000,
  "ipAddress": "192.168.1.100",
  "port": 8080,
  "macAddress": "AA:BB:CC:DD:EE:FF"
}
```

System API Stream Details

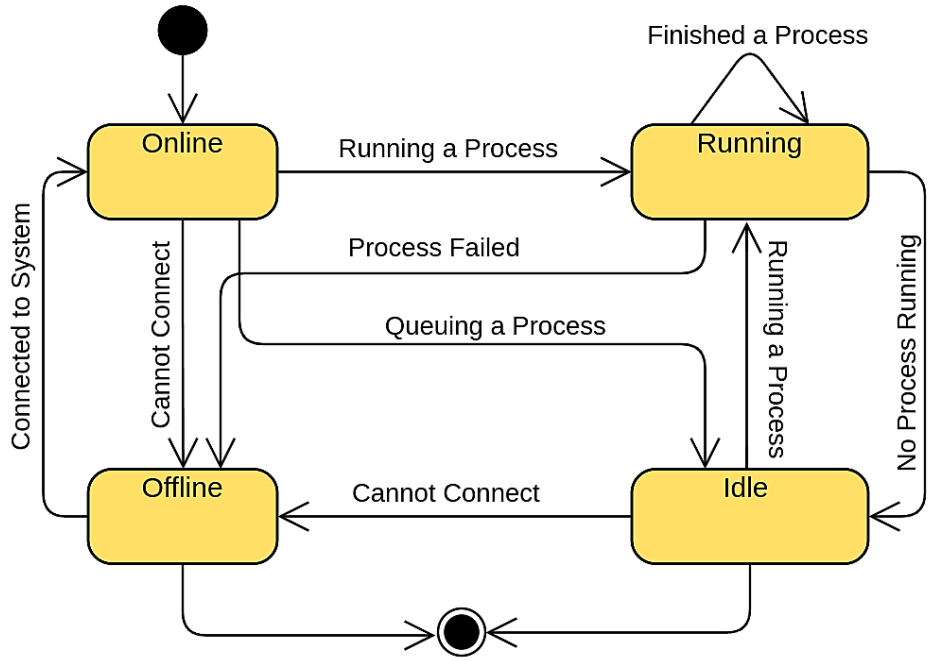
```
{
 "streamId": "ABC",
 "delay": 500,
 "generators": ["AA:BB:CC:DD:EE:FF"],
 "verifiers": ["11:22:33:44:55:66"],
 "payloadType": 2,
 "numberOfPackets": 1000,
 "payloadLength": 256,
 "seed": 12345,
 "broadcastFrames": 1200,
 "interFrameGap": 10,
 "timeToLive": 64,
 "transportLayerProtocol": 1,
 "flowType": 0,
 "checkContent": 1
}
```

This is used for serializing the Stream Entry JSON that the system API will execute, after validation.

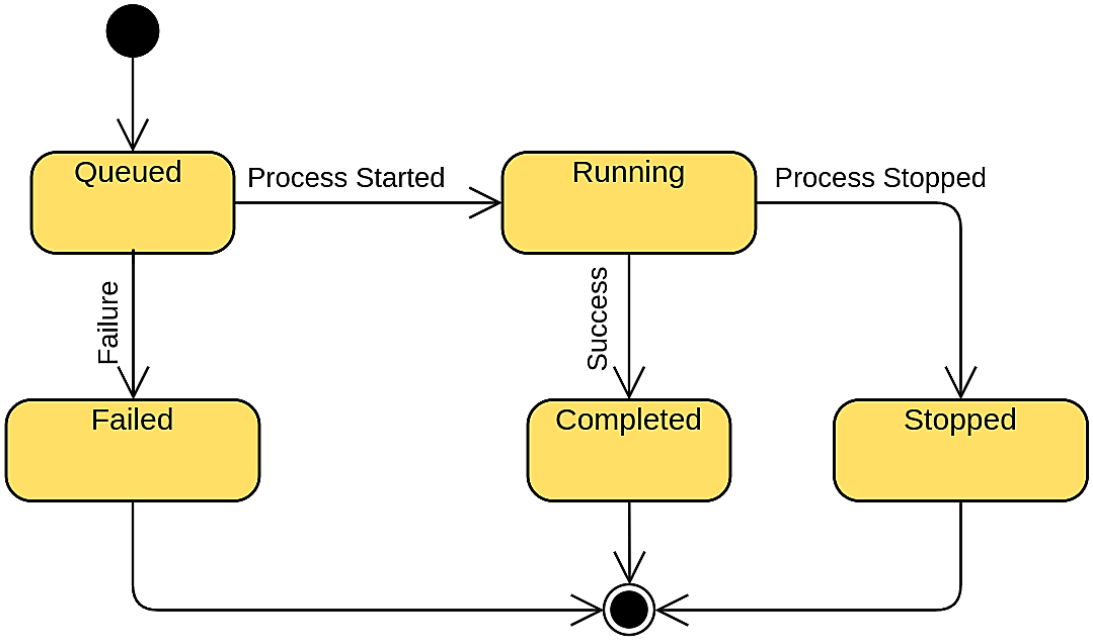
State Machines

The following are the State Machines for the main components of the system.

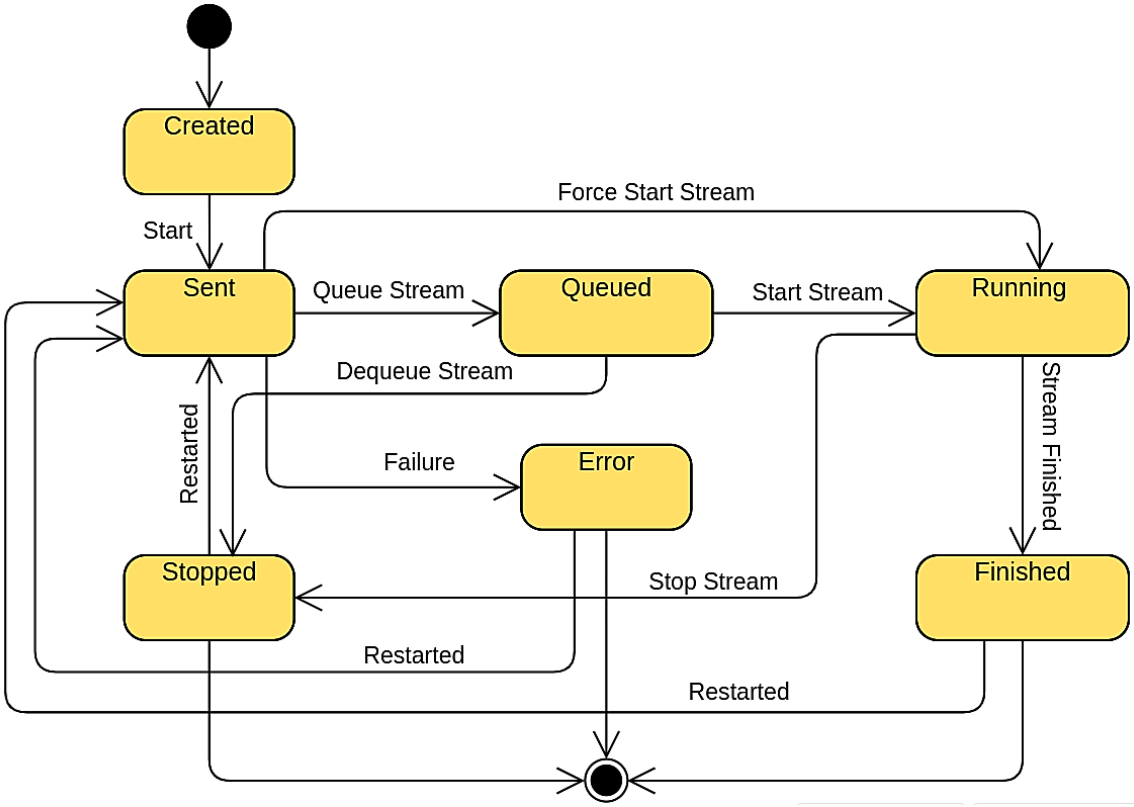
Devices



Processes



Streams



Approach

Our goal was to check that each component of the system meets the specified requirements, and functions correctly. We followed a systematic approach to testing, including unit testing, integration testing, system testing, and acceptance testing, performance testing, and other depending on the specific components.

For unit testing, we tested each component individually, verifying that it worked correctly in isolation, which was done to all components of the system.

For integration testing, split the system into two components that both were heavily tested during the integration testing. The first is the Admin Client Components that contains the frontend and centre point, and the other is the Low-Level Components which contain the system API for communication, and the components responsible for sending and receiving data.

For system testing, we tested the system, including all components and interfaces, starting from the network layer all the way to the front end's charts.

For acceptance testing, we verified that the system met the specified requirements, both functional and non-functional, and that it was ready for deployment. We also tested for user scenarios and ensured that the system was user-friendly and followed the design guidelines of the project.

For performance testing, we verified that the system was able to handle large amounts of data, and that it met the required performance standards.

We also tested for security on the system's API.

Finally, we followed a continuous testing approach, where we tested the system at every stage of development, to ensure that any issues were caught early and resolved quickly.

We used a combination of manual and automated testing throughout the process, leveraging automation tools such as postman, Thunder Client, and Flutter's built-in testing framework. And fakers for generating fake data for testing, and some additional tools for performance testing. We also performed regression testing after any changes to ensure that existing functionality was not affected.

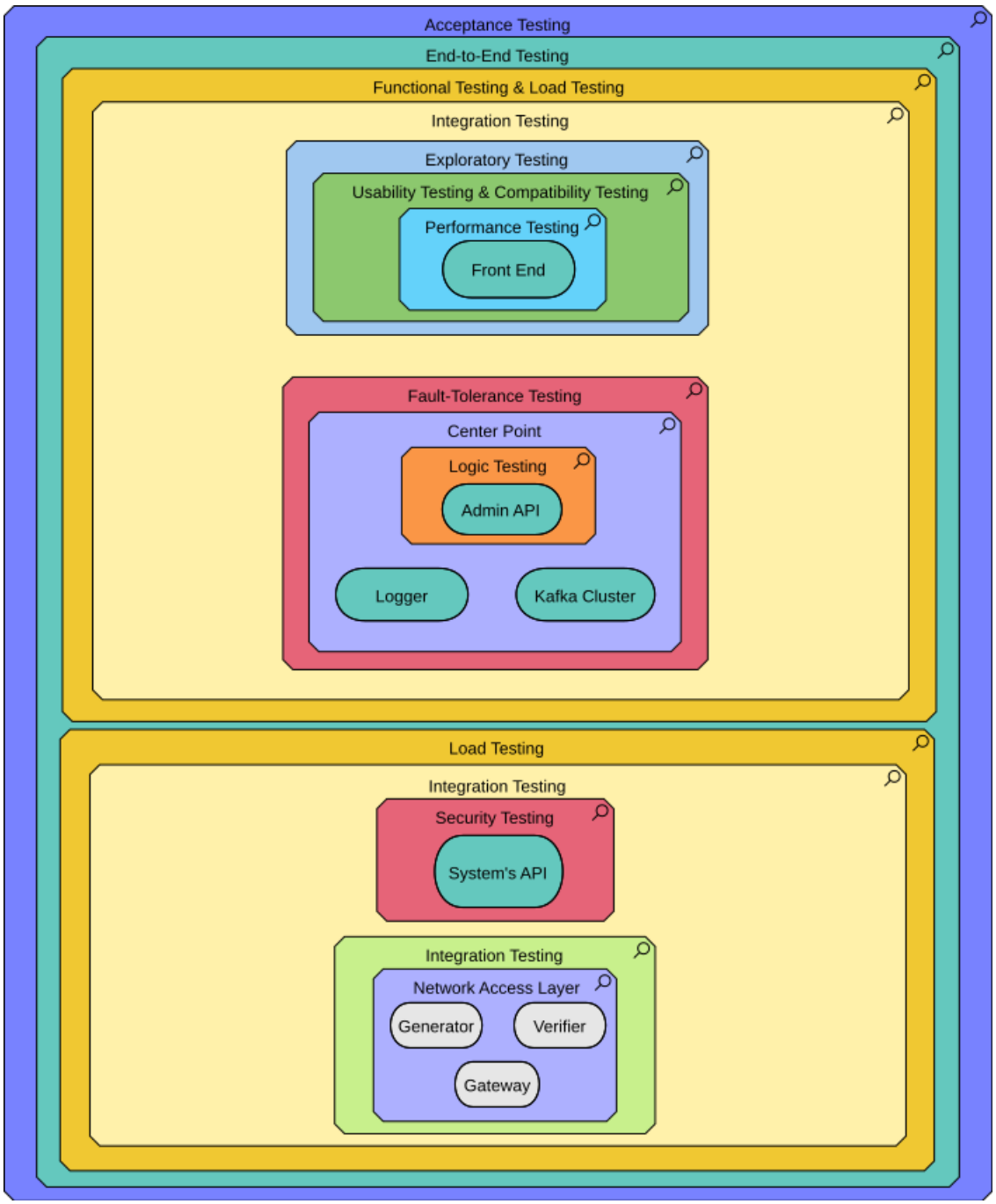
In terms of risk prioritization, we focused on testing the most critical functionalities and used automation testing where possible to save time.

Test Coverage

To simplify things, we created test cases for each component, and organized them into categories that were easy to manage. These categories were based on the type of testing, such as unit, integration, system, acceptance, performance, or security, etc.

The following is a graph specifying the types of testing done on each component relative to other components in the same container.

Each component in the hierarchy starts from the top for each component's unit testing, then all the way down to the System or End-to-End testing.



Notice that the Network Access Layer Component is treated as one component, since there is always an expected Verifier when generating data going through the switch.

A lot of components had different types of testing strategies but are not mentioned in the graphs since they were specific to each component and were documented separately. However, the main idea was to have full test coverage and make sure that every component of the system is tested thoroughly to meet the project's requirements.

Each component in the system needed coverage for all the states that it can be in, including normal, boundary, and error cases. We also made sure to test any dependencies that the component had, and to cover any edge cases that could impact the system's stability.

Conclusion

In conclusion, we have followed a comprehensive and systematic approach to testing all components and functionalities of the system. By conducting unit testing, integration testing, system testing, acceptance testing, performance testing, and security testing, we have ensured that the system meets the specified requirements and is ready for deployment.

Using a combination of manual and automated testing tools, we have achieved full test coverage and maintained a level of quality throughout the development process. Continuous testing and regression testing have been critical in catching any issues early and resolving them quickly.

Through risk prioritization, we focused on testing the most critical functionalities and leveraged automation testing to save time and resources. The thorough testing of each component and their dependencies, as well as covering normal, boundary, and error cases.

Also, no matter how much we test a system, there is always a chance that there may be software bugs that are not caught during testing. Deploying the application and collecting feedback from users is an important step in identifying and resolving software bugs. Users may encounter issues that were not anticipated during testing and may provide valuable feedback that can help improve the application.

Chapter 6: Future Work

The following are additional features that were not implemented in this project for several scheduling-related reasons but will provide great benefit if implemented in this project in the future.

Historical Data Analysis

The system by default stores a lot of data from past runs in a dedicated database. A new subsystem could be developed to make use of the historical data to predict trends in the system's behavior, identify hot-spots and assess performance levels across time using an artificial intelligence model trained on the available data.

Command Line Interface

The system's admin interface already can run on a variety of operating systems. But the user might need to use a command line interface to accelerate doing certain tasks such as stream creation and managing settings.

Example of such an interface:

> EJam --add -d 192.168.1.1	Add new device of with a certain IP address
> EJam --add -s stream1 192.168.1.1 192.168.1.2	Add new stream and specify devices
> EJam --add -s stream2 ALL	Add new stream with all devices involved
> EJam --stop stream2	Stop a certain stream
> EJam run	Run the system with the current configuration
> EJam clear	Resets all streams and forget all devices

Passive Monitoring Mode

In addition to the active system monitoring mode that runs during test execution, a new subsystem could be developed to monitor actual traffic and identify problems in the flow of packets while users are using the network for daily usage purposes. The system should be able to notify the administrator of such problems and allow him to act accordingly.

Improve The Security Level

The system has not currently gone into the process of security testing and malicious usage protection iterations. The communication protocols used in various parts of the system could make use of an encryption layer.
The REST API should accept communications from the admin device only after verifying the authenticity of the source.
The admin interface would provide more security if there was a sign-in system with only authorized users able to sign in and use the tool.

References

- ABRAHAM SILBERSCHATZ. (n.d.). Interprocess Communication. In Operating System Concepts, Ninth Edition (pp. 122-136). Essay.
- Norman, D. A. (2013). The Design of Everyday Things. Basic Books.
- GeeksforGeeks. (n.d.). Socket Programming in C/C++. Retrieved from https://www.geeksforgeeks.org/socket-programming-cc/
- MPI Forum. (n.d.). MPI: A Message-Passing Interface Standard. Retrieved from https://www.mpi-forum.org/docs/mpi-2.2/mpi22-report/node208.htm
- Wikipedia. (n.d.). Cyclic Redundancy Check. Retrieved from https://en.wikipedia.org/wiki/Cyclic_redundancy_check
- GeeksforGeeks. (n.d.). Modulo-2 Binary Division. Retrieved from https://www.geeksforgeeks.org/modulo-2-binary-division/
- GeeksforGeeks. (n.d.). Modulo-2 Binary Division. Retrieved from https://www.geeksforgeeks.org/modulo-2-binary-division/
- HubSpot Blog. (n.d.). REST APIs: How They Work and What You Need to Know. Retrieved from https://blog.hubspot.com/website/what-is-rest-api
- GeeksforGeeks. (n.d.). REST API (Introduction). Retrieved from https://www.geeksforgeeks.org/rest-api-introduction/
- RFC Editor. (1997). Benchmarking Methodology for Network Interconnect Devices. RFC 2889. Retrieved from https://www.rfc-editor.org/rfc/rfc2889.html
- RFC Editor. (1991). Benchmarking Terminology for Network Interconnection Devices. RFC 1242. Retrieved from https://www.rfc-editor.org/rfc/rfc1242
- RFC Editor. (1998). Definitions of Managed Objects for the SONET/SDH Interface Type. RFC 2285. Retrieved from https://www.rfc-editor.org/rfc/rfc2285
- RFC Editor. (1999). Benchmarking Methodology for Network Interconnect Devices. RFC 2544. Retrieved from https://www.rfc-editor.org/rfc/rfc2544
- Rust Programming Language. (n.d.). Retrieved from https://www.rust-lang.org/
- Flutter. (n.d.). Retrieved from https://docs.flutter.dev/
- YAML Ain't Markup Language (YAML) Version 1.2. (n.d.). Retrieved from https://yaml.org/
- Apache Avro. (n.d.). Retrieved from https://avro.apache.org/
- Paessler AG. (n.d.). Retrieved from https://www.paessler.com/

- RFC Editor. (1997). Benchmarking Methodology for Network Interconnect Devices. RFC 2889. Retrieved from https://www.rfc-editor.org/rfc/rfc2889.html
- RFC Editor. (1991). Benchmarking Terminology for Network Interconnection Devices. RFC 1242. Retrieved from https://www.rfc-editor.org/rfc/rfc1242
- RFC Editor. (1998). Definitions of Managed Objects for the SONET/SDH Interface Type. RFC 2285. Retrieved from https://www.rfc-editor.org/rfc/rfc2285
- RFC Editor. (1999). Benchmarking Methodology for Network Interconnect Devices. RFC 2544. Retrieved from https://www.rfc-editor.org/rfc/rfc2544
- Atlassian. (n.d.). Agile and Scrum. Retrieved from https://www.atlassian
- Tokio. (n.d.). Tokio Tutorial. Retrieved from https://tokio.rs/tokio/tutorial
- Serde. (n.d.). Serde Derive. Retrieved from https://serde.rs/derive.html
- Apache Kafka. (n.d.). Introduction to Apache Kafka. Retrieved from https://kafka.apache.org/intro
- Confluent Developer. (n.d.). Tutorials. Retrieved from https://developer.confluent.io/tutorials/
- Syncfusion Flutter Widgets. (n.d.). Retrieved from https://flutter.syncfusion.com/
- Docker. (n.d.). Get Started, Part 1: Orientation and setup. Retrieved from https://docs.docker.com/get-started/overview/
- Wikipedia. (n.d.). Regular Expression. Retrieved from https://en.wikipedia.org/wiki/Regular_expression
- Actix. (n.d.). What is Actix?. Retrieved from https://actix.rs/docs/whatis
- Flutter. (n.d.). Profiling Flutter Apps. Retrieved from https://docs.flutter.dev/cookbook/testing/integration/profiling
- Wikipedia. (n.d.). Exploratory Testing. Retrieved from https://en.wikipedia.org/wiki/Exploratory_testing
- Wikipedia. (n.d.). Regression Testing. Retrieved from https://en.wikipedia.org/wiki/Regression_testing
- Joshi, P., Harrold, M. J., & Rothermel, G. (2012). An Extensive Comparison of Four Regression Test Selection Techniques. https://www.sciencedirect.com/science/article/abs/pii/S0164121212002403