CITY
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BSc Computer Science

Paperclip

Networking for Games

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Contents

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Abstract

This project attempts to define and implement networking tools including a lightweight protocol for use with game technology and an account and game session management server.

1 Introduction

1.1 Problem Description

When creating a multiplayer game, every developer must integrate a few key features. Even though every multilayer game shares these same key features, a developer must build these from scratch. This is time consuming and means that a developer is limited in the amount of initial development they can put into their game. Though some implementations of a custom networking protocol exist (described in the Literature Review [3]), no implementation provides both a variety of rich-features with full flexibility in when/which features are used.

1.2 Objectives

1.2.1 Primary Objectives

1. Create a scalable system for managing user accounts and inter-account interactions including matchmaking and friends.
2. Create a custom UDP protocol that implements key features required for game communication missing from vanilla UDP. This includes features to improve reliability and security.

1.2.2 Secondary Objectives The secondary objectives are split into sub objectives as follows:

Secondary Objectives
Turn-based game demo
Real-time game demo
Large packet size limit
Authenticated Communication
Secure Communication
Reliable Communication
Lightweight Communication
Modularity

1.3 Beneficiaries

The project is intended to be used by game developers when programming networking for multiplayer games.

1.4 Assumptions and limitations

Originally, the project focused primarily on a rich-feature account and game session server however, its scope was largely decreased as greater emphasis was put on the implementation of the UDP protocol. Additionally, the sub-objective of creating a real-time game demo was not completed due to time constraints. Similarly, the depth of the turn-based demo was minimized.

2 Output Summary

Name	**udp**
Type	Python Package
Size	2093 lines (after formatting)
Credit	
Description	Implimentation of custom udp protocol with client and server
Usage	Base objects for game developer to build on for implimation into their game.
Link	
Name	**server**
Type	Python Package
Size	700 lines (after formatting)
Credit	
Description	Flask RESTful server responsible for handling comuncation between clients and the database, therfore also responsible for authentifcation and certificate validation. Also creates lobbies which include a game server for clients to connect to. Contains the model definitions for use with the database.
Link	
Name	**client**
Type	Python Package
Size	467 lines (after formatting)
Credit	Makes use of a version inputimeout which was modifed to disable the automatic appending of new lines on a timeout.
Description	A cmd line client example for end user use. Handles comunication to RESTful server via dialog with client. Also responsible for creating game client instances. Makes use of inputimeout.
Usage	End user client.
Link	
Name	**rps**
Type	Python Package
Size	440 lines (after formatting)
Credit	
Description	A turn-based game demo using the UDP python package. Includes both a client (for use with the client package) and a server (for use as a game server with the server package).
Usage	The package can be slit into two main parts: - The client is used by the client package to communicate with the game server once a game session has been started. - The server is used by the server package when creating a game session.
Link	
Name	**tests**
Type	Python tests
Size	264 lines (after formatting)
Credit	
Description	A pytest script to test that implimented features are working as exspected.
Usage	Used to validate functionality.
Link	

3 Literature Review

3.1 Network Protocols

When considering the transport layer the two primary options for sending data are `TCP` (Eddy, 2022) and `UDP` (Postel, 1980). Both have their own strengths and weaknesses.

3.1.1 TCP `TCP` is a protocol that uses a connection-based approach. It offers a reliable, ordered and error-checked data stream. It is used for a variety of other protocols such as `HTTP`, `FTP` and `SMTP`. These features, while offering benefits also come with drawbacks such as additional overhead which in part contributes to `TCP` prioritizing data integrity at the expense of latency.

- Reliable

  - The sender is notified if a packet is successfully, or unsuccessfully, delivered to its recipient. This means the data is re-sent in the event of packet loss, ensuring that all data is received (unless of a major failure such as the recipient losing connection e.g. though power loss). This, however, incurs a larger overhead than unreliable protocols leading to typically slower data transfer.
- Ordered
  - Packets are received by their destination in the same order they are sent. This is achieved by assigning a sequence number to each segment of data. The receiver is then able to reassemble the data in the correct order. This, however, can lead to increased latency when a recipient is waiting for a packet after receiving its descendant causing the data stream to hang.
- Error-checked
  - A checksum is included with the packet data. This allows for a recipient to verify that the data is received in the same state it was sent. In the event of data corruption, the data is re-requested. This also contributes to increased latency as the recipient must wait for the packet to be retransmitted.

3.1.2 UDP In contrast, `UDP` is a connectionless protocol that is unreliable, unordered and provides no error-correction at the interface level (i.e. error-correction must be implemented on the application layer if desired). Despite these simplicities, `UDP` is arguably more suited to fast, real-time communication where speed is prioritized over integrity.

- Connectionless
  - Due to `UDP` being a connectionless protocol, `UDP` is able to broadcast and multicast packets without any additional overhead. This, for example, is useful when a server has to send a game-state update to all game clients.
- Unreliable
  - There are no systems in place to detect if a packet is successfully delivered. This, therefore, means that there is a significant reduction in latency as no resubmission takes place but also means that packets can be lost without either the sender or the recipient being aware.
- Unordered
  - Packets may arrive in any order and it is up to the application to determine the original order. There is no built-in information in the packet to infer the original order either and thus, if this information is desired, must be encoded into the packet payload. This, however, gives the recipient more flexibly, allowing outdated packets to simply be ignored in the event that a newer packet has already been processed.
- No error-checking
  - Though the `UDP` contains a checksum field, this is not mandatory (at least for `IPv4`). In the event the checksum is used, any packets that fail the checksum will be dropped at the transport layer and will not reach the application. Due to this, it can be beneficial to not include a checksum in the header and instead implement some form of data validation in the data payload instead.

3.1.3 Comparison When working with time critical data such as that required for real-time video games, particularly those with fast-paced interactions, like FPS such as *Quake* (id Software, 1996) or fighting games such as *Street Fighter IV* (Capcom, 2008) TCP's overhead leads to a too great latency. Many systems would also prefer to just discard packets in the event of a failure as waiting for retransmission will yield old and outdated information no longer relevant to the current state of the system. These such use-cases are ideal for UDP, though some additional features may have to be implemented on the application level (some borrowed from TCP). The consensus among game developers is typically to implement a custom protocol based on UDP.

> "Using TCP is the worst possible mistake you can make when developing a multiplayer game." *UDP vs. TCP* (Fiedle, 2008b)

Several implementations attempt to add key features to the UDP specification such as:

- Value's *GameNetworkingSockets* (ValveSoftware, 2022) allows for a pseudo-connection over UDP as well as allowing reliable and unreliable packets. Though the implementation includes mandatory encryption it lacks any form of compression.
- *ENet* (Salzman, 2024), created for the open-source FPS *Cube* (van Oortmerssen, 2005), provides, solely, reliable UDP packets.

When working with data where latency is not a concern, TCP's built-in benefits make it a somewhat more suitable choice. For turn-based games like some 4X games such as *Civilization III* (Firaxis Games, 2001) and board games such as *Connect Four* (Howard Wexler, 1974), where latency is less critical, there is argument to be made for either TCP (without *Nagle's Algorithm*) or UDP. When communicating with a matchmaking or account database, such as through a RESTful server, the benefits of TCP, particularly the added security, far outweigh the potential latency.

3.2 RESTful API

In *Architectural Styles and the Design of Network-based Software Architectures* (Roy Thomas Fielding, 2000) Fielding introduces the REpresentational State Transfer (REST) architectural style. The term RESTful can be used to describe HTTP-based APIs that meet some REST features but this often scrutinizes as an API either adherers to REST or does not. Most uses of the term RESTful actually refer to *HTTP-based Type I* and *HTTP-based Type II* (Jan Algermissen, 2010) where neither adhere to the use of *Hypermedia as the Engine of Application State* defined in REST. The types differ in the use of *Self-Descriptive Messages* i.e. the use of specific media types over generic. General principles state that REST is superior to Type II which in turn is superior to Type I.

> "Depending on the degree to which existing media types apply to the problem domain HTTP-based Type II should be considered over HTTP-based Type I because the start-up cost is almost identical. A transition from HTTP-based Type II to REST at a later point in time, however, is rather easy." *Classification*

of HTTP-based APIs (Jan Algermissen, 2010)

Despite this, this document uses the term `RESTful` interchangeably with `HTTP-based Type` due to the communities adoption of the term.

3.3 Security Algorithms

3.3.1 TLS `Transport Layer Security` (`TLS`) (Rescorla, 2018) and the similar `Datagram Transport Layer Security` (`DTLS`) are cryptographic protocols designed to provide secure communication. The protocol describes the data exchanged between the client and server in the handshake. This exchange includes the sharing of an asymmetric (public) key which is used in a key exchange to generate a symmetric session key for use in the rest of communication (i.e. with application data). The `Finished` packet includes a hash of the handshake communications using the session key thus allowing both parties to validate the exchange. The handshake also contains the exchange of certificate(s) allowing parties to validate the identity of the other party.

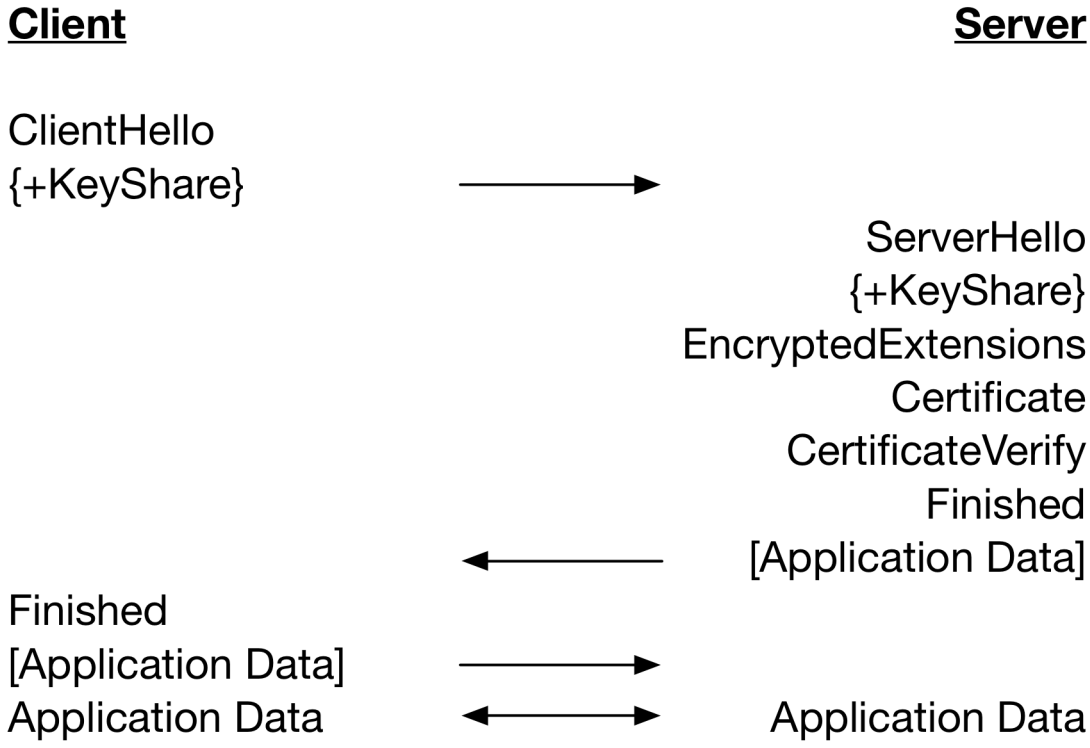

Figure 1: A example of a TLS 1.3 full handshake including a server certificate (wolfSSL, 2019)

3.3.2 Session Keys There are several different options for the asymmetric key used in the key exchange. The primary options (used in `TSL 1.3`) are either an `Elliptic Curve` (`EC`)

or Finite Field (FF) which use an Elliptic Curve Diffie-Hellman (ECDH) and Finite Field Diffie-Hellman (FFDH or, more commonly, DH) key exchange respectively. Both are preferred in ephemeral (ECDHE, DHE) form meaning that keys are regenerated for each new session thus meaning the system is less venerable of replay attacks.

The Performance of Elliptic Curve Based Group Diffie-Hellman Protocols for Secure Group Communication over Ad Hoc Networks (Wang, Ramamurthy and Zou, 2006) compares the performance of ECHD against DH and finds that EC outperforms DH in, among other things, both communication time and key generation speed. As such, ECHD(E) is considered to be the preferred method for session key generation.

3.3.3 Authentication The certificate used in the TLS handshake is typically in the form of an X.509 (Internet Engineering Task Force, 2006) containing an identity and a public key which is signed using the respective private key. There are serval options for choice in key pair used, with the most common being RSA (Ronald L. Rivest, 1978) and Elliptic Curve Digital Signature Algorithm (ECDSA). DSA, though currently still used, is being phased out largely due to its comparative weakness to other algorithms. ECDSA offers the equivalent level of security to RSA with a smaller key size as well as typically faster encryption and description speeds. This can be particularly relevant with a repeated key exchange, but is less relevant in the context of X.509 verification as this process will typically only occur once per session. Historically, RSA has been the de facto choice, but recent years have seen ECDSA grow in adoption. RSA's dominance is largely associated with the algorithm's maturity and existing wide adoption and, for this reason, remains a suitable choice for X.509 signing.

4 Method

4.0 Tools

4.0.1 Programming Language The project is written in Python. This was a language I was most familiar with. The Flask package was used for the RESTful API server in conjunction with SQLAlchemy to communicate with the database.

4.0.2 Database The database language chosen was mySQL. This was deployed in a Docker stack during development for convenience.

4.0.3 IDE Visual Studio (VS) Code was chosen as the primary IDE to write Python. VS Code supports a large variety of different languages via first and third-party plug-ins which was useful when working with some of the additional file types using in this project (e.g. .env, .yaml, .md). Additionally, I was reasonably experienced with creating custom launch.json debug configurations allowing for easy debugging of file in parallel.

4.0.4 Source Control Git and Github were using throughout development for source control management. Branches were frequently used to allow for parallel implementation of different features.

4.1 Methodology

The methodology used thought the project was the `Agile Feature-Driven Development` (`FDD`) method. This was well suited to the project as it enabled for objectives to be adaptive as a better understanding of the system requirements was gained. Additionally, it allowed for features to be designed, implemented and tested in parallel, ensuring each component was working as expected, before combining into a final cohesive package.

4.2 Analysis

The majority of the analysis can be seen in the *literature review*. Some additional analysis, however, was performed throughout the project as each feature was implemented.

4.3 Design

4.3.1 Packet Specification As stated in the literature review, a custom feature-rich `UDP` protocol would need to be defined. The additional features include:

- Packet Order
  - There would need to be some way for the recipient to be able to determine the order in which packets were sent thus allowing for old packets to be discarded.
- Reliability
  - There would need to be some way for a sender to be confident that the recipient had received the packet they had sent.
- Error-checking
  - Though `UDP` provides a built-in checksum, using a custom data validation method would give me both more control as well as the option to still receive corrupted packets on the application layer as the TCP checksum occurs below the application layer.
- Fragmentation
  - Packets should be able to split a packet into fragments. This would be particularly useful when sending a large amount of data via `UDP`.
- Compression
  - Packets should be able to indicate if a packet's data has been compressed thus allowing decompression to happen automatically. Though compression would be likely unpractical with typical packet traffic (likely increasing payload size), packets with large amounts of data such as fragmented packets could be compressed to reduce the number of fragments (thus reducing the number of points of failure).
- Encryption
  - Encryption would provide various benefits such as a recipient being confident in the sender as well as adding security against any attackers. It would also mitigate against packet fabrication. Packets should be able to indicate, in a similar fashion to compression, that they are encrypted so they can be decrypted automatically.

These features were formalized in a Packet Specification document

4.3.2 Database Models The database models were designed using a UML Entity Relationship Diagram (ERD).

4.3.3 API Specification When working with the API, the most logical implementation was to create a RESTful HTTP (TCP) server. Using flask, the web-server could act as a middleman for communication with the database. This allows for data sanitation, easy authorization control and easy scalability.

The TCP server would also be responsible for:

- Matchmaking and joining Lobbies
- Creating Lobbies (and the relevant game servers)
- Managing Accounts
  - Friends
  - Scores
- Certificate Validation

These features were formalize in an API Specification document.

4.4 Implementation

4.4.1 Iteration 1 The first iteration focused on setting up the basis for the custom udp implementation.

4.4.1.1 Packet Specification Implementation Before creating any Client or Server implementation the packet structure defined in PACKET_SPEC was implemented in class definitions with the reliant methods to convert to and from bytes.

4.4.1.2 UDP Node A base class Node was created. The Node class is responsible for sending and receiving packets.

4.4.1.2.1 Client

A Client class was created, inheriting from Node. The Client class overrides the send methods to use a given targetAddress. This means that clients can be created for a specific Server

4.4.1.2.1 Server

A Server class was created, inheriting from Node. The Server is initially passive waiting for and replying to incoming packets from a Client.

4.4.1.3 DEFAULT Packet The DEFAULT packet sending and receiving was implemented for Node using the packet.Packet class defined earlier.

4.4.2.1 Threading The Client and Server are refactored to allow for simultaneous sending and receiving.

Python's (or more specifically CPython's) Global Interpreter Lock (GIL) is a mutex that prevents multiple threads from executing Python bytecode at once. This mitigates against race conditions. The GIL is not however a catch all and some actions required additional locking.

4.4.2 Iteration 2 The second iteration focused on expanding the custom UDP implementation with a focus on implementing the authentication and security features outlined in the packet specification.

4.4.1.1 Reliable Flag and ACK Packets The RELIABLE flag ensures that packets are delivered. A Node will resend a RELIABLE packet until it receives acknowledgment through an ACK packet.

4.4.2.2 AUTH Packets The AUTH packet is used for authenticating a Node during the handshake. The public key and certificate fields defined in the packet specification are implementation agnostic. Ultimately, Elliptic Curve (EC) Keys were chosen for use as the key used in the AUTH packet. For certificates, and therefore identity verification, X.509 in conjunction with RSA signing is used. The Node class has fields for a X.509 certificate and EC Private Key whereas the RSA key is defined in the Client and Server.

4.4.2.3 Handshake The Handshake is loosely defined defined in the packet specification. As the key chosen for the AUTH packet was EC an Elliptic-curve Diffie-Hellman (ECHD) is used for session key generation.

4.4.2.4 Flags Each flag and is behavior is defined in packet specification. Each flag was implemented such that flag behavior's are automatically performed before sending and after reiving.

4.4.3 Iteration 3 The third iteration focused on finishing implementation of the features outlined in the packet specification.

4.4.3.1 ACK Bits and Rolling Reset The Node class was updated to use the available ack bits in the ACK packet's headers to provide an additional layer of reliability. Additionally, a rolling reset of the recorded ACKed bits was implemented. Without this, upon sequenceId wrap around, a Node can be misinformed about that bits have been ACKed.

4.4.3.2 HEARTBEAT Packets The HEARTBEAT packet sending and receiving was implemented using packet.HeartbeatPacket. This allows for the Server to remove unresponsive Clients in a heartbeatThread.

4.4.3.3 Callbacks Callbacks were implemented allowing for data to propagate through game Server and Clients as well allowing for packet data to reach the *application* layer.

4.4.3.4 ERROR Packets The `ERROR` packet sending and receiving was implemented using `packet.ErrorPacket`. Additionally, the errors outlined in the packet specification were implemented as `Exceptions` in `udp.errors`. These `Exceptions` and their relevant handling were put throughout the project.

4.4.3.5 Disconnects The `DisconnectError` is used whenever a `Node` is gracefully terminating. The implementation of the error varies between the `Client` and `Server` with `Client` terminating and the `Server` removing the `Client`.

4.4.4 Iteration 4 The fourth iteration focused on creating the RESTful server and the database models as well as a turn-based game demo. Finally, a end-user `client` was created.

4.4.4.1 DotEnv The `CONST`s defined across the project were consolidated into a `.env` file. This constance are then loaded at run-time using the `dotenv` package. This provided structure to the project and allowed for easier control over the various variables.

4.4.4.2 Logging Logging using the `logging` model was implemented across the package. The `logger` was set to output to both the console as well as a `paperclip.log` file. This outputs were given different 'levels' to avoid cluttering the console output while retaining all generated outputs in the log file.

4.4.4.3 Database Models The database modules defined in the `ERD` were implemented as `SQLAlchemy db.models` allowing the `Server` to initiate the database with the appropriate tables on start-up. Various changes were made between the design and final implementation to match the projects new requirements. These are outlined in the *Results* section.

4.4.4.4 RESTful Server The `TCP RESTful API Server` was implemented using as a `Flask` app. Authentication using `HTTPBasicAuth` is implemented allow for either a username and password or a session key to be used.

The endpoints for the various `API` functionalities are implemented according to the `API` specification.

4.4.4.5 Certificates and Handshake The `udp` handshake is amended to use the `RESTful` server as an authenticator for certificates. Additionally, the `udp.auth` method to generate certificates is expanded to accept and embed an `Account.id` and an `Account.username` in the certificate fields.

4.4.4.6 RPS Demo A turn-based game demo (Rock, Paper, Scissors) was created containing a game `Server` and `Client`. The `Server` is responsible for evaluating each turn sending the results to the `Clients`. The `Client` is responsible for taking a player input and sending it to the `Server` the `Client` then displays the results received.

4.4.4.7 Client A end-user command-line user-interface `client` was created. The `client` package contains wrappers for communication with `RESTful` server, including authentication. The `client` package then provides a text-based environment for a user for each `API` endpoint. The `client` is also responsible for creating a game `Client` and joining the relevant game `Server`. Finally, the matchmaking logic was implemented to allow for automatic `Lobby` joining when available.

4.5 Tests

The `pytest` module was used to define serval test.

4.6 Reused Code and Tutorials

The `client` package makes use of `inputimeout` package (Mitsuo Heijo, 2017) to allow for non-blocking inputs. This code was modified to allow prevent the automatic appending of a new line after each timeout.

A large amount of inspiration was taken from the *Reliability and Congestion Avoidance over UDP* (Fiedle, 2008a), in perticualry the use of `ack_bits` in an `ACK` package.

5 Results

5.3 Design

5.3.1 Packet Specification A formal *Packet Specification* was created laying out the different packet types, their flags and flags behaviour and well as various other headers. Additionally, the *Packet Specification* describes a handshake.

The *Packet Specification* is omitted from results section for clarity but is available in full in the documents appendices [`Appendices 9.4`].

5.3.2 Database Models A `ERD` was created defining the structure of the various database models and their relationships.

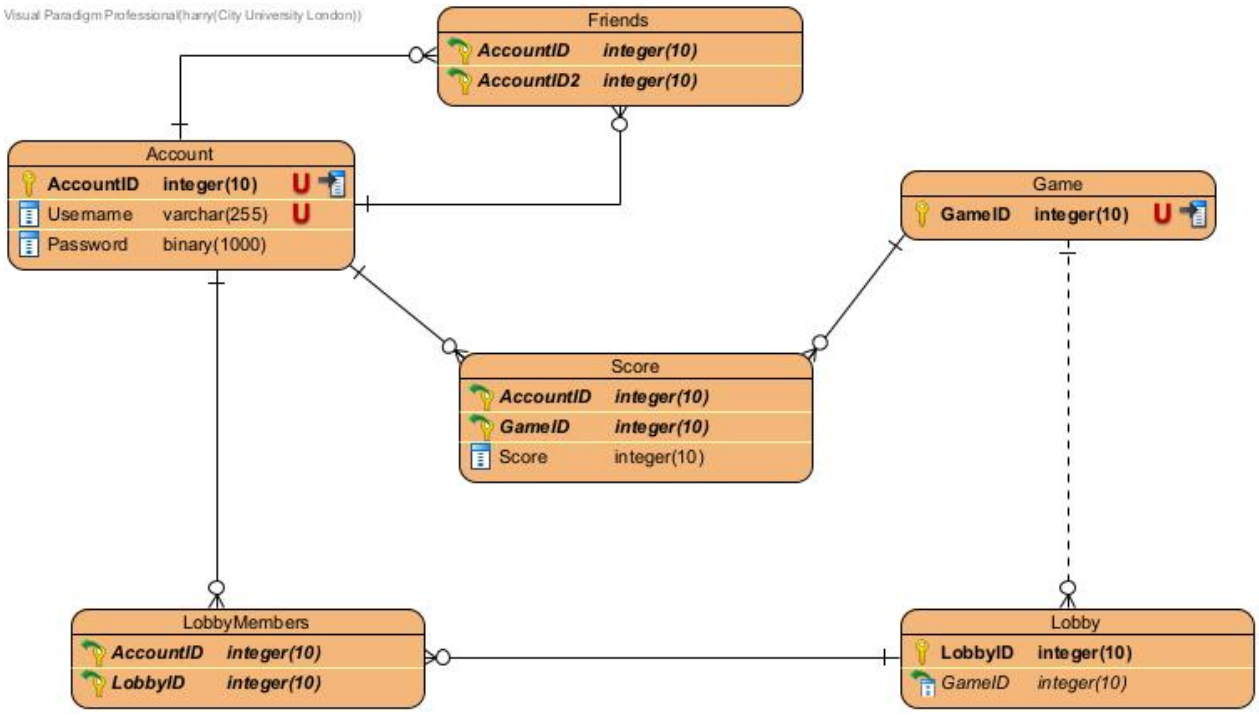

Figure 2: Database Models ERD

5.3.3 API Specification A formal *API Specification* was created describing the various endpoints the `RESTful API Server`.

The *API Specification* is omitted from results section for clarity but is available in full in the documents appendices [`Appendices 9.5`].

5.4 Implementation

5.4.1 Iteration 1

5.4.1.1 Packet Specification Implementation Each packet type (defined in the packet spec) is implemented as its own class. All packet classes inherit from a base `Packet` equivalent to the `DEFAULT` packet. The packet classes contain the defined fields as well as static methods to convert from a class instance into bytes (*pack*) and vice versa (*unpack*). The `struct` package allows for converting to and from some integer value into a fixed size bytes with the appropriate padding as well as handling endianness (as `UDP` uses big-endian). Most class fields are either already integers or can be easily represented as an integer (enum, boolean) but some fields (e.g. public key, certificate, data) require more complex casting. Additionally, the `udp.packet` script includes various `Enums` containing definitions of the `Flags` and packet `Types` and `CONSTs` which define the sizes (in bits) of the headers. These are both used in generation of default (empty) header values as well as a reference in other scripts.

```
1 from enum import Enum
2 class Type(Enum):
```

```
    DEFAULT = 0
    ACK = 1
    AUTH = 2
    HEARTBEAT = 3
    ERROR = 4

class Flag(Enum):
    RELIABLE = 0
    CHECKSUM = 1
    COMPRESSED = 2
    ENCRYPTED = 3
    FRAG = 4
```

5.4.1.2 UDP Node Both the `udp.Client` and `udp.Server` classes inherit from a `udp.Node` base class.

5.4.1.2.1 Sending Data

The `Node` class provides methods for sending `Packets` using `socket.socket`. The `sendPacket` method takes an address and a packet instance and dispatches the packed packet to the given host.

```
def sendPacket(self, addr:tuple[str, int], p:packet.Packet) -> None:
        self.socket.sendto(p.pack(p), (addr[0],addr[1]))
```

The `sendPacket` method is typically not directly called, with relevant send methods existing for each packet type. As `Node` is responsible for keeping an internal `sequenceId`, is able to set each packet and then increment its record.

```
def sendDefault(self, addr:tuple[str, int], data:bytes|None=None) -> None:
        p = packet.Packet(sequence_id=self.sequenceId, data=data)
        self.sequenceId += 1
        self.sendPacket(addr, p)
```

5.4.1.2.2 Receiving Data

The `Node` class also provides a method for receiving packets from the `socket`. This allows for packets to be packed into an instance before they are returned.

```
def receivePacket(self) -> tuple[packet.Packet, tuple[str, int]]:
    data, addr = self.socket.recvfrom(BUFFER_SIZE)
    p = packet.unpack(data)
    return p, addr
```

5.4.1.2.3 UDP Client

The `Client` also includes a target address and overrides the `Node`'s send methods to set the destination to be its target address. The `addr` field is still included in the method so that function calls from `Node` do not break.

```
def sendDefault(self, addr:tuple[str,int]=None, data:bytes|None=None):
    return super().queueDefault(self.targetAddr, data=data)
```

5.4.1.2.4 UDP Server

The `Server` is initially passive, only replying to incoming packets from a client.

```
def mainloop(self):
    while True:
        p, addr = self.receivePacket()
        # logic to process and reply (if needed)
        # e.g. self.sendDefault(addr, data=b"Hello Client")
```

5.4.1.3 DEFAULT Packet The `DEFAULT` packet takes a list of booleans flags in addition to a data field. The flags field defaults to any list of `False` if no flags are specified.

```
def sendDefault(self, addr:tuple[str, int], flags: list[bool] = [0 for _ in
    range(packet.FLAGS_SIZE)], data:bytes|None=None) -> None:
    p = packet.Packet(sequence_id=self.sequenceId, flags=flags, data=data)
    self.sequenceId += 1
    self.sendPacket(addr, p)
```

```
def receiveDefault(p: packet.Packet, addr: tuple[str, int]):
    pass
```

5.4.1.4 Threading In order to be able to send and receive packets simultaneously both actions are contained in a `threading.Thread`.

5.4.1.4.1 Thread Safety

The `GIL` does not protect against such interaction as the `+=` operator. As such the `sequenceId` variable must be incremented using a `threading.Lock` so that all threads can increment the `sequenceId` safely.

```
def incrementSequenceId(self) -> None:
    with self.sequenceIdLock:
        self.sequenceId += 1
```

The `threading` module also provides the `Event` class. This allows easy communication between threads and is used for the `isRunning` field to stop all threads whenever any thread resets the `Event` to `False`.

5.4.1.4.2 Inbound Thread

The `inboundThread` field is defined as `Thread(name="Inbound", target=self.listen, daemon=True)` on a `Node`'s `__init__`.

The `listen` method waits for an incoming package and yield to the `receive` method. This happens in a loop until `isRunning` is reset.

```
def listen(self):
    while self.isRunning.is_set():
        p, addr = self.receivePacket()
        self.receive(p, addr)
```

The `receive` method is responsible for passing the package to the appropriate packet type receive method.

```
def receive(self, p: packet.Packet, addr: tuple[str, int]):
    if p is not None:
        match (p.packet_type):
            case packet.Type.DEFAULT:
                return self.receiveDefault(p, addr)
            # other packet type cases omitted for clarity
            case _:
                raise TypeError(f"Unknown packet type '{p.packet_type}' for
                    packet {p}")
```

The `Server` uses it own `listen` method. It uses this to only allow certain packets depending on the state of the client's handshake. If the client has not yet initiated handshake, and thus does not exist, all packets other than `AUTH` are dropped. If a client has started, and thus exists, but has not completed the handshake only `AUTH` and `ACK` packets are passed. The `Server` otherwise accepts all packets from a *connected* client (i.e. a client with a completed handshake).

```
def listen(self) -> None:
    while self.isRunning.is_set():
        p, addr = self.receivePacket()
        if p is not None and addr is not None:
            if self.checkClientExists(addr):  # client exists
                if self.getHandshake(addr):  # client handshake complete =>
                    allow all packet types
                    self.receive(p, addr)
                else:
                    if p.packet_type in (packet.Type.AUTH, packet.Type.ACK):
                        # client handshake incomplete => drop all non-AUTH |
                        non-ACK packets
                        self.receive(p, addr)
            else:
```

```
12                 if p.packet_type in (packet.Type.AUTH):  # client not exists
                       => drop all non-AUTH packets
13                     self.receive(p, addr)
```

5.4.1.4.3 Outbound Thread

The `outboundThread` field is defined as `Thread(name=f"Outbound", target=self.sendQueue, daemon=True)` on a `Node`'s `__init__`. In order for the the `sendQueue` method to be able to send packages they first need to be added to a `queue.Queue`. A `Queue` is a thread-safe data structure with built in locking, allowing for multiple threads to safely add and remove data in the same variable.

```
1 def sendQueue(self):
2         while self.isRunning.is_set():
3             addr, p = self.queue.get()
4             self.sendPacket(addr, p)
5             self.queue.task_done()
6             time.sleep(SLEEP_TIME)  # some small time delay
```

The send methods are replaced by their receptive queue methods. Instead of sending the packet they instead yield to the `queuePacket` method.

```
1 def queueDefault(self, addr:tuple[str, int], data:bytes|None=None) -> None:
2     p = packet.Packet(sequence_id=self.sequenceId, data=data)
3     self.incrementSequenceId()
4     self.queuePacket(addr, p)
```

The `queuePacket` method, in turn, appends the packet (with the relent destination address) to the queue. This method is also used to apply the reliant flag behavior(s).

```
1 def queuePacket(self, addr: tuple[str, int], p: packet.Packet) -> None:
2     # logic for flags omitted
3     self.queue.put((addr, p))
```

5.4.1.4.4 Server Clients

The `Server`, now being threaded, is able to accept multiple clients. Whenever a new handshake is started by a client, a new `Node` is created and added to a dictionary field `clients` (using the client address as the key). The `Node` uses the server's socket to send replies to a client and as such the `Node` class is refactored to take a `socket` as well as a `Lock`. The `Lock` is used whenever a packet is sent, to ensure thread-safety. Using a `Node` for tracking clients allows for each client connection to have its own `sequenceId`, (as well as `sessionKey`, `ecKey`, etc. described in later iterations).

```
1 def makeClient(self, clientAddr: tuple[str, int]) -> None:
2         c = node.Node(
3             clientAddr,
4             sendLock=self.sendLock,
5             socket=self.socket,
```

```
        )
        c.outboundThread.start()
        with self.clientsLock:
            self.clients[clientAddr] = c
```

Additionally, all `Node` fields are refactored to use getter and setters taking an addr. This allows the `Server` class to override the setter and getters to instead return the relevant field from client in the dictionary. The `Server` also uses a `Lock` when retrieving client attributes.

```
def getSequenceId(self, clientAddr: tuple[str, int]) -> int | None:
        with self.clientsLock:
            return (
                self.clients[clientAddr].sequenceId
                if clientAddr in self.clients
                else None
            )
```

5.4.2 Iteration 2

5.4.2.1 RELIABLE Flag and ACK Packets

5.4.2.1.1 Sending a RELIABLE packet

When queuing a `RELIABLE` packet the `Node` sets the relevant sentAckBit to false before adding to the send queue.

```
def queuePacket(self, addr: tuple[str, int], p: packet.Packet) -> None:
    if p.flags[packet.Flag.RELIABLE.value]:
        self.setSentAckBit(addr, p.sequence_id, False) # set relevant ack bit
            to False
    self.queue.put((addr, p))
```

After a `Node` sends a packet with the `RELIABLE` flag set it appends the packet back to the end of the queue. The next time the `Node` goes to send the packet it first checks against its record of received ACKed packets. If the packet has already been ACK, the recipient has given confirmation of receival and the packet does not need to be resent. This helps to mitigate against packet loss as *critical* packets which are marked as `RELIABLE` will be resent until the `Node` is confident that that the recipient has received it.

```
def sendQueue(self):
    while self.isRunning.is_set():
        addr, p = self.queue.get()
        if p.flags[packet.Flag.RELIABLE.value]:
            if self.getSentAckBit(addr, p): # checks if ACKed
                self.queue.task_done()
                continue # skips
            else:
                self.sendPacket(addr, p) # sends
                self.queue.task_done()
```

```
                self.queue.put((addr, p)) # re-adds to the queue
        else:
            self.sendPacket(addr, p)
            self.queue.task_done()
        time.sleep(SEND_SLEEP_TIME)
```

5.4.2.1.2 Receiving a RELIABLE packet

When a `Node` receives a packet with the `RELIABLE` flag set, in addition to processing the packet as normal, the `Node` appends an `ACK` packets to its queue. The `ACK` package's `ACK ID` is set to the `Sequence ID` of the incoming package. The `Node` also keeps a record of sent `ACK` packet's to ensure that any repeat packets do not propagate to the *application layer*.

```
def handleReliable(self, p: packet.Packet, addr: tuple[str, int]) -> bool:
        if p.flags[packet.Flag.RELIABLE.value]:
            self.setRecvAckBit(addr, p.sequence_id, True) # set relevant recv
                bit
            self.queueACK(addr, p.sequence_id) # queues and ACK
            return True
        else:
            return False
```

The `handleReliable` method is called by the `handleFlags` method. This method is responsible for processing all flags *before* the `Node` attempts to process the packet instance.

```
def handleFlags(self, p: packet.Packet, addr: tuple[str, int]) -> bool:
    self.handleReliable(p, addr)
    return True
```

As such, the `receive` method is modified to first handle flags before processing.

```
def receive(self, p: packet.Packet, addr: tuple[str, int]):
    if p is not None:
        if self.handleFlags(p, addr):
            match (p.packet_type):
                # packet type cases omitted for clarity
                case _:
                    raise TypeError(f"Unknown packet type '{p.packet_type}'
                        for packet {p}")
```

5.4.2.1.3 Sending an ACK Packet

In addition to all of the fields used to queue a `DEFAULT` packet, the `ACK` packet also takes an `ackId` representing the packet to which the `ACK` is acknowledging.

```
def queueACK(self, addr: tuple[str, int], ackId: int, flags: list[bool] = [0
    for _ in range(packet.FLAGS_SIZE)], data: bytes | None = None) -> None:
        p = packet.AckPacket(
            sequence_id=self.getSequenceId(addr),
```

```
            flags=flags,
            ack_id=ackId,
            data=data,
        )
        self.incrementSequenceId(addr)
        self.queuePacket(addr, p)
```

5.4.2.1.4 Receiving an ACK Packet

When a `Node` receives an `ACK` packet is sets the relevant `ACK ID` in is record of received ACKed packets to `true`, thus preventing resending a confirmed packet.

```
def receiveAck(self, p: packet.AckPacket, addr: tuple[str, int]) ->
    tuple[packet.Packet, tuple[str, int]]:
    self.setSentAckBit(addr, p.ack_id, True)
    return (p, addr)
```

5.4.2.2 AUTH Packets The `X.509` certificates are generated in `udp.auth` taking a RSA private key for signing and are self-signed (i.e the subject is also the issuer).

```
def generateUserCertificate(key) -> x509.Certificate:
    name = [
        x509.NameAttribute(NameOID.ORGANIZATION_NAME, ORG_NAME), # ORG_NAME
            defined as const e.g. "Paperclip"
        x509.NameAttribute(NameOID.COMMON_NAME, COMMON_NAME), # COMMON_NAME
            defined as const e.g. "127.0.0.1"
    ]
    subject = issuer = x509.Name(name) # self signed
    cert = (
        x509.CertificateBuilder()
        .subject_name(subject)
        .issuer_name(issuer)
        .public_key(key.public_key())
        .serial_number(x509.random_serial_number())
        .not_valid_before(datetime.datetime.now(datetime.timezone.utc))
        .not_valid_after(
            datetime.datetime.now(datetime.timezone.utc) +
                datetime.timedelta(days=1) # valid for one day
        )
        .add_extension(
            x509.SubjectAlternativeName([x509.DNSName("localhost")]), # self
                signed
            critical=False,
        )
        .sign(key, hashes.SHA256())
```

```
    )
    return cert
```

The key and certificate are converted to and from `DER` bytes format when packing and unpacking.

```
def getDerFromPublicEc(publicKey: ec.EllipticCurvePublicKey) -> bytes:
    ecDer = publicKey.public_bytes(
        encoding=serialization.Encoding.DER,
        format=serialization.PublicFormat.SubjectPublicKeyInfo,
    )
    return ecDer
```

```
def getPublicEcFromDer(publicKeyDer: bytes) -> ec.EllipticCurvePublicKey:
    ec_ = serialization.load_der_public_key(publicKeyDer)
    return ec_
```

5.4.2.2.1 Sending an AUTH Packet

The `queueAuth` packet takes the additional fields of a certificate and a public key.

```
def queueAuth(self, addr: tuple[str, int], cert: Certificate, publicEc:
    auth.ec.EllipticCurvePublicKey) -> None:
    p = packet.AuthPacket(
        sequence_id=self.getSequenceId(addr), certificate=cert,
            public_key=publicEc
    )
    self.incrementSequenceId(addr)
    self.queuePacket(addr, p)
```

5.4.2.2.2 Receiving an AUTH Packet

The base `Node` class contains a `receiveAuth` method exclusively for use in overriding.

```
def receiveAuth(self, p: packet.AuthPacket, addr: tuple[str, int]) ->
    tuple[packet.Packet, tuple[str, int]]:
        raise NotImplementedError(
            "Node should not receive auth. A child class must overriding."
        )
```

The `Server` overrides this method with the logic for handling a handshake. The `Client` class, however, does not make use of this method as it handles all AUTH packets during its `connect` method.

5.4.2.3 Handshake The handshake is implemented according to the packet specification. The session key is generated with a `ECDH` key exchange in `udp.auth`.

```
def generateSessionKey(localKey: ec.EllipticCurvePrivateKey, peerKey:
    ec.EllipticCurvePublicKey) -> bytes:
    sessionSecret = localKey.exchange(ec.ECDH(), peerKey)
    sessionKey = HKDF(
        algorithm=hashes.SHA256(), length=32, salt=None, info=b"handshake
            data"
    ).derive(sessionSecret)
    return sessionKey
```

The `Finished` is computed by calculating the `HMAC` of the finishedLabel and messages using the session key.

```
def generateFinished(sessionKey: bytes, finishedLabel: bytes, messages:
    bytes):
    hashValue = hashes.Hash(hashes.SHA256())
    hashValue.update(messages)
    hashValue = hashValue.finalize()
    prf = hmac.HMAC(sessionKey, hashes.SHA256())
    prf.update(finishedLabel)
    prf.update(hashValue)
    prf = prf.finalize()
    return prf
```

5.4.2.3.1 Client Handshake

The `Client` is responsible for starting the handshake using the `connect` method. It starts by starting the `outboundThread` so it is able to send packets. It is then able to send a `AUTH` packet. The client then waits to receive both the `AUTH` and `ACK` packet from the `Server`.

When the `AUTH` packet is received the `Client` first generates the session key. It is then able to compute the `Finished` which is sent as the data field of an `ACK` packet. It also checks the validity of the `Server`'s certificate, aborting the connection attempt on a failure.

When both the `ACK` and `AUTH` packets are received the `Client` checks the validity of the `Finished` by checking its version of `Finished` against the contents of the `ACK` packet. On a failure, the connection is aborted. On a success, the `Client` starts the `inboundThread` and the connection is considered complete.

```
def connect(self) -> None:
    self.outboundThread.start() # start outbound
    self.queueAuth(self.targetAddr, self.cert, self.ecKey.public_key()) #
        send auth
    authPacket = None
    ackPacket = None
    while True:
```

```
7         p, addr = self.receivePacket()
8         if p is not None:
9             # logic
10            if p.packet_type == packet.Type.AUTH: # AUTH packet -> generate
                  session key, validate certificate, queueFinished
11                authPacket = p
12                self.sessionKey = auth.generateSessionKey(
13                    self.ecKey, p.public_key
14                )
15                if not self.validateCertificate(p.certificate):
16                    # certificate not valid
17                    # abort
18                    break
19                self.queueFinished(
20                    self.targetAddr, p.sequence_id, self.sessionKey
21                )
22            elif p.packet_type == packet.Type.ACK: # ACK packet
23                ackPacket = p
24                self.receiveAck(p, addr)
25            if authPacket is not None and ackPacket is not None: # wait until
                  both parts received
26                break
27        else:
28            # Server not responsive
29            # abort
30            break
31    if self.validateHandshake(ackPacket.data): # check finished
32        # success
33        self.inboundThread.start() # start inbound
34    else:
35        # abort
```

5.4.2.3.2 Server Handshake

The `Server`, being a passive listener to the handshake, overrides `receiveAuth` to respond accordingly. The handshake logic varies slightly depending on if the client is a new or existing client (i.e. reconnecting).

If the client is new, the `Server` first ensures it has space (set by the `maxClients` field) and then creates a new client.

If a new client has been created or the client already exists, the `Server` first checks the validity of the client's certificate. The `Server` then regenerates the `Node`'s `ecKey` to be used in generating the sessionKey. It is then able to send both the reply `AUTH` and `ACK` (containing the generated `Finished`).

```
def receiveAuth(self, p: packet.AuthPacket, addr: tuple[str, int]) ->
    tuple[packet.AuthPacket, tuple[str, int]]:
    if addr not in self.clients:  # new client
        if self.isNotFull():  # check space
            valid, accountId = self.validateCertificate(p.certificate)
            if not valid:
                # invalid certificate
                # abort
                return
            else:
                self.makeClient(addr, p.certificate, accountId)
                self.regenerateEcKey(addr)
                sessionKey = auth.generateSessionKey(
                    self.getEcKey(addr), p.public_key
                )
                self.setSessionKey(addr, sessionKey) # sets client sessionKey
                    for later reference
                self.queueAuth(addr, self.cert,
                    self.getEcKey(addr).public_key())
                self.queueFinished(addr, p.sequence_id,
                    self.getSessionKey(addr))
        else:
            # no space
            # abort
            return
    else:
        sessionKey = auth.generateSessionKey(self.getEcKey(addr),
            p.public_key)
    if addr in self.clients: # existing client
        if self.getSessionKey(addr) != sessionKey:  # new client sessionKey
            valid, accountId = self.validateCertificate(p.certificate)
            if not valid:
                # invalid certificate
                # abort
                # remove client
                return
            else:
                self.regenerateEcKey(addr)
                sessionKey = auth.generateSessionKey(
                    self.getEcKey(addr), p.public_key
                )
                self.setSessionKey(addr, sessionKey)  # make new session key
                self.queueAuth(addr, self.cert,
                    self.getEcKey(addr).public_key())
                self.queueFinished(addr, p.sequence_id,
```

```
                    self.getSessionKey(addr))
40    return (p, addr)
```

When the `Server` receives an `ACK` packet the server it checks that the packet's data matches the generated `Finished`. If the check fails, the connection is aborted and the handshake is not set to complete.

```
1 def receiveAck(self, p: packet.AckPacket, addr: tuple[str, int]) -> None:
2         super().receiveAck(p, addr)
3         if p.data is not None and not self.getHandshake(addr):  # ack has
              payload & client has not completed handshake => validate handshake
4             if not self.validateHandshake(addr, p.data): # checks and sets
                  the clients handshake
5                 # invalid finish
6                 # abort
7                 return
8             else:
9                 # success
10                pass
```

5.4.2.4 Flags All flags behaviors are executed on a packet (where set) before sending and after receiving meaning that the data yielded to the *application* layer is as it was originally set.

5.4.2.4.1 ENCRYPT

Encryption and decryption is performed using `AES` with the session key and a 16-bit init vector.

```
1 def generateCipher(sessionKey: bytes, iv: bytes = generateInitVector()) ->
     tuple[Cipher, bytes]:
2     cipher = Cipher(algorithms.AES(sessionKey), modes.CBC(iv))
3     return cipher, iv
```

5.4.2.4.1.1 Encryption

When a `Node` goes to queue a packet with the `ENCRYPT` flag set it calls `p.encryptData(self.getSessionKey` (where `p` is the packet). The `encryptData` method generates an `init vector` and subsequent `cipher` before performing the encryption on the data.

```
1 def encryptData(self, session_key: bytes) -> None:
2     self.flags[Flag.ENCRYPTED.value] = 1 # ensure flag set
3     iv = (
4         self.init_vector
5         if self.init_vector is not None
6         else auth.generateInitVector() # equivalent to os.urandom(16)
```

```
    )
    cipher, iv = auth.generateCipher(session_key, iv)
    self.init_vector = iv # assign to header
    self.data = auth.encryptBytes(cipher, self.data)
```

The `encryptBytes` method includes the `autoPad` boolean. This ensure thats the `rawBytes` are a suitable length for the `cipher` to encrypt.

```
def encryptBytes(cipher: Cipher, rawBytes: bytes, autoPad=True) -> bytes:
    if autoPad:
        padder = padding.PKCS7(algorithms.AES.block_size).padder()
        rawBytes = padder.update(rawBytes) + padder.finalize()
    encryptor = cipher.encryptor()
    encryptedBytes = encryptor.update(rawBytes) + encryptor.finalize()
    return encryptedBytes
```

5.4.2.4.1.2 Decryption

When a `Node` receives a packet with the `ENCRYPT` flag set, it calls `p.decryptData(self.getSessionKey(add` (where `p` is the packet). The `decryptData` method first checks that the packet is flagged appropriately (to prevent trying to decrypt an unencrypted packet). It then generates a `cipher` using the packet's init vector and uses this to decrypt the packet data.

```
def decryptData(self, session_key: bytes) -> None:
    if self.flags[Flag.ENCRYPTED.value]:
        cipher = auth.generateCipher(session_key, self.init_vector)[0]
        self.data = auth.decryptBytes(cipher, self.data)
    else:
        # not flagged for decryption
```

The `decryptBytes` method contains the `autoUnpad` boolean. This is used to automatically remove any padding left by the encryption process.

```
def decryptBytes(cipher: Cipher, encryptedBytes: bytes, autoUnpad: bool =
   True) -> bytes:
    decryptor = cipher.decryptor()
    decryptedBytes = decryptor.update(encryptedBytes) + decryptor.finalize()
    if autoUnpad:
        unpadder = padding.PKCS7(algorithms.AES.block_size).unpadder()
        decryptedBytes = unpadder.update(decryptedBytes) + unpadder.finalize()
    return decryptedBytes
```

5.4.2.4.2 COMPRESS

The `COMPRESSED` flag allows for the data to be automatically compressed and decompressed when the flag is set.

5.4.2.4.2.1 Compression

When the `Node` goes to queue a packet with the `COMPRESSED` flag set it first calls for the packet to be compressed using the packet's `compressData` method.

```
def compressData(self) -> None:
    self.flags[Flag.COMPRESSED.value] = 1 # ensure flag set
    self.data = utils.compressData(self.data)
```

The `utils.compressData` method uses the `zlib` library with the default `level`, which compromises speed with efficiency, but the negative of the default `wbits` to enure that no header or checksum is appended to the bytes as this would create unnecessary overhead.

```
def compressData(data: bytes) -> bytes:
    # default speed
    # no header or checksum
    return zlib.compress(data, -1, -15)
```

5.4.2.4.2.2 Decompression

When a `Node` receives a packet with the `COMPRESS` flag set it first calls for the packet to be decompressed using the packet's `decompressData` method.

```
def decompressData(self) -> None:
    if self.flags[Flag.COMPRESSED.value]:
        self.data = utils.decompressData(self.data)
    else:
        # not flagged for decompression
```

The `utils.decompressData` method performs the `zlib` decompression using the same `wbits` as the compression to not expect a header or checksum.

```
def decompressData(data: bytes) -> bytes:
    # no header or checksum
    return zlib.decompress(data, -15)
```

5.4.2.4.3 CHECKSUM

The checksum is defined in the packet specification as a `CRC-32` checksum of a packet's data. The `zlib` library includes a method to generate a `CRC-32` checksum, which this project utilizes.

```
def generateChecksum(data: bytes) -> int:
    return zlib.crc32(data)
```

5.4.2.4.3.1 Setting a Checksum

When a `Node` goes to queue a packet with the `CHECKSUM` flag set, it first calls for the checksum to be set using the packet's `setChecksum` method.

```
def setChecksum(self) -> None:
    self.flags[Flag.CHECKSUM.value] = 1 # ensure flag set
```

```
3     data = self.data if self.data is not None else b"" # sets to empty byte
          string if None
4     self.checksum = utils.generateChecksum(data) # assign to header
```

5.4.2.4.3.2 Validating a Checksum

When a `Node` receives a packet with the `CHECKSUM` flag set, it first checks the packet's data against the checksum using the packet's `validateChecksum` method. The `Node` does not drop the packet on a failure but does raise a warning that the checksum failed.

```
1 def validateChecksum(self) -> bool:
2     if self.flags[Flag.CHECKSUM.value]:
3         data = self.data if self.data is not None else b"" # sets to empty
              byte string if None
4         return self.checksum == utils.generateChecksum(data)
5     else:
6         # not flagged for checksum validation
```

5.4.2.4.4 FRAG

The `FRAG` flag allows for the automatic *fragmentation* of the packet's data into serval sub-packages. These are then resembled into a final *super-packet* once the recipient has collected all the fragments.

5.4.2.4.4.1 Fragmentation

When the `Node` goes to queue a packet with the `FRAG` flag set, the `Node` first calls the packet's `fragment` method. This method splits the packets data into fragmented chunks and creates a list of *fragment* packets.

```
1  def fragment(self):
2      self.flags[Flag.FRAG.value] = 1 # ensure flag set
3      header = Packet._getHeader(self) # returns dictionary of packet's headers
           (where set)
4      fragData = utils.fragmentData(self.data)
5      fragment_number = len(fragData)
6      return [
7          self._createFragment(
8              header, fragment_id=i, fragment_number=fragment_number, data=data
                   # set fragment_id, fragment_number and data through
                   comprehension
9          )
10         for i, data in enumerate(fragData)
11     ]
```

The `_createFragment classmethod` creates a new class instance with the given attributes.

```python
@classmethod
def _createFragment(
    cls, header: dict, fragment_id: int, fragment_number: int, data: bytes
):
    return cls(
        **header,
        fragment_id=fragment_id,
        fragment_number=fragment_number,
        data=data,
    )
```

The `utils.fragmentData` method splits the data into a list of bytes, splitting the data into fragments with a max size `MAX_FRAGMENT_SIZE`. The `MAX_FRAGMENT_SIZE` is set to 988 to keep the total packet size under 1024 (`SOCKET_BUFFER_SIZE`) when including the maximum theoretical header size.

```python
def fragmentData(data: bytes) -> list[bytes]:
    return [
        data[i : i + MAX_FRAGMENT_SIZE] for i in range(0, len(data),
            MAX_FRAGMENT_SIZE)
    ]
```

5.4.2.4.4.2 Defragmentation

In order to collect all the fragments for reassembly, the `Node` class contains a dictionary `fragBuffer` using the fragments `sequence_id` as the key and a list of the fragments as the values. When a `Node` receives a packet with the `FRAG` flag set it appends it to the `fragBuffer` (creating a new entry if required). It then checks to see if all the `fragBuffer[p.sequence_id]` are set. If so, the fragments can be recompiled into the *super-packet* and passed to `receive` and the buffer entry can be deleted.

```python
def handleFrag(self, p: packet.Packet, addr: tuple[str, int]) -> bool:
    if p.flags[packet.Flag.FRAG.value]:
        if p.sequence_id not in self.getFragBuffer(addr): # new fragment
            sequence id
            self.getFragBuffer(addr)[p.sequence_id] = [
                None for _ in range(p.fragment_number) # Empty list with size
                    == p.fragment_number
            ]
        self.getFragBuffer(addr)[p.sequence_id][p.fragment_id] = p
        if all(self.getFragBuffer(addr)[p.sequence_id]): # all list members
            not None
            defrag = p.defragment(self.getFragBuffer(addr)[p.sequence_id])
            del self.getFragBuffer(addr)[p.sequence_id] # remove fragment
                sequence id from dict
            self.receive(defrag, addr)
        return True
```

```
    else:
        return False
```

The `defragment classmethod` creates a new *super-packet* from a list of fragments.

```
@classmethod
def defragment(cls, frags):
    if frags[0].flags[Flag.FRAG.value]: # assumes all packets flag state
        based on the first's
        header = Packet._getHeader(frags[0])
        header["flags"][Flag.FRAG.value] = 0 # de-sets the FRAG flag
        data = utils.defragmentData([frag.data for frag in frags])
        return cls(**header, data=data)
    else:
        # not flagged for defragmentation
```

The `utils.defragmentData` method takes a list of bytes and returns the joined cohesive bytes.

```
def defragmentData(fragments: list[bytes]) -> bytes:
    return b"".join(fragments)
```

5.4.2.4.5 Automatic Handling

The `Node`'s `queuePacket` method is now able to handle all flag variants. The order in which the `Node` performs each flag action is based on the order described by the `Flags`.

```
def queuePacket(self, addr: tuple[str, int], p: packet.Packet) -> None:
    # reliable -> checksum -> compress -> encrypt -> frag
    if p.flags[packet.Flag.RELIABLE.value]:
        self.setSentAckBit(addr, p.sequence_id, False)
    if p.flags[packet.Flag.CHECKSUM.value]:
        p.setChecksum()
    if p.flags[packet.Flag.COMPRESSED.value]:
        p.compressData()
    if p.flags[packet.Flag.ENCRYPTED.value]:
        p.encryptData(self.getSessionKey(addr))
    if p.flags[packet.Flag.FRAG.value]:
        frags = p.fragment()
        for frag in frags:
            self.getQueue(addr).put((addr, frag)) # queue each fragment
    else:
        self.getQueue(addr).put((addr, p)) # queue packet
```

Similarly, the `Nodes handleFlags` method is now able to handle all flag variants. The order in which the `Node` handles each flag is based on the **reverse** of the order described by the

`Flags`. All the handle methods return a boolean indicating if the flag is present and, thus, the flag action was performed. This is used to return a boolean based on if the packet was a fragment packet. The `receive` method checks the result of `handleFlags` and skips further processing in the event that the flag was a fragment.

```
def handleFlags(self, p: packet.Packet, addr: tuple[str, int]) -> bool:
    # defrag -> decrypt -> decompress -> validate checksum -> reliable
    if self.handleFrag(p, addr):
        return False
    else:
        self.handleEncrypted(p, addr)
        self.handleCompressed(p, addr)
        self.handleChecksum(p, addr)
        self.handleReliable(p, addr)
        return True
```

5.4.3 Iteration 3

5.4.3.1 ACK Bits and Rolling Reset The `Node` class utilizes it local record of sent ACKed to set the `ACK Bits`. This helps to mitigate against packet loss as each `ACK` packet also includes an acknowledgment of the last 16 packets (if received). This means when a `Node` revives an `ACK` packet as well as setting the `ACK ID` in its received ACKed packets it also iterates over all the bits in the `ACK Bits` (with their ID set according to the packet specification) and sets accordingly.

```
def receiveAck(self, p: packet.AckPacket, addr: tuple[str, int]) ->
    tuple[packet.Packet, tuple[str, int]]:
    self.setNewestSeqId(
        addr, self.getNewerSeqId(self.getNewestSeqId(addr), p.sequence_id)
    )
    self.setSentAckBit(addr, p.ack_id, True)
    # set all bits from ack bits to true (to mitigate lost ack)
    for i, j in enumerate(range(p.ack_id - 1, p.ack_id - 1 -
        packet.ACK_BITS_SIZE, -1)):
        if p.ack_bits[i]:
            self.setSentAckBit(addr, j, True)
    return (p, addr)
```

The `Node` class also implements a rolling reset on its record of sent ACKs. Without this, the record becomes incorrect after the `sequence id` wrap around at 2^{16}. To do this the `Node` keeps a record of the *newest* sequence id it has received. To calculate the newer of two ids both ids are subtracted from each other to create two difference values which are both modded with 2^{16}. The smallest difference gives the newer id.

```
def getNewerSeqId(currentSeqId: int, newSeqId: int) -> int:
    currentDiff = (newSeqId - currentSeqId) % (2**16)
```

```
    newDiff = (currentSeqId - newSeqId) % (2**16)
    if newDiff < currentDiff:
        return currentSeqId
    else:
        return newSeqId
```

Every time a packet is received, it is checked against the newest sequence id and the newest id is updated accordingly. Then, when a `RELIABLE` packet is received, after updating the newest sequence id it calls `resetBits`.

```
def handleReliable(self, p: packet.Packet, addr: tuple[str, int]) -> bool:
    if p.flags[packet.Flag.RELIABLE.value]:
        self.setNewestSeqId(
            addr, self.getNewerSeqId(self.getNewestSeqId(addr), p.sequence_id)
        )
        self.setRecvAckBit(addr, p.sequence_id, True)
        self.resetRecvAckBits(addr)
        self.queueACK(addr, p.sequence_id)
        return True
    else:
        return False
```

The `resetBits` method iterates its sent ACKs from the `newest sequence id` to `(newest sequence id + half of array)% 2**16` and resets the bits to `None`. This resets half of all bits after the newest sequence id, accounting for the wrap around, to ensure that there is never confusion from a previously ACKed packet from before a wrap around.

```
def resetBits(sentACKs: list[bool | None]) -> None:
    ACK_RESET_SIZE = 2**15 # 2**16 / 2
    end = (newestSeqId - ACK_RESET_SIZE) % 2**16
    counter = 0
    while counter != end:
        sentACKs[(newestSeqId + 1 + counter) % 2**16] = None
        counter += 1
```

5.4.3.2 HEARTBEAT Packets

When a `Node` receives a packet it updates is `heartbeat` field to be the current datetime (`datetime.datetime.now()`). When a `Server` receives a packet from a client is also updates its heartbeat record for that client.

The `queueHeartbeat` method takes the additional boolean `heartbeat`.

```
def queueHeartbeat(self, addr: tuple[str, int], heartbeat: bool, flags:
    list[bool] = [0 for _ in range(packet.FLAGS_SIZE)], data: bytes | None =
    None) -> None:
        p = packet.HeartbeatPacket(
```

```
            sequence_id=self.getSequenceId(addr),
            flags=flags,
            heartbeat=heartbeat,
            data=data,
        )
        self.incrementSequenceId(addr)
        self.queuePacket(addr, p)
```

The `heartbeatThread` uses the `heartbeat` method.

```
def startThreads(self) -> None:
        super().startThreads()
        self.heartbeatThread.start()
```

The `Server` checks every `HEARTBEAT_MIN_TIME` (30 seconds) each *connected* client's heartbeat delta (`now() - client.heartbeat`). If the heartbeat delta is greater than some `HEARTBEAT_MAX_TIME` (120 seconds) the client is dropped as it can be assumed to have either terminated or be unresponsive. Otherwise, if the heartbeat delta is greater than `HEARTBEAT_MIN_TIME` the `Server` polls the client by sending a `PING` `HEARTBEAT` packet.

```
def heartbeat(self) -> None:
        while self.isRunning.is_set():
            time.sleep(HEARTBEAT_MIN_TIME)
            with self.clientsLock:
                clients = [k for k in self.clients.keys()]
            for clientAddr in clients:
                heartbeat = self.getHeartbeat(clientAddr)
                delta = (datetime.now() - heartbeat).seconds
                if delta > HEARTBEAT_MAX_TIME:
                    self.removeClient(
                        clientAddr,
                        debugStr=f"due to heartbeat timeout (last contact was
                            {heartbeat})",
                    )
                elif delta > HEARTBEAT_MIN_TIME:
                    self.queueHeartbeat(clientAddr, heartbeat=False)
```

```
def removeClient(self, clientAddr: tuple[str, int], debugStr="") -> None:
    if self.checkClientExists(clientAddr):
        cId = self.getClientId(clientAddr)
        with self.clientsLock:
            self.clients[clientAddr].isRunning.clear()
            del self.clients[clientAddr]
            if self.onClientLeave:
                self.onClientLeave(clientAddr, cId)
```

When a `Node` receives a `PING` HEARTBEAT packet is responds with a `PONG` heartbeat.

```
def receiveHeartbeat(
        self, p: packet.HeartbeatPacket, addr: tuple[str, int]
    ) -> tuple[packet.Packet, tuple[str, int]]:
        if not p.heartbeat:
            self.queueHeartbeat(addr, heartbeat=True)
            pass
        return (p, addr)
```

5.4.3.3 Callbacks

The `Node` class can be initiated with an `onReceiveData` callback (taking an addr and some data). This callback is executed whenever a default packet is received, allowing for yielding to an *application* layer.

The `Client` class can additionally be initiated with an `onConnect` callback (taking an addr). The callback is called after a successful handshake is completed, allowing for a game client to begin its `mainloop`.

The `Server` class can additionally be initiated with an `onClientJoin` and `onClientLeave` callback (taking an addr and a ID). These callbacks are called whenever a client is added (i.e. completes a handshake successfully) or removed from the `Server`'s record, allowing for a game server to track its members.

5.4.3.4 ERROR Packets

5.4.3.4.1 Exceptions

The python file `udp.error` includes custom `Exceptions` for all errors defined in the Packet Specification as well as `Enum` definitions for the `Major`, and each `Minor`, error code. A base `PaperClipError` class is defined, inheriting `Exception`. Additionally, a base `Minor` enum class is defined to be used as a parent class to the various minors.

```
class Major(Enum):
    ERROR = 0
    CONNECTION = 1
    DISCONNECT = 2
    PACKET = 3

class Minor(Enum): pass

class PaperClipError(Exception): """Unknown error"""
```

The three `Major` error types then inherent from `PaperClipError`. The relevant `Minor` error code and their `Exceptions` are defined using the `Minor` enum and the `Minor`'s parent `Major` Exception respectively. The method `getConnectionError` takes a `ConnectionErrorCodes` and returns the relevant `ConnectionError`. The method `getConnectionCode` performs the reverse. This pattern is defined for all `Major` and `Minor` Codes and their relevant `Exceptions`.

```
# connection
class ConnectionErrorCodes(Minor):
    CONNECTION = 0
    NO_SPACE = 1
    CERTIFICATE_INVALID = 2
    FINISH_INVALID = 3

class ConnectionError(PaperClipError): """Handshake connection could not be finished"""

class NoSpaceError(ConnectionError): """Server has insufficient space to accept new clients"""

class CertificateInvalidError(ConnectionError): """Certificate is invalid / can not be validated"""

class FinishInvalidError(ConnectionError): """Finish is invalid"""

_connectionErrors = {
    ConnectionErrorCodes.CONNECTION: ConnectionError,
    ConnectionErrorCodes.NO_SPACE: NoSpaceError,
    ConnectionErrorCodes.CERTIFICATE_INVALID: CertificateInvalidError,
    ConnectionErrorCodes.FINISH_INVALID: FinishInvalidError,
}

def getConnectionError(minor: ConnectionErrorCodes | int) -> ConnectionError:
    try:
        minor = minor if isinstance(minor, Minor) else
            ConnectionErrorCodes(minor)
        if minor in _connectionErrors:
            return _connectionErrors[minor]
        else:
            return PaperClipError
    except ValueError:
        return PaperClipError

def getConnectionCode(error: ConnectionError) -> ConnectionErrorCodes:
    try:
        return list(_connectionErrors.keys())[
            list(_connectionErrors.values()).index(error)
        ]
    except ValueError:
        return PaperClipError
```

Convenience methods allow for conversion between `Enums` and `PaperClipErrors`. The

`getError` method takes, either Enum or integer, `Major` and `Minor` codes are returns the relevant `Exception`.

```
def getError(major: Major | int, minor: Minor | int = 0) -> PaperClipError:
    try:
        major = major if isinstance(major, Major) else Major(major)
        match major:
            case Major.CONNECTION:
                return getConnectionError(minor)
            case Major.DISCONNECT:
                return getDisconnectError(minor)
            case Major.PACKET:
                return getPacketError(minor)
            case _:
                return PaperClipError
    except TypeError:
        return PaperClipError
```

The `getMinor` method takes a `Major` a int value minor and returns the respective `Minor`.

```
def getMinor(major: Major, minor: int) -> Minor:
    match major:
        case Major.CONNECTION:
            return ConnectionErrorCodes(minor)
        case Major.DISCONNECT:
            return DisconnectErrorCodes(minor)
        case Major.PACKET:
            return PacketErrorCodes(minor)
        case _:
            return Minor
```

The `getErrorCode` method performs the reverse of the `getError` method, taking an `PaperClipError` and returning the relevant `Major` and `Minor` `Enum`.

```
def getErrorCode(error: PaperClipError) -> tuple[Major, Minor]:
    match error:
        case c if issubclass(c, ConnectionError):
            return (Major.CONNECTION, getConnectionCode(error))
        case d if issubclass(d, DisconnectError):
            return (Major.DISCONNECT, getDisconnectCode(error))
        case p if issubclass(p, PacketError):
            return (Major.PACKET, getPacketCode(error))
        case _:
            return (Major.ERROR, Minor)
```

5.4.3.4.2 Sending an ERROR Packet

The Node's queueError method takes the additional Major and Minor fields. The method includes the check Node's sequenceId is None in which case it uses the value of 0 instead.

```
def queueError(
    self, addr: tuple[str, int], major: error.Major | int, minor: error.Minor
       | int, flags: list[int] = [0 for _ in range(packet.FLAGS_SIZE)], data:
       bytes | None = None
    ) -> None:
    sId = self.getSequenceId(addr)
    p = packet.ErrorPacket(
        sequence_id=sId if sId is not None else 0,
        flags=flags,
        major=major,
        minor=minor,
        data=data,
    )
    if sId is not None:
        self.incrementSequenceId(addr)
    self.queuePacket(addr, p)
```

ERROR packets are automatically queued whenever a PaperclipError is generated by surrounding any action that could potentially yield a relent error with try/except blocks. This includes all the unpacking of all the fields in the Packet with each raising the relevant PacketError. Additionally, ConnectionErrors can arise during the handshake with both the Client and Server aborting and sending the relevant ERROR packet.

```
def receivePacket(self,) -> tuple[packet.Packet, tuple[str, int]] |
   tuple[None, None]:
    data, addr = self.socket.recvfrom(SOCKET_BUFFER_SIZE)
    try:
        p = packet.unpack(data) # unpacking can yield a PacketError
        return p, addr
    except error.PacketError as e:
        major, minor = error.getErrorCod(e)
        self.queueError(addr, major, minor)
        return None, None
```

```
def receive(self, p: packet.Packet, addr: tuple[str, int]) ->
   tuple[packet.Packet, tuple[str, int]] | None:
    if p is not None:
        if self.handleFlags(p, addr):
            match p.packet_type:
                # packet type cases omitted for clarity
                case _: # unknown packet type
                    self.queueError(
                        addr,
                        major=error.Major.PACKET,
```

```
                        minor=error.PacketErrorCodes.PACKET_TYPE,
                        data=p.sequence_id,
                    )
```

5.4.3.4.3 Receiving an ERROR Packet

When receiving an `ERROR` packet, the `receive` method passes the packet to the `receiveError` method within a `try/except` block. The `receiveError` method derives and raises the relevant `PaperclipError` from the packet's `Major` and `Minor` fields. The data field is used to append additional information to the derived `Exception`. This causes the `try/except` block to pass the error to `handleError` which, in turn, passes the error to the relevant error handler.

```
case packet.Type.ERROR:
    try:
        return self.receiveError(p, addr)
    except error.PaperClipError as e:
        self.handleError(p, addr, e)
```

```
def receiveError(self, p: packet.ErrorPacket, addr: tuple[str, int]) -> None:
        raise error.getError(p.major, p.minor)(p.data)
```

```
def handleError(self, p: packet.ErrorPacket, addr: tuple[str, int], e:
    error.PaperClipError) -> None:
    match e:
        case error.ConnectionError():
            self.handleConnectionError(p, addr, e)
        case error.DisconnectError():
            self.handleDisconnectError(p, addr, e)
        case error.PacketError():
            self.handlePacketError(p, addr, e)
        case _:
            raise e
```

If a `Node` receives a `ConnectionError` the `Node` abort's the connection and calls the `quit` method to gracefully stop threads.

```
    def handleConnectionError(self, p: packet.ErrorPacket, addr: tuple[str,
        int], e: error.ConnectionError) -> None:
        match e:
            case error.NoSpaceError():
                return self.quit("no server space", e)
            case error.CertificateInvalidError():
                return self.quit("invalid certificate", e)
            case error.FinishInvalidError():
                return self.quit("invalid finish", e)
            case _:
                raise e
```

The `handleDisconnectError` provides a method to be overridden by the `Client` and `Server`.

```
    def handleDisconnectError(
        self, p: packet.ErrorPacket, addr: tuple[str, int], e:
           error.DisconnectError) -> None:
        match e:
            case error.ServerDisconnectError:
                pass  # overwrite
            case error.ClientDisconnectError:
                pass  # overwrite
            case _:
                raise e
```

If a `Node` receives a `PacketError` it performs no additional actions.

```
    def handlePacketError(self, p: packet.ErrorPacket, addr: tuple[str, int],
       e: error.PacketError) -> None:
        pass
```

5.4.3.5 Disconnects The `Node` provides an overridable convenience method for sending a `DisconnectError`. Both the `Client` and `Server` override this method to replace the minor with `error.DisconnectErrorCodes.CLIENT_DISCONNECT` and `error.DisconnectErrorCodes.SERVER_DISCONNECT` respectively.

```
def queueDisconnect(self, addr: tuple[str, int], flags: list[bool] = [0 for _
   in range(packet.FLAGS_SIZE)], data: bytes | None = None) -> None:
    self.queueError(
        addr,
        flags=flags,
        major=error.Major.DISCONNECT,
        minor=error.DisconnectErrorCodes.DISCONNECT,
        data=data,
    )
```

5.4.3.5.1 Client Disconnect

The `Client` overrides the `handleDisconnectError` method to call `_quit` on a `ServerDisconnectError`. The methods `quit` and `_quit` perform the same actions of gracefully stopping the threads but `quit` also includes sending a `ClientDisconnectError` to the server **before** terminating. As the `Server` has initiated the termination, `_quit` is called to skip sending the error.

```
def handleDisconnectError(
        self, p: packet.ErrorPacket, addr: tuple[str, int], e:
           error.DisconnectError
    ) -> None:
```

```
        match e:
            case error.ServerDisconnectError():
                self._quit(e)
            case error.ClientDisconnectError():
                pass  # should not react to client disconnect
            case _:
                raise e
```

5.4.3.5.2 Server Disconnect

The `Client` overrides the `handleDisconnectError` method to call `removeClient` to close the client instance `Node`. Unlike the `Client`, the `Server` does not terminate.

```
def handleDisconnectError(
        self, p: packet.ErrorPacket, addr: tuple[str, int], e:
           error.DisconnectError
    ) -> None:
        match e:
            case error.ServerDisconnectError():
                pass  # should not react to server disconnect
            case error.ClientDisconnectError():
                self.removeClient(addr, "The client has closed")
            case _:
                raise e
```

The `Server` also overrides the `queueDisconnect` to send a `ServerDisconnectError` to **all** clients. This is called on a `Server` `quit` (along with the termination of threads).

```
def queueDisconnect(self, flags: list[bool] = [0 for _ in
   range(packet.FLAGS_SIZE)], data: bytes | None = None):
    with self.clientsLock:
        clientAddrs = [addr for addr in self.clients]
    for addr in clientAddrs:
        self.queueError(
            addr,
            flags=flags,
            major=error.Major.DISCONNECT,
            minor=error.DisconnectErrorCodes.SERVER_DISCONNECT,
            data=data,
        )
```

5.4.4 Iteration 4

5.4.4.1 DotEnv Variables previously defined as `CONST`s are moved into a central `.env` file. This allows for easier value management.

```
# .env

# udp
S_HOST=127.0.0.1
S_PORT=2024
C_HOST=127.0.0.1
C_PORT=2025
## node
SOCKET_BUFFER_SIZE = 1024
SEND_SLEEP_TIME = 0.1
QUEUE_TIMEOUT = 10
SOCKET_TIMEOUT = 20
## server
HEARTBEAT_MAX_TIME = 120
HEARTBEAT_MIN_TIME = 30
MAX_CLIENTS
## auth
ORG_NAME = Paperclip
COMMON_NAME = 127.0.0.1
## utils
MAX_FRAGMENT_SIZE = 988

# client
TCP_PORT = 5000

# app
FLASK_APP = server
PRUNE_TIME = 58
SECRET_KEY = MyVerySecretKey
SQLALCHEMY_DATABASE_URI = mysql://root:root@localhost:3306/paperclip

# debug
DEBUG = True
```

The variables can then be loaded from the `os.environ` by first calling `dotenv.load_dot(".env")`. This is done each each package's `__init__` file.

The `udp.__init__` loads all the relevant variables for the `udp` package to constants, which can then in turn be imported in each script using `from . import VAR_NAME_ONE, VAR_NAME_TWO, VAR_NAME_N` (where `VAR_NAME` is the name of the `CONST` to be imported)

```
import os
import dotenv

dotenv.load_dotenv(".env")
S_HOST = os.environ.get("S_HOST")
```

```
S_PORT = int(os.environ.get("S_PORT"))
C_HOST = os.environ.get("C_HOST")
C_PORT = int(os.environ.get("C_PORT"))
# node
SOCKET_BUFFER_SIZE = int(os.environ.get("SOCKET_BUFFER_SIZE"))
SEND_SLEEP_TIME = float(os.environ.get("SEND_SLEEP_TIME"))
QUEUE_TIMEOUT = int(os.environ.get("QUEUE_TIMEOUT"))
SOCKET_TIMEOUT = int(os.environ.get("SOCKET_TIMEOUT"))
# server
HEARTBEAT_MAX_TIME = int(os.environ.get("HEARTBEAT_MAX_TIME"))
HEARTBEAT_MIN_TIME = int(os.environ.get("HEARTBEAT_MIN_TIME"))
MAX_CLIENTS = (
    int(os.environ.get("MAX_CLIENTS"))
    if os.environ.get("MAX_CLIENTS") is not None
    else float("inf")
)
# auth
ORG_NAME = os.environ.get("ORG_NAME")
COMMON_NAME = os.environ.get("COMMON_NAME")
# utils
MAX_FRAGMENT_SIZE = int(os.environ.get("MAX_FRAGMENT_SIZE"))
```

5.4.4.2 Logging A `logging.Logger` is used to provided runtime logging of system outputs. The logging module provides the option of logging with different levels (e.g. `DEBUG`, `INFO`, `ERROR`) allowing different situations to provide different outputs. A logger is initiated in the `udp.__init__` with a default log level of `DEBUG`. Additionally, `bcolors` includes a various `ASCII` color codes to allow for rich-color output to the console.

```
import logging
import sys

class bcolors:
    HEADER = "\033[95m"
    OKBLUE = "\033[94m"
    OKCYAN = "\033[96m"
    OKGREEN = "\033[92m"
    WARNING = "\033[93m"
    FAIL = "\033[91m"
    ENDC = "\033[0m"
    BOLD = "\033[1m"
    UNDERLINE = "\033[4m"

logger = logging.getLogger(__name__)
logger.setLevel(logging.DEBUG)
```

A `StreamHandler` `printHandler` is defined to output to `sys.stdout` with the default level of `INFO` allowing all messages with `INFO` or higher (i.e. not `DEBUG`) to be printed to the console. `printHandler` is given a `logging.Formatter` so that the `threadName` (colored blue) is recorded with the inputted message.

```
printHandler = logging.StreamHandler(sys.stdout)
printHandler.setLevel(logging.INFO)
printHandler.setFormatter(
    logging.Formatter(f"{bcolors.OKBLUE}%(threadName)s{bcolors.ENDC} -
       %(message)s")
)
logger.addHandler(printHandler)
```

A `FileHandler` `fileHandler` is defined to output to `paperclip.log` with the default level `DEBUG` meaning all messages are recorded. `fileHandler` is given a `Formatter` such that each message contains the `asctime`, `levelname` and `threadName` in addition to the inputted message. Additionally, a custom `logging.Filter` `ColorFilter` is defined to remove any ASCII color codes from messages allowing for log messages to include color codes for **only** the console output.

```
class ColorFilter(logging.Filter):
    colorCodes = [
        getattr(bcolors, attr) for attr in dir(bcolors) if not
           attr.startswith("__")
    ]

    def filter(self, record: logging.LogRecord) -> bool:
        for color in self.colorCodes:
            record.msg = record.msg.replace(color, "")
        return True

fileHandler = logging.FileHandler("paperclip.log")
fileHandler.setLevel(logging.DEBUG)
fileHandler.addFilter(ColorFilter())
fileHandler.setFormatter(
    logging.Formatter("%(asctime)s - %(levelname)s - %(threadName)s -
       %(message)s")
)
logger.addHandler(fileHandler)
```

The `logger.info` method is used to record typical behaviors.

```
logger.info(f"{bcolors.OKBLUE}> {addr} :{bcolors.ENDC}
   {bcolors.OKCYAN}{p}{bcolors.ENDC}") # INFO: log outgoing packet
logger.info(f"{bcolors.OKBLUE}< {addr} :{bcolors.ENDC}
   {bcolors.OKCYAN}{p}{bcolors.ENDC}") # INFO: log incoming packet
```

The `logger.warning` method is used to record whenever something has not occurred as expected (without causing an error)

```
logger.warning(f"\tInvalid checksum: {p}") # WARNING: log invalid checksum
```

The `logger.error` method is used to record whenever an error occurs.

```
logger.error(f"{bcolors.FAIL}# > {bcolors.ENDC}{bcolors.OKBLUE}{addr}
    :{bcolors.ENDC} {bcolors.FAIL}{type(e).__name__}:{e.args[0] if len(e.args)
    > 0 else ''}{p}{bcolors.ENDC}") # WARNING: log a PaperclipError
```

The `logger.critical` method is used to record whenever a **critical** error occurs meaning the program is unable to continue running.

```
logger.critical(f"Invalid peer cert {p.certificate}") # CRITICAL: log invalid
    (server) certificate yielding an abort
```

```
127.0.0.1 - - [10/May/2024 08:38:27] "GET /auth/token HTTP/1.1" 401 -
127.0.0.1 - - [10/May/2024 08:38:34] "GET /auth/token HTTP/1.1" 401 -
127.0.0.1 - - [10/May/2024 08:38:38] "GET /auth/token HTTP/1.1" 401 -
127.0.0.1 - - [10/May/2024 08:38:53] "GET /auth/token HTTP/1.1" 200 -
127.0.0.1 - - [10/May/2024 08:38:53] "GET /auth/key HTTP/1.1" 200 -
127.0.0.1 - - [10/May/2024 08:38:57] "GET /friends/ HTTP/1.1" 200 -
127.0.0.1 - - [10/May/2024 08:39:12] "GET /auth/token HTTP/1.1" 200 -
127.0.0.1 - - [10/May/2024 08:39:12] "GET /auth/key HTTP/1.1" 200 -
127.0.0.1 - - [10/May/2024 08:39:13] "GET /friends/ HTTP/1.1" 200 -
127.0.0.1 - - [10/May/2024 08:39:54] "GET /games/ HTTP/1.1" 200 -
127.0.0.1 - - [10/May/2024 08:39:58] "GET /lobby/find HTTP/1.1" 404 -
5001:Inbound - Listening @ ('127.0.0.1', 5001)
127.0.0.1 - - [10/May/2024 08:39:58] "POST /lobby/create HTTP/1.1" 201 -
127.0.0.1 - - [10/May/2024 08:39:59] "GET /lobby/ HTTP/1.1" 200 -
5001:Inbound - < ('127.0.0.1', 2025) : <0:AUTH 0 00000000 b'' [961:0]>
5001:Inbound - # Handshake with ('127.0.0.1', 2025) starting.
127.0.0.1 - - [10/May/2024 08:40:00] "GET /auth/certificate/validate HTTP/1.1" 200 -
2025:Outbound - > ('127.0.0.1', 2025) : <0:AUTH 0 00000000 b'' [891:0]>
127.0.0.1 - - [10/May/2024 08:40:00] "GET /auth/certificate/validate HTTP/1.1" 200 -
5001:Inbound - < ('127.0.0.1', 2025) : <0:ACK 1:0 00000000 b'\x04;\xee\xd0.\xb1\xb2\xe1\xddw\xb4'...'z' [46:32]>
5001:Inbound - # Handshake with ('127.0.0.1', 2025) successful.
2025:Outbound - > ('127.0.0.1', 2025) : <0:ACK 1:0 00000000 b'\x04;\xee\xd0.\xb1\xb2\xe1\xddw\xb4'...'z' [46:32]>
5001:Inbound - < ('127.0.0.1', 2025) : <0:DEFAULT 2 10000000 b'{"choice": '...'}' [19:13]>
2025:Outbound - > ('127.0.0.1', 2025) : <0:ACK 2:2 00000000 b'' [14:0]>
2025:Outbound - > ('127.0.0.1', 2025) : <0:HEARTBEAT 3 00000000 b'' [7:0]>
5001:Inbound - < ('127.0.0.1', 2025) : <0:HEARTBEAT 3 00000000 b'' [7:0]>
```

Figure 3: example of server console output

5.4.4.3 Database Models The database models are implemented as `SQLAlchemy db.models`.

```
uri = os.environ.get("SQLALCHEMY_DATABASE_URI") # get uri from .env
_init = False
if not database_exists(uri): # create database if not exists
    _init = True
```

```
    create_database(uri)
app.config["SQLALCHEMY_DATABASE_URI"] = uri

db.init_app(app)

with app.app_context():
    db.create_all() # create all tables

if _init: # if database was created
    with app.app_context(): # create some dummy data
        # init games
        from rps import ID, NAME, MIN_PLAYERS, MAX_PLAYERS
        Statement.createGame(ID, NAME, MIN_PLAYERS, MAX_PLAYERS)
        # example accounts
        m = Statement.createAccount("Mario", "ItsAMe123")
        p = Statement.createAccount("Peach", "MammaMia!")
        b = Statement.createAccount("Bowser", "M4r10SucK5")
        Statement.createFriends(m.id, p.id)
        Statement.createFriends(p.id, b.id)
```

The models were largely implemented according to the `ERD` with some additional fields. The `Statement` class contains various convenience methods for acting on the database (i.e. getting, creating and deleting rows).

5.4.4.3.1 Friends Model

The `Friends` class is implemented according to the `ERD`.

```
class Friends(db.Model):
    account_one_id = db.Column(
        db.Integer, db.ForeignKey("account.id"), primary_key=True
    )
    account_two_id = db.Column(
        db.Integer, db.ForeignKey("account.id"), primary_key=True
    )
```

The `Statement` for creating friends ensures that `idOne < idTwo`. This allows for easier look-ups of the data as the oder of the given accountIds can be derived.

```
class Statement:
    @staticmethod
    def getFriends(accountId: int) -> list[Account]: # retrieve list of
        Accounts who are Friends with id
        friends = Friends.query.filter( # filter where either account_one_id
            or account_two_id is accountId
            (Friends.account_one_id == accountId)
            | (Friends.account_two_id == accountId)
```

```
        )
        friends = [ # get the account_id of the other account
            friend.account_one_id
            if friend.account_one_id != accountId
            else friend.account_two_id
            for friend in friends
        ]
        friends = [Statement.getAccount(id) for id in friends] # get list of
            accounts
        return friends

    @staticmethod
    def createFriends(accountIdOne: int, accountIdTwo: int) -> Friends: #
        create, commit and return Friends
        # enure that idOne < idTwo for index efficiency & easier look-up
        idOne = min(accountIdOne, accountIdTwo)
        idTwo = max(accountIdOne, accountIdTwo)
        friends = Friends(account_one_id=idOne, account_two_id=idTwo)
        db.session.add(friends)
        db.session.commit()
        return friends

    @staticmethod
    def removeFriends(accountIdOne: int, accountIdTwo: int) -> bool: # delete
        Friends. True on success.
        # ensure that idOne < idTwo
        idOne = min(accountIdOne, accountIdTwo)
        idTwo = max(accountIdOne, accountIdTwo)
        friends = Friends.query.filter(
            (Friends.account_one_id == idOne) & (Friends.account_two_id ==
                idTwo)
        )
        if friends is not None:
            friends.delete() # delete
            db.session.commit()
            return True
        else:
            return False
```

5.4.4.3.2 Game Model

The `Game` model was expanded to also include a string `Name`, for better usability, as well as integer `min_players` and `max_players` fields so a game server is able to start the game after enough members have joined as well as prevent too many players from joining respectively. The `max_players` is also used so the `API Server` (via the `LobbyHandler`) can tell which

Lobbies are full.

```
class Game(db.Model):
    id = db.Column(db.Integer, primary_key=True)
    name = db.Column(db.String(255), unique=True, nullable=False)
    min_players = db.Column(db.Integer, default=1)
    max_players = db.Column(db.Integer)
```

Statements are defined to allow for the creation and retrieval of Games. The getGames method allows for all games to be retrieved.

```
class Statement:
    @staticmethod
    def getGame(gameId: int) -> Game:
        return Game.query.filter_by(id=gameId).scalar() # retrieve Game by id

    @staticmethod
    def getGames() -> list[Game]:
        return Game.query.all() # retrieve all Game

    @staticmethod
    def createGame(id:int, name:str, min_players:int, max_players:int) ->
        Game: # create, commit and return Game
        game = Game(id=id, name=name, min_players=min_players,
            max_players=max_players)
        db.session.add(game)
        db.session.commit()
        return game

    @staticmethod
    def findGame(gameName: str) -> Game | None:
        return Game.query.filter_by(name=gameName).scalar() # retrieve Game
            by name
```

5.4.4.3.3 Account Model

The Account model was expanded to also include private_key and public_key which are DER bytes formatted versions of each account's RSA key. SQLAlchemy also allows for models to contain additional methods for use with instance variables. This allowed for security features such as the hashing of passwords and generation of RSA key to be performed on a new instance before it is committed to the database.

```
class Account(db.Model):
    id = db.Column(db.Integer, primary_key=True)
    username = db.Column(db.String(255), unique=True, nullable=False)
    password = db.Column(db.String(162), nullable=False)
    private_key = db.Column(db.LargeBinary(1337)) # DER bytes private RSA key
    public_key = db.Column(db.LargeBinary(294)) # DER bytes public RSA key
```

```
7
8       def hashPassword(self, password: str) -> None:
9           self.password = generate_password_hash(password)
10
11      def verifyPassword(self, password: str) -> bool:
12          return check_password_hash(self.password, password)
13
14      def generateKey(self, password: bytes) -> None:
15          k = auth.generateRsaKey()
16          self.private_key = auth.getDerFromRsaPrivate(k, password) # encrypts
                DER with password for security
17          self.public_key = auth.getDerFromRsaPublic(k.public_key())
18
19      @staticmethod
20      def decryptKey(self, key: bytes, password: bytes) ->
            auth.rsa.RSAPublicKey:
21          k = auth.getRsaPrivateFromDer(key, password)
22          return k
```

`Statements` are defined to allow for the creation and retrieval of `Accounts`. The `createAccount` method ensures that the password is hashed as well as generating a RSA key for the `Account` before the it is committed.

```
1  class Statement:
2      # get
3      @staticmethod
4      def getAccount(userId: int) -> Account:
5          return Account.query.filter_by(id=userId).scalar() # retrieve Account
               by id
6
7      # create
8      @staticmethod
9      def createAccount(username: str, password: str) -> Account: # create,
           commit and return Account
10         account = Account(username=username)
11         account.hashPassword(password) # hash password
12         account.generateKey(password.encode()) # generate RSA key
13         db.session.add(account)
14         db.session.commit()
15         return account
16
17     # find
18     @staticmethod
19     def findAccount(username: str) -> Account | None:
20         return Account.query.filter_by(username=username).scalar() # retrieve
               Account by username
```

5.4.4.3.4 Lobby Model

Finally, upon reflection, the `Lobby` and `LobbyMembers` models and their behaviour were better suited as python class instances (i.e. were removed from the database). The `Lobby` model was refactored into a `Lobby` class which is responsible for initiating and running a game server instance. In addition to this, the `Lobby` class is responsible for tracking and reporting lobby members, so no `LobbyMembers` class is needed.

```
def isNotFull(self) -> bool:
    return self.gameServer.isNotFull()

def isEmpty(self) -> bool:
    return len(self.members) == 0
```

A `LobbyHandler` class was created to manage the creation of `Lobbys` and the `API Server` uses this when dispatching new `Lobbys` rather than creating them directly. The `LobbyHandler` is also responsible for *pruning* lobbies. In a `pruneThread` the `LobbyHandler` iterates over all of the `Lobby` instances and checks their heartbeat (in a similar fashion to how a `udp.Server` removes old clients). The `prune` method creates a copy of `lobbies` list to iterate over (rather than iterating over the `lobbies` themselves). It can be assumed that any `Lobbies` created during the execution of the prune loop will not be old enough to be pruned. If a `Lobby` has contained no members for some `PRUNE_TIME` (60 seconds) the `LobbyHandler` stops and removes it to free up resources.

```
def prune(self) -> None:
        while self.isRunning:
            with self.lobbiesLock:
                lobbies = self.lobbies.copy() # create copy to iterate over
                    for better thread-safety.
            for lobby in lobbies:
                if lobby.isPrune():
                    logger.info(
                        f"{bcolors.FAIL}# Lobby {lobby} was removed due to
                            PRUNE
                            (delta={lobby._heartbeatDelta()}){bcolors.ENDC}"
                    )
                    self.deleteLobby(lobby.addr)
            time.sleep(PRUNE_TIME)
```

The `Lobby` contains the `isPrune` method allowing the `LobbyHandler` to determine if the `Lobby` should be deleted.

```
def isPrune(self) -> bool:
    if isinstance(self.heartbeat, datetime.datetime):
        delta = self._heartbeatDelta()
        if delta > PRUNE_TIME:  # check if server has been empty for >
            PRUNE_TIME
            return True
```

```
    return False

def _heartbeatDelta(self) -> int:
        return (datetime.datetime.now() - self.heartbeat).seconds
```

When a client joins the `Lobby` it sets the heartbeat to `true` to indicate it has active members. When a client leaves the `Lobby`, if the `Lobby`'s has no members, it sets the heartbeat to `now()`.

```
def onJoin(self, addr: tuple[str, int], accountId: int) -> None:
    self.members.append(accountId)
    self.heartbeat = True

def onLeave(self, addr: tuple[str, int], accountId: int) -> None:
    self.members.remove(accountId)
    if self.isEmpty():
        self.heartbeat = datetime.datetime.now()
```

5.4.4.4 RESTful Server The `RESTful Server` was implemented using as a `Flask` app.

5.4.4.4.1 API Authentication

`HTTPBasicAuth` allows for easy authentication with a username and password and can restrict access to certain endpoints unless authentication is provided (using the `@auth.login_required` decorator). `JSON Web Tokens` (`JWT`) are used for session tokens, allowing a user to instead request and use a token for the rest of the session (or until the token expires) instead of using a username and password. This can help mitigate against any man-in-the-middle attacks as, if a token is successfully intercepted, it will only be useable for a limited time and the accounts credentials are not exposed.

The `verifyPassword` method used by `auth` first checks if it has been given a token. Otherwise, the method attempts to validate with the username and password.

```
auth = HTTPBasicAuth()

@auth.verify_password
def verifyPassword(username: str, password: str) -> bool:
    account = Statement.validateToken(username)  # check token
    if not account:  # if token not valid
        account = Statement.findAccount(username=username)  # check account
        if not account or not account.verifyPassword(
            password
        ):  # if account not exist or wrong password
            return False
    g.account = account # store (until overwrite) in flask globals
    return True
```

JWT tokens are generated using the Account class's generateToken method. The tokens include the Account.id and remain valid for expiration seconds (default to 600).

```
def generateToken(self, expiration: int = 600) -> str:
        data = {
            "id": self.id,
            "exp": datetime.datetime.now() +
               datetime.timedelta(seconds=expiration),
        }
        token = jwt.encode(data, current_app.config["SECRET_KEY"],
           algorithm="HS256")
        return token
```

Tokens are validated using Statement.validateToken which calls the Account.validateToken static method.

```
class Statement:
    @staticmethod
    def validateToken(token: str) -> Account | None:
        return Account.validateToken(token)
```

The Account.validateToken method performs the JWT decode function on the token. This includes checks for token expiry. On a success it returns the Account with the relevant id.

```
@staticmethod
def validateToken(token: str):
    try:
        data = jwt.decode(
            token,
            current_app.config["SECRET_KEY"],
            leeway=datetime.timedelta(seconds=10),
            algorithms=["HS256"],
        )
    except:
        return None
    account = Statement.getAccount(data.get("id"))
    return account
```

5.4.4.4.2 Endpoints

The endpoints are implemented according to the API specification.

5.4.4.4.2.1 Auth

The createAccount method is exposed at /auth/register and accepts **only** POST requests. The method takes a username and password field from the request's JSON and creates a new account. The Account.id and Account.username are returned with the HTTP code 201 to indicate successful account creation.

```python
@main.route("/auth/register", methods=["POST"])
def createAccount():
    username = request.json.get("username")
    password = request.json.get("password")
    if not (username or password):  # check not null
        abort(400)  # missing args
    if Statement.findAccount(username):  # check if account exists
        abort(400)  # account already exists
    account = Statement.createAccount(username, password)
    return jsonify({"account-id": account.id, "username": account.username}),
        201
```

The `getAuthToken` method is exposed at `/auth/token` and accepts **only** `GET` requests. The method generates and returns a token derived from the logged-in `Account`.

```python
@main.route("/auth/token")
@auth.login_required
def getAuthToken():
    return jsonify({"token": g.account.generateToken()})
```

The `getKey` method is exposed at `/auth/key` and accepts **only** `GET` requests. The method retrieves the `DER private_key` associated with the logged-in `Account`. The key is `base64` encoded as a sanitation step to ensure it can be encoded in `URL` safe `JSON`.

```python
@main.route("/auth/key")
@auth.login_required
def getKey():
    return jsonify(
        {
            "key": base64.encodebytes(g.account.private_key).decode(),
            "account-id": g.account.id,
        }
    )
```

5.4.4.4.2.2 Friends

The `getFriends` method is exposed at `/friends` and accepts **only** `GET` requests. The method returns a list of dictionaries of all `Account.id` and `Account.username` where the `Account` is friends with the logged-in account.

```python
@main.route("/friends/")
@auth.login_required
def getFriends():
    friends = Statement.getFriends(g.account.id)
    return jsonify(
        {
            "friends": [
```

```
                {"id": account.id, "username": account.username} for account
                    in friends
            ]
        }
    )
```

The `addFriend` method is exposed at `/friends/add` and accepts **only** `POST` request. The method derives two accounts, one from the logged-in account and the other from the username field in the request's `JSON`. The method then creates a new `Friends` entry and returns the `Account.id` and `Account.username` of both `Accounts` along with the `HTTP` code 201.

```
@main.route("/friends/add", methods=["POST"])
@auth.login_required
def addFriend():
    username = request.json.get("username")
    if username is None:
        abort(400)  # missing args
    account = g.account
    other = Statement.findAccount(username)
    if other is None:
        abort(404)
    Statement.createFriends(account.id, other.id)
    return jsonify(
        {
            "account": {"id": account.id, "username": account.username},
            "other": {"id": other.id, "username": other.username},
        }
    ), 201
```

The `removeFriend` method is exposed at `/friend/remove` and accepts **only** `DELETE` requests. The method derives two accounts, in the same way as `addFriend` and deletes the `Friends` from the database. The method returns 204 to indicate a successful deletion

```
@main.route("/friend/remove", methods=["DELETE"])
@auth.login_required
def removeFriend():
    username = request.json.get("username")
    if username is None:
        abort(400)  # missing args
    account = g.account
    other = Statement.findAccount(username)
    if other is None:
        abort(404) # no such account
    success = Statement.removeFriends(account.id, other.id)
    if success:
        return jsonify(data=[]), 204
```

```
    else:
        abort(404) # no such friends
```

5.4.4.4.2.3 Games

The `getGames` method is exposed at `/games` and accepts **only** `GET` request. The method returns a list of all available games.

```
@main.route("/games/")
@auth.login_required
def getGames():
    return jsonify({game.id: game.name for game in Statement.getGames()})
```

5.4.4.4.2.4 Lobby

The `getLobby` method is exposed at `/lobby` and acceptes **only** `GET` requests. The method derives a `Lobby` from the `LobbyHandler`, using the the `lobby-id` in the request's `JSON`, and returns the `Lobby`'s `id`, `addr` and `gameId`.

```
@main.route("/lobby/")
@auth.login_required
def getLobby():
    lobbyId = request.json.get("lobby-id")
    if not lobbyId:
        abort(400)  # missing args
    lobby = lobbyHandler.getLobby(lobbyId)
    return jsonify(
        {"lobby-id": lobby.id, "lobby-addr": lobby.getAddr(), "game-id":
            lobby.gameId}
    )
```

The `getLobbies` method at `/lobby/all` complies all lobbies currently in the `LobbyHandler`. It the returns a variety of information on each lobby in a list of dictionaries. The information includes the `lobby-id`, the `game` (with `game-id` and `game-name`) associated with the `Lobby`, the max `size` and if the lobby `is-full`.

```
@main.route("/lobby/all")
@auth.login_required
def getLobbies():
    lobbies = LobbyHandler.getAll()
    games = {game.id: game.name for game in Statement.getGames()}
    data = lambda lobby: {
        "game": {"game-id": lobby.game_id, "game-name": games[lobby.game_id]},
        "size": Statement.getLobbySize(lobby.id),
        "is-full": Statement.getIsLobbyFree(lobby.id),
    }
    return jsonify({lobby.id: data(lobby) for lobby in lobbies})
```

The `findLobby` method at `/lobby/find` finds a `Lobby` instance with available space (i.e. `isNotFull`) using either the `gameId` or `gameName` provided in the request's `JSON`. The method returns the `lobby-id`, `lobby-addr` and `game-id` in a dictionary.

```
@main.route("/lobby/find")
@auth.login_required
def findLobby():
    gameId = request.json.get("game-id")
    gameName = request.json.get("game-name")
    if not (gameId or gameName):  # check args
        abort(400)  # missing args
    game = None
    if gameId:  # check gameId not null
        game = Statement.getGame(gameId)
    if not game:  # check gameId null
        if gameName:  # check gameName not null
            game = Statement.findGame(gameName)
    if not game:  # check game null
        abort(404)  # no game found
    lobby = lobbyHandler.findLobbies(game.id)
    lobby = lobby[0] if len(lobby) > 0 else None
    if lobby is not None:
        return jsonify(
            {
                "lobby-id": lobby.id,
                "lobby-addr": lobby.getAddr(),
                "game-id": lobby.gameId,
            }
        )
    else:
        abort(404)
```

The `createLobby` method is exposed at `/lobby/create` and accepts **only** `POST` requests. The method creates a new `Lobby` instance using the `LobbyHandler` and the game.id derived from either the `game-id` or `game-name` included in the request's `JSON`.

```
@main.route("/lobby/create", methods=["POST"])
@auth.login_required
def createLobby():
    gameId = request.json.get("game-id")
    gameName = request.json.get("game-name")
    if not (gameId or gameName):  # check args
        abort(400)  # missing args
    game = None
    if gameId:  # check gameId not null
        game = Statement.getGame(gameId)
```

```
    if not game:  # check gameId null
        if gameName:  # check gameName not null
            game = Statement.findGame(gameName)
    if not game:  # check game null
        abort(404)  # no game found
    addr = _getAddr()
    lobby = lobbyHandler.createLobby(addr, game.id)
    return jsonify(
        {"lobby-id": lobby.id, "lobby-addr": lobby.getAddr(), "game-id":
            lobby.gameId}
    ), 201
```

The `getMembers` method at `/lobby/members/` returns a dictionary of all members of all lobbies.

```
@main.route("/lobby/members")
@auth.login_required
def getMembers():
    return jsonify(lobbyHandler.getMembers())

# LobbyHandler.getMembers
def getMembers(self) -> dict[int, list[int]]:
        with self.lobbiesLock:
            return {lobby.id: lobby.members for lobby in self.lobbies}
```

The `getFriendLobbies` method at `/lobby/friends` returns all `Lobbys` which contain an `Account` which is `Friends` with the logged-in `Account` as long as the `Lobby` has space. It calls `lobbyHandler.getMember` to retrieve the relevant `Lobbys`.

```
@main.route("/lobby/friends")
@auth.login_required
def getFriendLobbies():
    friends = Statement.getFriends(g.account.id)
    lobbyInfo = lambda lobby: {
        "lobby-id": lobby.id,
        "game-id": lobby.gameId,
        "game-name": Statement.getGame(lobby.gameId).name,
    }
    accountInfo = lambda account: {
        "account-id": account.id,
        "username": account.username,
    }
    lobbies = [
        {
            "account": accountInfo(account),
            "lobbies": [
```

```
                lobbyInfo(lobby) for lobby in
                    lobbyHandler.getMember(account.id)
            ],
        }
        for account in friends
        if len(lobbyHandler.getMember(account.id)) > 0
    ]
    return jsonify(lobbies)
```

The `LobbyHandler.getMember` method returns a list of all `Lobbys` an containing an `Account` with `Account.id == accountId`. It performs an additional check to only return `Lobbys` with available space (i.e. `isNotFull()`).

```
def getMember(self, accountId: int) -> list[Lobby]:
    with self.lobbiesLock:
        return [
            lobby
            for lobby in self.lobbies
            if lobby.isNotFull() and accountId in lobby.getMembers()
        ]
```

5.4.4.5 Certificates and Handshake Update The `validateCert` method is exposed at `auth/certificate/validate` and accepts **only** `GET` requests. The method a `DER` certificate from the request's `JSON` and (after `base64` decoding) converted to a `x509.Certificate` instance. The `Account` can then be derived using the `account-id` from the certificate attributes and the associated `DER` `Account.public_key` can be retried and converted to an `rsa.RSAPublicKey` instance. If an `account-id` is not present the certificate is checked against the `Server`'s `RSA` key. The validity can then be checked and returned along with the derived `Account.id`.

```
@main.route("/auth/certificate/validate")
def validateCert():
    valid = False
    certificate = request.json.get("certificate")
    certificate = base64.decodebytes(certificate.encode()) # base64 decode
    if certificate is not None:
        certificate = udp.auth.getCertificateFromDer(certificate) # get
            x509.Certificate instance
        attributes = udp.auth.getUserCertificateAttributes(certificate)
        if attributes["account-id"] is not None:
            account = Statement.getAccount(attributes["account-id"]) # get
                Account instance
            publicKey = udp.auth.getRsaPublicFromDer(account.public_key) #
                get rsa.RSAPublicKey instance
```

```
        else:
            publicKey = rsaKey.public_key()
        valid = udp.auth.validateCertificate(certificate, publicKey)
        return jsonify({"valid": valid, "account-id":
            attributes["account-id"]})
    else:
        abort(400)  # missing args
```

The `udp.auth.validateCertificate` method takes a `x509.Certificate` and `rsa.RSAPublicKey` instance. The method first checks that the certificate period. If the certificate has not expired the `publicKey` can then be used to verity the `certificate`. If a `InvalidSignature Exception` does not arises the method returns `True`. Otherwise, if either the period or verify checks fail, the method returns `False`.

```
def validateCertificate(certificate: x509.Certificate, publicKey:
    rsa.RSAPublicKey) -> bool:
    # period
    now = datetime.datetime.now(datetime.timezone.utc)
    if not (certificate.not_valid_before_utc <= now <=
        certificate.not_valid_after_utc): # check in period
        return False
    # signature
    try:
        publicKey.verify( # check against publicKey
            certificate.signature,
            certificate.tbs_certificate_bytes,
            aPadding.PKCS1v15(),
            certificate.signature_hash_algorithm,
        )
    except InvalidSignature:
        return False
    return True
```

The `udp.auth.generateUserCertificate` method is updated to allow for an `Account.id userId` and `Account.username username` to be passed for embedding into the `x509.NameAttributes`.

```
def generateUserCertificate(key, userId: int | str | None = None, username:
    str | None = None) -> x509.Certificate:
    name = [
        x509.NameAttribute(NameOID.ORGANIZATION_NAME, ORG_NAME),
        x509.NameAttribute(NameOID.COMMON_NAME, COMMON_NAME),
    ]
    if userId is not None:
        name.append(x509.NameAttribute(NameOID.USER_ID, str(userId)))
    if username is not None:
```

```
        name.append(x509.NameAttribute(NameOID.PSEUDONYM, username))
    subject = issuer = x509.Name(name)
    cert = (
            ### omitted for clarity
    )
    return cert
```

The `udp.Client.validateCertificate` method can now be defined using a `requests.get` to retrieve validation from the `RESTful` server.

```
def validateCertificate(self, certificate: auth.x509.Certificate) -> bool:
        url = f"http://{self.targetHost}:5000/auth/certificate/validate"
        headers = {"Content-Type": "application/json"}
        certificate = base64.encodebytes(
            auth.getDerFromCertificate(certificate)
        ).decode()
        data = {"certificate": certificate}
        try:
            r = requests.get(url, headers=headers, data=json.dumps(data))
            if r.status_code == 200:
                return r.json()["valid"]
            else:
                return False
        except:
            # server unresponsive
            return False
```

The `udp.Server.validateCertificate` is implemented as the same except for returning the `account-id` instead of the boolean `True`.

```
def validateCertificate(self, certificate: auth.x509.Certificate) -> bool|int:
    # omitted for clarity
        if r.status_code == 200:
            return r.json()["valid"], r.json()["account-id"]
        else:
            return False
    # omitted for clarity
```

5.4.4.6 RPS Demo The Rock, Paper, Scissors (`rps`) python package contains a game `rps.Server` and `rps.Client` using `udp.Server` and `udp.Client` respectively.

The choice and outcomes are defined in the package `__init__` allowing both the `Client` and `Server` to import them.

```
class Choice:
```

```
    ROCK = 0
    PAPER = 1
    SCISSORS = 2


class Outcome:
    LOOSE = 0
    WIN = 1
    DRAW = 2
```

The `Game` attributes are defined in `game_config.yaml`.

```
NAME: "RPS"
ID: 1
MIN_PLAYERS: 2
MAX_PLAYERS: 2
```

These can then be loaded using the `yaml` package in the `__init__`.

```
# config
CONFIG_PATH = os.path.join(os.path.dirname(__file__), "game_config.yaml")

with open(CONFIG_PATH) as f:
    config = yaml.safe_load(f)

ID = config["ID"]
NAME = config["NAME"]
MIN_PLAYERS = config["MIN_PLAYERS"]
MAX_PLAYERS = config["MAX_PLAYERS"]
```

5.4.4.6.1 Client

The `Client` contains a simple command line UI which guides the user through playing RPS. Once a user has inputted its choice it sends the choice (with the `RELIABLE` flag set) to the `Server` and waits for a reply. Upon receiving the outcome and scores, it displays the output to the user and waits for a new choice to be selected.

The `Client` uses the `onReceiveData` callback to receive data into the `receive` method where the data is added to a `queue.Queue recvQueue` after being decoded. All data is sent as `RELIABLE` default packets containing a `JSON` encoded payload.

```
def send(self, addr: tuple[str, int], data: json) -> None:
    self.udpClient.queueDefault(
        addr, flags=lazyFlags(Flag.RELIABLE), data=self.encodeData(data)
    )

def receive(self, addr: tuple[str, int], data: bytes) -> None:
    self.recvQueue.put((addr, self.decodeData(data)))
```

```
    if self.onReceiveData:
        self.onReceiveData(addr, data)

@staticmethod
def encodeData(data: dict) -> bytes:
    return json.dumps(data).encode()

@staticmethod
def decodeData(data: bytes) -> dict:
    return json.loads(data.decode())
```

The `gameloop` method takes a user input `choice` and sends it to the `Server`. It then waits for the `recvQueue` to contain a reply and then updates the score and displays the results to the user. The `gameThread` is defined as `self.gameThread = Thread(name=f"{addr[1]}:Gameloop", target=self.gameloop, daemon=True)` allowing the `gameloop` to execute in its own thread.

```
def gameloop(self) -> None:
    print(f"{bcolors.HEADER}\n\nRock Paper Scissors{bcolors.ENDC}")
    try:
        while self.isRunning:
            choice = None
            print("Choice R[0], P[1], S[2]: ")
            while choice is None:
                try:
                    choice = inputimeout("", timeout=10).strip()
                    if choice == "q":
                        print(
                            f"{bcolors.FAIL}Quitting. Please
                                wait...{bcolors.ENDC}"
                        )
                        self.isRunning = False
                        break
                    choice = int(choice)
                    if choice not in (0, 1, 2):
                        print(
                            f"{bcolors.FAIL}Invalid choice
                                '{choice}'.{bcolors.ENDC}"
                        )
                        choice = None
                except ValueError:
                    print(f"{bcolors.FAIL}Invalid choice.{bcolors.ENDC}")
                    choice = None
                except KeyboardInterrupt:
                    print(f"{bcolors.FAIL}Quitting. Please
                        wait...{bcolors.ENDC}")
```

```
                    self.isRunning = False
                    break
                except TimeoutOccurred:
                    if not self.isRunning:
                        break
            if self.isRunning:
                self.send(self.udpClient.targetAddr, {"choice": choice})
                print("Waiting for other player...")
                while self.isRunning:
                    try:
                        addr, data = self.recvQueue.get(timeout=QUEUE_TIMEOUT)
                        break
                    except Empty:
                        pass  # check still running
                if self.isRunning:
                    match data["outcome"]:
                        case 0:
                            o = f"You {bcolors.FAIL}LOOSE{bcolors.ENDC}. "
                        case 1:
                            o = f"You {bcolors.OKGREEN}WIN{bcolors.ENDC}. "
                        case 2:
                            o = f"You {bcolors.OKCYAN}DRAW{bcolors.ENDC}. "
                        case _:
                            o = ""
                    print(
                        f"\n{o}You Picked {data['choice']}. They picked
                           {data['otherChoice']}.\nThe score is
                           {data['score']['score']}:{data['otherScore']['score']}."
                    )
                    if data["outcome"] == Outcome.WIN:
                        self.score += 1
                    self.recvQueue.task_done()
    finally:
        self.udpClient._quit()
```

The `Client` utilizes the `onConnect` to start the `gameThread`.

```
def onConnect(self, addr: tuple[str, int]) -> None:
        self.gameThread.start()
        try:
            self.udpClient.mainloop(self.quit)
        except error.PaperClipError as e:
            match e:
                case error.ServerDisconnectError():
                    print(
                        f"{bcolors.FAIL}Server connection terminated due to
```

```
                            {error.DisconnectErrorCodes.SERVER_DISCONNECT.name}:
                            {e.args[0]}\nPlease wait while connection closes
                            gracefully...{bcolors.ENDC}"
                    )
                case _:
                    raise e
        if self.gameThread.is_alive():
            self.gameThread.join()
        return None
```

5.4.4.6.2 Server

The `Server` waits for two `Clients` to join and send their choices. The server then calculates the outcome (i.e. `WIN`, `LOSE`, `DRAW`) and sends this to both `Clients` along with their new scores.

The `Server` contains two static methods `evaluateWin` and `evaluatePlayerChoices` which are used to calculate the winner to two choices.

```
@staticmethod
def evaluateWin(choiceOne: int, choiceTwo: int) -> int:
    match choiceOne:
        case Choice.ROCK:
            match choiceTwo:
                case Choice.ROCK:
                    return Outcome.DRAW
                case Choice.PAPER:
                    return Outcome.LOOSE
                case Choice.SCISSORS:
                    return Outcome.WIN
                case _:
                    raise ValueError
        case Choice.PAPER:
            match choiceTwo:
                case Choice.ROCK:
                    return Outcome.WIN
                case Choice.PAPER:
                    return Outcome.DRAW
                case Choice.SCISSORS:
                    return Outcome.LOOSE
                case _:
                    raise ValueError
        case Choice.SCISSORS:
            match choiceTwo:
                case Choice.ROCK:
                    return Outcome.LOOSE
                case Choice.PAPER:
```

```
                    return Outcome.WIN
                case Choice.SCISSORS:
                    return Outcome.DRAW
                case _:
                    raise ValueError
        case _:
            raise ValueError

@staticmethod
def evaluatePlayerChoices(choices: list[tuple[tuple[str, int], int]]):
    outcomes = [
        (choices[0][0], Server.evaluateWin(choices[0][1], choices[1][1])),
        (choices[1][0], Server.evaluateWin(choices[1][1], choices[0][1])),
    ]
    return outcomes
```

The `onClientJoin` and `onClientLeave` callbacks are utilized to manage the `Server`'s player record `players`. `players` takes the form `dict[tuple[str, int], dict[str, int]]` where `Client` addresses are used as a key and the values contain a dictatory of player `accountId`s and `score`s. These values are retrieved and set through getters and setter which make use of a `thread.Lock` to ensure thread-safety.

```
def playerJoin(self, addr: tuple[str, int], accountId: int) -> None:
    with self.playersLock:
        self.players[addr] = {"score": 0, "accountId": accountId}
    if self.onClientJoin:
        self.onClientJoin(addr, accountId)

def playerLeave(self, addr: tuple[str, int], accountId: int) -> None:
    with self.playersLock:
        del self.players[addr]
    if self.onClientLeave:
        self.onClientLeave(addr, accountId)
```

The `Server` `mainloop` method waits for `MAX_PLAYERS` to join. Once enough players have join, the method calls `getChoices` and computes the `outcomes`. The `outcomes` are then restructured for each client into a payload and the scores are updated and included in the payload. The relevant payload is then dispatched to each client. The loop then checks that it is both running and the `Server` has the appropriate number of players. If so the loop repeats.

```
def mainloop(self) -> None:
        self.udpServer.startThreads()
        try:
            while self.isRunning:
                if self.playerCount == MAX_PLAYERS:
```

```
                    choices = self.getChoices()
                    outcomes = self.evaluatePlayerChoices(choices)
                    replies = {}
                    for addr, outcome in outcomes:
                        replies[addr] = {
                            "outcome": outcome,
                            "choice": [v for k, v in choices if k == addr][0],
                            "otherChoice": [v for k, v in choices if k !=
                                addr][0],
                        }
                        if outcome == Outcome.WIN:
                            self.incrementPlayer(addr)
                    scores = self.getPlayers()
                    for addr in replies:
                        replies[addr] |= {
                            "score": scores[addr],
                            "otherScore": [v for k, v in scores.items() if k
                                != addr][
                                0
                            ],
                        }
                        self.send(addr, replies[addr])
        finally:
            self.quit()
```

The `getChoices` method waits for inputs from all players before returning their choices.

```
def getChoices(self) -> list[tuple[tuple[str, int], int]]:
        choices = {}
        while self.isRunning:
            try:
                addr, data = self.recvQueue.get(timeout=QUEUE_TIMEOUT)
                choices[addr] = data["choice"]
                if len(choices) == 2:
                    choices = [(addr, choice) for addr, choice in
                        choices.items()]
                    self.recvQueue.task_done()
                    return choices
            except Empty:
                pass  # check still running
```

5.4.4.7 Client The `Client` python package contains a simple command line UI that handles communication (including providing the reliant authentication) to the RESTful server using the `requests` package. Once a user creates a new or joins a `Lobby` the `Client` creates

the relevant game client and connects to the game server. If a user exits a game, it is returned to the `Client` command line UI.

5.4.4.7.1 Authentication

On `Client` initialization the `Client` uses the provided username and password to retrieve the session token.

```
@staticmethod
def getToken(username: str, password: str) -> str:
    url = SERVER_URL + "/auth/token"
    r = requests.get(url, auth=(username, password))
    assert r.status_code == 200, r
    return r.json()["token"]
```

The `Client` then uses `requests.auth.HTTPBasicAuth` for the rest of the session communications.

```
class Client:
    def __init__(self, username: str, password: str, token: str | None =
        None) -> None:
        self.username = username
        self.password = password
        self.gameClient = None
        self.token = (
            token if token is not None else self.getToken(self.username,
                self.password)
        )
        self.auth = HTTPBasicAuth(self.token, "")
        self.getKey(password.encode())
```

The `Client` maps all of the `RESTful` endpoints to methods containing the relevant endpoint and request (with auth).

5.4.4.7.2 UI

The user is initially greeted with the options to either log-in or create an account.

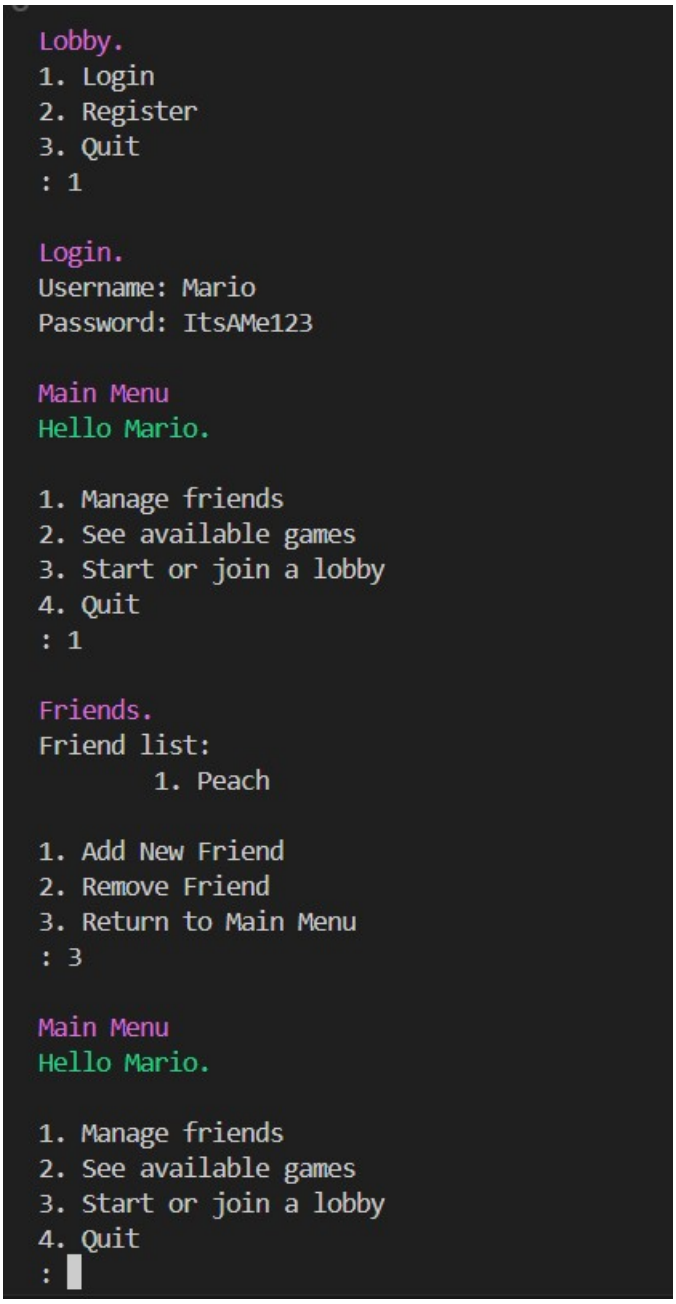

Figure 4: example output of client with logging and friends

The user is guided through various text menus allowing them to perform various task including:

- viewing and managing account `Friends`
- view all `Games`
- create or join a `Lobby`

Figure 5: example output of client with matchmaking and game client creation

5.4.4.7.3 Matchmaking

The `Lobbies` menu includes the option for matchmaking. The `_matchmaking` method first attempts to find an available `Lobby`. If this fails, the method creates a new `Lobby`. The relevant game `Client` is then created and connected to the game `Server`.

```
1 def _matchmaking(client: Client):
2     print(f"{bcolors.HEADER}\nMatchmaking.{bcolors.ENDC}")
3     game = _gameInput(client)
4     if game is None:
5         return None
6     try:
7         lobby = client.findLobby(gameName=game)
```

```
    except AssertionError:
        lobby = client.createLobby(gameName=game)
    time.sleep(1)
    client.join(lobby["lobby-id"])
    return None
```

The `join` method handles creating the relevant game `Client` and joining the `Lobby` using the provided `lobbyId`.

```
def join(self, lobbyId: int) -> None:
        print(f"\n{bcolors.WARNING}Joining Lobby '{lobbyId}'{bcolors.ENDC}")
        data = self.getLobby(lobbyId)
        if data["lobby-addr"] is not None:
            match data["game-id"]:
                case 1:
                    self.gameClient = RpsClient(
                        (TCP_HOST, C_PORT),
                        data["lobby-addr"],
                        rsaKey=self.key,
                        userId=self.id,
                        username=self.username,
                    )
                    self.gameClient.connect()
                case _:
                    raise ValueError(f"Unknown gameId {data['game-id']}")
```

5.5 Tests

The `pytest` module was used to define serval test.

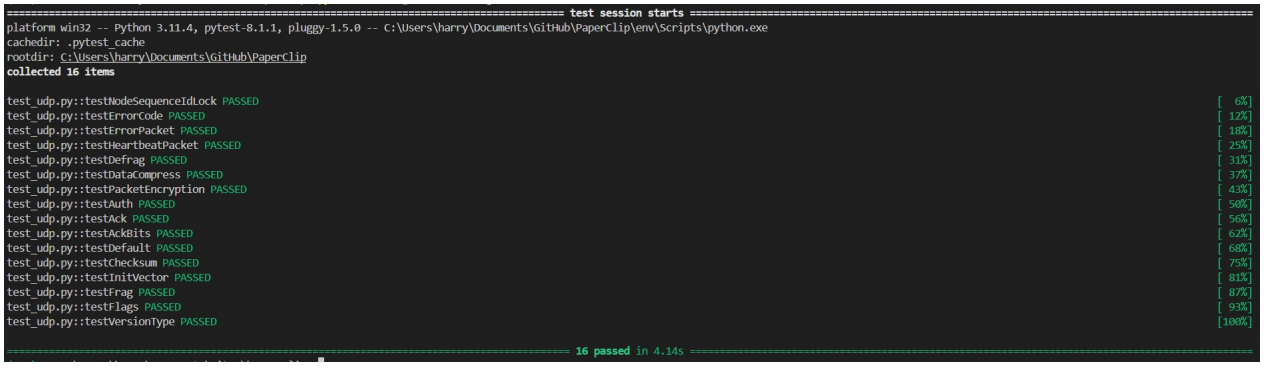

Figure 6: example output of `pytest -v`

6 Conclusion

6.1 Project Objective

The main objectives for this project where:

1. Create a scalable system for managing user accounts and inter-account interactions including matchmaking and friends.
2. Create a custom UDP protocol than implement key features required for game communication missing from vanilla UDP. These include reliability and security.

Both objectives have been met.

6.1.1 Objective One The `server` package provides a method to manipulate the various account and inter-account rows from the database which in turn provides scalable storage of data. It additionally provides the necessary information required to find or create `Lobbys`.

The `client` package provides a user-friendly interface for interactions with the `Server`. Additionally, using the information provided by the `Server`, is able to matchmake by joining available lobbies, and only creating new ones where needed/requested.

6.1.2 Objective Two The `udp` package defines the required `UDP` packets and implements their key features in the `udp.Client` and `udp.Server` communication.

6.1.3 Secondary Objectives

- Turn-based game demo
  - Implemented in the `rps` package.
- Real-time game demo
  - Omitted due to time constraints.
- Large packet size limit
  - Implemented in the `udp` package with the use of the `FRAG` flag.
- Authenticated Communication
  - Implemented in the `udp` package with the use of the `AUTH` packet containing a `X.509 Certificate`.
- Secure Communication
  - Implemented in the `udp` package with the use of the `ENCRYPT` flag.
- Reliable Communication
  - Implemented in the `udp` package with the use of the `RELIABLE` flag.
- Lightweight Communication
  - Implemented with the custom `UDP` protocol defined in `udp` which negates `TCP`'s overhead.
- Modularity
  - Implemented in the project's overall structure such that a game can be defined in a package.

6.2 Feature Evaluation

6.2.1 Reflection on Handshake Finished The handshake `Finished` is generated by calculating a `Hash-based Message Authentication Code` (`HMAC`) using the session key. Though the `EC` keys used to generate the session key are ephemeral, the handshake exchange is still vulnerable to man-in-the-middle attacks. This could be mitigated by including some random int in each AUTH packet which is, in turn, included in the `Finished HMAC` calculation.

6.2.2 Port Selection and Assignment The `Server` is responsible for selecting and assigning ports to any game servers it creates. The method for selection is rather rudimentary as the `Server` will just iterate from a given starting value indefinitely during run time. There are, therefore, no additional checks to validate either the availability (i.e. is the port is free) or suitability (e.g. within some reasonable range) of the port selected. A more advanced system could be implemented allowing for ports used by the `Server` to be monitored and released (e.g. by `LobbyHandler`) after use such that they could be reused.

6.2.3 Packet ERRORs Though Packer ERRORs are raised during run time and then sent to the packet author, there is no mechanism in place to resend the packet. This would require a greater overhead as all recent packets would need to be stored such that they could be retired if a packet error occurred. This is ultimately outside of the scope of this project.

6.2.4 Automatic Game Importing Though each game can be defined modularly using a package, the relevant game `Server` and `Client` must be explicitly imported into both the `server` and `client` packages. This limitation is largely due to the nature of `Python` imports and package structure. Some attempt could be made with the use of the underlying methods used by the `import` keyword but this would likely generate messy 'un-pythonic' code.

6.2.5 Congestion Control Currently, the custom `udp` implements no congestion control. The use of a `Round-Time-Time` (`RTT`) could be used to artificially rate-limit a `Node`'s send rate. The `HEARTBEAT` packet contains an unused `data` field which would be a subtile candidate for transferring additional information about a `Node`'s network status.

6.2.6 Features Cut for Time The `Scores` model and the highscore tracking functionality was ultimately abandoned due to time constraints. This feature could be implemented by returning the score values (already tracked by `Lobby` instances) and committing to the database.

Additionally, the stretch goal for a real-time game demo was never implemented. This would have been a more suitable demonstration of the efficiency of the `Packet` implementation but required far greater overhead for design and implementation than its turn-based counterpart.

7 Glossary

- Address, addr: a tuple containing an `IP address` and `port number` in the form (`IP`, `port`).
- Advanced Encryption Standard (`AES`): `AES` is a symmetric encryption algorithm used to secure sensitive data.
- Application Programming Interface (`API`): An `API` is a software interface allowing for two or more computer programs or components to communicate.
- Asymmetric Encryption: Asymmetric Encryption is a cryptographic technique where a pair of keys (a public and private key) are used for encryption and decryption. Messages encrypted with a given key pair's public key can only be decrypted with the respective private key (and visa versa).
- CRC-32: `CRC-32` is a 32-bit checksum based on the data content of a given object.
- Checksum: A checksum is a value calculated from a data packet using some mathematical algorithm such that the same data input always yields the same checksum. The checksum is used to validate data integrity after transmission to ensure no corruption has occurred.
- Constant (`CONST`): A constant is a value that cannot be changed during the execution of a program.
- Daemon: A daemon is a background process. Daemons will typically run continuously until stopped and operate silently, without direct user interaction.
- Diffie-Hellman (`DH`): Diffie-Hellman is a key exchange algorithm used to create a shared secret key between two parties. It allows the parties to agree on a secret key without the need to explicitly share the key over some communication channel.
- Distinguished Encoding Rules (`DER`): `DER` is a standard for encoding data structures into binary form for transmission or storage. It is a more restrictive variant of BER that ensures, among other things, that the shortest possible length encoding is used.
- Docker: Docker is a platform for creating and managing containers. Containers are lightweight, standalone and portable environments that typically package an application with its required dependencies.
- Elliptic-curve (`EC`): Elliptic-curve is a form of asymmetric cryptography based on the structure of elliptic curves over finite fields.
- Elliptic-curve Diffie-Hellman (`ECDH`): `ECDH` is a form of Diffie-Hellman that utilizes Elliptic-curve keys.
- Elliptic-curve Diffie-Hellman Ephemeral (`ECDHE`): `ECDHE` is the ephemeral form of `ECDH`. `ECHDE` provides forward security by generating a new ephemeral key pair for each session thus yielding a unique secret key.

- Entity-Relationship Diagram (`ERD`): An `ERD` is a `UML` representation of data models, their attributes and the relationships between them in a database.
- Enum: An enum is a data type that consists of a set of named values with a distinct constant value.
- Exception: An exception is an event that occurs during the execution of a program that disrupts the typical flow of instructions (i.e. an error).
- Flask: Flask is a micro-web framework package for Python.
- Git: Git is a source control system that tracks changes (and blame) for a given set of computer files.
- GitHub: GitHub is a developer platform providing cloud storage and management of Git projects.
- Global Interpreter Lock (`GIL`): The `GIL` is a mechanism used to ensure that only one thread executes bytecode at any given time.
- Hash-based Message Authentication Code (`HMAC`): `HMAC` is a type of message authentication code that involves the combination of a cryptographic hash function and a secret key to generate a unique code.
- Hypertext Transfer Protocol (`HTTP`): `HTTP` is a networking, application layer, protocol for distributed hypermedia information systems. `HTTP` provides the foundation for data communication on the World Wide Web.
- JSON Web Token (`JWT`): `JTW` is a standard for creating data with, optional signature and/or encryption, whose payload contains some `JSON` value typically asserting some number of claims (e.g. username is foo).
- JavaScript Object Notation (`JSON`): `JSON` is a data interchange format that uses human-readable text to store and transmit data objects consisting of attribute-value pairs. Despite its namesake, `JSON` is platform agnostic.
- Mutex: A mutex is a programming construct used to prevent multiple threads from accessing a shared resource simultaneously.
- MySQL: MySQL is a relational database management system (`RDBMS`).
- Private Key: The private key is one-half of the asymmetric key pair and is kept secret.
- Public Key: The public key is one-half of the asymmetric key pair and is freely distributed.
- Python: Python is a high-level, general-purpose programming language.
- Queue: A queue is a First-In-First-Out (`FIFO`) data structure.
- Race Condition: In concurrent programming, a race condition arises when the outcome of a program is affected by the unpredictable timing of multiple threads accessing a shared resource.

- Rivest-Shamir-Adleman (`RSA`): `RSA` is a form of asymmetric cryptography that utilizes the factorization of large integers.
- SQLAlchemy: SQLAlchemy is a `SQL` toolkit and object-relational-mapper (`ORM`) for Python.
- Session Key: A session key is a temporary cryptographic key used for encryption and decryption during a specific communication session between two parties.
- Symmetric Encryption: Symmetric Encryption is a cryptographic technique where the same key is used for both encryption and decryption of data.
- Thread: A thread is a lightweight process that can execute independently and concurrently with other threads in the same process.
- Transmission Control Protocol (`TCP`): `TCP` is a networking, transport layer, protocol that enables connection-based communication. It provides reliable, ordered and error-checked packet transmission.
- Try/Except Block: A try/except block is a mechanism used for exception handling. Any exceptions raised during the try block will be checked against the exception(s) defined in the except block. If the raised exception matches any of the defined exceptions, the exception is caught and not raised any further.
- Unified Modeling Language (`UML`): `UML` is a general-purpose visual modelling language for use with system design.
- User Datagram Protocol (`UDP`): `UDP` is a networking, transport layer, protocol that enables connectionless communication. It prioritizes speed over reliability and, as such, is unreliable and unordered.
- Visual Studio Code (`VS Code`): Visual Studio Code is a free, open-source code editor.
- X.509: `X.509` is a standard format for certificates allowing for signing with an asymmetric key. A `X.509` will typically also contain some information about the identity of the author.
- Zlib: Zlib is a software library used for data compression.

8 References

Capcom, D. (2008) 'Street fighter IV'. Capcom.

Eddy, W. (2022) *Transmission Control Protocol (TCP)*. 9293. RFC 9293; RFC Editor. Available at: https://doi.org/10.17487/RFC9293.

Fiedle, G. (2008a) *Reliability and congestion avoidance over UDP*. Available at: https://web.archive.org/web/20180823011635/https://gafferongames.com/post/reliability_ordering_and_congestion_avoidance_over_udp/ (Accessed: 8 May 2024).

Fiedle, G. (2008b) *UDP vs. TCP*. Available at: https://web.archive.org/web/20180823015049/https://gafferongames.com/post/udp_vs_tcp/ (Accessed: 8 May 2024).

Firaxis Games (2001) 'Sid meier's civilization III'. Infogrames Interactive.

Howard Wexler (1974) 'Connect four'. Milton Bradley.

id Software (1996) 'Quake'. GT Interactive.

Internet Engineering Task Force (2006) *X.509 public key infrastructure certificate and certificate revocation list (CRL) profile*. Internet Engineering Task Force (IETF). Available at: https://www.rfc-editor.org/rfc/rfc5280.html.

Jan Algermissen (2010) *Classification of HTTP APIs*. algermissen.io. Available at: http://algermissen.io/classification_of_http_apis.html (Accessed: 29 January 2023).

Mitsuo Heijo (2017) 'Inputimeout', *GitHub repository*. GitHub. Available at: https://github.com/johejo/inputimeout.

Postel, J. (1980) *User Datagram Protocol*. 768. RFC 768; RFC Editor. Available at: https://doi.org/10.17487/RFC0768.

Rescorla, E. (2018) *The Transport Layer Security (TLS) Protocol Version 1.3*. 8446. RFC 8446; RFC Editor. Available at: https://doi.org/10.17487/RFC8446.

Ronald L. Rivest, L.M.A., Adi Shamir (1978) 'A method for obtaining digital signatures and public-key cryptosystems', *Communications of the ACM*, 21(2), pp. 120–126. Available at: https://doi.org/10.1145/359340.359342.

Roy Thomas Fielding (2000) *Architectural styles and the design of network-based software architectures*. PhD thesis. University of California, Irvine. Available at: https://www.ics.uci.edu/~fielding/pubs/dissertation/top.htm.

Salzman, L. (2024) 'ENet', *GitHub repository*. GitHub. Available at: https://github.com/lsalzman/enet.

ValveSoftware (2022) 'GameNetworkingSockets', *GitHub repository*. GitHub. Available at: https://github.com/ValveSoftware/GameNetworkingSockets.

van Oortmerssen, W. (2005) 'Cube'.

Wang, Y., Ramamurthy, B. and Zou, X. (2006) 'The performance of elliptic curve based group diffie-hellman protocols for secure group communication over ad hoc networks', in *2006 IEEE international conference on communications*, pp. 2243–2248. Available at: https://doi.org/10.1109/ICC.2006.255104.

wolfSSL (2019) *TLS 1.3 performance analysis – full handshake*. Available at: https://www.wolfssl.com/tls-1-3-performance-part-2-full-handshake-2/.

9 Appendices

9.1 Project Definition Document

Cover Sheet

- PaperClip: A backend networking and account management solution for game servers.
- Author: Harry Whitehorn - harry.whitehorn@city.ac.uk
- Course: BSc Computer Science
- Consultant: Stephanie Wilson - s.m.wilson@city.ac.uk
- Proposed by: Harry Whitehorn
- Proprietary Interests: N/A
- Word Count: 697

Proposal

Problem to be solved Networking and user interaction is a basic requirement for many online video games. This can require a large amount of time and cost from developers. This project will aim to provide a lightweight solution to both of these elements that can then be easily applied to a game-sever.

There are a variety of different methods for handling game-time networking such as delay-based and rollback. The former is more suited to slow or turn based games due to the nature of an implicit delay as users synchronize. Fast-paced games such as shooters or fighting games rely on quick interactions meaning that delay-based networking is not suitable. Rollback works by predicting and then updating the inputs of non-local players.

Figure 7: Screenshot of *Civ II (1996)*

MicroProse (1996) *Civ II (1996)* is a turn based game suitable for delay-based.

Figure 8: Screenshot of *Super Street Fighter II Turbo HD Remix (2008)*

Backbone Entertainment (2008) *Super Street Fighter II Turbo HD Remix* was one of the first games released with rollback.

Project objectives The primary objective of this project is to create a lightweight networking and user account solution. This can better be described with two main goals:

1. This project shall manage connections between a game-sever and game-client. This will include handling both matchmaking and in-play communications.
2. This project shall manage storing and retrieving non-volatile information from a database sever. This will include user information and, therefore, handling account validation as well as leaderboards.
3. Create a variety of small and simple games to implement the networking and account features.

Further objectives include:

- A ELO/rank based system for matching players of a equal skill level.
- Account interaction such as friends and private lobbies.
- Customable bot accounts for relevant use in multiplayer environments.
- Ensuring that the solution is lightweight, reliable and platform-agnostic.
- Dockerize.

Beneficiaries The primary beneficiaries include:

- Me, due to learning network intricacies.
- Independent or small game development teams, who might lack either the time or resources to develop custom handling for multiplayer.

Work Plan The project will be created primarily to work with the godot game engine. Additional game engine support will be implemented and testing if there is ample time but this is not expected. The best language to use will be part of the initial research, but python is a likely candidate. Additionally, the database management system best suited will be part of the research but some potential candidates include SQLite and MariaDB.

Figure 9: workplan

Risks

Objective	Risk	Severity	Score	Risks	Actions
Network	2	5	10	Vulnerabilities	Ensure that the system is not vulnerable to any malicious interaction. Including 'cheating'.
Accounts	1	4	4	GDPR	Limit type of stored data and where data is relevant unsure stored in accordance to GDPR.
Safeguarding	2	4	8	User safety	Limit interactions between user accounts.
Development	5	5	25	Time	Ensure that progress is made in accordance with work plan and actively update when system requirements change.

Objective	Risk	Severity	Score	Risks	Actions
Testing	3	4	12	Engagement	Ensure in advance that participants are willing and have the appropriate time and resources to complete required testing.
	4	4	16	Time	Ensure that time is left to testing can be completed. (See development actions.)
Matchmaking	3	1	3	Developing appropriate ELO/rank system may prove to be too complex.	ELO/rank system can be dropped in favour of random matchmaking if the former cannot be developed within the time constraints.
Bots	4	2	8	Developing appropriate bot system may prove to be too complex.	Bot system can be dropped if it cannot be finished in time.

Research Ethics Checklist

See `Ethics_Review_Form.doc`

References

1. MicroProse, 1996, *Civilization II*, MicroProse
2. DASHBot, (2010). *CivII 01.png*. [image online] Wikipedia. Available at: https://en.wikipedia.org/wiki/File:CivII_01.png [Accessed 10 Feb. 2024].
3. Backbone Entertainment, 2008, *Super Street Fighter II Turbo HD Remix*, Capcom
4. Gamescore Blog, (2008). *Super Street Fighter II Turbo HD Remix 12*. [image online] Available at: https://www.flickr.com/photos/gamerscore/3058520175 [Accessed 10 Feb. 2024].

9.2 Deployment Guide

Requirements Requires: `python 3.11+`, `mysql server`.

Note This projects makes use of `ANSI` color prints.

This feature is shipped with `Windows 10 - Build 16257` and later but may require enabling. Instructions for registry to enable global default..

Failure to enable `ANSI` color prints may result in color codes (e.g. `"\033[94m"`) being printed to the terminal.

mysql A mysql server must be set up. The connection path must then be set as `SQLALCHEMY_DATABASE_URI` in the `.env`. For convenience, the following is a example docker-compose to set up a mysql server and adminer. This is the method use in testing thus the example path set in the `.env`.

```
# docker-compose.yaml
version: '3.1'

services:

  adminer:
    image: adminer
    ports:
      - 8080:8080

  db:
    image: mysql:5.6
    environment:
      MYSQL_ROOT_PASSWORD: root
    ports:
      - 3306:3306
```

Python

Setup Optional: `python -m venv env` and activate

Install packages: `pip install -r requirements.txt`

Env

Example `.env`, **must** be place in app root

```
# udp
S_HOST=127.0.0.1
S_PORT=2024
C_HOST=127.0.0.1
C_PORT=2025
## node
SOCKET_BUFFER_SIZE = 1024
SEND_SLEEP_TIME = 0.1
QUEUE_TIMEOUT = 10
SOCKET_TIMEOUT = 20
## server
HEARTBEAT_MAX_TIME = 120
HEARTBEAT_MIN_TIME = 30
MAX_CLIENTS
## auth
```

```
ORG_NAME = Paperclip
COMMON_NAME = 127.0.0.1
## utils
MAX_FRAGMENT_SIZE = 988

# client
TCP_PORT = 5000

# app
FLASK_APP=server
PRUNE_TIME = 58
SECRET_KEY = MyVerySecretKey
SQLALCHEMY_DATABASE_URI = mysql://root:root@localhost:3306/paperclip

# debug
DEBUG = True
```

Run Server: `python -m flask run`

Client: `python -m client` or `python -m client` *`offset`* (where *`offset`* is some `int` such that `C_PORT` (from `.env`) becomes `C_PORT+=offset`)

Tests: `pytest -v` (Note: may take some time with no output due to testing of thread locks)

9.3 Package

9.3.1 udp

```python
# udp.__init__
import logging
import os
import sys

import dotenv

__version__ = 0

dotenv.load_dotenv(".env")
S_HOST = os.environ.get("S_HOST")
S_PORT = int(os.environ.get("S_PORT"))
C_HOST = os.environ.get("C_HOST")
C_PORT = int(os.environ.get("C_PORT"))
# node
SOCKET_BUFFER_SIZE = int(os.environ.get("SOCKET_BUFFER_SIZE"))
```

```
SEND_SLEEP_TIME = float(os.environ.get("SEND_SLEEP_TIME"))
QUEUE_TIMEOUT = int(os.environ.get("QUEUE_TIMEOUT"))
SOCKET_TIMEOUT = int(os.environ.get("SOCKET_TIMEOUT"))
# server
HEARTBEAT_MAX_TIME = int(os.environ.get("HEARTBEAT_MAX_TIME"))
HEARTBEAT_MIN_TIME = int(os.environ.get("HEARTBEAT_MIN_TIME"))
MAX_CLIENTS = (
    int(os.environ.get("MAX_CLIENTS"))
    if os.environ.get("MAX_CLIENTS") is not None
    else float("inf")
)
# auth
ORG_NAME = os.environ.get("ORG_NAME")
COMMON_NAME = os.environ.get("COMMON_NAME")
# utils
MAX_FRAGMENT_SIZE = int(os.environ.get("MAX_FRAGMENT_SIZE"))


class bcolors:
    HEADER = "\033[95m"
    OKBLUE = "\033[94m"
    OKCYAN = "\033[96m"
    OKGREEN = "\033[92m"
    WARNING = "\033[93m"
    FAIL = "\033[91m"
    ENDC = "\033[0m"
    BOLD = "\033[1m"
    UNDERLINE = "\033[4m"


class ColorFilter(logging.Filter):
    colorCodes = [
        getattr(bcolors, attr) for attr in dir(bcolors) if not
            attr.startswith("__")
    ]

    def filter(self, record: logging.LogRecord) -> bool:
        for color in self.colorCodes:
            record.msg = record.msg.replace(color, "")
        return True


logger = logging.getLogger(__name__)
logger.setLevel(logging.DEBUG)

```

```
printHandler = logging.StreamHandler(sys.stdout)
printHandler.setLevel(logging.INFO)
printHandler.setFormatter(
    logging.Formatter(f"{bcolors.OKBLUE}%(threadName)s{bcolors.ENDC} -
        %(message)s")
)
logger.addHandler(printHandler)

fileHandler = logging.FileHandler("paperclip.log")
fileHandler.setLevel(logging.DEBUG)
fileHandler.addFilter(ColorFilter())
fileHandler.setFormatter(
    logging.Formatter("%(asctime)s - %(levelname)s - %(threadName)s -
        %(message)s")
)
logger.addHandler(fileHandler)
```

```
# upd.__main__
from . import client, server


def runServer():
    s = server.Server((S_HOST, S_PORT))
    s.startThreads()
    return s


def runClient():
    c = client.Client((C_HOST, C_PORT), (S_HOST, S_PORT))
    c.connect()
    return c


if __name__ == "__main__":
    import time

    from . import C_HOST, C_PORT, S_HOST, S_PORT

    s = runServer()
    time.sleep(1)
    c = runClient()
    time.sleep(1)
    x = None
```

```
    x = input("> ")
    while x != "END":
        c.queueDefault(data=x.encode())
        x = input("> ")
    c.isRunning.clear()
    time.sleep(1)
    s.isRunning.clear()
    time.sleep(1)
    print("END")
```

```
# udp.auth
import datetime
import os

from cryptography import x509
from cryptography.exceptions import InvalidSignature
from cryptography.hazmat.primitives import hashes, hmac, padding,
    serialization
from cryptography.hazmat.primitives.asymmetric import ec, rsa
from cryptography.hazmat.primitives.asymmetric import padding as aPadding
from cryptography.hazmat.primitives.ciphers import Cipher, algorithms, modes
from cryptography.hazmat.primitives.kdf.hkdf import HKDF
from cryptography.x509.oid import NameOID

from . import COMMON_NAME, ORG_NAME


def generateRsaKey() -> rsa.RSAPrivateKey:
    key = rsa.generate_private_key(
        public_exponent=65537,
        key_size=2048,
    )
    return key


def getDerFromRsaPrivate(key: rsa.RSAPrivateKey, password: bytes) -> bytes:
    der = key.private_bytes(
        encoding=serialization.Encoding.DER,
        format=serialization.PrivateFormat.PKCS8,
        encryption_algorithm=serialization.BestAvailableEncryption(password),
    )
    return der

```

```
33
34 def getRsaPrivateFromDer(data: bytes, password: bytes) -> rsa.RSAPrivateKey:
35     key = serialization.load_der_private_key(data, password=password)
36     return key
37
38
39 def getDerFromRsaPublic(key: rsa.RSAPublicKey) -> bytes:
40     der = key.public_bytes(
41         encoding=serialization.Encoding.DER,
42         format=serialization.PublicFormat.SubjectPublicKeyInfo,
43     )
44     return der
45
46
47 def getRsaPublicFromDer(data: bytes) -> rsa.RSAPublicKey:
48     key = serialization.load_der_public_key(data)
49     return key
50
51
52 def generateUserCertificate(
53     key, userId: int | str | None = None, username: str | None = None
54 ) -> x509.Certificate:
55     name = [
56         x509.NameAttribute(NameOID.ORGANIZATION_NAME, ORG_NAME),
57         x509.NameAttribute(NameOID.COMMON_NAME, COMMON_NAME),
58     ]
59     if userId is not None:
60         name.append(x509.NameAttribute(NameOID.USER_ID, str(userId)))
61     if username is not None:
62         name.append(x509.NameAttribute(NameOID.PSEUDONYM, username))
63     subject = issuer = x509.Name(name)
64     cert = (
65         x509.CertificateBuilder()
66         .subject_name(subject)
67         .issuer_name(issuer)
68         .public_key(key.public_key())
69         .serial_number(x509.random_serial_number())
70         .not_valid_before(datetime.datetime.now(datetime.timezone.utc))
71         .not_valid_after(
72             datetime.datetime.now(datetime.timezone.utc) +
                datetime.timedelta(days=1)
73         )
74         .add_extension(
75             x509.SubjectAlternativeName([x509.DNSName("localhost")]),
76             critical=False,
```

```
        )
        .sign(key, hashes.SHA256())
    )

    return cert


def getUserCertificateAttributes(certificate: x509.Certificate) -> list:
    accountId = certificate.subject.get_attributes_for_oid(NameOID.USER_ID)
    accountId = accountId[0].value if len(accountId) > 0 else None
    username = certificate.subject.get_attributes_for_oid(NameOID.PSEUDONYM)
    username = username[0].value if len(username) > 0 else None
    return {"account-id": accountId, "username": username}


def validateCertificate(
    certificate: x509.Certificate, publicKey: rsa.RSAPublicKey
) -> bool:
    # period
    now = datetime.datetime.now(datetime.timezone.utc)
    if not (certificate.not_valid_before_utc <= now <=
       certificate.not_valid_after_utc):
        return False
    # signature
    try:
        publicKey.verify(
            certificate.signature,
            certificate.tbs_certificate_bytes,
            aPadding.PKCS1v15(),
            certificate.signature_hash_algorithm,
        )
    except InvalidSignature:
        return False
    return True


def generateEcKey() -> ec.EllipticCurvePrivateKey:
    key = ec.generate_private_key(ec.SECP384R1())
    return key


def getDerFromPublicEc(publicKey: ec.EllipticCurvePublicKey) -> bytes:
    ecDer = publicKey.public_bytes(
        encoding=serialization.Encoding.DER,
        format=serialization.PublicFormat.SubjectPublicKeyInfo,
```

```
    )
    return ecDer


def getPublicEcFromDer(publicKeyDer: bytes) -> ec.EllipticCurvePublicKey:
    ec_ = serialization.load_der_public_key(publicKeyDer)
    return ec_


def getDerFromCertificate(certificate: x509.Certificate) -> bytes:
    return certificate.public_bytes(serialization.Encoding.DER)


def getCertificateFromDer(certificateDer: bytes) -> x509.Certificate:
    return x509.load_der_x509_certificate(certificateDer)


def generateSessionKey(
    localKey: ec.EllipticCurvePrivateKey, peerKey: ec.EllipticCurvePublicKey
) -> bytes:
    sessionSecret = localKey.exchange(ec.ECDH(), peerKey)
    sessionKey = HKDF(
        algorithm=hashes.SHA256(), length=32, salt=None, info=b"handshake
            data"
    ).derive(sessionSecret)
    return sessionKey


def encryptBytes(cipher: Cipher, rawBytes: bytes, autoPad=True) -> bytes:
    if autoPad:
        padder = padding.PKCS7(algorithms.AES.block_size).padder()
        rawBytes = padder.update(rawBytes) + padder.finalize()
    encryptor = cipher.encryptor()
    encryptedBytes = encryptor.update(rawBytes) + encryptor.finalize()
    return encryptedBytes


def decryptBytes(
    cipher: Cipher, encryptedBytes: bytes, autoUnpad: bool = True
) -> bytes:
    decryptor = cipher.decryptor()
    decryptedBytes = decryptor.update(encryptedBytes) + decryptor.finalize()
    if autoUnpad:
        unpadder = padding.PKCS7(algorithms.AES.block_size).unpadder()
        decryptedBytes = unpadder.update(decryptedBytes) + unpadder.finalize()
```

```
    return decryptedBytes


def generateInitVector() -> bytes:
    return os.urandom(16)


def generateCipher(
    sessionKey: bytes, iv: bytes = generateInitVector()
) -> tuple[Cipher, bytes]:
    cipher = Cipher(algorithms.AES(sessionKey), modes.CBC(iv))
    return cipher, iv


def generateFinished(sessionKey: bytes, finishedLabel: bytes, messages:
    bytes):
    hashValue = hashes.Hash(hashes.SHA256())
    hashValue.update(messages)
    hashValue = hashValue.finalize()

    prf = hmac.HMAC(sessionKey, hashes.SHA256())
    prf.update(finishedLabel)
    prf.update(hashValue)
    prf = prf.finalize()

    return prf
```

```
# udp.client
import base64
import json
import socket

import requests
from cryptography.hazmat.primitives.asymmetric.rsa import RSAPrivateKey

from udp.error import Major, Minor

from . import auth, bcolors, error, logger, node, packet


class Client(node.Node):
    targetAddr: tuple[str, int]
    rsaKey: RSAPrivateKey
```

```
    onConnect: None
    onDisconnect: None

    def __init__(
        self,
        addr,
        targetAddr,
        rsaKey: RSAPrivateKey | None = None,
        accountId: int | str | None = None,
        username: str | None = None,
        onConnect=None,
        onDisconnect=None,
        onReceiveData=None,
    ) -> None:
        self.targetAddr = targetAddr
        self.rsaKey = rsaKey if rsaKey is not None else auth.generateRsaKey()
        self.onConnect = onConnect
        self.onDisconnect = onDisconnect
        s = socket.socket(type=socket.SOCK_DGRAM)
        super().__init__(
            addr,
            cert=auth.generateUserCertificate(self.rsaKey, accountId,
                username),
            accountId=accountId,
            socket=s,
            onReceiveData=onReceiveData,
        )
        self.regenerateEcKey()
        self.bind(self.addr)

    @property
    def targetHost(self) -> str | None:
        return self.targetAddr[0] if self.targetAddr is not None else None

    @property
    def targetPort(self) -> int | None:
        return self.targetAddr[1] if self.targetAddr is not None else None

    def queueDefault(
        self,
        addr: tuple[str, int] = None,
        flags: list[bool] = [0 for _ in range(packet.FLAGS_SIZE)],
        data: bytes | None = None,
    ) -> None:
        return super().queueDefault(self.targetAddr, flags=flags, data=data)
```

```
61
62      def queueACK(
63          self,
64          addr: tuple[str, int] = None,
65          ackId: int = None,
66          flags: list[bool] = [0 for _ in range(packet.FLAGS_SIZE)],
67          data: bytes | None = None,
68      ) -> None:
69          return super().queueACK(self.targetAddr, ackId, flags=flags,
                data=data)
70
71      def queueError(
72          self,
73          addr: tuple[str, int] = None,
74          major: Major | int = 0,
75          minor: Minor | int = 0,
76          flags: list[bool] = [0 for _ in range(packet.FLAGS_SIZE)],
77          data: bytes | None = None,
78      ) -> None:
79          return super().queueError(self.targetAddr, major, minor, flags, data)
80
81      def queueDisconnect(
82          self,
83          addr: tuple[str, int] = None,
84          flags: list[bool] = [0 for _ in range(packet.FLAGS_SIZE)],
85          data: bytes | None = None,
86      ) -> None:
87          self.queueError(
88              self.targetAddr,
89              flags=flags,
90              major=error.Major.DISCONNECT,
91              minor=error.DisconnectErrorCodes.CLIENT_DISCONNECT,
92              data=data,
93          )
94
95      def connect(self) -> None:
96          try:
97              logger.info(
98                  f"{bcolors.WARNING}# Handshake with {self.targetAddr}
                        starting.{bcolors.ENDC}"
99              )
100             self.outboundThread.start()
101             self.queueAuth(self.targetAddr, self.cert,
                    self.ecKey.public_key())
102             authPacket = None
```

```
103             ackPacket = None
104             while True:
105                 p, addr = self.receivePacket()
106                 if p is not None:
107                     # logic
108                     if p.packet_type == packet.Type.AUTH:
109                         logger.info(
110                             f"{bcolors.OKBLUE}< {addr} :{bcolors.ENDC}
                                {bcolors.OKCYAN}{p}{bcolors.ENDC}"
111                         )
112                         authPacket = p
113                         self.sessionKey = auth.generateSessionKey(
114                             self.ecKey, p.public_key
115                         )
116                         if not self.validateCertificate(p.certificate):
117                             logger.critical(f"Invalid peer cert
                                {p.certificate}")
118                             self.queueError(
119                                 major=error.Major.CONNECTION,
120                                 minor=error.ConnectionErrorCodes.CERTIFICATE_INVALID,
121                                 data=b"Invalid Certificate.",
122                             )
123                             break
124                         self.queueFinished(
125                             self.targetAddr, p.sequence_id, self.sessionKey
126                         )
127                     elif p.packet_type == packet.Type.ACK:
128                         logger.info(
129                             f"{bcolors.OKBLUE}< {addr} :{bcolors.ENDC}
                                {bcolors.OKCYAN}{p}{bcolors.ENDC}"
130                         )
131                         ackPacket = p
132                         self.receiveAck(p, addr)
133                     elif p.packet_type == packet.Type.ERROR:
134                         logger.info(
135                             f"{bcolors.OKBLUE}< {addr} :{bcolors.ENDC}
                                {bcolors.OKCYAN}{p}{bcolors.ENDC}"
136                         )
137                         self.receive(p, addr)
138                     else:
139                         logger.warning(
140                             f"{bcolors.WARNING}! {addr} :{bcolors.ENDC}
                                {bcolors.WARNING}{p}{bcolors.ENDC}"
141                         )
142                     if authPacket is not None and ackPacket is not None:
```

```
                        break
                else:
                    # timeout and abort
                    logger.critical("Server not responsive.")
            if self.validateHandshake(p.data):
                # success
                logger.info(
                    f"{bcolors.OKGREEN}Handshake success starting
                        mainloop...{bcolors.ENDC}"
                )
                self.inboundThread.start()
                if self.onConnect:
                    self.onConnect(addr)
            else:
                logger.critical(
                    f"Local finished value
                        {node.Node._generateFinished(self.sessionKey)} does
                        not match peer finished value {ackPacket.data}"
                )
                self.queueError(
                    major=error.Major.CONNECTION,
                    minor=error.ConnectionErrorCodes.FINISH_INVALID,
                    data=b"Invalid finish.",
                )
        except error.PaperClipError as e:
            raise e
        except Exception as e:
            raise e
        else:
            if self.isRunning.is_set():
                self._quit()

    # auth
    def validateCertificate(self, certificate: auth.x509.Certificate) -> bool:
        url = f"http://{self.targetHost}:5000/auth/certificate/validate"
        headers = {"Content-Type": "application/json"}
        certificate = base64.encodebytes(
            auth.getDerFromCertificate(certificate)
        ).decode()
        data = {"certificate": certificate}
        r = requests.get(url, headers=headers, data=json.dumps(data))
        if r.status_code == 200:
            return r.json()["valid"]
        else:
            return False
```

```
185
186     # misc
187     def quit(self, msg: str = "quit call", e: Exception = None) -> None:
188         self.queueDisconnect(data=msg.encode())
189         self.queue.join()
190         super().quit(msg, e)
191
192     def handleDisconnectError(
193         self, p: packet.ErrorPacket, addr: tuple[str, int], e:
                error.DisconnectError
194     ) -> None:
195         match e:
196             case error.ServerDisconnectError():
197                 self._quit(e)
198             case error.ClientDisconnectError():
199                 pass  # should not react to client disconnect
200             case _:
201                 raise e
202
203     def mainloop(self, onQuit=None) -> None:
204         try:
205             while self.isRunning.is_set():
206                 pass
207         except KeyboardInterrupt:
208             print(f"{bcolors.FAIL}Quitting. Please wait...{bcolors.ENDC}")
209         finally:
210             if onQuit is None:
211                 self.quit(e=self.exitError)
212             else:
213                 onQuit(e=self.exitError)
```

```
1  # udp.error
2  from enum import Enum
3
4
5  class Major(Enum):
6      ERROR = 0
7      CONNECTION = 1
8      DISCONNECT = 2
9      PACKET = 3
10
11
12 class Minor(Enum):
```

```
    pass


class PaperClipError(Exception):
    """Unknown error"""


# connection
class ConnectionErrorCodes(Minor):
    CONNECTION = 0
    NO_SPACE = 1
    CERTIFICATE_INVALID = 2
    FINISH_INVALID = 3


class ConnectionError(PaperClipError):
    """Handshake connection could not be finished"""


class NoSpaceError(ConnectionError):
    """Server has insufficient space to accept new clients"""


class CertificateInvalidError(ConnectionError):
    """Certificate is invalid / can not be validated"""


class FinishInvalidError(ConnectionError):
    """Finish is invalid"""


_connectionErrors = {
    ConnectionErrorCodes.CONNECTION: ConnectionError,
    ConnectionErrorCodes.NO_SPACE: NoSpaceError,
    ConnectionErrorCodes.CERTIFICATE_INVALID: CertificateInvalidError,
    ConnectionErrorCodes.FINISH_INVALID: FinishInvalidError,
}


def getConnectionError(minor: ConnectionErrorCodes | int) -> ConnectionError:
    try:
        minor = minor if isinstance(minor, Minor) else
            ConnectionErrorCodes(minor)
        if minor in _connectionErrors:
            return _connectionErrors[minor]
```

```
        else:
            return PaperClipError
    except ValueError:
        return PaperClipError


def getConnectionCode(error: ConnectionError) -> ConnectionErrorCodes:
    try:
        return list(_connectionErrors.keys())[
            list(_connectionErrors.values()).index(error)
        ]
    except ValueError:
        return PaperClipError


# disconnect
class DisconnectErrorCodes(Minor):
    DISCONNECT = 0
    SERVER_DISCONNECT = 1
    CLIENT_DISCONNECT = 2


class DisconnectError(PaperClipError):
    """A party is disconnecting"""


class ServerDisconnectError(DisconnectError):
    """The server is closing"""


class ClientDisconnectError(DisconnectError):
    """The client is closing"""


_disconnectErrors = {
    DisconnectErrorCodes.DISCONNECT: DisconnectError,
    DisconnectErrorCodes.SERVER_DISCONNECT: ServerDisconnectError,
    DisconnectErrorCodes.CLIENT_DISCONNECT: ClientDisconnectError,
}


def getDisconnectError(minor: DisconnectErrorCodes | int) -> DisconnectError:
    try:
        minor = minor if isinstance(minor, Minor) else
            DisconnectErrorCodes(minor)
```

```
        if minor in _disconnectErrors:
            return _disconnectErrors[minor]
        else:
            return PaperClipError
    except ValueError:
        return PaperClipError


def getDisconnectCode(error: DisconnectError) -> DisconnectErrorCodes:
    try:
        return list(_disconnectErrors.keys())[
            list(_disconnectErrors.values()).index(error)
        ]
    except ValueError:
        return PaperClipError


# packet
class PacketErrorCodes(Minor):
    PACKET = 0
    VERSION = 1
    PACKET_TYPE = 2
    FLAGS = 3
    SEQUENCE_ID = 4
    FRAGMENT_ID = 5
    FRAGMENT_NUMBER = 6
    INIT_VECTOR = 7
    COMPRESSION = 8
    CHECKSUM = 9


class PacketError(PaperClipError):
    """Packet cannot be read"""


class VersionError(PacketError):
    """Packet Version is invalid / does not match expected"""


class PacketTypeError(PacketError):
    """Packet Type is invalid / unknown"""


class FlagsError(PacketError):
    """Flags are invalid / unknown"""
```

```
146
147
148 class SequenceIdError(PacketError):
149     """Sequence Id is invalid / does not match expected"""
150
151
152 class FragmentIdError(PacketError):
153     """Fragment Id is invalid / unknown"""
154
155
156 class FragmentNumberError(PacketError):
157     """Fragment Number is invalid / unknown"""
158
159
160 class InitVectorError(PacketError):
161     """Init Vector is invalid / unknown i.e. decrypt fail"""
162
163
164 class CompressionError(PacketError):
165     """Decompression fail"""
166
167
168 class ChecksumError(PacketError):
169     """Checksum is invalid / unknown i.e. checksum fail"""
170
171
172 _packetErrors = {
173     PacketErrorCodes.PACKET: PacketError,
174     PacketErrorCodes.VERSION: VersionError,
175     PacketErrorCodes.PACKET_TYPE: PacketTypeError,
176     PacketErrorCodes.FLAGS: FlagsError,
177     PacketErrorCodes.SEQUENCE_ID: SequenceIdError,
178     PacketErrorCodes.FRAGMENT_ID: FragmentIdError,
179     PacketErrorCodes.FRAGMENT_NUMBER: FragmentNumberError,
180     PacketErrorCodes.INIT_VECTOR: InitVectorError,
181     PacketErrorCodes.COMPRESSION: CompressionError,
182     PacketErrorCodes.CHECKSUM: ChecksumError,
183 }
184
185
186 def getPacketError(minor: PacketErrorCodes | int) -> PacketError:
187     try:
188         minor = minor if isinstance(minor, Minor) else PacketErrorCodes(minor)
189         if minor in _packetErrors:
190             return _packetErrors[minor]
```

```
        else:
            return PaperClipError
    except ValueError:
        return PaperClipError


def getPacketCode(error: PacketError) -> PacketErrorCodes:
    try:
        return
           list(_packetErrors.keys())[list(_packetErrors.values()).index(error)]
    except ValueError:
        return PaperClipError


# convenience
def getError(major: Major | int, minor: Minor | int = 0) -> PaperClipError:
    try:
        major = major if isinstance(major, Major) else Major(major)
        match major:
            case Major.CONNECTION:
                return getConnectionError(minor)
            case Major.DISCONNECT:
                return getDisconnectError(minor)
            case Major.PACKET:
                return getPacketError(minor)
            case _:
                return PaperClipError
    except TypeError:
        return PaperClipError


def getMinor(major: Major, minor: int) -> Minor:
    match major:
        case Major.CONNECTION:
            return ConnectionErrorCodes(minor)
        case Major.DISCONNECT:
            return DisconnectErrorCodes(minor)
        case Major.PACKET:
            return PacketErrorCodes(minor)
        case _:
            return Minor


def getErrorCode(error: PaperClipError) -> tuple[Major, Minor]:
    match error:
```

```
        case c if issubclass(c, ConnectionError):
            return (Major.CONNECTION, getConnectionCode(error))
        case d if issubclass(d, DisconnectError):
            return (Major.DISCONNECT, getDisconnectCode(error))
        case p if issubclass(p, PacketError):
            return (Major.PACKET, getPacketCode(error))
        case _:
            return (Major.ERROR, Minor)
```

```
# udp.node
import time
from datetime import datetime
from queue import Empty, Queue
from socket import SOCK_DGRAM
from socket import socket as Socket
from threading import Event, Lock, Thread, get_ident

from cryptography.hazmat.primitives.asymmetric.ec import
    EllipticCurvePrivateKey
from cryptography.x509 import Certificate

from . import (
    QUEUE_TIMEOUT,
    SEND_SLEEP_TIME,
    SOCKET_BUFFER_SIZE,
    SOCKET_TIMEOUT,
    auth,
    bcolors,
    error,
    logger,
    packet,
)

ACK_RESET_SIZE = (2**packet.ACK_BITS_SIZE) // 2


class Node:
    addr: tuple[str, int]
    _sequenceId: int
    sentAckBits = list[bool | None]
    recvAckBits = list[bool | None]
    newestSeqId: int | None
    fragBuffer: dict[int, list[packet.Packet]]
```

```
    queue: Queue
    heartbeat: datetime | None
    # id
    cert: Certificate | None
    _accountId: int | None
    # session
    ecKey: EllipticCurvePrivateKey
    sessionKey: bytes | None
    handshake: bool
    # threads
    inboundThread: Thread
    outboundThread: Thread
    sequenceIdLock: Lock
    sendLock: Lock
    isRunning: Event
    # socket
    socket: Socket | None
    # callback
    onReceiveData: None
    # exitCode
    exitError: error.PaperClipError | None

    def __init__(
        self,
        addr: tuple[str, int],
        cert: Certificate | None = None,
        accountId: int | None = None,
        sendLock: Lock = Lock(),
        socket: Socket | None = Socket(type=SOCK_DGRAM),
        onReceiveData: None = None,
    ) -> None:
        self.addr = addr
        self.sequenceId = 0
        self.sentAckBits = [None for _ in range(2**packet.ACK_BITS_SIZE)]
        self.recvAckBits = [None for _ in range(2**packet.ACK_BITS_SIZE)]
        self.newestSeqId = 0
        self.fragBuffer = {}
        self.queue = Queue()
        # id
        self.cert = cert
        self.accountId = accountId
        # session
        self.sessionKey = None
        self.handshake = False
        # threads
```

```
        self.inboundThread = Thread(
            name=f"{self.port}:Inbound", target=self.listen, daemon=True
        )
        self.outboundThread = Thread(
            name=f"{self.port}:Outbound", target=self.sendQueue, daemon=True
        )
        self.sequenceIdLock = Lock()
        self.sendLock = sendLock
        self.isRunning = Event()
        self.isRunning.set()
        # socket
        self.socket = socket
        self.socket.settimeout(SOCKET_TIMEOUT)
        # callback
        self.onReceiveData = onReceiveData
        # exit
        self.exitError = None

    def bind(self, addr):
        self.socket.bind(addr)

    # properties
    @property
    def host(self) -> str:
        return self.addr[0]

    @property
    def port(self) -> int:
        return self.addr[1]

    @property
    def sequenceId(self) -> int:
        return self._sequenceId

    @sequenceId.setter
    def sequenceId(self, v: int) -> None:
        self._sequenceId = v % 2**packet.SEQUENCE_ID_SIZE

    def incrementSequenceId(self, addr: tuple[str, int]) -> None:
        with self.getSequenceIdLock(addr):
            self.sequenceId += 1

    @property
    def accountId(self) -> int:
        return self._accountId
```

```
124
125     @accountId.setter
126     def accountId(self, v: int | str | None) -> None:
127         try:
128             self._accountId = int(v)
129         except ValueError:
130             self._accountId = v
131         except TypeError:
132             self._accountId = None
133
134     def getSentAckBit(self, addr: tuple[str, int], p: packet.Packet) -> bool
        | None:
135         return self.sentAckBits[p.sequence_id]
136
137     def setSentAckBit(self, addr: tuple[str, int], ackBit: int, v: bool) ->
        None:
138         self.sentAckBits[ackBit] = v
139
140     def getSentAckBits(self, addr: tuple[str, int]) -> list[bool | None]:
141         return self.sentAckBits
142
143     def getRecvAckBit(self, addr: tuple[str, int], p: packet.Packet) -> bool
        | None:
144         return self.recvAckBits[p.sequence_id]
145
146     def getRecvAckBits(self, addr: tuple[str, int]) -> list[bool | None]:
147         return self.recvAckBits
148
149     def setRecvAckBit(self, addr: tuple[str, int], ackBit: int, v: bool) ->
        None:
150         self.recvAckBits[ackBit] = v
151
152     def resetRecvAckBits(self, addr: tuple[str, int]) -> None:
153         recvAckBits = self.getRecvAckBits(addr)
154         newestSeqId = self.getNewestSeqId(addr)
155         pointer = (newestSeqId - ACK_RESET_SIZE) % 2**packet.ACK_BITS_SIZE
156         counter = 0
157         while counter != pointer:
158             recvAckBits[(newestSeqId + 1 + counter) %
                2**packet.ACK_BITS_SIZE] = None
159             counter += 1
160
161     def getNewestSeqId(self, addr: tuple[str, int]) -> int:
162         return self.newestSeqId
163
```

```
164     def setNewestSeqId(self, addr: tuple[str, int], newestSeqId: int) -> None:
165         self.newestSeqId = newestSeqId
166 
167     @staticmethod
168     def getNewerSeqId(currentSeqId: int, newSeqId: int) -> int:
169         currentDiff = (newSeqId - currentSeqId) % (2**packet.SEQUENCE_ID_SIZE)
170         newDiff = (currentSeqId - newSeqId) % (2**packet.SEQUENCE_ID_SIZE)
171         if newDiff < currentDiff:
172             return currentSeqId
173         else:
174             return newSeqId
175 
176     def getSessionKey(self, addr: tuple[str, int]) -> int:
177         return self.sessionKey
178 
179     def getHandshake(self, addr: tuple[str, int]) -> bool:
180         return self.handshake
181 
182     def getFragBuffer(self, addr: tuple[str, int]) -> dict[int,
        list[packet.Packet]]:
183         return self.fragBuffer
184 
185     def getSequenceId(self, addr: tuple[str, int]) -> int:
186         return self.sequenceId
187 
188     def getSequenceIdLock(self, addr: tuple[str, int]) -> Lock:
189         return self.sequenceIdLock
190 
191     def getQueue(self, addr: tuple[str, int]) -> Queue:
192         return self.queue
193 
194     def getHeartbeat(self, addr: tuple[str, int]) -> datetime:
195         return self.heartbeat
196 
197     def setHeartbeat(self, addr: tuple[str, int], v: datetime) -> None:
198         self.heartbeat = v
199 
200     def regenerateEcKey(self) -> None:
201         self.ecKey = auth.generateEcKey()
202 
203     # sends
204     def sendPacket(self, addr: tuple[str, int], p: packet.Packet) -> None:
205         with self.sendLock:
206             try:
207                 self.socket.sendto(p.pack(p), (addr[0], addr[1]))
```

```
208                 logger.info(
209                     f"{bcolors.OKBLUE}> {addr} :{bcolors.ENDC}
                        {bcolors.OKCYAN}{p}{bcolors.ENDC}"
210                 )
211             except error.PacketError as e:
212                 logger.error(
213                     f"{bcolors.FAIL}# > {bcolors.ENDC}{bcolors.OKBLUE}{addr}
                        :{bcolors.ENDC}
                        {bcolors.FAIL}{type(e).__name__}:{e.args[0] if
                        len(e.args) > 0 else ''}{p}{bcolors.ENDC}"
214                 )
215
216     def sendQueue(self) -> None:
217         while self.isRunning.is_set():
218             try:
219                 addr, p = self.queue.get(timeout=QUEUE_TIMEOUT)
220                 if p.flags[packet.Flag.RELIABLE.value]:
221                     if self.getSentAckBit(addr, p):
222                         self.queue.task_done()
223                         continue
224                     else:
225                         self.sendPacket(addr, p)
226                         self.queue.task_done()
227                         self.queue.put((addr, p))
228                 else:
229                     self.sendPacket(addr, p)
230                     self.queue.task_done()
231                 time.sleep(SEND_SLEEP_TIME)
232             except Empty:
233                 pass  # check still running
234         else:
235             logger.info("| sendQueue thread stopping...")
236
237     def queuePacket(self, addr: tuple[str, int], p: packet.Packet) -> None:
238         if p.flags[packet.Flag.RELIABLE.value]:
239             self.setSentAckBit(addr, p.sequence_id, False)
240         if p.flags[packet.Flag.CHECKSUM.value]:
241             p.setChecksum()
242         if p.flags[packet.Flag.COMPRESSED.value]:
243             p.compressData()
244         if p.flags[packet.Flag.ENCRYPTED.value]:
245             p.encryptData(self.getSessionKey(addr))
246         if p.flags[packet.Flag.FRAG.value]:
247             frags = p.fragment()
248             for frag in frags:
```

```
                self.getQueue(addr).put((addr, frag))
        else:
            self.getQueue(addr).put((addr, p))

    def queueDefault(
        self,
        addr: tuple[str, int],
        flags: list[bool] = [0 for _ in range(packet.FLAGS_SIZE)],
        data: bytes | None = None,
    ) -> None:
        p = packet.Packet(sequence_id=self.getSequenceId(addr), flags=flags,
            data=data)
        self.incrementSequenceId(addr)
        self.queuePacket(addr, p)

    def queueACK(
        self,
        addr: tuple[str, int],
        ackId: int,
        flags: list[bool] = [0 for _ in range(packet.FLAGS_SIZE)],
        data: bytes | None = None,
    ) -> None:
        ack_bits = self.packRecvAckBits(self.getRecvAckBits(addr), ackId)
        p = packet.AckPacket(
            sequence_id=self.getSequenceId(addr),
            flags=flags,
            ack_id=ackId,
            ack_bits=ack_bits,
            data=data,
        )
        self.incrementSequenceId(addr)
        self.queuePacket(addr, p)

    def queueAuth(
        self,
        addr: tuple[str, int],
        cert: Certificate,
        publicEc: auth.ec.EllipticCurvePublicKey,
    ) -> None:
        p = packet.AuthPacket(
            sequence_id=self.getSequenceId(addr), certificate=cert,
                public_key=publicEc
        )
        self.incrementSequenceId(addr)
        self.queuePacket(addr, p)
```

```
292
293     def queueFinished(
294         self, addr: tuple[str, int], seqId: int, sessionKey: bytes
295     ) -> None:
296         finished = Node._generateFinished(sessionKey)
297         self.queueACK(addr, seqId, data=finished)
298
299     @staticmethod
300     def _generateFinished(sessionKey: bytes) -> bytes:
301         return auth.generateFinished(
302             sessionKey, finishedLabel=b"node finished", messages=b"\x13"
303         )
304
305     def queueHeartbeat(
306         self,
307         addr: tuple[str, int],
308         heartbeat: bool,
309         flags: list[bool] = [0 for _ in range(packet.FLAGS_SIZE)],
310         data: bytes | None = None,
311     ) -> None:
312         p = packet.HeartbeatPacket(
313             sequence_id=self.getSequenceId(addr),
314             flags=flags,
315             heartbeat=heartbeat,
316             data=data,
317         )
318         self.incrementSequenceId(addr)
319         self.queuePacket(addr, p)
320
321     def queueError(
322         self,
323         addr: tuple[str, int],
324         major: error.Major | int,
325         minor: error.Minor | int,
326         flags: list[int] = [0 for _ in range(packet.FLAGS_SIZE)],
327         data: bytes | None = None,
328     ) -> None:
329         sId = self.getSequenceId(addr)
330         p = packet.ErrorPacket(
331             sequence_id=sId if sId is not None else 0,
332             flags=flags,
333             major=major,
334             minor=minor,
335             data=data,
336         )
```

```
337         if sId is not None:
338             self.incrementSequenceId(addr)
339         self.queuePacket(addr, p)
340 
341     def queueDisconnect(
342         self,
343         addr: tuple[str, int],
344         flags: list[bool] = [0 for _ in range(packet.FLAGS_SIZE)],
345         data: bytes | None = None,
346     ) -> None:
347         self.queueError(
348             addr,
349             flags=flags,
350             major=error.Major.DISCONNECT,
351             minor=error.DisconnectErrorCodes.DISCONNECT,
352             data=data,
353         )
354 
355     # receives
356     def receivePacket(
357         self,
358     ) -> tuple[packet.Packet, tuple[str, int]] | tuple[None, None]:
359         try:
360             data, addr = self.socket.recvfrom(SOCKET_BUFFER_SIZE)
361             try:
362                 p = packet.unpack(data)
363                 return p, addr
364             except error.PacketError as e:
365                 logger.error(
366                     f"{bcolors.FAIL}# < {bcolors.ENDC}{bcolors.OKBLUE}{addr}
                        :{bcolors.ENDC}
                        {bcolors.FAIL}{type(e).__name__}:{e.args[0] if
                        len(e.args) > 0 else ''}{p}{bcolors.ENDC}"
367                 )
368                 major, minor = error.getErrorCod(e)
369                 self.queueError(addr, major, minor)
370                 return None, None
371         except ConnectionResetError:
372             return None, None
373         except TimeoutError:
374             return None, None
375 
376     def receive(
377         self, p: packet.Packet, addr: tuple[str, int]
378     ) -> tuple[packet.Packet, tuple[str, int]] | None:
```

```
379         if p is not None:
380             if self.handleFlags(p, addr):
381                 match p.packet_type:
382                     case packet.Type.DEFAULT:
383                         logger.info(
384                             f"{bcolors.OKBLUE}< {addr} :{bcolors.ENDC}
                                {bcolors.OKCYAN}{p}{bcolors.ENDC}"
385                         )
386                         return self.receiveDefault(p, addr)
387                     case packet.Type.ACK:
388                         logger.info(
389                             f"{bcolors.OKBLUE}< {addr} :{bcolors.ENDC}
                                {bcolors.OKCYAN}{p}{bcolors.ENDC}"
390                         )
391                         return self.receiveAck(p, addr)
392                     case packet.Type.AUTH:
393                         logger.info(
394                             f"{bcolors.OKBLUE}< {addr} :{bcolors.ENDC}
                                {bcolors.OKCYAN}{p}{bcolors.ENDC}"
395                         )
396                         return self.receiveAuth(p, addr)
397                     case packet.Type.HEARTBEAT:
398                         logger.info(
399                             f"{bcolors.OKBLUE}< {addr} :{bcolors.ENDC}
                                {bcolors.OKCYAN}{p}{bcolors.ENDC}"
400                         )
401                         return self.receiveHeartbeat(p, addr)
402                     case packet.Type.ERROR:
403                         logger.warning(
404                             f"{bcolors.OKBLUE}< {addr} :{bcolors.ENDC}
                                {bcolors.FAIL}{p}{bcolors.ENDC}"
405                         )
406                         try:
407                             return self.receiveError(p, addr)
408                         except error.PaperClipError as e:
409                             self.handleError(p, addr, e)
410                     case _:
411                         logger.warning(
412                             f"Unknown packet type '{p.packet_type}' for
                                packet {p}"
413                         )
414                         self.queueError(
415                             addr,
416                             major=error.Major.PACKET,
417                             minor=error.PacketErrorCodes.PACKET_TYPE,
```

```
                            data=p.sequence_id,
                        )

    def receiveDefault(
        self, p: packet.Packet, addr: tuple[str, int]
    ) -> tuple[packet.Packet, tuple[str, int]]:
        self.setNewestSeqId(
            addr, self.getNewerSeqId(self.getNewestSeqId(addr), p.sequence_id)
        )
        if self.onReceiveData:
            self.onReceiveData(addr, p.data)
        return (p, addr)

    def receiveAck(
        self, p: packet.AckPacket, addr: tuple[str, int]
    ) -> tuple[packet.Packet, tuple[str, int]]:
        self.setNewestSeqId(
            addr, self.getNewerSeqId(self.getNewestSeqId(addr), p.sequence_id)
        )
        self.setSentAckBit(addr, p.ack_id, True)
        # set all bits from ack bits to true (to mitigate lost ack)
        for i, j in enumerate(
            range(p.ack_id - 1, p.ack_id - 1 - packet.ACK_BITS_SIZE, -1)
        ):
            if p.ack_bits[i]:
                self.setSentAckBit(addr, j, True)
        return (p, addr)

    def receiveAuth(
        self, p: packet.AuthPacket, addr: tuple[str, int]
    ) -> tuple[packet.Packet, tuple[str, int]]:
        raise NotImplementedError(
            "Node should not receive auth. A child class must overwrite."
        )
        return (p, addr)

    def receiveHeartbeat(
        self, p: packet.HeartbeatPacket, addr: tuple[str, int]
    ) -> tuple[packet.Packet, tuple[str, int]]:
        if not p.heartbeat:
            self.queueHeartbeat(addr, heartbeat=True)
            pass
        return (p, addr)

    def receiveError(self, p: packet.ErrorPacket, addr: tuple[str, int]) ->
```

```
        None:
463         raise error.getError(p.major, p.minor)(p.data)
464
465     def listen(self) -> None:
466         logger.info(
467             f"{bcolors.HEADER}Listening @
                {self.socket.getsockname()}{bcolors.ENDC}"
468         )
469         while self.isRunning.is_set():
470             p, addr = self.receivePacket()
471             self.receive(p, addr)
472         else:
473             logger.info("| listen thread stopping...")
474
475     # flags handle
476     def handleFlags(self, p: packet.Packet, addr: tuple[str, int]) -> bool:
477         # defrag -> decrypt -> decompress -> validate checksum -> reliable
478         if self.handleFrag(p, addr):
479             return False
480         else:
481             self.handleEncrypted(p, addr)
482             self.handleCompressed(p, addr)
483             self.handleChecksum(p, addr)
484             self.handleReliable(p, addr)
485             return True
486
487     def handleReliable(self, p: packet.Packet, addr: tuple[str, int]) -> bool:
488         if p.flags[packet.Flag.RELIABLE.value]:
489             self.setNewestSeqId(
490                 addr, self.getNewerSeqId(self.getNewestSeqId(addr),
                    p.sequence_id)
491             )
492             self.setRecvAckBit(addr, p.sequence_id, True)
493             self.resetRecvAckBits(addr)
494             self.queueACK(addr, p.sequence_id)
495             return True
496         else:
497             return False
498
499     def handleFrag(self, p: packet.Packet, addr: tuple[str, int]) -> bool:
500         if p.flags[packet.Flag.FRAG.value]:
501             logger.info(
502                 f"\t{bcolors.OKBLUE}< {addr} :{bcolors.ENDC}{bcolors.WARNING}
                    FRAG {p.fragment_id}/{p.fragment_number} {p}{bcolors.ENDC}"
503             )
```

```
            if p.sequence_id not in self.getFragBuffer(addr):
                self.getFragBuffer(addr)[p.sequence_id] = [
                    None for _ in range(p.fragment_number)
                ]
            self.getFragBuffer(addr)[p.sequence_id][p.fragment_id] = p
            if all(self.getFragBuffer(addr)[p.sequence_id]):
                defrag = p.defragment(self.getFragBuffer(addr)[p.sequence_id])
                del self.getFragBuffer(addr)[p.sequence_id]
                self.receive(defrag, addr)
            return True
        else:
            return False

    def handleCompressed(self, p: packet.Packet, addr: tuple[str, int]) ->
        bool:
        if p.flags[packet.Flag.COMPRESSED.value]:
            p.decompressData()
            return True
        else:
            return False

    def handleEncrypted(self, p: packet.Packet, addr: tuple[str, int]) ->
        bool:
        if p.flags[packet.Flag.ENCRYPTED.value]:
            p.decryptData(self.getSessionKey(addr))
            return True
        else:
            return False

    def handleChecksum(self, p: packet.Packet, addr: tuple[str, int]) -> bool:
        if p.flags[packet.Flag.CHECKSUM.value]:
            if not p.validateChecksum():
                logger.warning(f"\tInvalid checksum: {p}")
            else:
                logger.info(f"\tValid checksum: {p}")
            return True
        else:
            return False

    # error handle
    def handleError(
        self, p: packet.ErrorPacket, addr: tuple[str, int], e:
            error.PaperClipError
    ) -> None:
        match e:
```

```
            case error.ConnectionError():
                self.handleConnectionError(p, addr, e)
            case error.DisconnectError():
                self.handleDisconnectError(p, addr, e)
            case error.PacketError():
                self.handlePacketError(p, addr, e)
            case _:
                raise e

    def handleConnectionError(
        self, p: packet.ErrorPacket, addr: tuple[str, int], e:
            error.ConnectionError
    ) -> None:
        match e:
            case error.NoSpaceError():
                return self.quit("no server space", e)
            case error.CertificateInvalidError():
                return self.quit("invalid certificate", e)
            case error.FinishInvalidError():
                return self.quit("invalid finish", e)
            case _:
                raise e

    def handleDisconnectError(
        self, p: packet.ErrorPacket, addr: tuple[str, int], e:
            error.DisconnectError
    ) -> None:
        match e:
            case error.ServerDisconnectError:
                pass  # overwrite
            case error.ClientDisconnectError:
                pass  # overwrite
            case _:
                raise e

    def handlePacketError(
        self, p: packet.ErrorPacket, addr: tuple[str, int], e:
            error.PacketError
    ) -> None:
        match e:
            case error.VersionError():
                pass
            case error.PacketTypeError():
                pass
            case error.FlagsError():
```

```
                pass
            case error.SequenceIdError():
                pass
            case error.FragmentIdError():
                pass
            case error.FragmentNumberError():
                pass
            case error.InitVectorError():
                pass
            case error.CompressionError():
                pass
            case error.ChecksumError():
                pass
            case _:
                raise e

    # util
    @staticmethod
    def packRecvAckBits(recvAckBits: list[bool], ackId: int) -> list[bool |
        None]:
        return [
            recvAckBits[i % 2**packet.ACK_BITS_SIZE]
            for i in range(ackId - 1, ackId - 1 - packet.ACK_BITS_SIZE, -1)
        ]

    # misc
    def startThreads(self) -> None:
        self.inboundThread.start()
        self.outboundThread.start()

    def validateCertificate(self, certificate: Certificate) -> bool:
        # overwrite
        return True

    def validateHandshake(self, finished: bytes) -> bool:
        self.handshake = Node._generateFinished(self.sessionKey) == finished
        return self.handshake

    def quit(self, msg: str = "quit call", e: Exception = None) -> None:
        logMsg = f"{bcolors.FAIL}# Quitting due to {msg}.{bcolors.ENDC}"
        if e is not None:
            logger.critical(logMsg)
        else:
            logger.info(logMsg)
        self.isRunning.clear()
```

```
632         if self.inboundThread.is_alive() and get_ident() !=
                self.inboundThread.ident:
633             self.inboundThread.join()
634         if self.outboundThread.is_alive() and get_ident() !=
                self.outboundThread.ident:
635             self.outboundThread.join()
636         self.socket.close()
637         logger.info(f"{bcolors.FAIL}# Quit finished.{bcolors.ENDC}")
638         if e is not None:
639             self.exitError = e
640             if get_ident() in (self.inboundThread.ident,
                    self.outboundThread.ident):
641                 pass
642             else:
643                 raise e
644 
645     def _quit(self, e: Exception = None) -> None:
646         self.exitError = e
647         self.isRunning.clear()
```

```
1  # udp.packet
2  import struct
3  from enum import Enum
4  
5  from cryptography.hazmat.primitives.asymmetric.ec import
       EllipticCurvePublicKey
6  from cryptography.x509 import Certificate
7  
8  from . import auth, error, logger, utils
9  
10 VERSION = 0
11 # SIZE in Bits
12 VERSION_SIZE = 4
13 PACKET_TYPE_SIZE = 4
14 FLAGS_SIZE = 8
15 SEQUENCE_ID_SIZE = 16
16 FRAGMENT_ID_SIZE = 8
17 FRAGMENT_NUM_SIZE = 8
18 INIT_VECTOR_SIZE = 16
19 CHECKSUM_SIZE = 16
20 ACK_ID_SIZE = SEQUENCE_ID_SIZE  # 16
21 ACK_BITS_SIZE = SEQUENCE_ID_SIZE  # 16
22 
```

```
23
24 class Type(Enum):
25     DEFAULT = 0
26     ACK = 1
27     AUTH = 2
28     HEARTBEAT = 3
29     ERROR = 4
30
31
32 class Flag(Enum):
33     RELIABLE = 0
34     CHECKSUM = 1
35     COMPRESSED = 2
36     ENCRYPTED = 3
37     FRAG = 4
38
39
40 class Heartbeat(Enum):
41     PING = 0
42     PONG = 1
43
44
45 def lazyFlags(*fs: list[Flag]) -> list[int]:
46     flags = [0 for _ in range(FLAGS_SIZE)]
47     for flag in fs:
48         flags[flag.value] = 1
49     return flags
50
51
52 class Packet:
53     version: int = VERSION
54     packet_type: Type = Type.DEFAULT
55     flags: list[int] = [0 for _ in range(FLAGS_SIZE)]
56     sequence_id: int = 0
57     fragment_id: int | None = None
58     fragment_number: int | None = None
59     init_vector: int | None = None
60     checksum: int | None = None
61     _data: bytes | None = None
62
63     def __init__(
64         self,
65         version: int = VERSION,
66         packet_type: Type = Type.DEFAULT,
67         flags: list[int] = [0 for _ in range(FLAGS_SIZE)],
```

```
68          sequence_id: int = None,
69          fragment_id: int | None = None,
70          fragment_number: int | None = None,
71          init_vector: int | None = None,
72          checksum: int | None = None,
73          data: bytes | None = None,
74      ) -> None:
75          self.version = version
76          self.packet_type = packet_type
77          self.flags = flags
78          self.sequence_id = sequence_id
79          self.fragment_id = fragment_id
80          self.fragment_number = fragment_number
81          self.init_vector = init_vector
82          self.checksum = checksum
83          self.data = data
84
85      # util
86      def encryptData(self, session_key: bytes) -> None:
87          try:
88              self.flags[Flag.ENCRYPTED.value] = 1
89              iv = (
90                  self.init_vector
91                  if self.init_vector is not None
92                  else auth.generateInitVector()
93              )
94              cipher, iv = auth.generateCipher(session_key, iv)
95              self.init_vector = iv
96              self.data = auth.encryptBytes(cipher, self.data)
97          except Exception as e:
98              raise error.InitVectorError(e)
99
100     def decryptData(self, session_key: bytes) -> None:
101         try:
102             if self.flags[Flag.ENCRYPTED.value]:
103                 cipher = auth.generateCipher(session_key, self.init_vector)[0]
104                 self.data = auth.decryptBytes(cipher, self.data)
105             else:
106                 logger.warning(
107                     f"Packet {self} is not flagged as ENCRYPTED
                            ({self.flags})."
108                 )
109         except Exception as e:
110             raise error.InitVectorError(e)
111
```

```
112     def compressData(self) -> None:
113         try:
114             self.flags[Flag.COMPRESSED.value] = 1
115             self.data = utils.compressData(self.data)
116         except Exception as e:
117             raise error.CompressionError(e)
118 
119     def decompressData(self) -> None:
120         try:
121             if self.flags[Flag.COMPRESSED.value]:
122                 self.data = utils.decompressData(self.data)
123             else:
124                 logger.warning(
125                     f"Packet {self} is not flagged as COMPRESSED
                            ({self.flags})."
126                 )
127         except Exception as e:
128             raise error.CompressionError(e)
129 
130     def setChecksum(self) -> None:
131         try:
132             self.flags[Flag.CHECKSUM.value] = 1
133             data = self.data if self.data is not None else b""
134             self.checksum = utils.generateChecksum(data)
135         except Exception as e:
136             raise error.ChecksumError(e)
137 
138     def validateChecksum(self) -> bool:
139         try:
140             if self.flags[Flag.CHECKSUM.value]:
141                 data = self.data if self.data is not None else b""
142                 return self.checksum == utils.generateChecksum(data)
143             else:
144                 logger.warning(
145                     f"Packet {self} is not flagged as CHECKSUM
                            ({self.flags})."
146                 )
147         except Exception as e:
148             raise error.ChecksumError(e)
149 
150     @staticmethod
151     def _getHeader(p) -> dict:
152         header = {
153             k: v
154             for k, v in vars(p).items()
```

```
            if k not in ("data", "fragment_id", "fragment_number")
        }
        return header

    def fragment(self):
        self.flags[Flag.FRAG.value] = 1
        header = Packet._getHeader(self)
        fragData = utils.fragmentData(self.data)
        fragment_number = len(fragData)
        return [
            self._createFragment(
                header, fragment_id=i, fragment_number=fragment_number,
                    data=data
            )
            for i, data in enumerate(fragData)
        ]

    @classmethod
    def _createFragment(
        cls, header: dict, fragment_id: int, fragment_number: int, data: bytes
    ):
        return cls(
            **header,
            fragment_id=fragment_id,
            fragment_number=fragment_number,
            data=data,
        )

    @classmethod
    def defragment(cls, frags):
        if frags[0].flags[Flag.FRAG.value]:
            header = Packet._getHeader(frags[0])
            header["flags"][Flag.FRAG.value] = 0
            data = utils.defragmentData([frag.data for frag in frags])
            return cls(**header, data=data)
        else:
            logger.warning(
                f"Packet {frags[0]} is not flagged as FRAG
                    ({frags[0].flags})."
            )

    # dunder
    def __str__(self) -> str:
        try:
            s = self.pack(self)
```

```
198         except error.PaperClipError:
199             s = b""
200         data = self.data if self.data is not None else b""
201         pSize = len(s)
202         dSize = len(data)
203         if len(data) > 12:
204             data = f"{data[:11]}...{str(data[-1:])[1:]}"
205         return f"<{self.version}:{self.packet_type.name} {self.sequence_id}
                {''.join(map(str,self.flags))} {data} [{pSize}:{dSize}]>"
206 
207     def __eq__(self, other) -> bool:
208         if isinstance(other, self.__class__):
209             return vars(self) == vars(other)
210         else:
211             return False
212 
213     # encode / decode
214     @staticmethod
215     def _encodeVersion(version: int) -> int:
216         try:
217             return version
218         except Exception as e:
219             raise error.VersionError(e)
220 
221     @staticmethod
222     def _decodeVersion(version: int) -> int:
223         try:
224             return version
225         except Exception as e:
226             raise error.VersionError(e)
227 
228     @staticmethod
229     def _encodeType(packet_type: Type) -> int:
230         try:
231             return packet_type.value
232         except Exception as e:
233             raise error.PacketTypeError(e)
234 
235     @staticmethod
236     def _decodeType(packet_type: int) -> Type:
237         try:
238             return Type(packet_type)
239         except Exception as e:
240             raise error.PacketTypeError(e)
241 
```

```
242     @staticmethod
243     def encodeVersionType(version: int, packet_type: Type) -> bytes:
244         return struct.pack(
245             "!B",
246             (Packet._encodeVersion(version) * 16) |
                    Packet._encodeType(packet_type),
247         )
248
249     @staticmethod
250     def decodeVersionType(versionType: bytes) -> tuple[int, Type]:
251         versionType = struct.unpack("!B", versionType)[0]
252         version = Packet._decodeVersion(versionType >> 4)
253         packet_type = Packet._decodeType(versionType & 15)
254         return version, packet_type
255
256     @staticmethod
257     def encodeFlags(flags: list[int]) -> bytes:
258         try:
259             return struct.pack("!B", int("".join(map(str, flags)), 2))
260         except Exception as e:
261             raise error.FlagsError(e)
262
263     @staticmethod
264     def decodeFlags(flags: bytes) -> list[int]:
265         try:
266             flags = struct.unpack("!B", flags)[0]
267             flags = [(flags >> i) & 1 for i in range(FLAGS_SIZE)]
268             flags.reverse()
269             return flags
270         except Exception as e:
271             raise error.FlagsError(e)
272
273     @staticmethod
274     def encodeSequenceId(sequence_id: int) -> bytes:
275         try:
276             return struct.pack("!I", sequence_id)
277         except Exception as e:
278             raise error.SequenceIdError(e)
279
280     @staticmethod
281     def decodeSequenceId(sequence_id: bytes) -> int:
282         try:
283             return struct.unpack("!I", sequence_id)[0]
284         except Exception as e:
285             raise error.SequenceIdError(e)
```

```
286
287     @staticmethod
288     def encodeFragmentId(fragment_id: int) -> bytes:
289         try:
290             return struct.pack("!B", fragment_id)
291         except Exception as e:
292             raise error.FragmentIdError(e)
293
294     @staticmethod
295     def decodeFragmentId(fragment_id: bytes) -> int:
296         try:
297             return struct.unpack("!B", fragment_id)[0]
298         except Exception as e:
299             raise error.FragmentIdError(e)
300
301     @staticmethod
302     def encodeFragmentNumber(fragment_number: int) -> bytes:
303         try:
304             return struct.pack("!B", fragment_number)
305         except Exception as e:
306             raise error.FragmentNumberError(e)
307
308     @staticmethod
309     def decodeFragmentNumber(fragment_number: bytes) -> int:
310         try:
311             return struct.unpack("!B", fragment_number)[0]
312         except Exception as e:
313             raise error.FragmentNumberError(e)
314
315     @staticmethod
316     def encodeInitVector(init_vector: bytes) -> bytes:
317         try:
318             return init_vector
319         except Exception as e:
320             raise error.InitVectorError(e)
321
322     @staticmethod
323     def decodeInitVector(init_vector: bytes) -> bytes:
324         try:
325             return init_vector
326         except Exception as e:
327             raise error.InitVectorError(e)
328
329     @staticmethod
330     def encodeChecksum(checksum: int) -> bytes:
```

```
331         try:
332             return struct.pack("!I", checksum)
333         except Exception as e:
334             raise error.ChecksumError(e)
335 
336     @staticmethod
337     def decodeChecksum(checksum: bytes) -> int:
338         try:
339             return struct.unpack("!I", checksum)[0]
340         except Exception as e:
341             raise error.ChecksumError(e)
342 
343     @staticmethod
344     def encodeHeader(
345         version: int,
346         packet_type: Type,
347         flags: list[int],
348         sequence_id: int,
349         fragment_id: int | None = None,
350         fragment_number: int | None = None,
351         init_vector: int | None = None,
352         checksum: int | None = None,
353     ) -> bytes:
354         versionType = Packet.encodeVersionType(version, packet_type)
355         flags = Packet.encodeFlags(flags)
356         sequence_id = Packet.encodeSequenceId(sequence_id)
357         fragment_id = (
358             Packet.encodeFragmentId(fragment_id) if fragment_id is not None
                else b""
359         )
360         fragment_number = (
361             Packet.encodeFragmentNumber(fragment_number)
362             if fragment_number is not None
363             else b""
364         )
365         init_vector = (
366             Packet.encodeInitVector(init_vector) if init_vector is not None
                else b""
367         )
368         checksum = Packet.encodeChecksum(checksum) if checksum is not None
            else b""
369         return (
370             versionType
371             + flags
372             + sequence_id
```

```
            + fragment_id
            + fragment_number
            + init_vector
            + checksum
        )

    @staticmethod
    def decodeHeader(
        header: bytes,
    ) -> tuple[
        int, Type, list[int], int, int | None, int | None, int | None, int |
            None, int
    ]:
        version, packet_type = Packet.decodeVersionType(header[0:1])
        flags = Packet.decodeFlags(header[1:2])
        sequence_id = Packet.decodeSequenceId(header[2:6])
        offset = 6
        if flags[Flag.FRAG.value]:
            fragment_id = Packet.decodeFragmentId(header[offset : offset + 1])
            fragment_number = Packet.decodeFragmentNumber(
                header[offset + 1 : offset + 2]
            )
            offset += 2
        else:
            fragment_id = None
            fragment_number = None
        if flags[Flag.ENCRYPTED.value]:
            init_vector = Packet.decodeInitVector(header[offset : offset +
                16])
            offset += 16
        else:
            init_vector = None
        if flags[Flag.CHECKSUM.value]:
            checksum = Packet.decodeChecksum(header[offset : offset + 4])
            offset += 4
        else:
            checksum = None
        return (
            version,
            packet_type,
            flags,
            sequence_id,
            fragment_id,
            fragment_number,
            init_vector,
```

```
            checksum,
            offset,
        )

    # pack / unpack
    @classmethod
    def _packHeader(cls, p) -> bytes:
        header = cls.encodeHeader(
            p.version,
            p.packet_type,
            p.flags,
            p.sequence_id,
            p.fragment_id,
            p.fragment_number,
            p.init_vector,
            p.checksum,
        )
        return header

    @classmethod
    def pack(cls, p) -> bytes:
        header = cls._packHeader(p)
        data = p.data if p.data is not None else b""
        return header + data

    @classmethod
    def _unpackHeader(cls, bytesP: bytes):
        *header, offset = cls.decodeHeader(bytesP)
        return *header, offset

    @classmethod
    def unpack(cls, bytesP: bytes):
        *header, offset = cls._unpackHeader(bytesP)
        data = bytesP[offset:] if offset < len(bytesP) else None
        return cls(*header, data=data)


class AckPacket(Packet):
    ack_id: int = 0
    ack_bits: list[int | None] = [None for _ in range(ACK_BITS_SIZE)]

    def __init__(
        self,
        version: int = VERSION,
        packet_type: Type.ACK = Type.ACK,
```

```
461         flags: list[int] = [0 for _ in range(FLAGS_SIZE)],
462         sequence_id: int = None,
463         fragment_id: int | None = None,
464         fragment_number: int | None = None,
465         init_vector: int | None = None,
466         checksum: int | None = None,
467         ack_id: int = None,
468         ack_bits: list[int | None] = [None for _ in range(ACK_BITS_SIZE)],
469         data: bytes | None = None,
470     ) -> None:
471         super().__init__(
472             version,
473             Type.ACK,
474             flags,
475             sequence_id,
476             fragment_id,
477             fragment_number,
478             init_vector,
479             checksum,
480             data,
481         )
482         self.ack_id = ack_id
483         self.ack_bits = ack_bits
484 
485     # dunder
486     def __str__(self) -> str:
487         s = self.pack(self)
488         data = self.data if self.data is not None else b""
489         pSize = len(s)
490         dSize = len(data)
491         if len(data) > 12:
492             data = f"{data[:11]}...{str(data[-1:])[1:]}"
493         return f"<{self.version}:{self.packet_type.name}
                {self.sequence_id}:{self.ack_id} {''.join(map(str,self.flags))}
                {data} [{pSize}:{dSize}]>"
494 
495     # encode / decode
496     @staticmethod
497     def encodeAckId(ack_id: int) -> bytes:
498         return struct.pack("!I", ack_id)
499 
500     @staticmethod
501     def decodeAckId(ack_id: bytes) -> int:
502         return struct.unpack("!I", ack_id)[0]
503 
```

```
504     @staticmethod
505     def encodeAckBits(ack_bits: list[int]) -> bytes:
506         return struct.pack(
507             "!I",
508             int(
509                 "".join(
510                     map(str, (int(bit) if bit is not None else 0 for bit in
                            ack_bits))
511                 ),
512                 2,
513             ),
514         )
515 
516     @staticmethod
517     def decodeAckBits(ack_bits: bytes) -> list[int]:
518         ack_bits = struct.unpack("!I", ack_bits)[0]
519         ack_bits = [(ack_bits >> i) & 1 for i in range(ACK_BITS_SIZE)]
520         ack_bits.reverse()
521         return ack_bits
522 
523     @staticmethod
524     def encodeHeader(
525         version: int,
526         packet_type: Type,
527         flags: list[int],
528         sequence_id: int,
529         fragment_id: int | None = None,
530         fragment_number: int | None = None,
531         init_vector: int | None = None,
532         checksum: int | None = None,
533         ack_id: int = 0,
534         ack_bits: list[int | None] = [None for _ in range(ACK_BITS_SIZE)],
535     ) -> bytes:
536         header = Packet.encodeHeader(
537             version,
538             packet_type,
539             flags,
540             sequence_id,
541             fragment_id,
542             fragment_number,
543             init_vector,
544             checksum,
545         )
546         ack_id = AckPacket.encodeAckId(ack_id)
547         ack_bits = AckPacket.encodeAckBits(ack_bits)
```

```
548         return header + ack_id + ack_bits
549
550     @staticmethod
551     def decodeHeader(
552         header: bytes,
553     ) -> tuple[
554         int,
555         Type,
556         list[int],
557         int,
558         int | None,
559         int | None,
560         int | None,
561         int | None,
562         int,
563         list[int | None],
564         int,
565     ]:
566         *h, offset = Packet.decodeHeader(header)
567         ack_id = AckPacket.decodeAckId(header[offset : offset + 4])
568         offset += 4
569         ack_bits = AckPacket.decodeAckBits(header[offset : offset + 4])
570         offset += 4
571         return *h, ack_id, ack_bits, offset
572
573     # pack / unpack
574     @classmethod
575     def _packHeader(cls, p) -> bytes:
576         header = cls.encodeHeader(
577             p.version,
578             p.packet_type,
579             p.flags,
580             p.sequence_id,
581             p.fragment_id,
582             p.fragment_number,
583             p.init_vector,
584             p.checksum,
585             p.ack_id,
586             p.ack_bits,
587         )
588         return header
589
590
591 class AuthPacket(Packet):
592     _public_key_size: int | None = None
```

```
    public_key: EllipticCurvePublicKey | None = None
    _certificate_size: int | None = None
    certificate: Certificate | None = None

    def __init__(
        self,
        version: int = VERSION,
        packet_type: Type = Type.AUTH,
        flags: list[int] = [0 for _ in range(FLAGS_SIZE)],
        sequence_id: int = None,
        fragment_id: int | None = None,
        fragment_number: int | None = None,
        init_vector: int | None = None,
        checksum: int | None = None,
        public_key_size: int | None = None,
        public_key: EllipticCurvePublicKey = None,
        certificate_size: int | None = None,
        certificate: Certificate | None = None,
    ) -> None:
        super().__init__(
            version,
            Type.AUTH,
            flags,
            sequence_id,
            fragment_id,
            fragment_number,
            init_vector,
            checksum,
            data=None,
        )
        self.public_key_size = public_key_size
        self.public_key = public_key
        self.certificate_size = certificate_size
        self.certificate = certificate

    # setter / getter
    @property
    def public_key_size(self) -> int | None:
        if self._public_key_size is None:
            self.public_key_size = (
                AuthPacket.getPublicKeyBytesSize(self.public_key)
                if self.public_key is not None
                else None
            )
        return self._public_key_size
```

```
638
639     @public_key_size.setter
640     def public_key_size(self, v: int | None) -> None:
641         self._public_key_size = v
642
643     @staticmethod
644     def getPublicKeyBytesSize(publicKey: EllipticCurvePublicKey) -> int:
645         return len(auth.getDerFromPublicEc(publicKey))
646
647     @property
648     def certificate_size(self) -> int | None:
649         if self._certificate_size is None:
650             self.certificate_size = (
651                 self.getCertificateByteSize(self.certificate)
652                 if self.certificate is not None
653                 else None
654             )
655         return self._certificate_size
656
657     @certificate_size.setter
658     def certificate_size(self, v: int | None) -> None:
659         self._certificate_size = v
660
661     @staticmethod
662     def getCertificateByteSize(certificate: Certificate) -> int:
663         return len(auth.getDerFromCertificate(certificate))
664
665     # encode / decode
666     @staticmethod
667     def encodePublicKeySize(public_key_size: int) -> bytes:
668         return struct.pack("!B", public_key_size)
669
670     @staticmethod
671     def decodePublicKeySize(public_key_size: bytes) -> int:
672         return struct.unpack("!B", public_key_size)[0]
673
674     @staticmethod
675     def encodePublicKey(public_key: EllipticCurvePublicKey) -> bytes:
676         return auth.getDerFromPublicEc(public_key)
677
678     @staticmethod
679     def decodePublicKey(public_key: bytes) -> EllipticCurvePublicKey:
680         return auth.getPublicEcFromDer(public_key)
681
682     @staticmethod
```

```
    def encodeCertificateSize(certificate_size: int) -> bytes:
        return struct.pack("!H", certificate_size)

    @staticmethod
    def decodeCertificateSize(certificate_size: bytes) -> int:
        return struct.unpack("!H", certificate_size)[0]

    @staticmethod
    def encodeCertificate(certificate: Certificate) -> bytes:
        return auth.getDerFromCertificate(certificate)

    @staticmethod
    def decodeCertificate(certificate: bytes) -> Certificate:
        return auth.getCertificateFromDer(certificate)

    @staticmethod
    def encodeHeader(
        version: int,
        packet_type: Type,
        flags: list[int],
        sequence_id: int,
        fragment_id: int | None = None,
        fragment_number: int | None = None,
        init_vector: int | None = None,
        checksum: int | None = None,
        public_key_size: int | None = None,
        public_key: EllipticCurvePublicKey | None = None,
        certificate_size: int | None = None,
        certificate: Certificate | None = None,
    ) -> bytes:
        header = Packet.encodeHeader(
            version,
            packet_type,
            flags,
            sequence_id,
            fragment_id,
            fragment_number,
            init_vector,
            checksum,
        )
        public_key_size = AuthPacket.encodePublicKeySize(public_key_size)
        public_key = AuthPacket.encodePublicKey(public_key)
        certificate_size = (
            AuthPacket.encodeCertificateSize(certificate_size)
            if certificate_size is not None
```

```
            else b""
        )
        certificate = (
            AuthPacket.encodeCertificate(certificate)
            if certificate is not None
            else b""
        )
        return header + public_key_size + public_key + certificate_size +
            certificate

    @staticmethod
    def decodeHeader(
        header: bytes,
    ) -> tuple[
        int,
        Type,
        list[int],
        int,
        int | None,
        int | None,
        int | None,
        int | None,
        int,
        EllipticCurvePublicKey,
        int | None,
        Certificate | None,
        int,
    ]:
        *h, offset = Packet.decodeHeader(header)
        public_key_size = AuthPacket.decodePublicKeySize(header[offset :
            offset + 1])
        offset += 1
        public_key = AuthPacket.decodePublicKey(
            header[offset : offset + public_key_size]
        )
        offset += public_key_size
        if offset < len(header):  # check if more bytes left to decode
            certificate_size = AuthPacket.decodeCertificateSize(
                header[offset : offset + 2]
            )
            offset += 2
            certificate = AuthPacket.decodeCertificate(
                header[offset : offset + certificate_size]
            )
            offset += certificate_size
```

```
771         else:
772             certificate_size = None
773             certificate = None
774         return *h, public_key_size, public_key, certificate_size,
                certificate, offset
775
776     # pack / unpack
777     @classmethod
778     def _packHeader(cls, p) -> bytes:
779         header = cls.encodeHeader(
780             p.version,
781             p.packet_type,
782             p.flags,
783             p.sequence_id,
784             p.fragment_id,
785             p.fragment_number,
786             p.init_vector,
787             p.checksum,
788             p.public_key_size,
789             p.public_key,
790             p.certificate_size,
791             p.certificate,
792         )
793         return header
794
795     @classmethod
796     def unpack(cls, bytesP: bytes):
797         *header, offset = cls._unpackHeader(bytesP)
798         return cls(*header)
799
800
801 class HeartbeatPacket(Packet):
802     heartbeat: bool
803
804     def __init__(
805         self,
806         version: int = VERSION,
807         packet_type: Type = Type.HEARTBEAT,
808         flags: list[int] = [0 for _ in range(FLAGS_SIZE)],
809         sequence_id: int = None,
810         fragment_id: int | None = None,
811         fragment_number: int | None = None,
812         init_vector: int | None = None,
813         checksum: int | None = None,
814         heartbeat: bool = 0,
```

```
        data: bytes | None = None,
    ) -> None:
        super().__init__(
            version,
            Type.HEARTBEAT,
            flags,
            sequence_id,
            fragment_id,
            fragment_number,
            init_vector,
            checksum,
            data,
        )
        self.heartbeat = heartbeat

    # encode / decode
    @staticmethod
    def encodeHeartbeat(heartbeat: bool) -> bytes:
        return struct.pack("!?", heartbeat)

    @staticmethod
    def decodeHeartbeat(heartbeat: bytes) -> bool:
        return struct.unpack("!?", heartbeat)[0]

    @staticmethod
    def encodeHeader(
        version: int,
        packet_type: Type,
        flags: list[int],
        sequence_id: int,
        fragment_id: int | None = None,
        fragment_number: int | None = None,
        init_vector: int | None = None,
        checksum: int | None = None,
        heartbeat: bool = 0,
    ) -> bytes:
        header = Packet.encodeHeader(
            version,
            packet_type,
            flags,
            sequence_id,
            fragment_id,
            fragment_number,
            init_vector,
            checksum,
```

```
        )
        heartbeat = HeartbeatPacket.encodeHeartbeat(heartbeat)
        return header + heartbeat

    @staticmethod
    def decodeHeader(
        header: bytes,
    ) -> tuple[
        int,
        Type,
        list[int],
        int,
        int | None,
        int | None,
        int | None,
        int | None,
        bool,
        int,
    ]:
        *h, offset = Packet.decodeHeader(header)
        heartbeat = HeartbeatPacket.decodeHeartbeat(header[offset : offset +
            1])
        offset += 1
        return *h, heartbeat, offset

    # pack / unpack
    @classmethod
    def _packHeader(cls, p) -> bytes:
        header = cls.encodeHeader(
            p.version,
            p.packet_type,
            p.flags,
            p.sequence_id,
            p.fragment_id,
            p.fragment_number,
            p.init_vector,
            p.checksum,
            p.heartbeat,
        )
        return header


class ErrorPacket(Packet):
    _major: error.Major
    _minor: error.Minor
```

```

    def __init__(
        self,
        version: int = VERSION,
        packet_type: Type = Type.ERROR,
        flags: list[int] = [0 for _ in range(FLAGS_SIZE)],
        sequence_id: int = None,
        fragment_id: int | None = None,
        fragment_number: int | None = None,
        init_vector: int | None = None,
        checksum: int | None = None,
        major: error.Major | int = error.Major.ERROR,
        minor: error.Minor | int = 0,
        data: bytes | None = None,
    ) -> None:
        super().__init__(
            version,
            Type.ERROR,
            flags,
            sequence_id,
            fragment_id,
            fragment_number,
            init_vector,
            checksum,
            data,
        )
        self.major = major
        self.minor = minor

    @property
    def major(self) -> error.Major:
        return self._major

    @major.setter
    def major(self, v: error.Major | int):
        if isinstance(v, error.Major):
            self._major = v
        else:
            self._major = error.Major(v)

    @property
    def minor(self) -> error.Minor:
        return self._minor

    @minor.setter
```

```
949     def minor(self, v: error.Minor | int):
950         if isinstance(v, error.Minor):
951             self._minor = v
952         else:
953             self._minor = error.getMinor(self.major, v)
954 
955     # dunder
956     def __str__(self) -> str:
957         s = self.pack(self)
958         data = self.data if self.data is not None else b""
959         pSize = len(s)
960         dSize = len(data)
961         return f"<{self.version}:{self.packet_type.name} {self.sequence_id}
                {''.join(map(str,self.flags))}
                {self.major.name}.{self.minor.name}: {data} [{pSize}:{dSize}]>"
962 
963     # encode / decode
964     @staticmethod
965     def _encodeMajor(major: error.Major) -> int:
966         return major.value
967 
968     @staticmethod
969     def _decodeMajor(major: int) -> error.Major:
970         return error.Major(major)
971 
972     @staticmethod
973     def _encodeMinor(minor: error.Minor) -> int:
974         return minor.value if minor != error.Minor else 0
975 
976     @staticmethod
977     def _decodeMinor(major: error.Major, minor: int) -> error.Minor:
978         return error.getMinor(major, minor)
979 
980     def encodeMajorMinor(major: int, minor: int) -> bytes:
981         majorMinor = (ErrorPacket._encodeMajor(major) * 16) |
                ErrorPacket._encodeMinor(
982             minor
983         )
984         return struct.pack("!B", majorMinor)
985 
986     def decodeMajorMinor(majorMinor: bytes) -> tuple[int, int]:
987         majorMinor = struct.unpack("!B", majorMinor)[0]
988         major = ErrorPacket._decodeMajor(majorMinor >> 4)
989         minor = ErrorPacket._decodeMinor(major, majorMinor & 15)
990         return major, minor
```

```
991
992     @staticmethod
993     def encodeHeader(
994         version: int,
995         packet_type: Type,
996         flags: list[int],
997         sequence_id: int,
998         fragment_id: int | None = None,
999         fragment_number: int | None = None,
1000        init_vector: int | None = None,
1001        checksum: int | None = None,
1002        major: int = 0,
1003        minor: int = 0,
1004    ) -> bytes:
1005        header = Packet.encodeHeader(
1006            version,
1007            packet_type,
1008            flags,
1009            sequence_id,
1010            fragment_id,
1011            fragment_number,
1012            init_vector,
1013            checksum,
1014        )
1015        majorMinor = ErrorPacket.encodeMajorMinor(major, minor)
1016        return header + majorMinor
1017
1018    @staticmethod
1019    def decodeHeader(
1020        header: bytes,
1021    ) -> tuple[
1022        int,
1023        Type,
1024        list[int],
1025        int,
1026        int | None,
1027        int | None,
1028        int | None,
1029        int | None,
1030        int,
1031        int,
1032        int,
1033    ]:
1034        *h, offset = Packet.decodeHeader(header)
1035        major, minor = ErrorPacket.decodeMajorMinor(header[offset : offset +
```

```
            1])
        offset += 1
        return *h, major, minor, offset

    # pack / unpack
    @classmethod
    def _packHeader(cls, p) -> bytes:
        header = cls.encodeHeader(
            p.version,
            p.packet_type,
            p.flags,
            p.sequence_id,
            p.fragment_id,
            p.fragment_number,
            p.init_vector,
            p.checksum,
            p.major,
            p.minor,
        )
        return header


def unpack(rawP:bytes) -> Packet:
    packet_type = Packet.decodeVersionType(rawP[0:1])[1]
    match packet_type:
        case Type.DEFAULT:
            return Packet.unpack(rawP)
        case Type.ACK:
            return AckPacket.unpack(rawP)
        case Type.AUTH:
            return AuthPacket.unpack(rawP)
        case Type.HEARTBEAT:
            return HeartbeatPacket.unpack(rawP)
        case Type.ERROR:
            return ErrorPacket.unpack(rawP)
        case _:
            logger.warning(f"Cannot unpack '{packet_type}' due to invalid
                packet type.")
```

```
# udp.server
import base64
import json
import socket
```

```
import time
from datetime import datetime
from threading import Event, Lock, Thread

import requests
from cryptography.hazmat.primitives.asymmetric.rsa import RSAPrivateKey

from . import (
    HEARTBEAT_MAX_TIME,
    HEARTBEAT_MIN_TIME,
    MAX_CLIENTS,
    auth,
    bcolors,
    error,
    logger,
    node,
    packet,
)


class Server(node.Node):
    clients: dict[tuple[str, int], node.Node]
    clientsLock: Lock
    clientDeleteEvent: Event
    rsaKey: RSAPrivateKey | None
    heartbeatThread: Thread
    onClientJoin: None
    onClientLeave: None
    maxClients: int

    def __init__(
        self,
        addr,
        maxClients: int = MAX_CLIENTS,
        rsaKey: RSAPrivateKey | None = None,
        onClientJoin=None,
        onClientLeave=None,
        onReceiveData=None,
    ) -> None:
        self.clients = {}
        self.clientsLock = Lock()
        self.clientDeleteEvent = Event()
        self.clientDeleteEvent.set()
        self.rsaKey = rsaKey if rsaKey is not None else auth.generateRsaKey()
        self.onClientJoin = onClientJoin
```

```
50          self.onClientLeave = onClientLeave
51          self.maxClients = maxClients
52          s = socket.socket(type=socket.SOCK_DGRAM)
53          super().__init__(
54              addr,
55              cert=auth.generateUserCertificate(self.rsaKey),
56              socket=s,
57              onReceiveData=onReceiveData,
58          )
59          self.heartbeatThread = Thread(
60              name=f"{self.port}:Heartbeat", target=self.heartbeat, daemon=True
61          )
62          self.bind(self.addr)
63
64      def receiveAck(self, p: packet.AckPacket, addr: tuple[str, int]) -> None:
65          super().receiveAck(p, addr)
66          if p.data is not None and not self.getHandshake(
67              addr
68          ):  # ack has payload & client has not completed handshake =>
                validate handshake
69              if not self.validateHandshake(addr, p.data):
70                  # raise ValueError(f"Local finished value does not match peer
                        finished value {p.data}")
71                  logger.error(
72                      f"Local finished value does not match peer finished value
                            {p.data}"
73                  )
74                  self.queueError(
75                      addr,
76                      major=error.Major.CONNECTION,
77                      minor=error.ConnectionErrorCodes.FINISH_INVALID,
78                      data=b"Invalid finish.",
79                  )
80              else:
81                  # print(f"{bcolors.OKGREEN}# Handshake with {addr}
                        successful.{bcolors.ENDC}")
82                  logger.info(
83                      f"{bcolors.OKGREEN}# Handshake with {addr}
                            successful.{bcolors.ENDC}"
84                  )
85                  if self.onClientJoin:
86                      self.onClientJoin(addr, self.getClientId(addr))
87
88      def receiveAuth(
89          self, p: packet.AuthPacket, addr: tuple[str, int]
```

```
90      ) -> tuple[packet.AuthPacket, tuple[str, int]]:
91          if addr not in self.clients:  # new client
92              if self.isNotFull():  # check space
93                  # print(f"{bcolors.WARNING}# Handshake with {addr}
                        starting.{bcolors.ENDC}")
94                  logger.info(
95                      f"{bcolors.WARNING}# Handshake with {addr}
                            starting.{bcolors.ENDC}"
96                  )
97                  valid, accountId = self.validateCertificate(p.certificate)
98                  if not valid:
99                      # raise ValueError(f"Invalid peer cert {p.certificate}")
100                     logger.error(f"Invalid peer cert {p.certificate}")
101                     self.queueError(
102                         addr,
103                         major=error.Major.CONNECTION,
104                         minor=error.ConnectionErrorCodes.CERTIFICATE_INVALID,
105                         data=b"Invalid Certificate.",
106                     )
107                 else:
108                     self.makeClient(addr, p.certificate, accountId)
109                     self.regenerateEcKey(addr)
110                     sessionKey = auth.generateSessionKey(
111                         self.getEcKey(addr), p.public_key
112                     )
113                     self.setSessionKey(addr, sessionKey)
114                     self.queueAuth(addr, self.cert,
                            self.getEcKey(addr).public_key())
115                     self.queueFinished(addr, p.sequence_id,
                            self.getSessionKey(addr))
116             else:
117                 # print(f"{bcolors.FAIL}# Handshake with {addr} denied due to
                        NO_SPACE.{bcolors.ENDC}")
118                 logger.warning(
119                     f"{bcolors.FAIL}# Handshake with {addr} denied due to
                            NO_SPACE.{bcolors.ENDC}"
120                 )
121                 self.queueError(
122                     addr,
123                     major=error.Major.CONNECTION,
124                     minor=error.ConnectionErrorCodes.NO_SPACE,
125                     data=b"Server is Full.",
126                 )
127         else:
128             sessionKey = auth.generateSessionKey(self.getEcKey(addr),
```

```
                p.public_key)
129         if addr in self.clients:
130             if self.getSessionKey(addr) != sessionKey:  # new client
                    sessionKey
131                 # print(f"{bcolors.WARNING}# Handshake with {addr}
                        reset.{bcolors.ENDC}")
132                 logger.info(
133                     f"{bcolors.WARNING}# Handshake with {addr}
                            reset.{bcolors.ENDC}"
134                 )
135                 valid, accountId = self.validateCertificate(p.certificate)
136                 if not valid:
137                     # raise ValueError(f"Invalid peer cert {p.certificate}")
138                     logger.warning(f"Invalid peer cert {p.certificate}")
139                     self.queueError(
140                         addr,
141                         major=error.Major.CONNECTION,
142                         minor=error.ConnectionErrorCodes.CERTIFICATE_INVALID,
143                         data=b"Invalid Certificate.",
144                     )
145                 else:
146                     self.regenerateEcKey(addr)
147                     # self.clients[addr].cert = p.certificate # shouldn't
                            change
148                     sessionKey = auth.generateSessionKey(
149                         self.getEcKey(addr), p.public_key
150                     )
151                     self.setSessionKey(addr, sessionKey)  # make new session
                            key
152                     self.queueAuth(addr, self.cert,
                            self.getEcKey(addr).public_key())
153                     self.queueFinished(addr, p.sequence_id,
                            self.getSessionKey(addr))
154         return (p, addr)
155
156     def queueDisconnect(
157         self,
158         flags: list[bool] = [0 for _ in range(packet.FLAGS_SIZE)],
159         data: bytes | None = None,
160     ):
161         with self.clientsLock:
162             clientAddrs = [addr for addr in self.clients]
163         for addr in clientAddrs:
164             self.queueError(
165                 addr,
```

```
                flags=flags,
                major=error.Major.DISCONNECT,
                minor=error.DisconnectErrorCodes.SERVER_DISCONNECT,
                data=data,
            )

    def getSessionKey(self, clientAddr: tuple[str, int]) -> bytes | None:
        with self.clientsLock:
            return self.clients[clientAddr].sessionKey

    def setSessionKey(self, clientAddr: tuple[str, int], sessionKey: bytes)
        -> None:
        with self.clientsLock:
            self.clients[clientAddr].sessionKey = sessionKey

    def getHandshake(self, clientAddr: tuple[str, int]) -> bool:
        with self.clientsLock:
            return self.clients[clientAddr].handshake

    def getSentAckBit(self, clientAddr: tuple[str, int], p: packet.Packet) ->
        bool:
        with self.clientsLock:
            return self.clients[clientAddr].sentAckBits[p.sequence_id]

    def setSentAckBit(self, clientAddr: tuple[str, int], ackBit: int, v:
        bool) -> None:
        with self.clientsLock:
            self.clients[clientAddr].sentAckBits[ackBit] = v

    def getSentAckBits(self, clientAddr: tuple[str, int]) -> list[bool]:
        with self.clientsLock:
            return self.clients[clientAddr].sentAckBits

    def getRecvAckBit(self, clientAddr: tuple[str, int], p: packet.Packet) ->
        bool:
        with self.clientsLock:
            return self.clients[clientAddr].recvAckBits[p.sequence_id]

    def getRecvAckBits(self, clientAddr: tuple[str, int]) -> list[bool]:
        with self.clientsLock:
            return self.clients[clientAddr].recvAckBits

    def setRecvAckBit(self, clientAddr: tuple[str, int], ackBit: int, v:
        bool) -> None:
        with self.clientsLock:
```

```
206             self.clients[clientAddr].recvAckBits[ackBit] = v
207
208     def getNewestSeqId(self, clientAddr: tuple[str, int]) -> int:
209         with self.clientsLock:
210             if clientAddr in self.clients:
211                 return self.clients[clientAddr].newestSeqId
212             else:
213                 return 0
214
215     def setNewestSeqId(self, clientAddr: tuple[str, int], newSeqId: int) ->
        None:
216         with self.clientsLock:
217             if clientAddr in self.clients:
218                 self.clients[clientAddr].newestSeqId = newSeqId
219
220     def getFragBuffer(
221         self, clientAddr: tuple[str, int]
222     ) -> dict[int, list[packet.Packet]]:
223         with self.clientsLock:
224             return self.clients[clientAddr].fragBuffer
225
226     def getEcKey(self, clientAddr: tuple[str, int]) ->
        auth.ec.EllipticCurvePrivateKey:
227         with self.clientsLock:
228             return self.clients[clientAddr].ecKey
229
230     def getSequenceId(self, clientAddr: tuple[str, int]) -> int | None:
231         with self.clientsLock:
232             return (
233                 self.clients[clientAddr].sequenceId
234                 if clientAddr in self.clients
235                 else None
236             )
237
238     def getQueue(self, clientAddr: tuple[str, int]) -> node.Queue:
239         with self.clientsLock:
240             return (
241                 self.clients[clientAddr].queue
242                 if clientAddr in self.clients
243                 else self.queue
244             )
245
246     def getSequenceIdLock(self, clientAddr: tuple[str, int]) -> Lock:
247         with self.clientsLock:
248             return self.clients[clientAddr].sequenceIdLock
```

```
249
250     def incrementSequenceId(self, clientAddr: tuple[str, int]) -> None:
251         with self.getSequenceIdLock(clientAddr):
252             with self.clientsLock:
253                 self.clients[clientAddr].sequenceId += 1
254
255     def getHeartbeat(self, clientAddr: tuple[str, int]) -> datetime:
256         with self.clientsLock:
257             return self.clients[clientAddr].heartbeat
258
259     def setHeartbeat(self, clientAddr: tuple[str, int], v: datetime) -> None:
260         with self.clientsLock:
261             self.clients[clientAddr].heartbeat = v
262
263     def regenerateEcKey(self, clientAddr: tuple[str, int]) -> None:
264         with self.clientsLock:
265             self.clients[clientAddr].regenerateEcKey()
266
267     def checkClientExists(self, clientAddr: tuple[str, int]) -> bool:
268         with self.clientsLock:
269             return clientAddr in self.clients
270
271     def validateHandshake(self, clientAddr: tuple[str, int], finished: bytes)
        -> bool:
272         with self.clientsLock:
273             return self.clients[clientAddr].validateHandshake(finished)
274
275     def getClientLength(self) -> int:
276         with self.clientsLock:
277             return len(self.clients)
278
279     def getClientId(self, clientAddr: tuple[str, int]) -> int:
280         with self.clientsLock:
281             return self.clients[clientAddr].accountId
282
283     def getClientIds(self) -> list[int]:
284         with self.clientsLock:
285             return [client.id for addr, client in self.clients.items()]
286
287     def isNotFull(self) -> bool:
288         with self.clientsLock:
289             return len(self.clients) < self.maxClients  # check space
290
291     def isEmpty(self) -> bool:
292         with self.clientsLock:
```

```
293             return len(self.clients) == 0
294
295     def listen(self) -> None:
296         logger.info(
297             f"{bcolors.HEADER}Listening @
                {self.socket.getsockname()}{bcolors.ENDC}"
298         )
299         while self.isRunning.is_set():
300             p, addr = self.receivePacket()
301             if p is not None and addr is not None:
302                 if self.checkClientExists(addr):  # client exists
303                     self.setHeartbeat(addr, datetime.now())
304                     if self.getHandshake(
305                         addr
306                     ):  # client handshake complete => allow all packet types
307                         self.receive(p, addr)
308                     else:
309                         if (
310                             p.packet_type
311                             in (packet.Type.AUTH, packet.Type.ACK,
                                packet.Type.ERROR)
312                         ):  # client handshake incomplete => drop all
                            non-AUTH | non-ACK | non-ERROR packets
313                             self.receive(p, addr)
314                 else:
315                     if p.packet_type in (
316                         packet.Type.AUTH,
317                         packet.Type.ERROR,
318                     ):  # client not exists => drop all non-AUTH | non-ERROR
                        packets
319                         self.receive(p, addr)
320                     else:
321                         logger.warning(
322                             f"{bcolors.WARNING}! {addr} :{bcolors.ENDC}
                                {bcolors.WARNING}{p}{bcolors.ENDC}"
323                         )
324         else:
325             logger.info("| listen thread stopping...")
326
327     def heartbeat(self) -> None:
328         while self.isRunning.is_set():
329             time.sleep(HEARTBEAT_MIN_TIME)
330             with self.clientsLock:
331                 clients = [k for k in self.clients.keys()]
332             for clientAddr in clients:
```

```
                heartbeat = self.getHeartbeat(clientAddr)
                delta = (datetime.now() - heartbeat).seconds
                if delta > HEARTBEAT_MAX_TIME:
                    self.removeClient(
                        clientAddr,
                        debugStr=f"due to heartbeat timeout (last contact was
                            {heartbeat})",
                    )
                elif delta > HEARTBEAT_MIN_TIME:
                    self.queueHeartbeat(clientAddr, heartbeat=False)
        else:
            logger.info("| heartbeat thread stopping...")

    def makeClient(
        self, clientAddr: tuple[str, int], cert: auth.x509.Certificate,
            accountId: int
    ) -> None:
        c = node.Node(
            clientAddr,
            cert=cert,
            accountId=accountId,
            sendLock=self.sendLock,
            socket=self.socket,
        )
        c.outboundThread.start()
        with self.clientsLock:
            self.clients[clientAddr] = c

    def removeClient(self, clientAddr: tuple[str, int], debugStr="") -> None:
        if self.checkClientExists(clientAddr):
            cId = self.getClientId(clientAddr)
            with self.clientsLock:
                logger.info(
                    f"{bcolors.FAIL}# Client {clientAddr} was removed{'
                        '+debugStr}.{bcolors.ENDC}"
                )
                self.clients[clientAddr].isRunning.clear()
                del self.clients[clientAddr]
                if self.onClientLeave:
                    self.onClientLeave(clientAddr, cId)

    # misc
    def startThreads(self) -> None:
        super().startThreads()
        self.heartbeatThread.start()
```

```

    def validateCertificate(self, certificate: auth.x509.Certificate) -> bool:
        url = f"http://{self.host}:5000/auth/certificate/validate"
        headers = {"Content-Type": "application/json"}
        certificate = base64.encodebytes(
            auth.getDerFromCertificate(certificate)
        ).decode()
        data = {"certificate": certificate}
        try:
            r = requests.get(url, headers=headers, data=json.dumps(data))
            if r.status_code == 200:
                return r.json()["valid"], r.json()["account-id"]
            else:
                return False
        except:  # noqa: E722
            # Cert server unresponsive
            return False

    def quit(
        self, msg: str = "quit call", e: Exception | None = None
    ) -> Exception | None:
        self.queueDisconnect(data=msg.encode())
        self.queue.join()
        e = super().quit(msg, e)
        if self.heartbeatThread.is_alive:
            self.heartbeatThread.join()
        return e

    def handleDisconnectError(
        self, p: packet.ErrorPacket, addr: tuple[str, int], e:
           error.DisconnectError
    ) -> None:
        match e:
            case error.ServerDisconnectError():
                pass  # should not react to server disconnect
            case error.ClientDisconnectError():
                self.removeClient(addr, "The client has closed")
            case _:
                raise e
```

```
# udp.utils
import zlib

```

```python
from . import MAX_FRAGMENT_SIZE


def compressData(data: bytes) -> bytes:
    # default speed
    # no header or checksum
    return zlib.compress(data, -1, -15)


def decompressData(data: bytes) -> bytes:
    # no header or checksum
    return zlib.decompress(data, -15)


def generateChecksum(data: bytes) -> int:
    return zlib.crc32(data)


def fragmentData(data: bytes) -> list[bytes]:
    return [
        data[i : i + MAX_FRAGMENT_SIZE] for i in range(0, len(data),
           MAX_FRAGMENT_SIZE)
    ]


def defragmentData(fragments: list[bytes]) -> bytes:
    return b"".join(fragments)
```

9.3.2 server

```python
# server.__init__
import os

import dotenv
from flask import Flask

from udp import logger  # noqa: F401

from .models import *  # noqa: F403

from sqlalchemy_utils import database_exists, create_database

dotenv.load_dotenv()
```

```
PRUNE_TIME = int(os.environ.get("PRUNE_TIME"))


def create_app():
    app = Flask(__name__)

    app.jinja_env.trim_blocks = True
    app.jinja_env.lstrip_blocks = True

    app.config["SECRET_KEY"] = os.environ.get("SECRET_KEY").encode()
    uri = os.environ.get("SQLALCHEMY_DATABASE_URI")
    _init = False
    if not database_exists(uri):
        _init = True
        create_database(uri)
    app.config["SQLALCHEMY_DATABASE_URI"] = uri

    db.init_app(app)  # noqa: F405

    with app.app_context():
        db.create_all()  # noqa: F405

    if _init:
        with app.app_context():
            # init games
            from rps import ID, NAME, MIN_PLAYERS, MAX_PLAYERS
            Statement.createGame(ID, NAME, MIN_PLAYERS, MAX_PLAYERS)  # noqa:
                F405
            # example accounts
            m = Statement.createAccount("Mario", "ItsAMe123")  # noqa: F405
            p = Statement.createAccount("Peach", "MammaMia!")  # noqa: F405
            b = Statement.createAccount("Bowser", "M4r10SucK5")  # noqa: F405
            Statement.createFriends(m.id, p.id)  # noqa: F405
            Statement.createFriends(p.id, b.id)  # noqa: F405

    from .main import main as main_blueprint

    app.register_blueprint(main_blueprint)

    return app
```

```
# server.lobbies
import os
```

```
3
4  import dotenv
5  from flask import Flask
6
7  from udp import logger  # noqa: F401
8
9  from .models import *  # noqa: F403
10
11 from sqlalchemy_utils import database_exists, create_database
12
13 dotenv.load_dotenv()
14 PRUNE_TIME = int(os.environ.get("PRUNE_TIME"))
15
16
17 def create_app():
18     app = Flask(__name__)
19
20     app.jinja_env.trim_blocks = True
21     app.jinja_env.lstrip_blocks = True
22
23     app.config["SECRET_KEY"] = os.environ.get("SECRET_KEY").encode()
24     uri = os.environ.get("SQLALCHEMY_DATABASE_URI")
25     _init = False
26     if not database_exists(uri):
27         _init = True
28         create_database(uri)
29     app.config["SQLALCHEMY_DATABASE_URI"] = uri
30
31     db.init_app(app)  # noqa: F405
32
33     with app.app_context():
34         db.create_all()  # noqa: F405
35
36     if _init:
37         with app.app_context():
38             # init games
39             from rps import ID, NAME, MIN_PLAYERS, MAX_PLAYERS
40             Statement.createGame(ID, NAME, MIN_PLAYERS, MAX_PLAYERS)  # noqa:
                F405
41             # example accounts
42             m = Statement.createAccount("Mario", "ItsAMe123")  # noqa: F405
43             p = Statement.createAccount("Peach", "MammaMia!")  # noqa: F405
44             b = Statement.createAccount("Bowser", "M4r10SucK5")  # noqa: F405
45             Statement.createFriends(m.id, p.id)  # noqa: F405
46             Statement.createFriends(p.id, b.id)  # noqa: F405
```

```
47
48      from .main import main as main_blueprint
49
50      app.register_blueprint(main_blueprint)
51
52      return app
```

```
1  # server.main
2  import atexit
3  import base64
4
5  from flask import (
6      Blueprint,
7      abort,
8      g,
9      jsonify,
10     request,
11 )
12 from flask_httpauth import HTTPBasicAuth
13
14 import udp.auth
15
16 from . import Statement
17 from .lobbies import LobbyHandler
18
19 main = Blueprint("main", __name__)
20 auth = HTTPBasicAuth()
21 rsaKey = udp.auth.generateRsaKey()
22 lobbyHandler = LobbyHandler(rsaKey=rsaKey)
23
24
25 def quit() -> None:
26     lobbyHandler.quit()
27
28
29 atexit.register(quit)
30
31
32 @auth.verify_password
33 def verifyPassword(username: str, password: str) -> bool:
34     account = Statement.validateToken(username)  # check token
35     if not account:  # if token not valid
36         account = Statement.findAccount(username=username)  # check account
```

```
        if not account or not account.verifyPassword(
            password
        ):  # if account not exist or wrong password
            return False
    g.account = account
    return True


# Index
@main.route("/")
def index():
    return jsonify({})


# auth
@main.route("/auth/register", methods=["POST"])
def createAccount():
    username = request.json.get("username")
    password = request.json.get("password")
    if not (username or password):  # check not null
        abort(400)  # missing args
    if Statement.findAccount(username):  # check if account exists
        abort(400)  # account already exists
    account = Statement.createAccount(username, password)
    return jsonify({"account-id": account.id, "username": account.username}),
        201


@main.route("/auth/token")
@auth.login_required
def getAuthToken():
    return jsonify({"token": g.account.generateToken()})


@main.route("/auth/key")
@auth.login_required
def getKey():
    return jsonify(
        {
            "key": base64.encodebytes(g.account.private_key).decode(),
            "account-id": g.account.id,
        }
    )


```

```
81 @main.route("/auth/certificate")
82 @auth.login_required
83 def getCert():
84     # return server certificate
85     return None
86
87
88 @main.route("/auth/certificate/validate")
89 def validateCert():
90     valid = False
91     certificate = request.json.get("certificate")
92     certificate = base64.decodebytes(certificate.encode())
93     if certificate is not None:
94         certificate = udp.auth.getCertificateFromDer(certificate)
95         attributes = udp.auth.getUserCertificateAttributes(certificate)
96         if attributes["account-id"] is not None:
97             account = Statement.getAccount(attributes["account-id"])
98             publicKey = udp.auth.getRsaPublicFromDer(account.public_key)
99         else:
100            publicKey = rsaKey.public_key()
101        valid = udp.auth.validateCertificate(certificate, publicKey)
102        return jsonify({"valid": valid, "account-id":
               attributes["account-id"]})
103    else:
104        abort(400)  # missing args
105
106
107 @main.route("/auth/test")
108 @auth.login_required
109 def authTest():
110     return jsonify({"hello": g.account.username})
111
112
113 # game
114 @main.route("/games/")
115 @auth.login_required
116 def getGames():
117     return jsonify({game.id: game.name for game in Statement.getGames()})
118
119
120 @main.route("/lobby/all")
121 @auth.login_required
122 def getLobbies():
123     lobbies = LobbyHandler.getAll()
124     games = {game.id: game.name for game in Statement.getGames()}
```

```
125     data = lambda lobby: {  # noqa: E731
126         "game": {"game-id": lobby.game_id, "game-name": games[lobby.game_id]},
127         "size": Statement.getLobbySize(lobby.id),
128         "is-full": Statement.getIsLobbyFree(lobby.id),
129     }
130     return jsonify({lobby.id: data(lobby) for lobby in lobbies})
131
132
133 @main.route("/lobby/create", methods=["POST"])
134 @auth.login_required
135 def createLobby():
136     gameId = request.json.get("game-id")
137     gameName = request.json.get("game-name")
138     if not (gameId or gameName):  # check args
139         abort(400)  # missing args
140     game = None
141     if gameId:  # check gameId not null
142         game = Statement.getGame(gameId)
143     if not game:  # check gameId null
144         if gameName:  # check gameName not null
145             game = Statement.findGame(gameName)
146     if not game:  # check game null
147         abort(404)  # no game found
148     addr = _getAddr()
149     lobby = lobbyHandler.createLobby(addr, game.id)
150     return jsonify(
151         {"lobby-id": lobby.id, "lobby-addr": lobby.getAddr(), "game-id":
                lobby.gameId}
152     ), 201
153
154
155 def _getAddr():
156     host, port = request.host.split(":")
157     port = int(port)
158     return (host, port)
159
160
161 @main.route("/lobby/")
162 @auth.login_required
163 def getLobby():
164     lobbyId = request.json.get("lobby-id")
165     if not lobbyId:
166         abort(400)  # missing args
167     lobby = lobbyHandler.getLobby(lobbyId)
168     return jsonify(
```

```
169         {"lobby-id": lobby.id, "lobby-addr": lobby.getAddr(), "game-id":
                lobby.gameId}
170     )
171
172
173 @main.route("/lobby/members")
174 @auth.login_required
175 def getMembers():
176     return jsonify(lobbyHandler.getMembers)
177
178
179 @main.route("/lobby/find")
180 @auth.login_required
181 def findLobby():
182     gameId = request.json.get("game-id")
183     gameName = request.json.get("game-name")
184     if not (gameId or gameName):  # check args
185         abort(400)  # missing args
186     game = None
187     if gameId:  # check gameId not null
188         game = Statement.getGame(gameId)
189     if not game:  # check gameId null
190         if gameName:  # check gameName not null
191             game = Statement.findGame(gameName)
192     if not game:  # check game null
193         abort(404)  # no game found
194     lobby = lobbyHandler.findLobbies(game.id)
195     lobby = lobby[0] if len(lobby) > 0 else None
196     if lobby is not None:
197         return jsonify(
198             {
199                 "lobby-id": lobby.id,
200                 "lobby-addr": lobby.getAddr(),
201                 "game-id": lobby.gameId,
202             }
203         )
204     else:
205         abort(404)
206
207
208 @main.route("/friends/")
209 @auth.login_required
210 def getFriends():
211     friends = Statement.getFriends(g.account.id)
212     return jsonify(
```

```
        {
            "friends": [
                {"id": account.id, "username": account.username} for account
                    in friends
            ]
        }
    )


@main.route("/friends/add", methods=["POST"])
@auth.login_required
def addFriend():
    username = request.json.get("username")
    if username is None:
        abort(400)  # missing args
    account = g.account
    other = Statement.findAccount(username)
    if other is None:
        abort(404)
    Statement.createFriends(account.id, other.id)
    return jsonify(
        {
            "account": {"id": account.id, "username": account.username},
            "other": {"id": other.id, "username": other.username},
        }
    ), 201


@main.route("/friend/remove", methods=["DELETE"])
@auth.login_required
def removeFriend():
    username = request.json.get("username")
    if username is None:
        abort(400)  # missing args
    account = g.account
    other = Statement.findAccount(username)
    if other is None:
        abort(404)
    success = Statement.removeFriends(account.id, other.id)
    if success:
        return jsonify(data=[]), 204
    else:
        abort(404)


```

```
@main.route("/lobby/friends")
@auth.login_required
def getFriendLobbies():
    friends = Statement.getFriends(g.account.id)
    lobbyInfo = lambda lobby: {  # noqa: E731
        "lobby-id": lobby.id,
        "game-id": lobby.gameId,
        "game-name": Statement.getGame(lobby.gameId).name,
    }
    accountInfo = lambda account: {  # noqa: E731
        "account-id": account.id,
        "username": account.username,
    }
    lobbies = [
        {
            "account": accountInfo(account),
            "lobbies": [
                lobbyInfo(lobby) for lobby in
                    lobbyHandler.getMember(account.id)
            ],
        }
        for account in friends
        if len(lobbyHandler.getMember(account.id)) > 0
    ]
    return jsonify(lobbies)
```

```
# server.models
import datetime

import jwt
from flask import current_app
from flask_sqlalchemy import SQLAlchemy
from werkzeug.security import check_password_hash, generate_password_hash

import udp.auth as auth

db = SQLAlchemy()


# models
class Friends(db.Model):
    account_one_id = db.Column(
        db.Integer, db.ForeignKey("account.id"), primary_key=True
```

```
18      )
19      account_two_id = db.Column(
20          db.Integer, db.ForeignKey("account.id"), primary_key=True
21      )
22
23
24  class Scores(db.Model):
25      id = db.Column(db.Integer, primary_key=True)
26      score = db.Column(db.Integer, nullable=False)
27      account_id = db.Column(db.Integer, db.ForeignKey("account.id"),
            nullable=False)
28      game_id = db.Column(db.Integer, db.ForeignKey("game.id"), nullable=False)
29
30
31  class Account(db.Model):
32      id = db.Column(db.Integer, primary_key=True)
33      username = db.Column(db.String(255), unique=True, nullable=False)
34      password = db.Column(db.String(162), nullable=False)
35      private_key = db.Column(db.LargeBinary(1337))
36      public_key = db.Column(db.LargeBinary(294))
37
38      def hashPassword(self, password: str) -> None:
39          self.password = generate_password_hash(password)
40
41      def verifyPassword(self, password: str) -> bool:
42          return check_password_hash(self.password, password)
43
44      def generateToken(self, expiration: int = 600) -> str:
45          data = {
46              "id": self.id,
47              "exp": datetime.datetime.now() +
                    datetime.timedelta(seconds=expiration),
48          }
49          token = jwt.encode(data, current_app.config["SECRET_KEY"],
                algorithm="HS256")
50          return token
51
52      @staticmethod
53      def validateToken(token: str):
54          try:
55              data = jwt.decode(
56                  token,
57                  current_app.config["SECRET_KEY"],
58                  leeway=datetime.timedelta(seconds=10),
59                  algorithms=["HS256"],
```

```
            )
        except:  # noqa: E722
            return None
        account = Statement.getAccount(data.get("id"))
        return account

    def generateKey(self, password: bytes) -> None:
        k = auth.generateRsaKey()
        self.private_key = auth.getDerFromRsaPrivate(k, password)
        self.public_key = auth.getDerFromRsaPublic(k.public_key())

    @staticmethod
    def decryptKey(self, key: bytes, password: bytes) ->
       auth.rsa.RSAPublicKey:
        k = auth.getRsaPrivateFromDer(key, password)
        return k


class Game(db.Model):
    id = db.Column(db.Integer, primary_key=True)
    name = db.Column(db.String(255), unique=True, nullable=False)
    min_players = db.Column(db.Integer, default=1)
    max_players = db.Column(db.Integer)


class Statement:
    # get
    @staticmethod
    def getGame(gameId: int) -> Game:
        return Game.query.filter_by(id=gameId).scalar()

    @staticmethod
    def getGames() -> list[Game]:
        return Game.query.all()

    @staticmethod
    def getAccount(userId: int) -> Account:
        return Account.query.filter_by(id=userId).scalar()

    @staticmethod
    def getFriends(accountId: int) -> list[Account]:
        friends = Friends.query.filter(
            (Friends.account_one_id == accountId)
            | (Friends.account_two_id == accountId)
        )
```

```
        friends = [
            friend.account_one_id
            if friend.account_one_id != accountId
            else friend.account_two_id
            for friend in friends
        ]
        friends = [Statement.getAccount(id) for id in friends]
        return friends

    # create
    @staticmethod
    def createAccount(username: str, password: str) -> Account:
        account = Account(username=username)
        account.hashPassword(password)
        account.generateKey(password.encode())
        db.session.add(account)
        db.session.commit()
        return account

    @staticmethod
    def createFriends(accountIdOne: int, accountIdTwo: int) -> Friends:
        idOne = min(accountIdOne, accountIdTwo)
        idTwo = max(accountIdOne, accountIdTwo)
        friends = Friends(account_one_id=idOne, account_two_id=idTwo)
        db.session.add(friends)
        db.session.commit()
        return friends

    @staticmethod
    def createGame(id:int, name:str, min_players:int, max_players:int) ->
       Game:
        game = Game(id=id, name=name, min_players=min_players,
           max_players=max_players)
        db.session.add(game)
        db.session.commit()
        return game

    # find
    @staticmethod
    def findAccount(username: str) -> Account | None:
        return Account.query.filter_by(username=username).scalar()

    @staticmethod
    def validateToken(token: str) -> Account | None:
        return Account.validateToken(token)
```

```
147
148     @staticmethod
149     def findGame(gameName: str) -> Game | None:
150         return Game.query.filter_by(name=gameName).scalar()
151
152     # delete
153     @staticmethod
154     def removeFriends(accountIdOne: int, accountIdTwo: int) -> bool:
155         idOne = min(accountIdOne, accountIdTwo)
156         idTwo = max(accountIdOne, accountIdTwo)
157         friends = Friends.query.filter(
158             (Friends.account_one_id == idOne) & (Friends.account_two_id ==
                    idTwo)
159         )
160         if friends is not None:
161             friends.delete()
162             db.session.commit()
163             return True
164         else:
165             return False
```

9.3.3 rps

```
1  # rps.__init__
2  import os
3
4  import yaml
5
6
7  class bcolors:
8      HEADER = "\033[95m"
9      OKBLUE = "\033[94m"
10     OKCYAN = "\033[96m"
11     OKGREEN = "\033[92m"
12     WARNING = "\033[93m"
13     FAIL = "\033[91m"
14     ENDC = "\033[0m"
15     BOLD = "\033[1m"
16     UNDERLINE = "\033[4m"
17
18
19 class Choice:
20     ROCK = 0
```

```
    PAPER = 1
    SCISSORS = 2


class Outcome:
    LOOSE = 0
    WIN = 1
    DRAW = 2


QUEUE_TIMEOUT = 10

# config
CONFIG_PATH = os.path.join(os.path.dirname(__file__), "game_config.yaml")

with open(CONFIG_PATH) as f:
    config = yaml.safe_load(f)

ID = config["ID"]
NAME = config["NAME"]
MIN_PLAYERS = config["MIN_PLAYERS"]
MAX_PLAYERS = config["MAX_PLAYERS"]
```

```
# rps.__main__
import threading

from . import client, server


def runServer():
    s = server.Server((S_HOST, S_PORT))
    sT = threading.Thread(target=s.mainloop, daemon=True)
    sT.start()
    return s, sT


def runClient():
    c = client.Client((C_HOST, C_PORT), (S_HOST, S_PORT))
    return c


if __name__ == "__main__":
    import time
```

```
21
22      from udp import C_HOST, C_PORT, S_HOST, S_PORT
23
24      print("\n" * 4)
25      s, sT = runServer()
26      time.sleep(1)
27      c = runClient()
28      c.connect()
29      time.sleep(1)
30      c.isRunning = False
31      time.sleep(1)
32      s.isRunning = False
33      time.sleep(1)
34      print("END")
```

```
1  # rps.client
2  import json
3  from queue import Empty, Queue
4  from threading import Thread
5
6  import udp.error as error
7  from inputimeout import TimeoutOccurred, inputimeout
8  from udp.auth import rsa
9  from udp.client import Client as UdpClient
10 from udp.packet import Flag, lazyFlags
11
12 from . import QUEUE_TIMEOUT, Outcome, bcolors
13
14
15 class Client:
16     isRunning: bool
17     recvQueue: Queue
18     score: int
19     onReceiveData: None
20     gameThread: Thread
21     udpClient: UdpClient
22
23     def __init__(
24         self,
25         addr: tuple[str, int],
26         targetAddr: tuple[str, int],
27         rsaKey: rsa.RSAPrivateKey|None = None,
28         userId: int | str | None = None,
```

```
        username: str | None = None,
        onReceiveData=None,
    ) -> None:
        self.isRunning = True
        self.recvQueue = Queue()
        self.score = 0
        self.onReceiveData = onReceiveData
        self.gameThread = Thread(
            name=f"{addr[1]}:Gameloop", target=self.gameloop, daemon=True
        )
        self.udpClient = UdpClient(
            addr,
            targetAddr,
            rsaKey=rsaKey,
            accountId=userId,
            username=username,
            onConnect=self.onConnect,
            onReceiveData=self.receive,
        )

    def send(self, addr: tuple[str, int], data: json) -> None:
        self.udpClient.queueDefault(
            addr, flags=lazyFlags(Flag.RELIABLE), data=self.encodeData(data)
        )

    def receive(self, addr: tuple[str, int], data: bytes):
        self.recvQueue.put((addr, self.decodeData(data)))
        if self.onReceiveData:
            self.onReceiveData(addr, data)

    @staticmethod
    def encodeData(data: dict) -> bytes:
        return json.dumps(data).encode()

    @staticmethod
    def decodeData(data: bytes) -> dict:
        return json.loads(data.decode())

    def connect(self) -> None:
        try:
            self.udpClient.connect()
        except error.PaperClipError as e:
            match e:
                case error.NoSpaceError():
                    print(
```

```
74                          f"{bcolors.FAIL}Failed to join server due to
                                {error.ConnectionErrorCodes.NO_SPACE.name}:
                                {e.args[0]}{bcolors.ENDC}"
75                      )
76                  case error.CertificateInvalidError():
77                      print(
78                          f"{bcolors.FAIL}Failed to join server due to
                                {error.ConnectionErrorCodes.CERTIFICATE_INVALID.name}:
                                {e.args[0]}{bcolors.ENDC}"
79                      )
80                  case error.FinishInvalidError():
81                      print(
82                          f"{bcolors.FAIL}Failed to join server due to
                                {error.ConnectionErrorCodes.FINISH_INVALID.name}:
                                {e.args[0]}{bcolors.ENDC}"
83                      )
84                  case _:
85                      raise e
86
87      def onConnect(self, addr: tuple[str, int]) -> None:
88          self.gameThread.start()
89          try:
90              self.udpClient.mainloop(self.quit)
91          except error.PaperClipError as e:
92              match e:
93                  case error.ServerDisconnectError():
94                      print(
95                          f"{bcolors.FAIL}Server connection terminated due to
                                {error.DisconnectErrorCodes.SERVER_DISCONNECT.name}:
                                {e.args[0]}\nPlease wait while connection closes
                                gracefully...{bcolors.ENDC}"
96                      )
97                  case _:
98                      raise e
99          if self.gameThread.is_alive():
100             self.gameThread.join()
101         return None
102
103     def gameloop(self) -> None:
104         print(f"{bcolors.HEADER}\n\nRock Paper Scissors{bcolors.ENDC}")
105         try:
106             while self.isRunning:
107                 choice = None
108                 print("Choice R[0], P[1], S[2]: ")
109                 while choice is None:
```

```
110                     try:
111                         choice = inputimeout("", timeout=10).strip()
112                         if choice == "q":
113                             print(
114                                 f"{bcolors.FAIL}Quitting. Please
                                        wait...{bcolors.ENDC}"
115                             )
116                             self.isRunning = False
117                             break
118                         choice = int(choice)
119                         if choice not in (0, 1, 2):
120                             print(
121                                 f"{bcolors.FAIL}Invalid choice
                                        '{choice}'.{bcolors.ENDC}"
122                             )
123                             choice = None
124                     except ValueError:
125                         print(f"{bcolors.FAIL}Invalid choice.{bcolors.ENDC}")
126                         choice = None
127                     except KeyboardInterrupt:
128                         print(f"{bcolors.FAIL}Quitting. Please
                                wait...{bcolors.ENDC}")
129                         self.isRunning = False
130                         break
131                     except TimeoutOccurred:
132                         if not self.isRunning:
133                             break
134                 if self.isRunning:
135                     self.send(self.udpClient.targetAddr, {"choice": choice})
136                     print("Waiting for other player...")
137                     while self.isRunning:
138                         try:
139                             addr, data =
                                    self.recvQueue.get(timeout=QUEUE_TIMEOUT)
140                             break
141                         except Empty:
142                             pass  # check still running
143                     if self.isRunning:
144                         match data["outcome"]:
145                             case 0:
146                                 o = f"You {bcolors.FAIL}LOOSE{bcolors.ENDC}. "
147                             case 1:
148                                 o = f"You {bcolors.OKGREEN}WIN{bcolors.ENDC}.
                                        "
149                             case 2:
```

```
                                o = f"You {bcolors.OKCYAN}DRAW{bcolors.ENDC}.
                                    "
                            case _:
                                o = ""
                        print(
                            f"\n{o}You Picked {data['choice']}. They picked
                                {data['otherChoice']}.\nThe score is
                                {data['score']['score']}:{data['otherScore']['score']}."
                        )
                        if data["outcome"] == Outcome.WIN:
                            self.score += 1
                        self.recvQueue.task_done()
            finally:
                self.udpClient._quit()

    def quit(self, msg: str = "quit call", e: Exception | None = None) ->
        None:
            self.isRunning = False
            self.udpClient.quit(msg, e)
```

```
# game_config.yaml
NAME: "RPS"
ID: 1
MIN_PLAYERS: 2
MAX_PLAYERS: 2
```

```
# rps.server
import json
from queue import Empty, Queue
from threading import Lock

from udp.auth import rsa
from udp.packet import Flag, lazyFlags
from udp.server import Server as UdpServer

from . import MAX_PLAYERS, QUEUE_TIMEOUT, Choice, Outcome


class Server:
    isRunning: bool
    recvBuffer: Queue
```

```
    players: dict[tuple[str, int], dict[str, int]]
    playersLock: Lock
    udpServer: UdpServer
    onClientJoin: None
    onClientLeave: None
    onReceiveData: None

    def __init__(
        self,
        addr: tuple[str, int],
        rsaKey: rsa.RSAPrivateKey | None = None,
        onClientJoin=None,
        onClientLeave=None,
        onReceiveData=None,
    ):
        self.isRunning = True
        self.recvQueue = Queue()
        self.players = {}
        self.playersLock = Lock()
        self.onClientJoin = onClientJoin
        self.onClientLeave = onClientLeave
        self.onReceiveData = onReceiveData
        self.udpServer = UdpServer(
            addr,
            maxClients=MAX_PLAYERS,
            rsaKey=rsaKey,
            onClientJoin=self.playerJoin,
            onClientLeave=self.playerLeave,
            onReceiveData=self.receive,
        )

    def send(self, addr: tuple[str, int], data: dict) -> None:
        self.udpServer.queueDefault(
            addr, flags=lazyFlags(Flag.RELIABLE), data=self.encodeData(data)
        )

    def receive(self, addr: tuple[str, int], data: bytes) -> None:
        self.recvQueue.put((addr, self.decodeData(data)))
        if self.onReceiveData:
            self.onReceiveData(addr, data)

    @staticmethod
    def encodeData(data: dict) -> bytes:
        return json.dumps(data).encode()

```

```
61      @staticmethod
62      def decodeData(data: bytes) -> dict:
63          return json.loads(data.decode())
64
65      @staticmethod
66      def evaluateWin(choiceOne: int, choiceTwo: int) -> int:
67          match choiceOne:
68              case Choice.ROCK:
69                  match choiceTwo:
70                      case Choice.ROCK:
71                          return Outcome.DRAW
72                      case Choice.PAPER:
73                          return Outcome.LOOSE
74                      case Choice.SCISSORS:
75                          return Outcome.WIN
76                      case _:
77                          raise ValueError
78              case Choice.PAPER:
79                  match choiceTwo:
80                      case Choice.ROCK:
81                          return Outcome.WIN
82                      case Choice.PAPER:
83                          return Outcome.DRAW
84                      case Choice.SCISSORS:
85                          return Outcome.LOOSE
86                      case _:
87                          raise ValueError
88              case Choice.SCISSORS:
89                  match choiceTwo:
90                      case Choice.ROCK:
91                          return Outcome.LOOSE
92                      case Choice.PAPER:
93                          return Outcome.WIN
94                      case Choice.SCISSORS:
95                          return Outcome.DRAW
96                      case _:
97                          raise ValueError
98              case _:
99                  raise ValueError
100
101     @staticmethod
102     def evaluatePlayerChoices(choices: list[tuple[tuple[str, int], int]]):
103         outcomes = [
104             (choices[0][0], Server.evaluateWin(choices[0][1], choices[1][1])),
105             (choices[1][0], Server.evaluateWin(choices[1][1], choices[0][1])),
```

```
106         ]
107         return outcomes
108 
109     def getChoices(self) -> list[tuple[tuple[str, int], int]]:
110         choices = {}
111         while self.isRunning:
112             try:
113                 addr, data = self.recvQueue.get(timeout=QUEUE_TIMEOUT)
114                 choices[addr] = data["choice"]
115                 if len(choices) == 2:
116                     choices = [(addr, choice) for addr, choice in
                            choices.items()]
117                     self.recvQueue.task_done()
118                     return choices
119             except Empty:
120                 pass  # check still running
121 
122     def playerJoin(self, addr: tuple[str, int], accountId: int) -> None:
123         with self.playersLock:
124             self.players[addr] = {"score": 0, "accountId": accountId}
125         if self.onClientJoin:
126             self.onClientJoin(addr, accountId)
127 
128     def playerLeave(self, addr: tuple[str, int], accountId: int) -> None:
129         with self.playersLock:
130             # TODO: submit score
131             del self.players[addr]
132         if self.onClientLeave:
133             self.onClientLeave(addr, accountId)
134 
135     def isNotFull(self) -> bool:
136         return self.udpServer.isNotFull()
137 
138     def isEmpty(self) -> bool:
139         return self.udpServer.isEmpty()
140 
141     def getPlayers(self) -> dict[tuple[str, int], dict[str, int]]:
142         with self.playersLock:
143             return self.players.copy()
144 
145     def getPlayer(self, addr: tuple[str, int]) -> int:
146         with self.playersLock:
147             if addr in self.players:
148                 return self.players[addr]
149             else:
```

```
150                 return None
151
152     def setPlayer(self, addr: tuple[str, int], v: int) -> None:
153         with self.playersLock:
154             if addr in self.players:
155                 self.players[addr] = v
156
157     def incrementPlayer(self, addr: tuple[str, int]) -> None:
158         with self.playersLock:
159             self.players[addr]["score"] += 1
160
161     def getAccountId(self, addr: tuple[str, int]) -> int:
162         with self.playersLock:
163             return self.players[addr]["accountId"]
164
165     def getAccountIds(self, addr: tuple[str, int]) -> list[int]:
166         with self.playersLock:
167             return [player["accountId"] for player in self.players.values()]
168
169     @property
170     def playerCount(self) -> int:
171         with self.playersLock:
172             return len(self.players)
173
174     def mainloop(self) -> None:
175         self.udpServer.startThreads()
176         try:
177             while self.isRunning:
178                 if self.playerCount == MAX_PLAYERS:
179                     choices = self.getChoices()
180                     outcomes = self.evaluatePlayerChoices(choices)
181                     replies = {}
182                     for addr, outcome in outcomes:
183                         replies[addr] = {
184                             "outcome": outcome,
185                             "choice": [v for k, v in choices if k == addr][0],
186                             "otherChoice": [v for k, v in choices if k !=
                                addr][0],
187                         }
188                         if outcome == Outcome.WIN:
189                             self.incrementPlayer(addr)
190                     scores = self.getPlayers()
191                     for addr in replies:
192                         replies[addr] |= {
193                             "score": scores[addr],
```

```
                            "otherScore": [v for k, v in scores.items() if k
                                != addr][
                                0
                            ],
                        }
                        self.send(addr, replies[addr])
        finally:
            self.quit()

    def quit(self) -> None:
        self.isRunning = False
        self.udpServer.quit()
```

9.3.4 client

```
# client.__init__
import os
import sys

import dotenv

from udp import logger, logging

dotenv.load_dotenv()

TCP_HOST = os.environ.get("S_HOST")
TCP_PORT = int(os.environ.get("TCP_PORT"))
C_PORT = int(os.environ.get("C_PORT"))
SERVER_URL = f"http://{TCP_HOST}:{TCP_PORT}"

offset = sys.argv[1:]
try:
    offset = int(offset[0])
except ValueError:
    offset = None
except IndexError:
    offset = None

if os.environ.get("DEBUG") is not None:
    logger.setLevel(logging.WARNING)
    while offset is None:
        try:
            offset = int(input("\noffset: "))
```

```
        except ValueError:
            print("Invalid input.")
else:
    logger.setLevel(logging.ERROR)

if offset is not None:
    C_PORT += offset
```

```
# client.__main__
import base64
import json
import time

import requests
from requests.auth import HTTPBasicAuth

import udp.auth
from rps.client import Client as RpsClient
from udp import bcolors

from . import C_PORT, SERVER_URL, TCP_HOST


class Client:
    id: int
    username: str
    password: str
    gameClient: None
    token: str
    key: udp.auth.rsa.RSAPublicKey
    auth: HTTPBasicAuth

    def __init__(self, username: str, password: str, token: str | None =
        None) -> None:
        self.username = username
        self.password = password
        self.gameClient = None
        self.token = (
            token if token is not None else self.getToken(self.username,
                self.password)
        )
        self.auth = HTTPBasicAuth(self.token, "")
        self.getKey(password.encode())
```

```
34
35      # auth
36      @staticmethod
37      def getToken(username: str, password: str) -> str:
38          url = SERVER_URL + "/auth/token"
39          r = requests.get(url, auth=(username, password))
40          assert r.status_code == 200, r
41          return r.json()["token"]
42
43      @staticmethod
44      def createAccount(username: str, password: str) -> str:
45          url = SERVER_URL + "/auth/register"
46          headers = {"Content-Type": "application/json"}
47          data = {"username": username, "password": password}
48          r = requests.post(url, headers=headers, data=json.dumps(data))
49          assert r.status_code == 201, r
50          return r.json()["username"]
51
52      def getKey(self, password: bytes) -> udp.auth.rsa.RSAPrivateKey:
53          url = SERVER_URL + "/auth/key"
54          r = requests.get(url, auth=self.auth)
55          assert r.status_code == 200, r
56          self.id = r.json()["account-id"]
57          key = base64.decodebytes(r.json()["key"].encode())
58          self.key = udp.auth.getRsaPrivateFromDer(key, password)
59
60      # game
61      def getGames(self) -> dict:
62          url = SERVER_URL + "/games/"
63          r = requests.get(url, auth=self.auth)
64          assert r.status_code == 200, r
65          return r.json()
66
67      def getLobbies(self) -> dict:
68          url = SERVER_URL + "/lobby/all"
69          r = requests.get(url, auth=self.auth)
70          assert r.status_code == 200, r
71          return r.json()
72
73      def createLobby(
74          self, gameId: int | None = None, gameName: str | None = None
75      ) -> dict:
76          url = SERVER_URL + "/lobby/create"
77          headers = {"Content-Type": "application/json"}
78          data = {}
```

```
79          if gameId:
80              data["game-id"] = gameId
81          elif gameName:
82              data["game-name"] = gameName
83          r = requests.post(url, headers=headers, data=json.dumps(data),
                auth=self.auth)
84          assert r.status_code == 201, r
85          return r.json()
86
87      def getLobby(self, lobbyId: int) -> dict:
88          url = SERVER_URL + "/lobby/"
89          headers = {"Content-Type": "application/json"}
90          data = {"lobby-id": lobbyId}
91          r = requests.get(url, headers=headers, data=json.dumps(data),
                auth=self.auth)
92          assert r.status_code == 200
93          return r.json()
94
95      def findLobby(self, gameId: int | None = None, gameName: str | None =
            None) -> dict:
96          url = SERVER_URL + "/lobby/find"
97          headers = {"Content-Type": "application/json"}
98          data = {}
99          if gameId:
100             data["game-id"] = gameId
101         elif gameName:
102             data["game-name"] = gameName
103         r = requests.get(url, headers=headers, data=json.dumps(data),
                auth=self.auth)
104         assert r.status_code == 200, r
105         return r.json()
106
107     # friends
108     def friendLobbies(self) -> dict:
109         url = SERVER_URL + "/lobby/friends"
110         r = requests.get(url, auth=self.auth)
111         assert r.status_code == 200, r
112         return r.json()
113
114     def getFriends(self) -> dict:
115         url = SERVER_URL + "/friends/"
116         r = requests.get(url, auth=self.auth)
117         assert r.status_code == 200, r
118         return r.json()
119
```

```
120     def addFriend(self, username: str) -> dict:
121         url = SERVER_URL + "/friends/add"
122         headers = {"Content-Type": "application/json"}
123         data = {"username": username}
124         r = requests.post(url, headers=headers, data=json.dumps(data),
                auth=self.auth)
125         assert r.status_code == 201, r
126         return r.json()
127 
128     def removeFriend(self, username: str) -> bool:
129         url = SERVER_URL + "/friend/remove"
130         headers = {"Content-Type": "application/json"}
131         data = {"username": username}
132         r = requests.delete(url, headers=headers, data=json.dumps(data),
                auth=self.auth)
133         assert r.status_code == 204, r
134         return True
135 
136     # join
137     def join(self, lobbyId: int) -> None:
138         print(f"\n{bcolors.WARNING}Joining Lobby '{lobbyId}'{bcolors.ENDC}")
139         data = self.getLobby(lobbyId)
140         if data["lobby-addr"] is not None:
141             match data["game-id"]:
142                 case 1:
143                     self.gameClient = RpsClient(
144                         (TCP_HOST, C_PORT),
145                         data["lobby-addr"],
146                         rsaKey=self.key,
147                         userId=self.id,
148                         username=self.username,
149                     )
150                     self.gameClient.connect()
151                 case _:
152                     raise ValueError(f"Unknown gameId {data['game-id']}")
153 
154 
155 def mainloop():
156     print(f"{bcolors.HEADER}\nLobby.{bcolors.ENDC}")
157     print("1. Login\n2. Register\n3. Quit")
158     while True:
159         option = input(": ").strip()
160         match option:
161             case "1":
162                 _login()
```

```
                break
            case "2":
                _register()
                break
            case "3":
                break
            case _:
                print(f"{bcolors.FAIL}Error: Invalid input
                    '{option}'.{bcolors.ENDC}")


def _register(username: str | None = None, password: str | None = None):
    print(f"{bcolors.HEADER}\nRegister.{bcolors.ENDC}")
    account = None
    while account is None:
        while username is None or password is None:
            try:
                username = input("Username: ").strip()
                password = input("Password: ").strip()
            except:  # noqa: E722
                print(f"{bcolors.FAIL}Error: Invalid input.{bcolors.ENDC}")
        try:
            account = Client.createAccount(username, password)
        except AssertionError:
            print(
                f"{bcolors.FAIL}Account could not be created. Please try
                    again.{bcolors.ENDC}\n"
            )
            username = None
            password = None
    else:
        print(f"Account Created for '{account}'")
        _login(username, password)


def _login(username: str | None = None, password: str | None = None):
    print(f"{bcolors.HEADER}\nLogin.{bcolors.ENDC}")
    token = None
    while token is None:
        while username is None or password is None:
            try:
                username = input("Username: ").strip()
                password = input("Password: ").strip()
            except:  # noqa: E722
                print(f"{bcolors.FAIL}Error: Invalid input.{bcolors.ENDC}")
```

```
206         try:
207             token = Client.getToken(username, password)
208         except AssertionError:
209             print(
210                 f"{bcolors.FAIL}Invalid login details. Please try
                    again.{bcolors.ENDC}\n"
211             )
212             username = None
213             password = None
214     else:
215         client = Client(username, password, token)
216         _menu(client)
217
218
219 def _menu(client):
220     isRunning = True
221     while isRunning:
222         print(f"\n{bcolors.HEADER}Main Menu{bcolors.ENDC}")
223         print(f"{bcolors.OKGREEN}Hello {client.username}.{bcolors.ENDC}")
224         while True:
225             print(
226                 "\n1. Manage friends\n2. See available games\n3. Start or
                    join a lobby\n4. Quit"
227             )
228             option = input(": ").strip()
229             match option:
230                 case "1":
231                     _friends(client)
232                     break
233                 case "2":
234                     _game(client)
235                     break
236                 case "3":
237                     _lobby(client)
238                     break
239                 case "4":
240                     isRunning = False
241                     break
242                 case _:
243                     print(
244                         f"{bcolors.FAIL}Error: Invalid input
                            '{option}'.{bcolors.ENDC}"
245                     )
246
247
```

```
248 def _friends(client: Client):
249     while True:
250         print(f"{bcolors.HEADER}\nFriends.{bcolors.ENDC}")
251         friends = client.getFriends()
252         friends = "\n\t".join(
253             [
254                 f"{i+1}. {friend['username']}"
255                 for i, friend in enumerate(friends["friends"])
256             ]
257         )
258         print(f"Friend list: \n\t{friends}")
259         print("\n1. Add New Friend\n2. Remove Friend\n3. Return to Main Menu")
260         while True:
261             option = input(": ").strip()
262             match option:
263                 case "1" | "2":
264                     username = input("\nUsername: ").strip()
265                     match option:
266                         case "1":
267                             try:
268                                 client.addFriend(username)
269                                 print(
270                                     f"\n{bcolors.OKGREEN}Account '{username}'
                                         added as friend{bcolors.ENDC}"
271                                 )
272                                 break
273                             except AssertionError:
274                                 print(
275                                     f"\n{bcolors.FAIL}Error: No such account
                                         with username
                                         '{username}'.{bcolors.ENDC}"
276                                 )
277                         case "2":
278                             try:
279                                 client.removeFriend(username)
280                                 print(
281                                     f"\n{bcolors.OKGREEN}Account '{username}'
                                         removed as friend{bcolors.ENDC}"
282                                 )
283                                 break
284                             except AssertionError:
285                                 print(
286                                     f"\n{bcolors.FAIL}Error: No such account
                                         with username '{username}' in friend
                                         list.{bcolors.ENDC}"
```

```
                                    )
                case "3":
                    return None
                case _:
                    print(
                        f"{bcolors.FAIL}Error: Invalid input
                            '{option}'.{bcolors.ENDC}"
                    )


def _game(client: Client):
    while True:
        print(f"{bcolors.HEADER}\nGames{bcolors.ENDC}")
        availableGames = client.getGames()
        availableGames = "\n\t".join(
            [f"{id}. {game}" for id, game in availableGames.items()]
        )
        print(f"Available Games: \n\t{availableGames}")
        input("\nPress enter to return to main menu: ")
        return None


def _lobby(client: Client):
    while True:
        print(f"{bcolors.HEADER}\nLobby.{bcolors.ENDC}")
        print(
            "\n1. Matchmaking\n2. See Friends' Lobbies\n3. Join Lobby\n4.
               Create Lobby\n5. Return to Main Menu"
        )
        while True:
            option = input(": ").strip()
            match option:
                case "1":
                    _matchmaking(client)
                    break
                case "2":
                    _friendsLobbies(client)
                    break
                case "3":
                    _joinLobby(client)
                    break
                case "4":
                    _createLobby(client)
                    break
                case "5":
```

```
                    return None
                case _:
                    print(
                        f"{bcolors.FAIL}Error: Invalid input
                            '{option}'.{bcolors.ENDC}"
                    )


def _matchmaking(client: Client):
    print(f"{bcolors.HEADER}\nMatchmaking.{bcolors.ENDC}")
    game = _gameInput(client)
    if game is None:
        return None
    try:
        lobby = client.findLobby(gameName=game)
    except AssertionError:
        lobby = client.createLobby(gameName=game)
    time.sleep(1)
    client.join(lobby["lobby-id"])
    return None


def _friendsLobbies(client: Client):
    print(f"{bcolors.HEADER}\nFriends' Lobbies.{bcolors.ENDC}")
    lobbies = client.friendLobbies()
    lobbiesInfo = lambda lobbies: "\n\t\t".join(
        [
            f"{bcolors.OKCYAN}{lobby['lobby-id']}{bcolors.ENDC}.
                {lobby['game-name']}"
            for lobby in lobbies
        ]
    )  # noqa: E731
    lobbies = "\n\t".join(
        [
            f"\n\t{i+1}.
                {account['account']['username']}:\n\t\t{lobbiesInfo(account['lobbies'])}"
            for i, account in enumerate(lobbies)
        ]
    )
    print(f"\nLobbies:{lobbies}")
    print(
        f"Input {bcolors.OKCYAN}Lobby Id{bcolors.ENDC} to Join Friend or
            Press Enter to Return to Menu."
    )
    while True:
```

```
371         option = input(": ").strip()
372         if option == "":
373             return None
374         else:
375             try:
376                 option = int(option)
377                 client.join(option)
378                 return None
379             except ValueError:
380                 print(f"{bcolors.FAIL}Error: Invalid input.{bcolors.ENDC}")
381
382
383 def _joinLobby(client: Client):
384     print(f"{bcolors.HEADER}\nJoin Lobby.{bcolors.ENDC}")
385     lobbyId = None
386     while lobbyId is None:
387         try:
388             lobbyId = input("\nLobby Id: ").strip()
389             if lobbyId == "":
390                 return None
391             else:
392                 lobbyId = int(lobbyId)
393         except ValueError:
394             print(f"{bcolors.FAIL}Error: Invalid input.{bcolors.ENDC}")
395     try:
396         client.join(lobbyId)
397         return None
398     except:  # noqa: E722
399         return None
400
401
402 def _createLobby(client: Client):
403     print(f"{bcolors.HEADER}\nCreate Lobby.{bcolors.ENDC}")
404     game = _gameInput(client)
405     while True:
406         if game is None:
407             return None
408         try:
409             lobby = client.createLobby(gameName=game)
410             client.join(lobby["lobby-id"])
411             return None
412         except AssertionError:
413             print(f"{bcolors.FAIL}Error: Invalid input.{bcolors.ENDC}")
414
415
```

```
def _gameInput(client: Client) -> str:
    availableGames = client.getGames()
    games = "\n\t".join([f"{id}. {game}" for id, game in
        availableGames.items()])
    print(f"\nAvailable Games: \n\t{games}")
    game = None
    while game is None or game.lower() not in map(
        lambda x: x.lower(), availableGames.values()
    ):
        try:
            game = input("Game: ").strip()
            if game == "":
                return None
        except:  # noqa: E722
            print(f"{bcolors.FAIL}Error: Invalid input.{bcolors.ENDC}")
    return game


if __name__ == "__main__":
    mainloop()
```

```
# .env
# udp
S_HOST=127.0.0.1
S_PORT=2024
C_HOST=127.0.0.1
C_PORT=2025
## node
SOCKET_BUFFER_SIZE = 1024
SEND_SLEEP_TIME = 0.1
QUEUE_TIMEOUT = 10
SOCKET_TIMEOUT = 20
## server
HEARTBEAT_MAX_TIME = 120
HEARTBEAT_MIN_TIME = 30
MAX_CLIENTS
## auth
ORG_NAME = Paperclip
COMMON_NAME = 127.0.0.1
## utils
MAX_FRAGMENT_SIZE = 988

# client
```

```
TCP_PORT = 5000

# app
FLASK_APP = server
PRUNE_TIME = 58
SECRET_KEY = MyVerySecretKey
SQLALCHEMY_DATABASE_URI = mysql://root:root@localhost:3306/paperclip

# debug
DEBUG = True
```

```
cryptography==42.0.5
Flask==3.0.2
Flask-HTTPAuth==4.8.0
Flask-SQLAlchemy==3.1.1
SQLAlchemy-Utils==0.41.2
mysqlclient==2.2.4
requests==2.31.0
PyJWT==2.8.0
pytest==8.1.1
python-dotenv==1.0.1
PyYAML==6.0.1
```

```
# test_udp
import os
import threading
from random import choice, randint

from udp import C_HOST, C_PORT, auth, error, node, packet, utils


## node
def testNodeSequenceIdLock():
    n = node.Node((C_HOST, C_PORT))

    def test():
        for _ in range(100000):
            n.incrementSequenceId(n.addr)

    threads = [threading.Thread(target=test) for _ in range(10)]
    for t in threads:
```

```
        t.start()
    for t in threads:
        t.join()
    assert n.sequenceId == 16960, n.sequenceId


# error
def testErrorCode():
    major = choice([i for i in error.Major])
    minor = error.getMinor(major, randint(0, 2))
    mm = (major, minor)
    e = error.getError(*mm)()
    c = error.getErrorCode(e.__class__)
    assert mm == c, (mm, e, c)


def testErrorPacket():
    h = genRandAttr(packet.Type.ERROR)
    p = packet.ErrorPacket(*h)
    p.data = b"This is a test error"
    p.major = randint(1, 3)
    match p.major:
        case error.Major.CONNECTION:
            p.minor = randint(0, 3)
        case error.Major.DISCONNECT:
            p.minor = randint(0, 2)
        case error.Major.PACKET:
            p.minor = randint(0, 9)
        case _:
            p.minor = 0
    eP = p.pack(p)
    dP = packet.unpack(eP)
    assert p == dP, (p, eP, dP)


# Heartbeat
def testHeartbeatPacket():
    h = genRandAttr(packet.Type.HEARTBEAT)
    p = packet.HeartbeatPacket(*h)
    p.heartbeat = True
    eP = p.pack(p)
    dP = packet.unpack(eP)
    assert p == dP, (p, eP, dP)


```

```
# frag
def testDefrag():
    h = genRandAttr()
    data = os.urandom(16)
    p = packet.Packet(*h)
    p.flags[packet.Flag.FRAG.value] = 0
    p.fragment_id = None
    p.fragment_number = None
    p.data = data
    fP = p.fragment()
    dP = fP[0].defragment(fP)
    assert p == dP, (p, fP, dP)


## utils
def testDataCompress(d=os.urandom(16)):
    cD = utils.compressData(d)
    dD = utils.decompressData(cD)
    assert d == dD, (d, cD, dD)


## encrypt
def testPacketEncryption():
    h = genRandAttr()
    p = packet.Packet(*h)
    p.flags[packet.Flag.ENCRYPTED.value] = 1
    d = b"Hello World"
    p.data = d
    localKey = auth.generateEcKey()
    peerKey = auth.generateEcKey()
    localSessionKey = auth.generateSessionKey(localKey, peerKey.public_key())
    peerSessionKey = auth.generateSessionKey(peerKey, localKey.public_key())
    p.encryptData(localSessionKey)
    # print(p.data)
    p.decryptData(peerSessionKey)
    # print(p.data)
    assert d == p.data, (d, p.data)


## auth
def sessionKey():
    localKey = auth.generateEcKey()
    peerKey = auth.generateEcKey()
    localSessionKey = auth.generateSessionKey(localKey, peerKey.public_key())
    peerSessionKey = auth.generateSessionKey(peerKey, localKey.public_key())
```

```
    assert localSessionKey == peerSessionKey


def encryptDecrypt(inputText=b"Hello World"):
    localKey = auth.generateEcKey()
    peerKey = auth.generateEcKey()
    sessionKey = auth.generateSessionKey(localKey, peerKey.public_key())
    #
    localCipher, iv = auth.generateCipher(sessionKey)
    cipherText = auth.encryptBytes(localCipher, inputText)
    #
    peerCipher, _ = auth.generateCipher(sessionKey, iv)
    outputText = auth.decryptBytes(peerCipher, cipherText)
    #
    assert inputText == outputText, (inputText, outputText)


## packet
def genRandAttr(t=packet.Type.DEFAULT):
    v, pT, sId = randint(0, 1), t, randint(0, 2**packet.SEQUENCE_ID_SIZE - 1)
    f = [0 for _ in range(packet.FLAGS_SIZE)]
    if randint(0, 1):
        f[packet.Flag.FRAG.value] = 1
        fId, fNum = (
            randint(0, 2**packet.FRAGMENT_ID_SIZE - 1),
            randint(0, 2**packet.FRAGMENT_NUM_SIZE - 1),
        )
    else:
        fId, fNum = None, None
    if randint(0, 1):
        f[packet.Flag.ENCRYPTED.value] = 1
        # iv = randint(0, 2**INIT_VECTOR_SIZE-1)
        iv = auth.generateInitVector()
    else:
        iv = None
    if randint(0, 1):
        f[packet.Flag.CHECKSUM.value] = 1
        c = randint(0, 2**packet.CHECKSUM_SIZE - 1)
    else:
        c = None
    h = (v, pT, f, sId, fId, fNum, iv, c)
    return h


def testAuth():
```

```
154     pK, c = (
155         auth.generateEcKey().public_key(),
156         auth.generateUserCertificate(auth.generateRsaKey()),
157     )
158     pKS, cS = (
159         packet.AuthPacket.getPublicKeyBytesSize(pK),
160         packet.AuthPacket.getCertificateByteSize(c),
161     )
162     h = (*genRandAttr(packet.Type.AUTH), pKS, pK, cS, c)
163     # static test
164     eH = packet.AuthPacket.encodeHeader(*h)
165     dH = packet.AuthPacket.decodeHeader(eH)[:-1]
166     assert h == dH, (h, eH, dH)
167     # class tests
168     p = packet.AuthPacket(*h)
169     eP = p.pack(p)
170     dP = p.unpack(eP)
171     assert p == dP, (p, eP, dP)
172
173
174 def testAck():
175     # header
176     aId, aB = (
177         randint(0, 2**packet.ACK_ID_SIZE - 1),
178         [randint(0, 1) for _ in range(packet.ACK_BITS_SIZE)],
179     )
180     h = (*genRandAttr(packet.Type.ACK), aId, aB)
181     # static test
182     eH = packet.AckPacket.encodeHeader(*h)
183     dH = packet.AckPacket.decodeHeader(eH)[:-1]
184     assert h == dH, (h, eH, dH)
185     # class tests
186     p = packet.AckPacket(*h)
187     eP = p.pack(p)
188     dP = p.unpack(eP)
189     assert p == dP, (p, eP, dP)
190
191
192 def testAckBits():
193     aId, aB = (
194         randint(0, 2**packet.ACK_ID_SIZE - 1),
195         [randint(0, 1) for _ in range(packet.ACK_BITS_SIZE)],
196     )
197     eAId, eAB = packet.AckPacket.encodeAckId(aId),
        packet.AckPacket.encodeAckBits(aB)
```

```
198     dAId, dAB = packet.AckPacket.decodeAckId(eAId),
            packet.AckPacket.decodeAckBits(eAB)
199     assert (aId, aB) == (dAId, dAB), ((aId, aB), (eAId, eAB), (dAId, dAB))
200
201
202 def testDefault():
203     # header
204     h = genRandAttr()
205     # static test
206     eH = packet.Packet.encodeHeader(*h)
207     dH = packet.Packet.decodeHeader(eH)[:-1]
208     assert h == dH, (h, eH, dH)
209     # class tests
210     p = packet.Packet(*h)
211     eP = p.pack(p)
212     dP = p.unpack(eP)
213     assert p == dP, (p, eP, dP)
214
215
216 def testChecksum():
217     # checksum
218     c = randint(0, 2**packet.CHECKSUM_SIZE - 1)
219     eC = packet.Packet.encodeChecksum(c)
220     dC = packet.Packet.decodeChecksum(eC)
221     assert c == dC, (c, eC, dC)
222
223
224 def testInitVector():
225     # init vector
226     iv = randint(0, 2**packet.INIT_VECTOR_SIZE - 1)
227     eIv = packet.Packet.encodeInitVector(iv)
228     dIv = packet.Packet.decodeInitVector(eIv)
229     assert iv == dIv, (iv, eIv, dIv)
230
231
232 def testFrag():
233     # frag
234     fId, fN = (
235         randint(0, 2**packet.FRAGMENT_ID_SIZE - 1),
236         randint(0, 2**packet.FRAGMENT_NUM_SIZE - 1),
237     )
238     eFId, eFN = (
239         packet.Packet.encodeFragmentId(fId),
240         packet.Packet.encodeFragmentNumber(fN),
241     )
```

```
    dFId, dFN = (
        packet.Packet.decodeFragmentId(eFId),
        packet.Packet.decodeFragmentNumber(eFN),
    )
    assert (fId, fN) == (dFId, dFN), ((fId, fN), (eFId + eFN), (dFId, dFN))


def testFlags():
    # flags
    f = [randint(0, 1) for _ in range(packet.FLAGS_SIZE)]
    eF = packet.Packet.encodeFlags(f)
    dF = packet.Packet.decodeFlags(eF)
    assert f == dF, (f, eF, dF)


def testVersionType():
    # version type
    v, pT = (
        randint(0, 2**packet.VERSION_SIZE - 1),
        packet.Type(randint(0, max(t.value for t in packet.Type))),
    )
    eVt = packet.Packet.encodeVersionType(v, pT)
    dVt = packet.Packet.decodeVersionType(eVt)
    assert (v, pT) == dVt, ((v, pT), eVt, dVt)
```

9.3.8 inputimout Original code by Mitsuo Heijo (@johejo). Conatins modification to `inputimeout.win_inputimeout` to prevent the automatic appendation of a new line after a timeout.

```
from .inputimeout import inputimeout, TimeoutOccurred   # noqa
from .__version__ import (   # noqa
    __version__, __author__, __author_email__, __copyright__, __license__,
    __description__, __title__, __url__,
)
```

```
__title__ = 'inputimeout'
__description__ = 'Multi platform standard input with timeout'
__url__ = 'http://github.com/johejo/inutimeout'
__version__ = '1.0.4'
__author__ = 'Mitsuo Heijo'
__author_email__ = 'mitsuo_h@outlook.com'
```

```
__license__ = 'MIT'
__copyright__ = 'Copyright 2018 Mitsuo Heijo'
```

```
# Modified by @HarryWhitehorn on 2024/04/27:
# - Modified win_inputimeout to prevent automatically appending a newline

import sys

DEFAULT_TIMEOUT = 30.0
INTERVAL = 0.05

SP = ' '
CR = '\r'
LF = '\n'
CRLF = CR + LF


class TimeoutOccurred(Exception):
    pass


def echo(string):
    sys.stdout.write(string)
    sys.stdout.flush()


def posix_inputimeout(prompt='', timeout=DEFAULT_TIMEOUT):
    echo(prompt)
    sel = selectors.DefaultSelector()
    sel.register(sys.stdin, selectors.EVENT_READ)
    events = sel.select(timeout)

    if events:
        key, _ = events[0]
        return key.fileobj.readline().rstrip(LF)
    else:
        echo(LF)
        termios.tcflush(sys.stdin, termios.TCIFLUSH)
        raise TimeoutOccurred


def win_inputimeout(prompt='', timeout=DEFAULT_TIMEOUT, newline=False):
    echo(prompt)
```

```
    begin = time.monotonic()
    end = begin + timeout
    line = ''

    while time.monotonic() < end:
        if msvcrt.kbhit():
            c = msvcrt.getwche()
            if c in (CR, LF):
                echo(CRLF)
                return line
            if c == '\003':
                raise KeyboardInterrupt
            if c == '\b':
                line = line[:-1]
                cover = SP * len(prompt + line + SP)
                echo(''.join([CR, cover, CR, prompt, line]))
            else:
                line += c
        time.sleep(INTERVAL)

    if newline:
        echo(CRLF)
    raise TimeoutOccurred


try:
    import msvcrt

except ImportError:
    import selectors
    import termios

    inputimeout = posix_inputimeout

else:
    import time

    inputimeout = win_inputimeout
```

```
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```

```
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SOFTWARE.
```

9.4 Packet Specification

Packets

DEFAULT DEFAULT Packet Specification:

DEFAULT Packet																															
Offsets	Octet	0								1								2								3							
Octet	Bit	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
0	0	Version				Type				Flags								Sequence ID															
4	32	Fragment ID*								Fragment Number*								Init Vector*															
8	64	Checksum Hash*																Data*															

Table 2: *not required

Version

Including a packet version will allow for future changes in specification which out breaking older systems. A recipient must reject a packet if the version does not match the internal version.

Type

The next header is the packet type. This will instruct the recipient on how to unpack the packet. The types are defined as follows:

Types	
Type	**Enum**
DEFAULT	0
ACK	1
AUTH	2
HEARTBEAT	3
ERROR	4
RESERVED	5..15

For the DEFAULT packet, the packet type is 0 (padded to 4 bits).

Flags

The packet flags are a bit field of the different available flags. Each flag can be toggled independently with some implying the presents of certain headers. The flags are as follows:

Flags								
Octet	**1**							
Bit	**0**	**1**	**3**	**4**	**2**	**5**	**6**	**7**
Flag	RELIABLE	CHECKSUM	COMPRESSED	ENCRYPTED	FRAG	RESERVED		

Sequence ID

The 16-bit sequence ID proved an *unique* identifier for each packet. The Sequence ID is set according to the senders internal value and incremented after each assignment. This allows for the recipient to determine an order to the packets received. The sequence ID must wrap around at 2^{16} back to 0.

Fragment ID

The fragment ID is the position of the fragment in the total packet. This tells the recipient the how to reorder the data of the fragments packets into the final packet. For this header to be present FRAG must be set in the packet's flags.

Fragment Number

The fragment number is the total number of fragments making up the final packet. The recipient will keep collecting fragments until the number of received fragments is equal to the number stated in each fragments fragment number. At this point the final packet can be compiled yielding the full data. For this header to be present FRAG must be set in the packet's flags.

Init Vector

The init vector is 16 bit integer to be used by the recipient when decrypting the packet data. For this header to be present, the ENCRYPTED flag must be set.

Checksum Hash

The checksum is a hash off the packet's data to be checked upon receival. If the checksum check fails, the recipient should reject the packet. For this header to be present the CHECKSUM flag must be set.

Data

This is the data field of the packet. Upon a valid receival of a packet, the data is returned to the application layer.

ACK The ACK packet is sent as a reply to any received packets where the RELIABLE flag is set.

ACK packet specification:

ACK Packet																															
Offsets	**Octet**	**0**								**1**								**2**								**3**							
Octet	Bit	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**
8	**64**	*Default Packet Headers*																ACK ID															
12	**96**	ACK Bits																*Data**															

ACK Default Packet Headers

The packet type must be 1 (padded to 4 bits).

ACK ID

The ACK ID is the sequence ID of the packet that the ACK is in acknowledgment of.

ACK Bits

The ACK Bits is a bit field representing the status of the last 16 previous ACKs such that $[ID_{-1}, ID_{-2}, ID_{-3}, ..., ID_{-17}]$ where ID *is equal to the ACK ID of the ACK packet.* This help to mitigate against packet loss as each ACK packet also includes an acknowledgment of the last 16 packets (if received).

ACK Data

This is the data field of the packet. This is used during the handshake to send the finished data.

AUTH The AUTH packet is sent during the handshake between a client and server.

AUTH packet specification:

AUTH Packet																															
Offsets	**Octet**	**0**								**1**								**2**								**3**							
Octet	Bit	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**
8	**64**	*Default Packet Headers*																Reserved								EC Public Key Size (E)							
12	**96**	EC Public Key																															
...	**...**	...																															
10+E	**80+E**	EC Public Key																Certificate Size (C)*															
14+E	**168+E**	Certificate*																															
...	**...**	...																															
12+C+E	**96+C+E**	Certificate*																															

AUTH Default Packet Headers

The packet type must be 2 (padded to 4 bits).

Public Key Size

This is the size *in bytes* of the public key also included in the packet. As different key systems may yield different size keys this tells the recipient where the public key ends when unpacking the packet.

Public Key

This is the public key of the sender which is used in generating the session key.

Certificate Size

This is the size *in bytes* of the certificate also include in the packet. As different certificate systems / encodings may yield different sized certificated this, in conjunction with the public key size, tell the recipient where the certificate ends when unpacking the packet.

Certificate

This is the certificate of the sender. This allows for the recipient to validate the identity of the sender.

HEARTBEAT The HEARTBEAT packet is sent by the server at fixed intervals to check that a client is alive and responding as normal.

HEARTBEAT packet specification:

HEARTBEAT Packet																															
Offsets **Octet**	**Octet**	**0**								**1**								**2**								**3**					
Octet	Bit	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**
8	**64**	*Default Packet Headers*																Heartbeat								*Data**						

HEARTBEAT Default Packet Headers

The packet type must be set to 2 (padded to 4 bits).

Heartbeat

This is a boolean value (padded to 8 bits) dictating the nature of the packet with False and True dictating PING and PONG respectively. If a client receives a PING it must reply with a PONG. A server will expect to get a PONG value back and, after enough failures to reply, will mark a client connection for termination.

HEARTBEAT Data

Unused field.

ERROR The ERROR packet allows for connection members to declare if an error has occurred.

ERROR packet specification:

ERROR Packet																															
Offsets	Octet	0								1								2								3					
Octet	Bit	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
8	64	*Default Packet Headers*																Error Major				Error Minor				*Data**						

Error Major

This is the Major component of the error being declared.

Error Minor

This is the Minor component of the error being declared. It must be present but can be set to 0 (padded to 4 bits).

ERROR Data

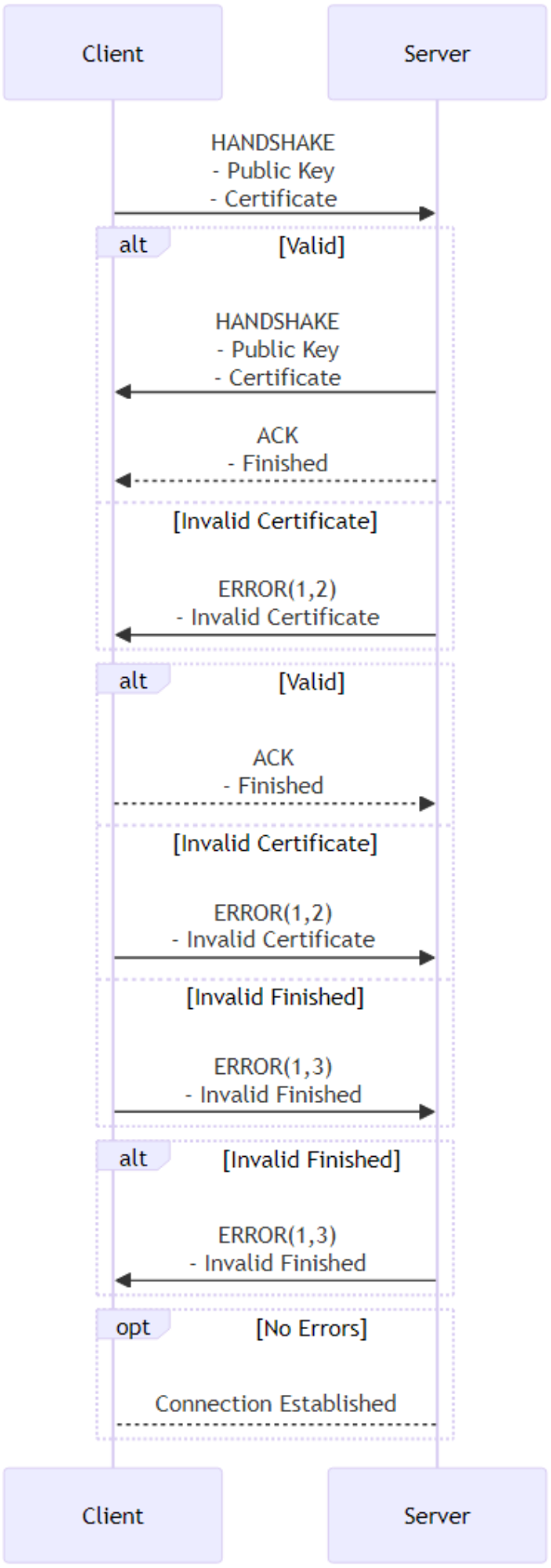
This field allows for additional information about the error to be shared. This used for logging purposes but can also be used for displaying *user-friendly* error messages to a client.

Error Codes The error codes are defined as follows:

Error Codes			
Major	**Minor**	**Name**	**Description**
1	**0**	**CONNECTION**	**Connection Handshake Could Not Finish**
	1	NO SPACE	Server has no more space
	2	CERTIFICATE INVALID	Certificate is invalid / cannot be validated
	3	FINISH INVALID	Finished is invalid
2	**0**	**DISCONNECT**	**A Party is Disconnecting**
	1	SERVER DISCONNECT	The server is closing, all clients must exit gracefully
	2	CLIENT DISCONNECT	The client is closing, the server must handle gracefully
3	**0**	**PACKET**	**The Packet Cannot be Read**
	1	VERSION	The packet version does not match the expected
	2	PACKET TYPE	Unknown / invalid packet type
	3	FLAGS	Unknown / invalid flags
	4	SEQUENCE ID	Sequence id does not match expected
	5	FRAGMENT ID	Unknown / invalid fragment id
	6	FRAGMENT NUMBER	Unknown / invalid fragment number
	7	INIT VECTOR	Unknown / invalid init vector i.e. decrypt fail
	8	COMPRESSION	Decompression fail
	9	CHECKSUM	Unknown / invalid checksum i.e. checksum fail
4..15		**RESERVED**	

Behavior

Handshake The handshake is always initiated by the client with the client sending an AUTH packet to the server. The server checks the certificate (if present) and either responds with its own AUTH packet or an ERROR packet. The server also sends an ACK packet containing the handshake finished. The client, upon receiving the server's AUTH packet performs the same checks and yields an ERROR packet on a failure. Otherwise, the client also calculates the finished and checks it against the server's version. If it's valid it replies with its own finished ACK otherwise sending an ERROR. The server also checks the client's value for finished and sends an error on failure. If no ERRORs were yielded the parties are considered connected and can begin communication otherwise the connection must be aborted by both parties.


Client
Server
HANDSHAKE
- Public Key
- Certificate
alt
[Valid]
HANDSHAKE
- Public Key
- Certificate
ACK
- Finished
[Invalid Certificate]
ERROR(1,2)
- Invalid Certificate
alt
[Valid]
ACK
- Finished
[Invalid Certificate]
ERROR(1,2)
- Invalid Certificate
[Invalid Finished]
ERROR(1,3)
- Invalid Finished
alt
[Invalid Finished]
ERROR(1,3)
- Invalid Finished
opt
[No Errors]
Connection Established
Client
Server

Session Key

Each party generated a session key using their own private key and the other parties public key in a key exchange. This session key is then used in conjunction with the init vector when encrypting and decrypting packet data.

Finished

The finished ACK packet contains a hash generated from the session key. This allows both parties to validate that the other party has the private key for their respective public key as well as acting as a pseudo-checksum to verify the handshake.

Certificate Validation

Certificate validation requires sending a TCP request to the TCP server with the certificate. The TCP server is then able to validate the certificate and yield its success or failure.

Flags Behaviour Reliable

If a packet is sent with the reliable flag, the sender should expect a ACK packet with the relevant ACK ID and should resend the packet until an ACK is received.

When a packet with the reliable flag set is received the recipient should first set its local record of ACKed packet's accordingly and then reply with an ACK packet. If the packet has already been ACKed the data should not be yielded to the application layer.

Checksum

If a packet is sent with the checksum flag set, the sender must calculate a CRC-32 hash with the packet's data and append it to the relevant header.

When a packet with the checksum flag set is received the recipient must recalculate a CRC-32 hash on the packet's data and check that it matches the packets checksum header. On a failure, the recipient must respond with a CHECKSUM ERROR (3.9) and discard the packet.

Compressed

If a packet is sent with the compressed flag set, the sender must perform a compression on the packet's data.

When a packet with the compressed flag set is received the recipient must decompress the packet's data before yielding to the application layer. If the decompression fails, the recipient must respond with a COMPRESSION ERROR (3.8) and discard the packet.

Encrypted

If a packet is sent with the encrypted flag set, the sender must perform an encryption on the packet's data using the session key and a randomly generated init vector. The init vector must then be appended to the relevant packet header.

When a packet with the encrypted flag set is received, the recipient must preform decrypt the packet's data using the session key and the init vector from the packet's headers before yielding the packet's data to the application layer. If the decryption fails, the recipient must respond with a INIT VECTOR ERROR (3.7) and discard the packet.

Frag

If a packet is sent with the frag flag set, the sender must split the data into sub-packets, each with the appropriate fragment id and fragment number.

When a packet with the frag flag set is received, the recipient must buffer the packet. It can then check to see if all other frag packets with the same sequence id have been already buffered by checking the fragment number. If so, the frag packets can be compiled into one packet, using each sub-packet's fragment id and the data can be yielded.

Disconnection Client Disconnect

When a client goes to terminate it must first send a CLIENT DISCONNECT ERROR (2.2) packet. It should then wait for acknowledgement before terminating gracefully. It may terminate after some timeout value if it fails to receive a response.

When a server receives a client disconnect is must acknowledge this before removing the client.

Server Disconnect

When a server goes to terminate it must first send a SERVER DISCONNECT ERROR (2.1) packet. It should then wait for acknowledgement from each client before terminating gracefully. It may terminate after some timeout value if it fails to receive a response from a client.

When a client receives a server disconnect it must acknowledge this before terminating itself (without sending a client disconnect).

9.5 API Specification

Login	Name	Endpoint	Method	Inputs	Returns	Description
Auth						
	Create Account	/auth/register	POST	Username & Password	Account	Register a new Account in the database.
	Get Token	/auth/token	GET		Session Token	Generate and provide a new session token for use by client.
	Get Key	/auth/token	GET		Private Key	Get Account private RSA key.
	Get Cetficiate	/auth/certificate	GET		Certificate	Get the server's certificate.
	Validate Certificate	/auth/certificate/validate	GET	Certificate	bool	Validate that a given certificate was singed by the account in the fields.
Games						
	Get Games	/games	GET		list[Game]	Return a list of all available games.
Lobby						
	Get Lobby	/lobby	GET	Lobby ID	Lobby	Return the lobby with the provided lobby ID.
	Get Lobbies	/lobby/all	GET		list[Lobby]	Return all lobbies.
	Create Lobby	/lobby/create	POST	Game Name | Game ID	Lobby	Create a new lobby with the given game and return it.
	Find Lobby	/lobby/find	GET	Game Name | Game ID	Lobby | None	Find a lobby with the given game that has available space
	Get Friends' Lobbies	/lobby/friends	GET		list[Lobby]	Return all lobbies with available space containing an Account registed as a Friend
Friends						
	Get Friends	/friends	GET		list[Friend]	Return a list of all Accounts registed as Friends
	Add Friend	/friends/add	POST	Username	Friend	Register a new Account as a Friend
	Remove Friend	/friends/remove	DELETE	Username		Remove an Account as a Friend

9.6 ERD Diagram

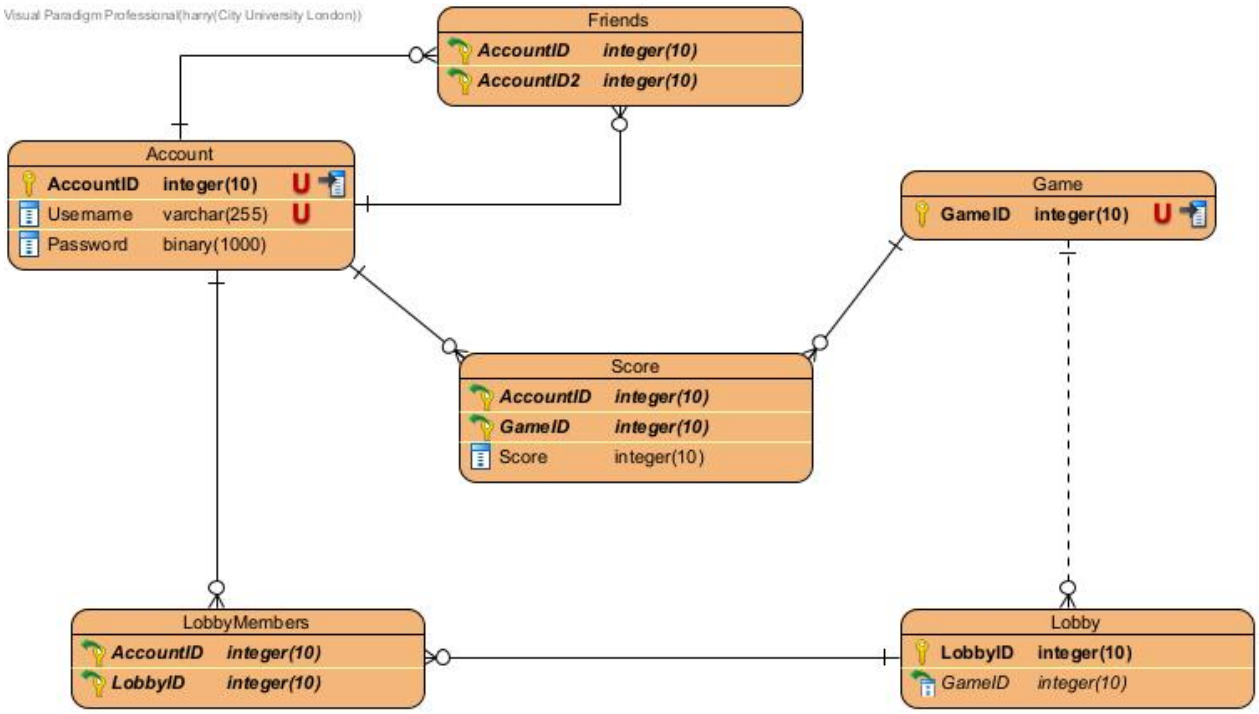


Figure 10: Database Models ERD