جامعة أبوظبي
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Computer Science & IT Department

CSC408 - Distributed Information Systems

Assignment 1

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Section: 77

Task 1

Description of simulation

In task 1, we developed a basic client-server application that employs UDP protocol for conducting mining operations, where clients transmit blocks to servers for nonce identification, ensuring hash generation with specified leading zeros. Within this framework, we use three main classes: Client, Server, and Block.

Internally, the process begins with the Client sending a Block object in JSON string format, consisting of the block number, data in the block, and the desired count of leading zeros, to the Server for mining. Upon reception, the Server searches for the nonce by brute forcing (incrementing nonce & verifying hash) until the right nonce is found, and subsequently returns the mined Block back to the Client. This process can be highlighted below in *figure 1*.

Our program takes input data through arguments, and in this task, we used 4 input arguments in the Client class:

- args[0] → IP address of the server
- args[1] → Block Number
- args[2] → Data to be mined
- args[3] → Leading zeroes

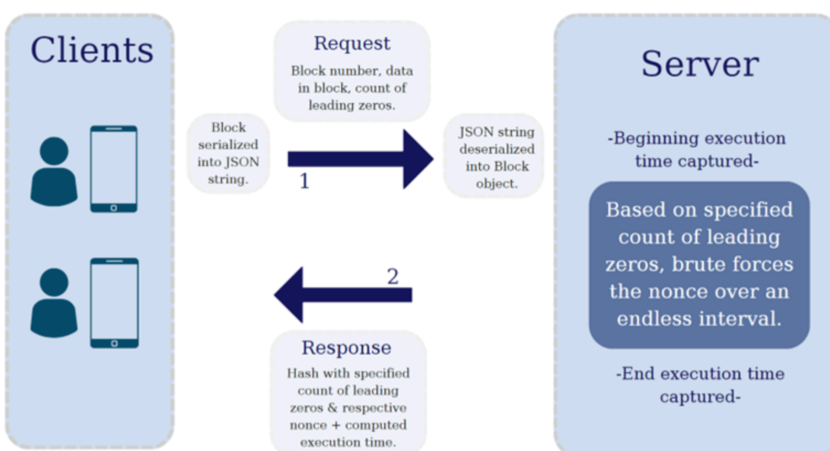


Figure 1 – abstract overview of task 1's flow of events.

Obtained Results

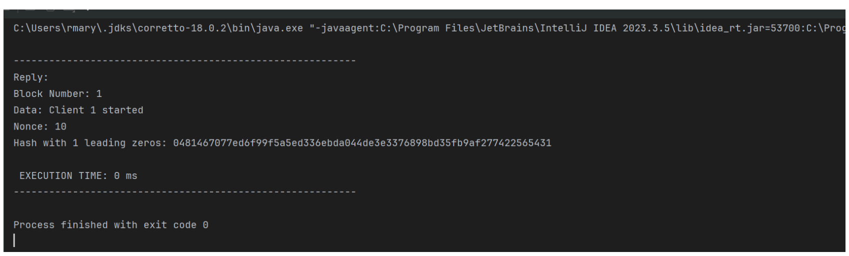
In order to analyze the efficiency of utilizing a single server in brute-forcing the nonce of multiple client blocks, we need to gather the required data. First, we began by running each client multiple times, providing the server with different numbers of leading zeros in order to capture their respective execution times.

Results per Client

In our implementation, we captured the JVM's internal time as soon as the server began mining the block. The time is captured again once the server finds the nonce with the specified count of leading zeros. This allows us to compute the execution time, in milliseconds, of each client when different leading zeros were passed to the server. Figures 2 - 8 below highlight the execution time for different runs.

1 Leading Zero:

Client 1:



Client 2:

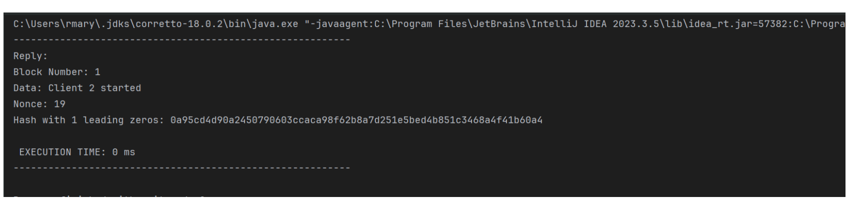


Figure 2a & 2b - Running both clients with 1 leading zero specified.

2 Leading Zeros:

Client 1:

```
C:\Users\rmary\.jdks\corretto-18.0.2\bin\java.exe "-javaagent:C:\Program Files\JetBrains\IntelliJ IDEA 2023.3.5\lib\idea_rt.jar=54472:C:\Progra

----------------------------------------------------------
Reply:
Block Number: 1
Data: Client 1 started
Nonce: 85
Hash with 2 leading zeros: 0018376c43b3f67ca0547756994fba2e2a0fc8722a190e9748400874f560441b

 EXECUTION TIME: 4 ms
----------------------------------------------------------

Process finished with exit code 0
```

Client 2:

```
C:\Users\rmary\.jdks\corretto-18.0.2\bin\java.exe "-javaagent:C:\Program Files\JetBrains\IntelliJ IDEA 2023.3.5\lib\idea_rt.jar=54479:C:\Prog

----------------------------------------------------------
Reply:
Block Number: 1
Data: Client 2 started
Nonce: 14
Hash with 2 leading zeros: 0042d480ff85f95ecbbad0b523af79ce8fe014c28e7a6996ab50d7bf5f352974

 EXECUTION TIME: 0 ms
----------------------------------------------------------
```

Figure 3a & 3b - Running both clients with 2 leading zeros specified.

3 Leading Zeroes:

Client 1:

```
C:\Users\rmary\.jdks\corretto-18.0.2\bin\java.exe "-javaagent:C:\Program Files\JetBrains\IntelliJ IDEA 2023.3.5\lib\idea_rt.jar=55195:C:\Program

----------------------------------------------------------
Reply:
Block Number: 1
Data: Client 1 started
Nonce: 3765
Hash with 3 leading zeros: 0001c57d6c384cdd1e653da62fca51728f60e92e7a07b4db75f2cbf7d1d9e5e8

 EXECUTION TIME: 41 ms
----------------------------------------------------------

Process finished with exit code 0
```

Client 2:

```
C:\Users\rmary\.jdks\corretto-18.0.2\bin\java.exe "-javaagent:C:\Program Files\JetBrains\IntelliJ IDEA 2023.3.5\lib\idea_rt.jar=55203:C:\Program

----------------------------------------------------------
Reply:
Block Number: 1
Data: Client 2 started
Nonce: 1039
Hash with 3 leading zeros: 000fc60ef181195c2ac768bd8797307dbdda66bfec5686d5b1a92c6f508c9962

 EXECUTION TIME: 7 ms
----------------------------------------------------------

Process finished with exit code 0
```

Figure 4a & 4b - Running both clients with 3 leading zeros specified.

4 Leading Zeroes:

Client 1:

```
C:\Users\rmary\.jdks\corretto-18.0.2\bin\java.exe "-javaagent:C:\Program Files\JetBrains\IntelliJ IDEA 2023.3.5\lib\idea_rt.jar=55270:C:\Progran

---------------------------------------------------------
Reply:
Block Number: 1
Data: Client 1 started
Nonce: 150219
Hash with 4 leading zeros: 00005a469a3859359d9d0390131076abfc15fc304292f91f5ca8249a37d5d05b

 EXECUTION TIME: 95 ms
---------------------------------------------------------
```

Client 2:

```
C:\Users\rmary\.jdks\corretto-18.0.2\bin\java.exe "-javaagent:C:\Program Files\JetBrains\IntelliJ IDEA 2023.3.5\lib\idea_rt.jar=55275:C:\Progra

---------------------------------------------------------
Reply:
Block Number: 1
Data: Client 2 started
Nonce: 114650
Hash with 4 leading zeros: 0000d26ddf8abb6a0f2afefc4ad82c057f23b4174afa2925e223e7e5b2ac2e4e

 EXECUTION TIME: 60 ms
---------------------------------------------------------

Process finished with exit code 0
```

Figure 5a & 5b - Running both clients with 4 leading zeros specified.

5 Leading Zeroes:

Client 1:

```
C:\Users\rmary\.jdks\corretto-18.0.2\bin\java.exe "-javaagent:C:\Program Files\JetBrains\IntelliJ IDEA 2023.3.5\lib\idea_rt.jar=57453:C:\Program
---------------------------------------------------------
Reply:
Block Number: 1
Data: Client 1 started
Nonce: 1527851
Hash with 5 leading zeros: 00000f779d3cd6a45e842dcd5fcb8e9b0dd21635c2a0a60bdd9ff960b0a58f4e

 EXECUTION TIME: 891 ms
---------------------------------------------------------

Process finished with exit code 0
```

Client 2:

```
C:\Users\rmary\.jdks\corretto-18.0.2\bin\java.exe "-javaagent:C:\Program Files\JetBrains\IntelliJ IDEA 2023.3.5\lib\idea_rt.jar=57458:C:\Program
---------------------------------------------------------
Reply:
Block Number: 1
Data: Client 2 started
Nonce: 1764282
Hash with 5 leading zeros: 00000cbc3c5f48615cd81221a3e3e1c784482b9a09b23e945f4d02aeeec5dbf1

 EXECUTION TIME: 830 ms
---------------------------------------------------------

Process finished with exit code 0
```

Figure 6a & 6b - Running both clients with 5 leading zeros specified.

6 Leading Zeroes:

Client 1:

```
C:\Users\rmary\.jdks\corretto-18.0.2\bin\java.exe "-javaagent:C:\Program Files\JetBrains\IntelliJ IDEA 2023.3.5\lib\idea_rt.jar=55793:C:\Program

---------------------------------------------------------
Reply:
Block Number: 1
Data: Client 1 started
Nonce: 11367202
Hash with 6 leading zeros: 0000006f979a4b458643a8f730c02fdac1c9d81dbb402c02f4e32105b2908625

 EXECUTION TIME: 7011 ms
---------------------------------------------------------

Process finished with exit code 0
```

Client 2:

```
C:\Users\rmary\.jdks\corretto-18.0.2\bin\java.exe "-javaagent:C:\Program Files\JetBrains\IntelliJ IDEA 2023.3.5\lib\idea_rt.jar=55798:C:\Program

---------------------------------------------------------
Reply:
Block Number: 1
Data: Client 2 started
Nonce: 671690
Hash with 6 leading zeros: 000000e50b8e939f7d64f84bfa4b90224c100ebe26f458b37a6f305d6134c46f

 EXECUTION TIME: 433 ms
---------------------------------------------------------

Process finished with exit code 0
```

Figure 7a & 7b - Running both clients with 6 leading zeros specified.

7 Leading Zeroes:

Client 1:

```
C:\Users\rmary\.jdks\corretto-18.0.2\bin\java.exe "-javaagent:C:\Program Files\JetBrains\IntelliJ IDEA 2023.3.5\lib\idea_rt.jar=55885:C

---------------------------------------------------------
Reply:
Block Number: 1
Data: Client 1 started
Nonce: 460961773
Hash with 7 leading zeros: 000000012a6f8f1308db6fb19475ccf483b2f73db456abf9aa87b8f2f3e3486d

 EXECUTION TIME: 271629 ms
---------------------------------------------------------

Process finished with exit code 0
```

Client 2:

```
C:\Users\rmary\.jdks\corretto-18.0.2\bin\java.exe "-javaagent:C:\Program Files\JetBrains\IntelliJ IDEA 2023.3.5\lib\idea_rt.jar=55890:C:\Progra

---------------------------------------------------------
Reply:
Block Number: 1
Data: Client 2 started
Nonce: 437975940
Hash with 7 leading zeros: 0000000e1ea518429ec2507f3d253416b95c123aa4ddd2aeeaa211c6b003bebf

 EXECUTION TIME: 256564 ms
---------------------------------------------------------

Process finished with exit code 0
```

Figure 8a & 8b - Running both clients with 7 leading zeros specified.

Results for entire system

In order to capture the execution time for the entire system, we captured the JVM's internal time as soon as Client 1 sent its request, then captured the time once again once Client 2 received its reply. This allowed us to capture the total elapsed time for the entire system operation. By subtracting the end time from the start time, we obtained the duration of the system's execution, which includes any additional overhead involved in handling the request and generating the response. Figures 9 - 15 below highlight the execution time for different runs.

1 Leading Zero:

```
START TIME: 191501272
----------------------------------------------------------
Reply:
Block Number: 1
Data: This is client 1
Nonce: 39
Hash with 1 leading zeros: 06181046ac198f0c1731e7d8fb408aaca075538bc301da350c9308f748793571

 EXECUTION TIME: 0 ms
----------------------------------------------------------
```

```
----------------------------------------------------------
Reply:
Block Number: 1
Data: This is client 2
Nonce: 11
Hash with 1 leading zeros: 058a237a455a97be460ddc8411d10947ef92790f7b90a90af736276617904af3

 EXECUTION TIME: 0 ms
----------------------------------------------------------
END TIME: 191503069
```

Figure 9a & 9b - Calculating the execution time for the system as a whole (1 leading zero).

2 Leading Zeros:

```
START TIME: 189058803
----------------------------------------------------------
Reply:
Block Number: 1
Data: This is client 1
Nonce: 241
Hash with 2 leading zeros: 0085a8f47035bcc4a8a2d2760e3ad6c3c36d9d19e6b58b9b59f66456ea26d725

 EXECUTION TIME: 1 ms
----------------------------------------------------------
```

```
----------------------------------------------------------
Reply:
Block Number: 1
Data: This is client 2
Nonce: 481
Hash with 2 leading zeros: 005aba4ec6c63778972c6ab849929c77772af93c7a0312d464fb1c50165fc2d2

 EXECUTION TIME: 2 ms
----------------------------------------------------------
END TIME: 189060586
```

Figure 10a & 10b - Calculating the execution time for the system as a whole (2 leading zeros).

3 Leading Zeros:

```
START TIME: 189188777
----------------------------------------------------------
Reply:
Block Number: 1
Data: This is client 1
Nonce: 978
Hash with 3 leading zeros: 00062c869e31e5f81f6629c2136de1c3afd30bbd8e704919d1aacdc0bcb35815

 EXECUTION TIME: 4 ms
----------------------------------------------------------
```

```
----------------------------------------------------------
Reply:
Block Number: 1
Data: This is client 2
Nonce: 1359
Hash with 3 leading zeros: 00063a63193000051d957dfa2ecf006a12de64613c0fd0862505cce332186a31

 EXECUTION TIME: 180 ms
----------------------------------------------------------
END TIME: 189190571
```

Figure 11a & 11b - Calculating the execution time for the system as a whole (3 leading zeros).

4 Leading Zeros:

```
START TIME: 189512176
----------------------------------------------------------
Reply:
Block Number: 1
Data: This is client 1
Nonce: 32627
Hash with 4 leading zeros: 000040580667b850eec4968fa29c81baa11b8b507fcda0edf6d114c55d28b3ec

 EXECUTION TIME: 148 ms
----------------------------------------------------------
```

```
----------------------------------------------------------
Reply:
Block Number: 1
Data: This is client 2
Nonce: 70866
Hash with 4 leading zeros: 0000f21e3cf913c0c584bdb638be36b7340ee1b8c671ebd07761cb5bc67a924d

 EXECUTION TIME: 77 ms
----------------------------------------------------------
END TIME: 189513992
```

Figure 12a & 12b - Calculating the execution time for the system as a whole (4 leading zeros).

5 Leading Zeros:

```
START TIME: 189702787
----------------------------------------------------------
Reply:
Block Number: 1
Data: This is client 1
Nonce: 557983
Hash with 5 leading zeros: 00000d8fd02fd8d03d229b9f2f76f55d85032beeea4e5983e2cc1bbd4c113402

 EXECUTION TIME: 355 ms
----------------------------------------------------------
```

```
----------------------------------------------------------
Reply:
Block Number: 1
Data: This is client 2
Nonce: 53995
Hash with 5 leading zeros: 00000708e70405c0ad9e4a478bdbe6d8583404f2f8982845521b7ee4ad49b1a8

 EXECUTION TIME: 28 ms
----------------------------------------------------------
END TIME: 189704562
```

Figure 13a & 13b- Calculating the execution time for the system as a whole (5 leading zeros).

6 Leading Zeros:

```
START TIME: 189858559
-----------------------------------------------------------
Reply:
Block Number: 1
Data: This is client 1
Nonce: 7949449
Hash with 6 leading zeros: 000000d927df446cffb0ebc673dada6ee74e19e797acb463a02947d56a8279bc

 EXECUTION TIME: 4096 ms
-----------------------------------------------------------
```

```
-----------------------------------------------------------
Reply:
Block Number: 1
Data: This is client 2
Nonce: 1633282
Hash with 6 leading zeros: 00000094de6051c00e1a4e386647c149a5fe93ced7689dfc5315d237dd76bf0f

 EXECUTION TIME: 750 ms
-----------------------------------------------------------
END TIME: 189863408
```

Figure 14a & 14b- Calculating the execution time for the system as a whole (6 leading zeros).

7 Leading Zeros:

```
START TIME: 190711824
-----------------------------------------------------------
Reply:
Block Number: 1
Data: This is client 1
Nonce: 332678379
Hash with 7 leading zeros: 0000000758a483bbcfd5939cc8462a9e7d4626f0492f1b8ac151fc39947110ef

 EXECUTION TIME: 276027 ms
-----------------------------------------------------------
```

```
-----------------------------------------------------------
Reply:
Block Number: 1
Data: This is client 2
Nonce: 149398662
Hash with 7 leading zeros: 000000070cdcd37f746741403efe6cebdca14c3d97ffe679bdff881b2922c5aa

 EXECUTION TIME: 98293 ms
-----------------------------------------------------------
END TIME: 191086150
```

Figure 15a & 15b- Calculating the execution time for the system as a whole (7 leading zeros).

Analysis of results

Analysis per client

After obtaining the data required for our analysis, we visualized our data in *Table 1* and *figure 16* shown below.

Leading Zeros	Client 1 execution time (ms)	Client 2 execution time (ms)
1	0	0
2	4	0
3	41	7
4	95	60
5	891	830
6	7011	433
7	271629	256564

Table 1 - Summary of data obtained from running both clients.

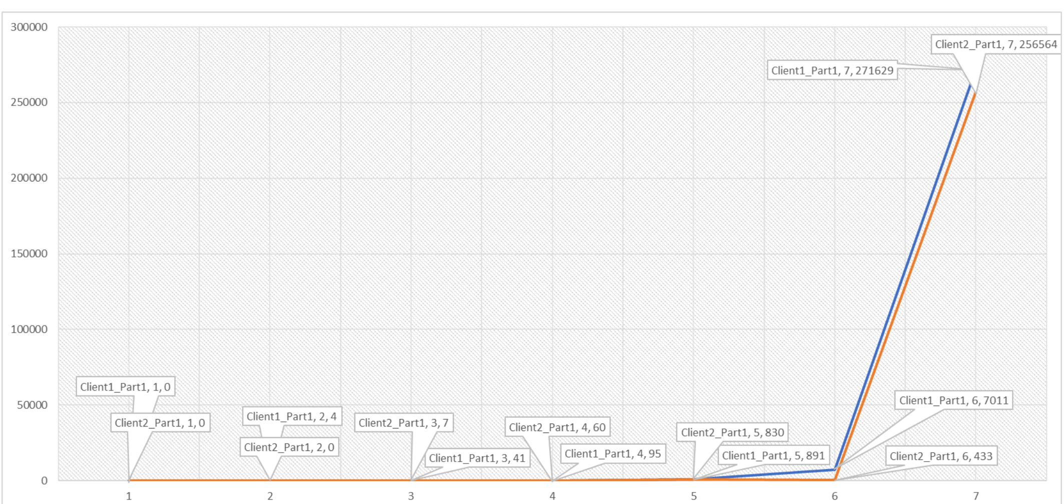


Figure 16 - A graph visualizing data obtained from running both clients.

As shown in *Table 1* and *Figure 16,* we observe a noticeable increase in execution times as the number of leading zeros required for hash generation increases. This trend highlights the exponential complexity of the mining process, particularly observable in execution times for higher leading zero counts, hinting that the number of leading zeros and execution time is directly proportional. Specifically, the execution times for both Client 1 and Client 2 greatly increases as the number of leading zeros progresses from 3 to 7. Such a pattern emphasizes the challenges present in single-server mining operations and the need of load balancing for scalability and efficiency in distributed systems.

Analysis of entire system

The procedure above was repeated to visualize the execution time of the whole system, shown below in *Table 2*.

Leading Zeros	Execution time (ms)
1	1797
2	1783
3	1794
4	1816
5	1775
6	4849
7	374326

Table 2 - Summary of execution time of our entire system

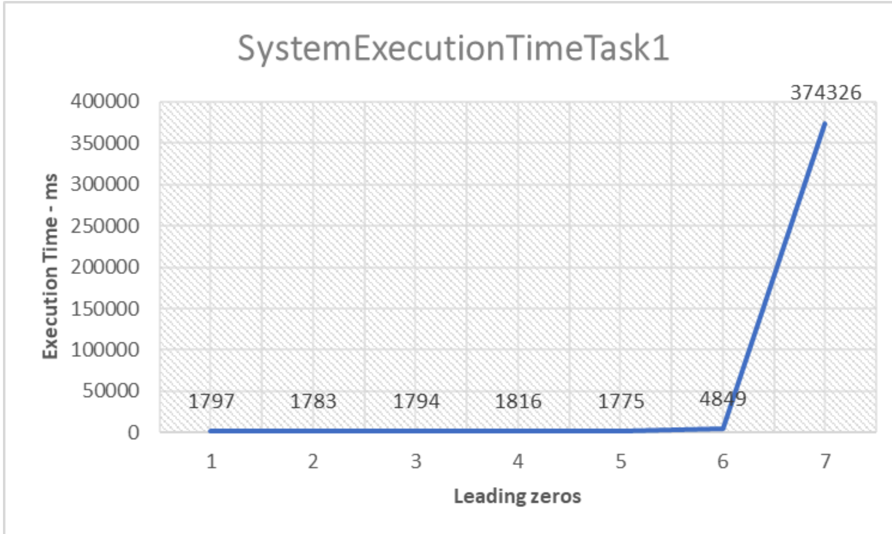


Figure 17 - A graph visualizing the execution time of the entire system, provided with different leading zeros.

Just as previously observed, as the leading zero count increases, the execution time also increases, indicating more work for the system. This further emphasizes the importance of efficient load balancing and scalability in maintaining system effectiveness, especially in distributed environments with varying workloads. Moreover, the table above highlights the impact of load imbalance, as observed by the extended wait times experienced by subsequent clients, such as Client 2, as the leading zero count rises. The delay reflects the system's **limited scalability**, as it struggles to efficiently distribute and process workload across multiple clients, reducing the system's responsiveness.

Task 2

Description of simulation:

In Task 2, our program utilized the UDP protocol to implement a distributed mining system using a Load Balancer to manage the workload more efficiently. The system, based on a three tier architecture, comprises four primary classes: Block, Client(s), Server, and the Load Balancer.

Clients initiate the mining process by sending Block objects containing crucial information such as block number, data, and leading zeros to the Load Balancer. This initiation marks the start of the mining operation. Upon receiving Blocks from Clients, the Load Balancer divides the nonce range into equal intervals and assigns each Server a specific range to work on. This distribution ensures that mining tasks are evenly distributed across all available Servers. Servers, upon receiving their assigned nonce intervals, search for the correct nonce using a brute-force approach. They increment nonce values within their allocated range until the correct nonce is found. Once a Server finds the correct nonce and successfully mines the Block, it sends the mined Block back to the respective Client. This completes the mining process for that particular Block. This process is shown below in *figure 18*.

Just as done in task 1, our program inputs the data through arguments. Our Load balancer takes in the following inputs

- args[0] → Number of servers
- args[1] → IP address of the server
- args[2] → Maximum nonce
- args[3] → Minimum nonce
- args[4] - args[n] → server ports.

The client, on the other hand, takes in the following arguments:

- Args[0] = IP address of host
- Args[1] = Block number
- Args[2] = Data in block
- Args[3] = Number of leading zeros.

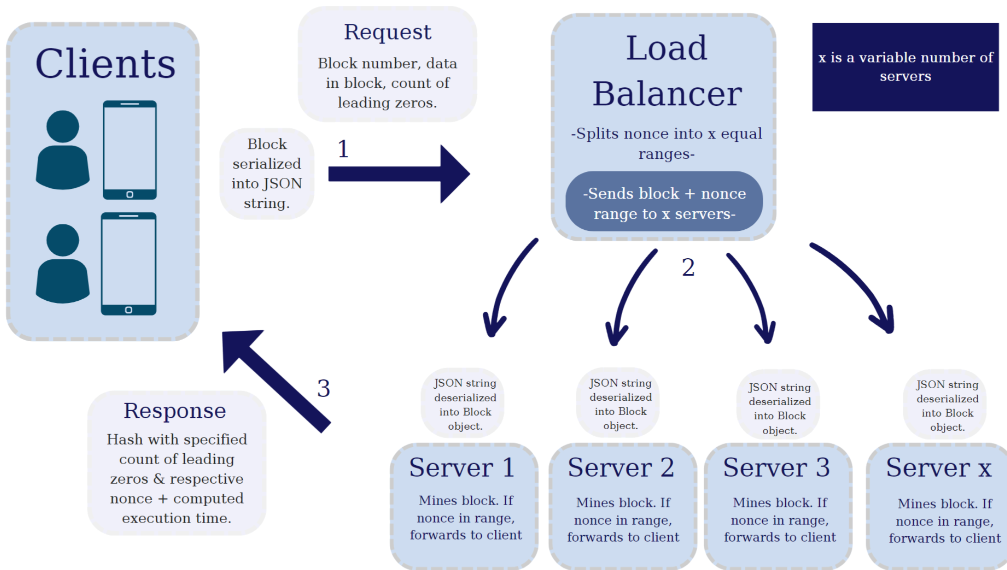


Figure 18– abstract overview of task 1's flow of events.

Obtained Results

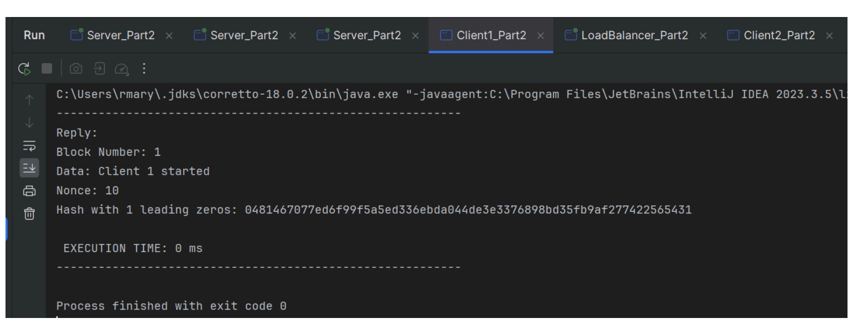
In order to extensively analyze the efficiency of distributing the mining task among multiple servers, we performed 2 trials. The first of which included distributing the task among 3 servers, and the second of which included distributing the task among 5 servers. The results can be seen below in *figures 19 to 31*.

Results per client

Second Trail - 5 Running Servers

1 Leading Zero:

Client 1:



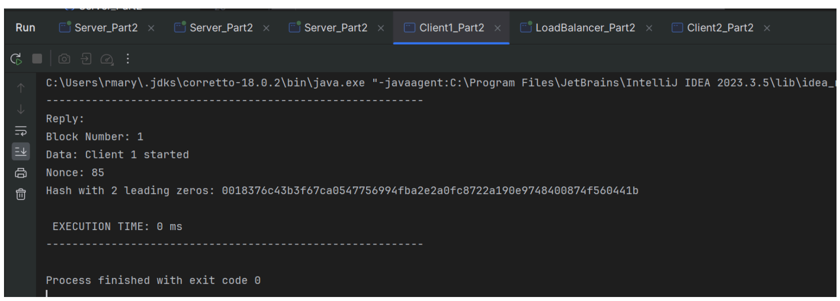
```
Run   Server_Part2   Server_Part2   Server_Part2   Client1_Part2   LoadBalancer_Part2   Client2_Part2
C:\Users\rmary\.jdks\corretto-18.0.2\bin\java.exe "-javaagent:C:\Program Files\JetBrains\IntelliJ IDEA 2023.3.5\l
--------------------------------------------------------
Reply:
Block Number: 1
Data: Client 1 started
Nonce: 10
Hash with 1 leading zeros: 0481467077ed6f99f5a5ed336ebda044de3e3376898bd35fb9af277422565431

 EXECUTION TIME: 0 ms
--------------------------------------------------------

Process finished with exit code 0
```

Client 2:

Figure 19a & 19b- Calculating the execution time when utilizing 3 servers (1 leading zero).

2 Leading Zeros:

Client 1:



Client 2:

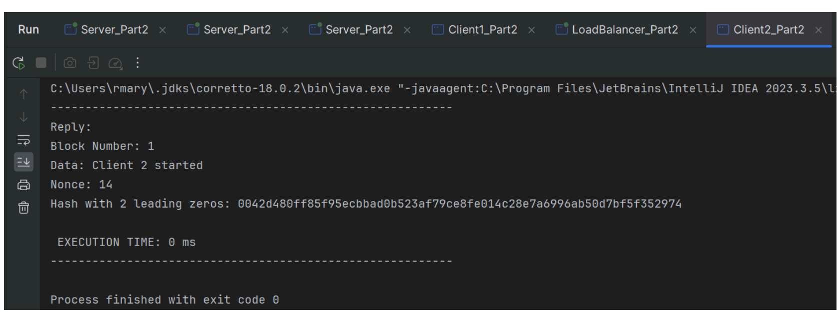
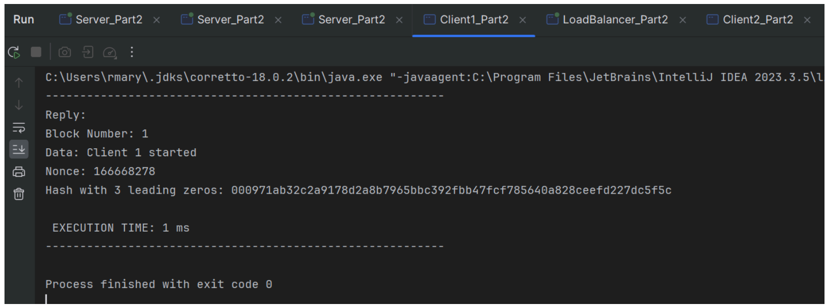


Figure 20a & 20b- Calculating the execution time when utilizing 3 servers (2 leading zeros).

3 Leading Zeroes:

Client 1:

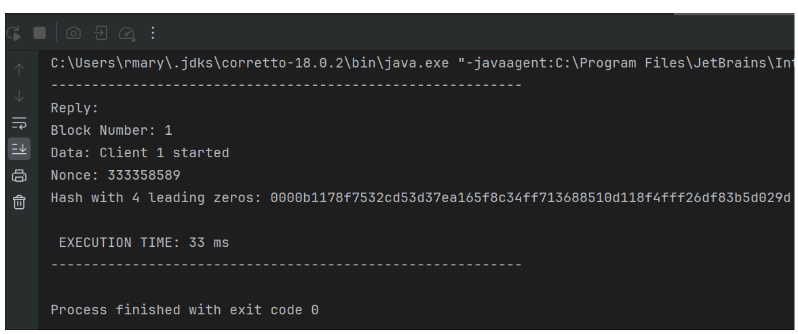


Client 2:

Figure 21a & 21b- Calculating the execution time when utilizing 3 servers (3 leading zeros).

4 Leading Zeroes:

Client 1:



Client 2:

Figure 22a & 22b- Calculating the execution time when utilizing 3 servers (4 leading zeros).

5 Leading Zeroes:

Client 1:

Client 2:

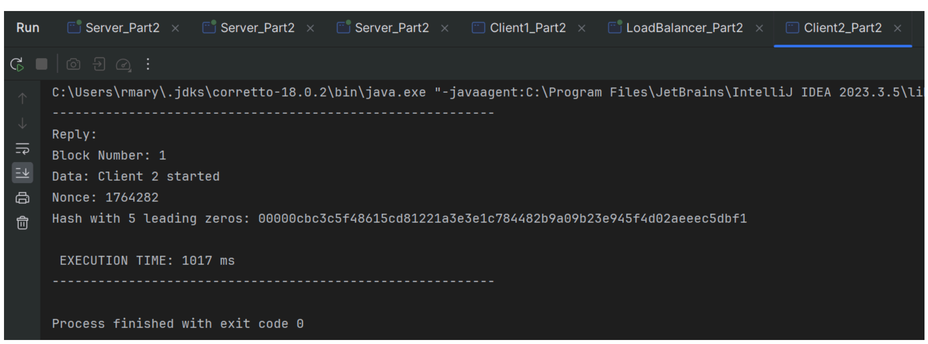
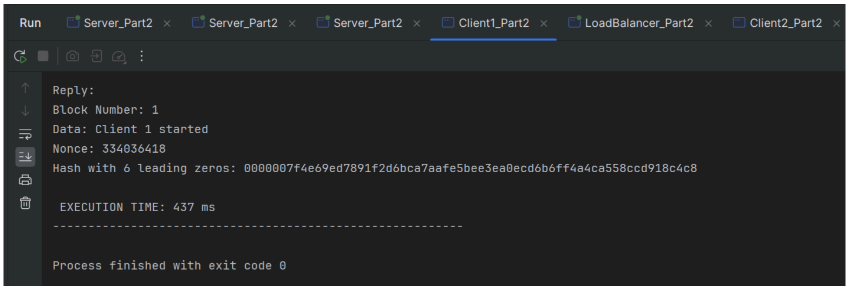


Figure 23a & 23b- Calculating the execution time when utilizing 3 servers (5 leading zeros).

6 Leading Zeroes:

Client 1:



Client 2:

Figure 24a & 24b- Calculating the execution time when utilizing 3 servers (6 leading zeros).

7 Leading Zeroes:

Client 1:

Client 2:

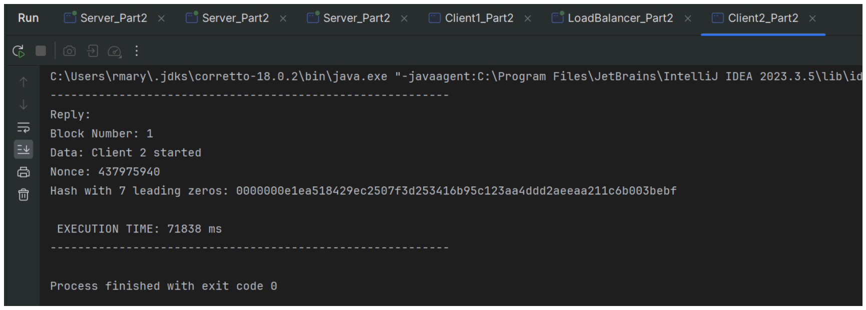


Figure 25a & 25b- Calculating the execution time when utilizing 3 servers (7 leading zeros).

Second Trail - 5 Running Servers

1 Leading Zero:

Client 1:

Client 2:

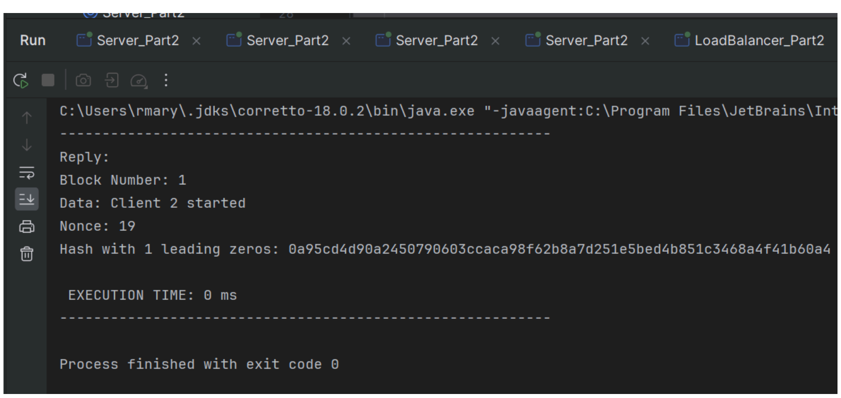


Figure 26a & 26b- Calculating the execution time when utilizing 5 servers (1 leading zero).

2 Leading Zeros:

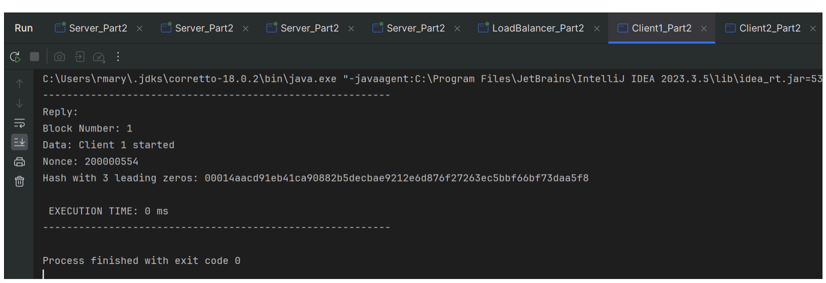
Client 1:

Client 2:

Figure 27a & 27b- Calculating the execution time when utilizing 5 servers (2 leading zeros).

3 Leading Zeroes:

Client 1:

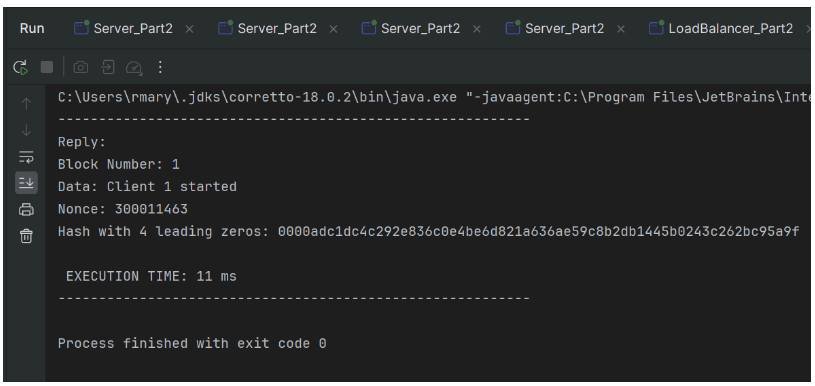


Client 2:

Figure 28a & 28b- Calculating the execution time when utilizing 5 servers (3 leading zeros).

4 Leading Zeroes:

Client 1:



Client 2:

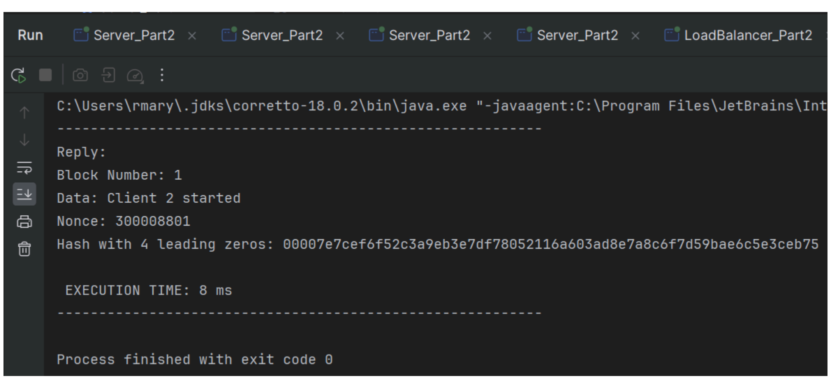


Figure 29a & 29b- Calculating the execution time when utilizing 5 servers (4 leading zeros).

5 Leading Zeroes:

Client 1:

Client 2:

Figure 30a & 30b- Calculating the execution time when utilizing 5 servers (5 leading zeros).

6 Leading Zeroes:

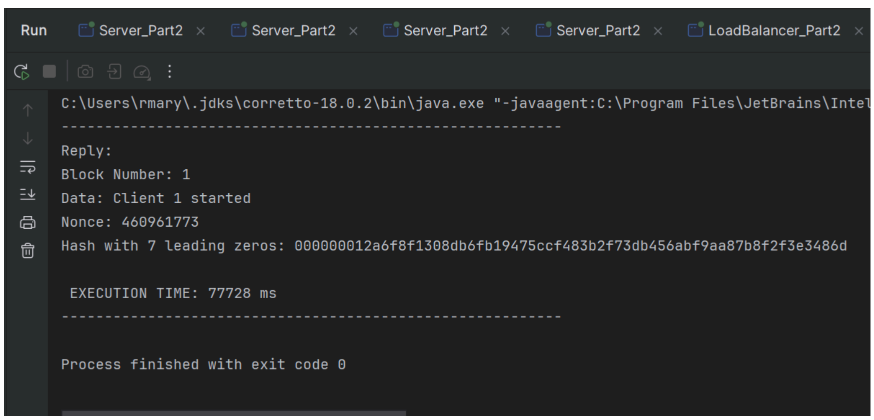
Client 1:

Client 2:

Figure 31a & 31b- Calculating the execution time when utilizing 5 servers (6 leading zeros).

7 Leading Zeroes:

Client 1:



Client 2:

Figure 32a & 32b- Calculating the execution time when utilizing 3 servers (7 leading zeros).

Results for entire system

Just as done in task 1's analysis section, in order to capture the execution time for the entire system, we captured the JVM's internal time as soon as Client 1 sent its request, then captured the time once again once Client 2 received its reply. Figures 33 - 39 below highlight the execution time for different runs.

1 Leading Zero

Client 1:

```
C:\Users\rmary\.jdks\corretto-18.0.2\bin\java.exe "-javaagent:C:\Program Files\JetBrains\In
Time Started:1431938350
----------------------------------------------------------
Reply:
Block Number: 1
Data: Client 1 started
Nonce: 166666668
Hash with 1 leading zeros: 0f1ecd026f5b1765f859edc073bf8684c183d46ab95b05eccdafb4ce27290d5c

 EXECUTION TIME: 0 ms
----------------------------------------------------------

Process finished with exit code 0
```

Client 2:

```
C:\Users\rmary\.jdks\corretto-18.0.2\bin\java.exe "-javaagent:C:\Program Files\JetBrains\Int
Time Ended:1431939780
----------------------------------------------------------
Reply:
Block Number: 1
Data: Client 2 started
Nonce: 19
Hash with 1 leading zeros: 0a95cd4d90a2450790603ccaca98f62b8a7d251e5bed4b851c3468a4f41b60a4

 EXECUTION TIME: 0 ms
----------------------------------------------------------

Process finished with exit code 0
```

Figure 33a & 33b- Execution time for the system as a whole, utilizing 3 servers (1 leading zero).

2 Leading Zeros

Client 1:

```
C:\Users\rmary\.jdks\corretto-18.0.2\bin\java.exe "-javaagent:C:\Program Files\JetBrains\Inte
Time Started:1431837919
----------------------------------------------------------
Reply:
Block Number: 1
Data: Client 1 started
Nonce: 85
Hash with 2 leading zeros: 0018376c43b3f67ca0547756994fba2e2a0fc8722a190e9748400874f560441b

 EXECUTION TIME: 0 ms
----------------------------------------------------------

Process finished with exit code 0
```

Client 2:

```
C:\Users\rmary\.jdks\corretto-18.0.2\bin\java.exe "-javaagent:C:\Program Files\JetBrains\Inte
Time Ended:1431839945
----------------------------------------------------------
Reply:
Block Number: 1
Data: Client 2 started
Nonce: 14
Hash with 2 leading zeros: 0042d480ff85f95ecbbad0b523af79ce8fe014c28e7a6996ab50d7bf5f352974

 EXECUTION TIME: 0 ms
----------------------------------------------------------

Process finished with exit code 0
```

Figure 34a & 34b- Execution time for the system as a whole, utilizing 3 servers (2 leading zeros).

3 Leading Zeroes

Client 1:

```
C:\Users\rmary\.jdks\corretto-18.0.2\bin\java.exe "-javaagent:C:\Program Files\JetBrains\Inte
Time Started:1431733170
----------------------------------------------------------
Reply:
Block Number: 1
Data: Client 1 started
Nonce: 166668278
Hash with 3 leading zeros: 000971ab32c2a9178d2a8b7965bbc392fbb47fcf785640a828ceefd227dc5f5c

 EXECUTION TIME: 1 ms
----------------------------------------------------------

Process finished with exit code 0
```

Client 2:

```
C:\Users\rmary\.jdks\corretto-18.0.2\bin\java.exe "-javaagent:C:\Program Files\JetBrains\Int
Time Ended:1431735203
----------------------------------------------------------
Reply:
Block Number: 1
Data: Client 2 started
Nonce: 1039
Hash with 3 leading zeros: 000fc60ef181195c2ac768bd8797307dbdda66bfec5686d5b1a92c6f508c9962

 EXECUTION TIME: 0 ms
----------------------------------------------------------

Process finished with exit code 0
```

Figure 35a & 35b- Execution time for the system as a whole, utilizing 3 servers (3 leading zeros).

4 Leading Zeroes

Client 1:

```
C:\Users\rmary\.jdks\corretto-18.0.2\bin\java.exe "-javaagent:C:\Program Files\JetBrains\Int
Time Started:1431588914
----------------------------------------------------------
Reply:
Block Number: 1
Data: Client 1 started
Nonce: 333358589
Hash with 4 leading zeros: 0000b1178f7532cd53d37ea165f8c34ff713688510d118f4fff26df83b5d029d

 EXECUTION TIME: 25 ms
----------------------------------------------------------

Process finished with exit code 0
```

Client 2:

```
C:\Users\rmary\.jdks\corretto-18.0.2\bin\java.exe "-javaagent:C:\Program Files\JetBrains\Int
Time Ended:1431590870
----------------------------------------------------------
Reply:
Block Number: 1
Data: Client 2 started
Nonce: 333335886
Hash with 4 leading zeros: 0000e8f12eee6352c3205616f7f267a945aa181dda450d0258b22c2d687ba5b6

 EXECUTION TIME: 2 ms
----------------------------------------------------------

Process finished with exit code 0
```

Figure 36a & 36b- Execution time for the system as a whole, utilizing 3 servers (4 leading zeros).

5 Leading Zeroes

Client 1:

```
C:\Users\rmary\.jdks\corretto-18.0.2\bin\java.exe "-javaagent:C:\Program Files\JetBrains\Int
Time Started:1431480180
----------------------------------------------------------
Reply:
Block Number: 1
Data: Client 1 started
Nonce: 333797197
Hash with 5 leading zeros: 00000c6befd2b58d67ec714ef62bde782eae9793e3dade8c70ab2ee1bd735abc

 EXECUTION TIME: 620 ms
----------------------------------------------------------

Process finished with exit code 0
```

Client 2:

```
C:\Users\rmary\.jdks\corretto-18.0.2\bin\java.exe "-javaagent:C:\Program Files\JetBrains\Int
Time Ended:1431484868
----------------------------------------------------------
Reply:
Block Number: 1
Data: Client 2 started
Nonce: 335245970
Hash with 5 leading zeros: 000008e042df75de30a1572beadabf9cb9bda866a7d194ec753bdf465a25f95b

 EXECUTION TIME: 2141 ms
----------------------------------------------------------

Process finished with exit code 0
```

Figure 37a & 37b- Execution time for the system as a whole, utilizing 3 servers (5 leading zeros).

6 Leading Zeroes

Client 1:

```
C:\Users\rmary\.jdks\corretto-18.0.2\bin\java.exe "-javaagent:C:\Program Files\JetBrains\Int
Time Started:1430465798
----------------------------------------------------------
Reply:
Block Number: 1
Data: Client 1 started
Nonce: 334036418
Hash with 6 leading zeros: 0000007f4e69ed7891f2d6bca7aafe5bee3ea0ecd6b6ff4a4ca558ccd918c4c8

 EXECUTION TIME: 1246 ms
----------------------------------------------------------

Process finished with exit code 0
```

Client 2:

```
C:\Users\rmary\.jdks\corretto-18.0.2\bin\java.exe "-javaagent:C:\Program Files\JetBrains\Int
Time Ended:1430474633
----------------------------------------------------------
Reply:
Block Number: 1
Data: Client 2 started
Nonce: 671690
Hash with 6 leading zeros: 000000e50b8e939f7d64f84bfa4b90224c100ebe26f458b37a6f305d6134c46f

 EXECUTION TIME: 466 ms
----------------------------------------------------------

Process finished with exit code 0
```

Figure 38a & 38b- Execution time for the system as a whole, utilizing 3 servers (6 leading zeros).

7 Leading Zeroes

Client 1:

```
C:\Users\rmary\.jdks\corretto-18.0.2\bin\java.exe "-javaagent:C:\Program Files\JetBrains\Int
Time Started:1431180470
----------------------------------------------------------
Reply:
Block Number: 1
Data: Client 1 started
Nonce: 460961773
Hash with 7 leading zeros: 000000012a6f8f1308db6fb19475ccf483b2f73db456abf9aa87b8f2f3e3486d

 EXECUTION TIME: 122894 ms
----------------------------------------------------------

Process finished with exit code 0
```

Client 2:

```
C:\Users\rmary\.jdks\corretto-18.0.2\bin\java.exe "-javaagent:C:\Program Files\JetBrains\Int
Time Ended:1431421998
----------------------------------------------------------
Reply:
Block Number: 1
Data: Client 2 started
Nonce: 437975940
Hash with 7 leading zeros: 0000000e1ea518429ec2507f3d253416b95c123aa4ddd2aeeaa211c6b003bebf

 EXECUTION TIME: 118626 ms
----------------------------------------------------------

Process finished with exit code 0
```

Figure 39a & 39b- Execution time for the system as a whole, utilizing 3 servers (7 leading zeros).

Analysis of Results

First Trail Analysis

Client 2 consistently demonstrates lower execution times compared to Client 1 across all levels of mining difficulty, indicating a relatively faster performance. This suggests that Client 2 efficiently handles the mining tasks, encountering fewer computational challenges than Client 1. However, both clients experience increased execution times as the number of leading zeros increases, with Client 1 exhibiting notably longer times, especially in the later stages of difficulty. The disparity between the clients suggests potential differences in resource allocation, system configurations, or computational efficiency. Client 2's superior performance implies a more optimized execution process compared to Client 1.

Second Trial Analysis

With the inclusion of more servers, **both clients experience slight decreases in execution times** across all levels of mining difficulty compared to the 3-server configuration.

Three Servers Vs Five Servers

The transition from 3 servers to 5 servers results in **shorter execution times for both clients** across all difficulty levels. This suggests that while additional servers can potentially distribute the workload more evenly, they may reduce overheads and improve performance. The consistent performance trends across different server configurations highlight the interplay between resource utilization, and CPU scheduling for each instance in distributed mining systems. While *Table 2* below summarizes the execution times for both trials, *figure 40* visualizes their key differences.

	Trail 1 - 3 Running Servers		Trail 2 - 5 Running Servers	
Leading Zeros	Client 1 execution time (ms)	Client 2 execution time (ms)	Client 1 execution time (ms)	Client 2 execution time (ms)
1	0	0	0	0
2	0	0	0	0
3	1	0	0	0
4	33	3	11	8
5	291	1017	75	326
6	437	368	9283	308
7	83505	71838	77728	57856

Table 3 - Summary of execution time for trails 1 and 2

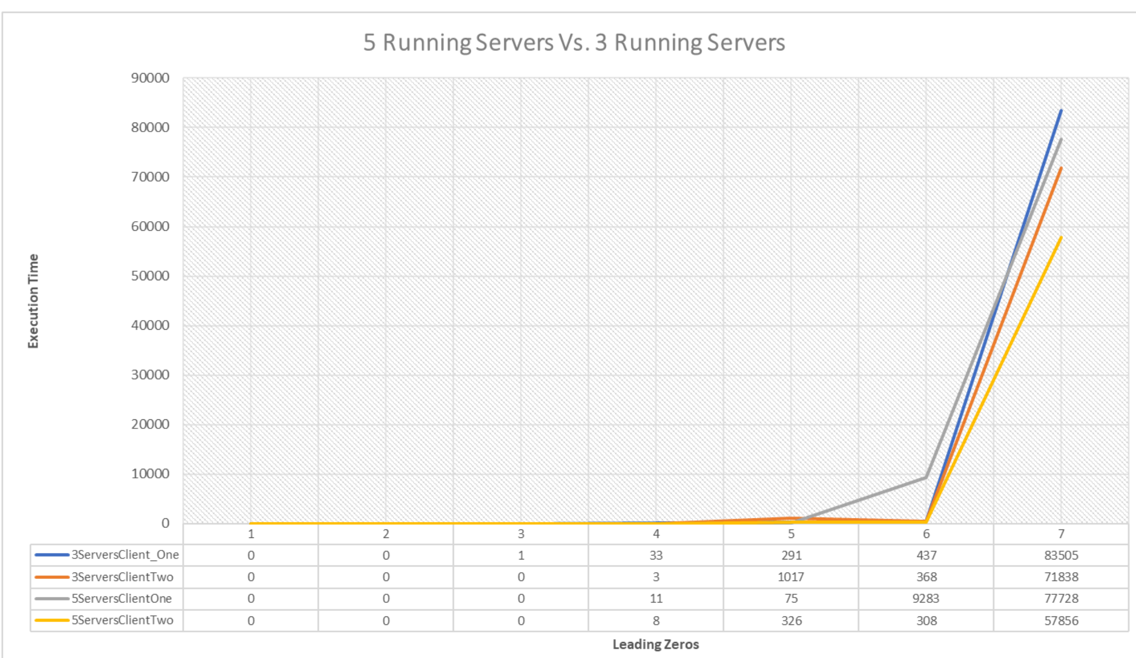


Figure 40 - A graph visualizing the execution time of trials 1 and 2.

Entire system Analysis

The procedure above was repeated to visualize the execution time of the whole system, shown below in *Table 4*.

Leading Zeros	Execution time (ms)
1	1,430
2	2,026
3	2,033
4	1,956
5	4,688
6	8,835
7	241,528

Table 4 - Summary of execution time of our entire system

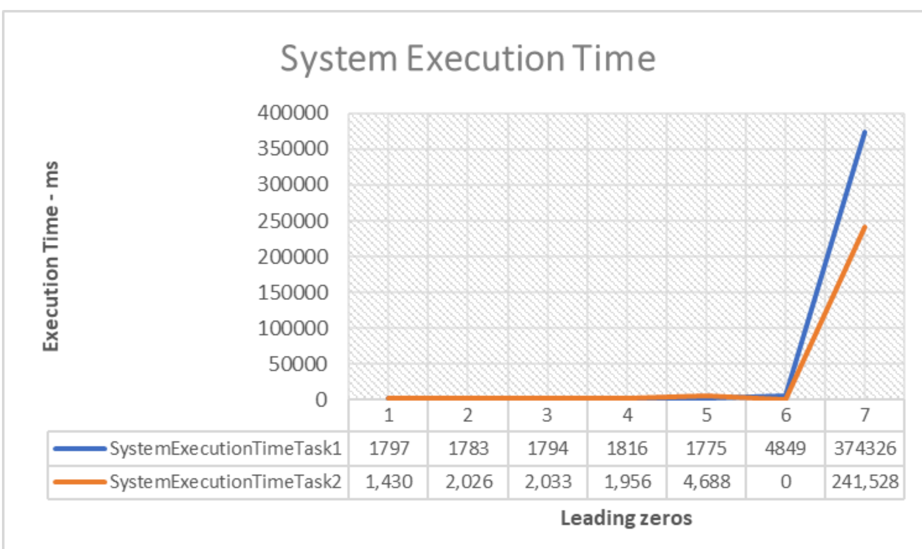


Figure 41 - A graph visualizing the execution time of the entire system, provided with different leading zeros.

As the number of leading zeros required for the hash increases, the difficulty of finding a valid hash also increases exponentially, as consistent with all other trials. Consequently, the mining process becomes more computationally intensive, leading to longer execution times. This further emphasizes the importance of efficient load balancing and scalability in maintaining system effectiveness, especially in distributed environments with varying workloads. Therefore, the use of multiple servers in which the load balancer equally distributes the nonce ranges allows for efficiency. **The more servers we add, the less wait time needed for clients.** Moreover, the table above highlights the impact of load balance, as observed by the reduced wait times experienced by subsequent clients, such as Client 2, as the leading zero count rises.

Conclusion

In summary, the analysis of Task 1's single-server mining system revealed that execution times increased as the number of leading zeros for hash generation grew, indicating heightened computational complexity. Load imbalance resulted in extended wait times for subsequent clients as leading zero counts rose, underscoring the need for efficient load balancing. Task 2, on the other hand. introduced a distributed mining system with load balancing, showcasing improved efficiency and reduced client wait times with additional servers. Overall, the findings emphasize the critical role of load balancing in enhancing system scalability and performance in distributed environments, guiding future optimizations for efficient mining operations.