Name: Andrew Hayes
Student ID: 21321503
E-mail: a.hayes18@universityofgalway.ie

CT420

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Assignment 1: NTP Benchmarking

1 NTP Installation

As I already use a Linux-based operating system on my personal laptop, I first attempted to run `ntpq` without installing anything, assuming it would be installed; to my surprise, Arch Linux is so minimalist that it doesn't even come with the `ntpd` package by default and I had to install it myself! That explains why my system clock has always been two minutes behind for the past few years! After installing `ntpd` and enabling the daemon, and watching my system clock slowly speed up until it matched UTC, I checked that it was working properly by running `ntpq -p` a few times:

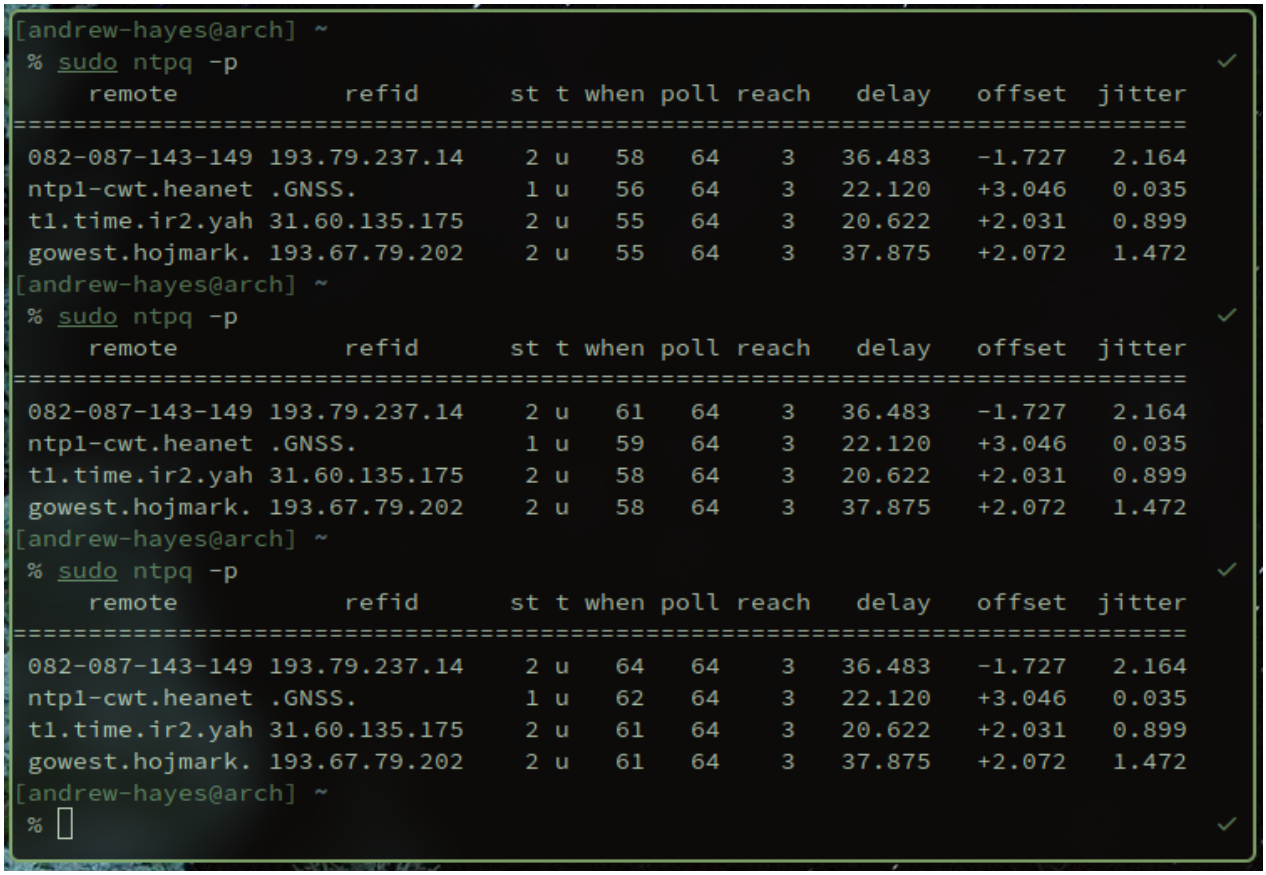

Figure 1: Verifying that the NTP daemon is running, via `ntpq`

2 NTP Configuration

To select my servers in different locations for this assignment, I went through the pools for each location on `https://www.ntppool.org/` and added each one to my `/etc/ntpc.conf` file one at a time, removing all other servers from the configuration file each time. Then, I restarted the `ntpd` service by running `sudo systemctl restart ntpd`. Finally, I ran `ntpq -p` and picked a `remote` for each area at random.

```
server bray.walcz.net   # Ireland
server 213.5.132.231    # United Kingdom
server 150.241.82.187   # Europe (Sweden)
server arm1.maxhost.io  # United States
server 159.196.178.7    # Australia
server 202.65.114.202   # Asia (Indonesia)
```

Listing 1: Servers added to `/etc/ntp.conf`

```
[andrew-hayes@arch] ~
 % ntpq -p                                                              ✓ 1s
     remote           refid      st t when poll reach   delay   offset  jitter
==============================================================================
+213.5.132.231 ( 145.185.133.33   4 u   81 1024  377   45.981   +5.197   6.519
+150.241.82.187  193.182.111.13   3 u   61 1024  377   74.808   +3.800   4.012
-159.196.178.7   .PPS.            1 u   28 1024  377  308.857  -22.633  29.387
-202.65.114.202  202.65.114.203   2 u 1020 1024  377  207.773   -5.473  32.092
*2a01:258:fffe:f 193.120.142.71   2 u 1044 1024  377   41.311   +8.047  29.335
-2603:c020:0:836 128.138.140.44   2 u 1034 1024  377  201.211  -12.652  17.856
[andrew-hayes@arch] ~
 %                                                                      ✓ 10s
```

Figure 2: Output of `ntpq -p` with new servers added

2.1 Ireland Server

The Ireland server I added had `remote` `bray.walcz.net` and appeared in the `nptq -p` output with `remote` `2a01:258:fffe:f` which is just an abbreviated form of the IPv6 address `2a01:258:fffe:f800:0:0:0:1`.

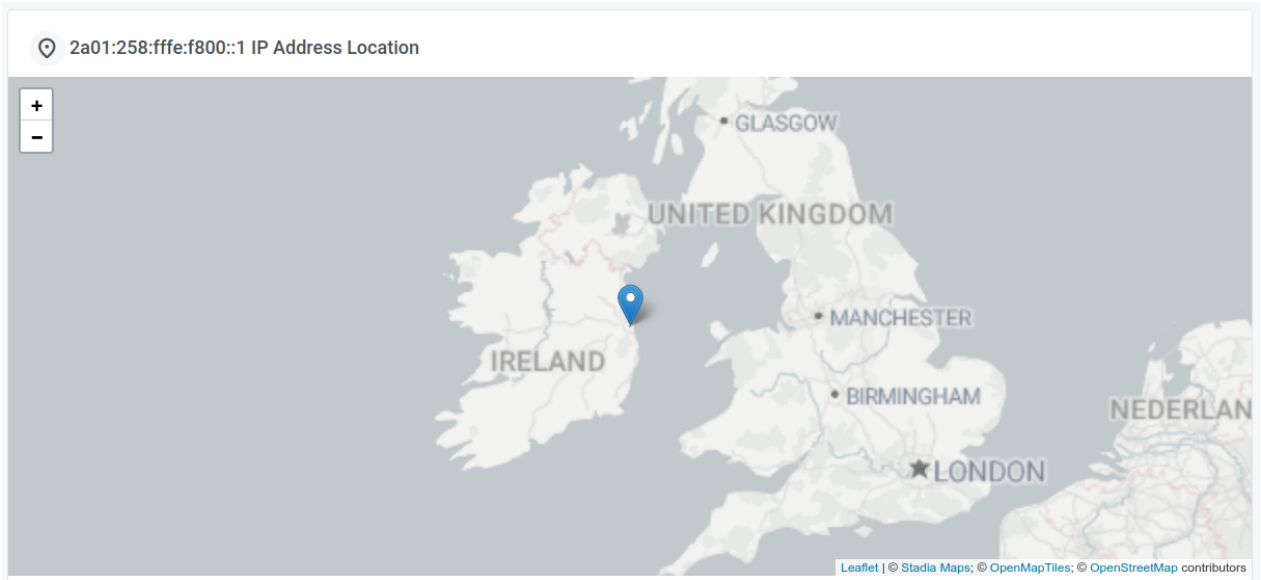

Figure 3: Location of my chosen Ireland server (source: `https://www.ipaddress.com/`)

According to `https://gps-coordinates.org/distance-between-coordinates.php` the distance between the latitude and longitude of Galway (as given in the assignment specification) and the Ireland server is 187.07 kilometres. The server seemed to be blocking ICMPv6 packets sent via `traceroute`, so I instead used `sudo traceroute -T -p 443` to send TCP packets to circumvent this. The number of hops to the destination server was 11.

```
[andrew-hayes@arch] ~
 % sudo traceroute -T -p 443 2a01:258:fffe:f800:0:0:0:1                                                    ✓ 1s
traceroute to 2a01:258:fffe:f800:0:0:0:1 (2a01:258:fffe:f800::1), 30 hops max, 80 byte packets
 1  2a02:8084:a0a0:bd00:9e24:72ff:fe38:8f0d (2a02:8084:a0a0:bd00:9e24:72ff:fe38:8f0d)  20.039 ms  20.549 ms  20.532 ms
 2  * * *
 3  ie-galway-ram-b-irb-2902.v6.aorta.net (2a02:8080:8:3::1)  28.443 ms  28.819 ms  28.804 ms
 4  ie-dub02a-rc1-lo0-0.v6.aorta.net (2001:730:2c00::5474:80f7)  34.670 ms  34.651 ms  34.634 ms
 5  ie-dub02a-ri1-lo0-0.v6.aorta.net (2001:730:2e00::5474:8022)  34.117 ms  34.577 ms  34.557 ms
 6  * * *
 7  2001:668:0:2:ffff:0:5995:8ba2 (2001:668:0:2:ffff:0:5995:8ba2)  30.513 ms  27.266 ms  27.242 ms
 8  * * *
 9  2a01:258:0:4:: (2a01:258:0:4::)  25.083 ms  27.343 ms  27.916 ms
10  2a01:258:0:4::1 (2a01:258:0:4::1)  26.594 ms  27.116 ms  26.421 ms
11  2a01:258:fffe:f800::1 (2a01:258:fffe:f800::1)  31.997 ms  28.383 ms  26.743 ms
[andrew-hayes@arch] ~
 %                                                                                                        ✓ 1s
```

Figure 4: Output of `sudo traceroute -T -p 443 2a01:258:fffe:f800:0:0:0:1`

2.2 UK Server

The UK server I added had `remote 213.5.132.231`.

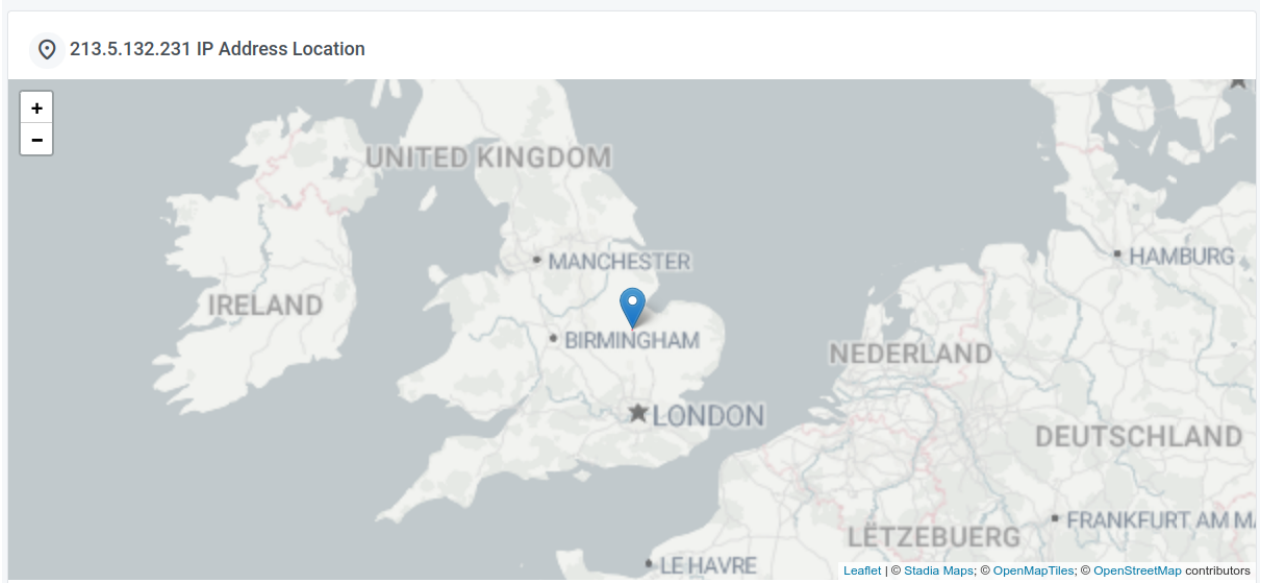

Figure 5: Location of my chosen UK server (source: `https://www.ipaddress.com/`)

According to `https://gps-coordinates.org/distance-between-coordinates.php` the distance between the latitude and longitude of Galway (as given in the assignment specification) and the United Kingdom server is 595.76 kilometres. The server also seemed to be blocking ICMPv6 packets sent via `traceroute`, so I instead used `sudo traceroute -T -p 443` to send TCP packets to circumvent this. The number of hops to the destination server was 12.

```
[andrew-hayes@arch] ~
 % sudo traceroute -T -p 443 213.5.132.231                                                                 ✓ 15s
traceroute to 213.5.132.231 (213.5.132.231), 30 hops max, 60 byte packets
 1  _gateway (192.168.0.1)  18.567 ms  18.510 ms  18.483 ms
 2  * * *
 3  ie-dub01a-rc1-ae-14-0.aorta.net (84.116.239.129)  33.675 ms  33.650 ms  33.636 ms
 4  ie-dub02a-ri1-ae-73-0.aorta.net (84.116.134.110)  33.120 ms  33.594 ms  33.576 ms
 5  dln-b4-link.ip.twelve99.net (213.248.85.54)  33.550 ms  37.592 ms  37.913 ms
 6  * * *
 7  * * ldn-bb2-link.ip.twelve99.net (62.115.120.10)  31.165 ms
 8  ldn-b3-link.ip.twelve99.net (62.115.140.71)  30.684 ms ldn-b3-link.ip.twelve99.net (62.115.122.181)  31.057 ms ldn-b3-
link.ip.twelve99.net (62.115.140.71)  31.021 ms
 9  dsmgrpgbltd-ic-374043.ip.twelve99-cust.net (62.115.184.135)  33.809 ms  34.173 ms  34.475 ms
10  sibson.eu.as50391.net (94.126.238.41)  33.815 ms  27.180 ms  30.571 ms
11  oxygen.darksky.io (213.5.132.225)  30.488 ms  30.035 ms  31.739 ms
12  231.132.5.213.ptr.as50391.net (213.5.132.231)  31.758 ms  35.307 ms  34.888 ms
[andrew-hayes@arch] ~
 %                                                                                                        ✓ 1s
```

Figure 6: Output of `sudo traceroute -T -p 443 213.5.132.231`

2.3 Europe Server

The Europe server I added had `remote 150.241.82.187`.

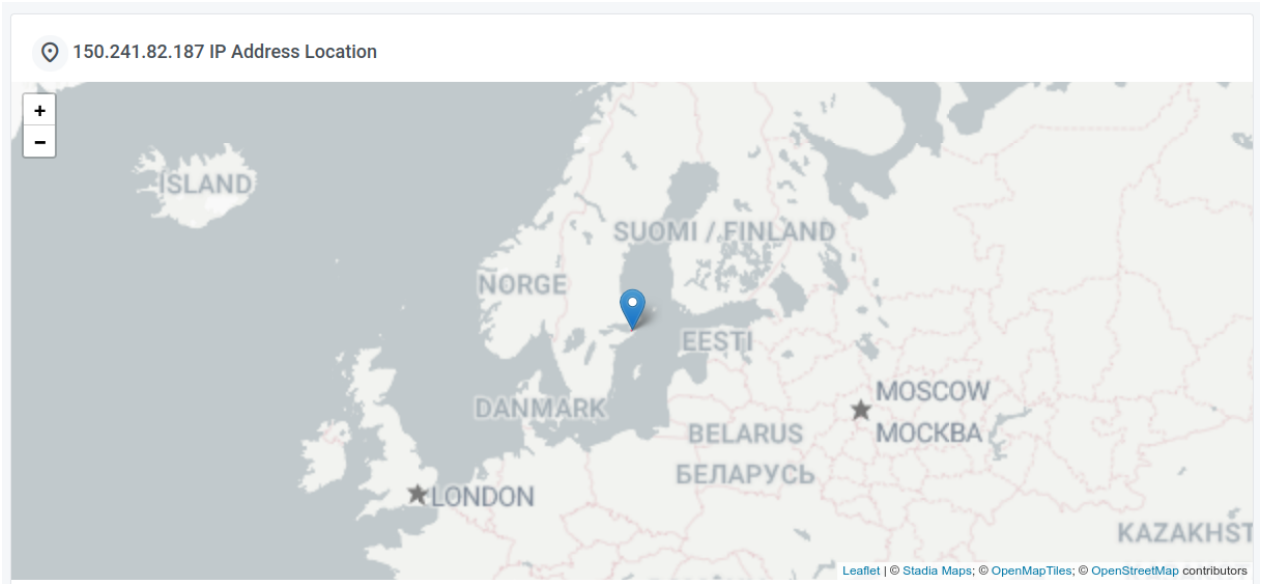

Figure 7: Location of my chosen Europe server (source: `https://www.ipaddress.com/`)

According to `https://gps-coordinates.org/distance-between-coordinates.php` the distance between the latitude and longitude of Galway (as given in the assignment specification) and the Europe Server is 1788.51 kilometres. The number of hops to the destination server was 14.

```
[andrew-hayes@arch] ~
 % traceroute 150.241.82.187
traceroute to 150.241.82.187 (150.241.82.187), 30 hops max, 60 byte packets
 1  _gateway (192.168.0.1)  19.153 ms  19.549 ms  19.516 ms
 2  ie-dub01a-rt3.aorta.net (84.116.236.62)  40.829 ms  41.479 ms  41.452 ms
 3  ie-dub01a-rc1-ae-14-0.aorta.net (84.116.239.129)  41.800 ms  41.780 ms  41.449 ms
 4  ie-dub02a-ri1-ae-73-0.aorta.net (84.116.134.110)  41.365 ms  41.347 ms  41.327 ms
 5  dln-b4-link.ip.twelve99.net (213.248.85.54)  40.124 ms  40.108 ms  40.088 ms
 6  dln-b3-link.ip.twelve99.net (62.115.139.118)  41.245 ms  19.971 ms  19.815 ms
 7  * ldn-bb2-link.ip.twelve99.net (62.115.120.10)  39.997 ms *
 8  * * hbg-bb2-link.ip.twelve99.net (62.115.122.160)  50.385 ms
 9  sto-bb2-link.ip.twelve99.net (62.115.127.23)  61.608 ms  61.959 ms  61.923 ms
10  * sto-b3-link.ip.twelve99.net (62.115.118.109)  61.836 ms *
11  * * *
12  87.239.27.106.inetcom.ru (87.239.27.106)  65.734 ms  58.467 ms 87.239.27.108.inetcom.ru (87.239.27.108)  54.775 ms
13  * * *
14  entertaining-toy.aeza.network (150.241.82.187)  77.140 ms  73.393 ms  73.875 ms
[andrew-hayes@arch] ~
 %                                                                                    ✓ 2s
```

Figure 8: Output of `traceroute 150.241.82.187`

2.4 United States Server

The United States server I added had `remote arm1.maxhost.io` and appeared in the `ntpq -p` output with `remote 2603:c020:0:836` which is an abbreviated for of the IPv6 address `2603:c020:0000:0836::`.

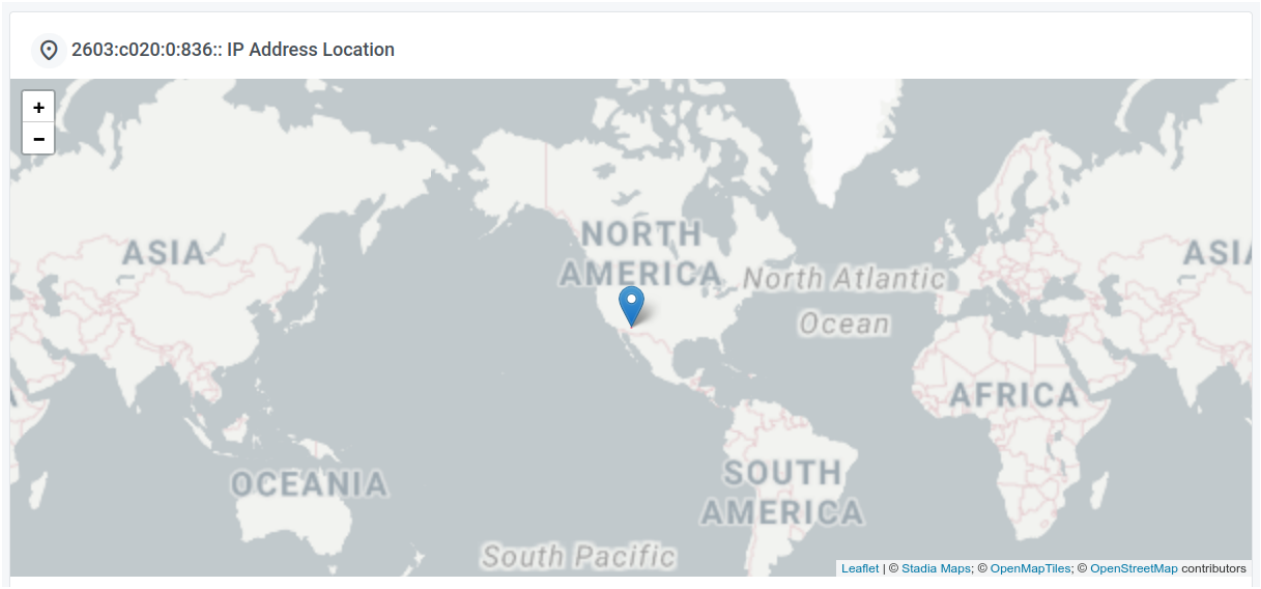

Figure 9: Location of my chosen United States server (source: `https://www.ipaddress.com/`)

According to `https://gps-coordinates.org/distance-between-coordinates.php` the distance between the latitude and longitude of Galway (as given in the assignment specification) and the United States server is 7863.25 kilometres. The server seemed to be blocking both ICMPv6 and TCP packets sent via `traceroute`. As a final attempt, I tried to pretend to be an NTP packet by pinging the well-known NTP port `123` with UDP packets but that didn't work. In each attempt, the `traceroute` stopped making progress at the 9th hop, so I'm guessing that the 10th hop might be the server itself had the `traceroute` gone through.

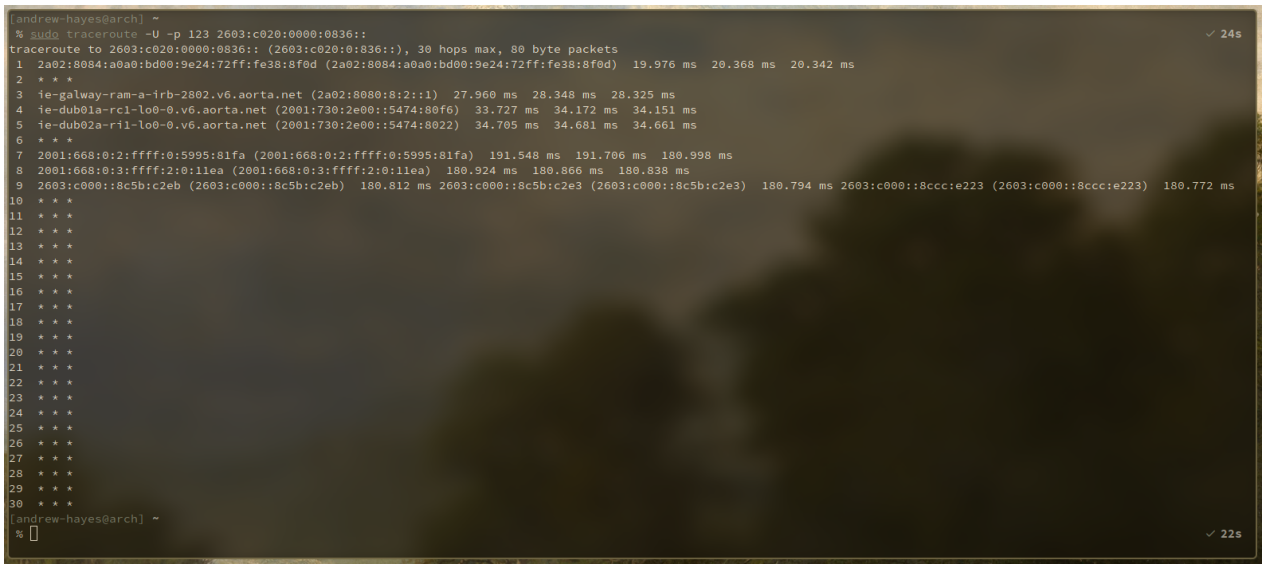

Figure 10: Output of `sudo traceroute -U -p 123 2603:c020:0000:0836::`

2.5 Australia Server

The Australia server I added had `remote 159.196.178.7`.

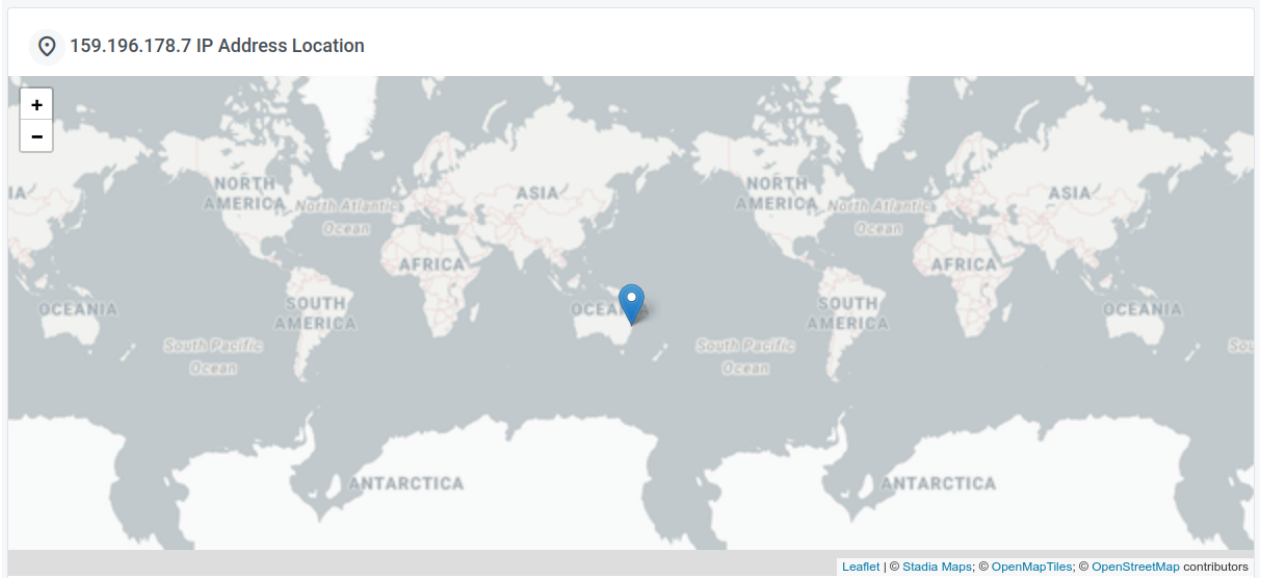

Figure 11: Location of my chosen Australia server (source: `https://www.ipaddress.com/`)

According to `https://gps-coordinates.org/distance-between-coordinates.php` the distance between the latitude and longitude of Galway (as given in the assignment specification) and the Australia server is 16790.45 kilometres. The server also seemed to be blocking ICMPv6 packets sent via `traceroute`, so I instead used `sudo traceroute -T -p 443` to send TCP packets to circumvent this. The number of hops to the destination server was 15.

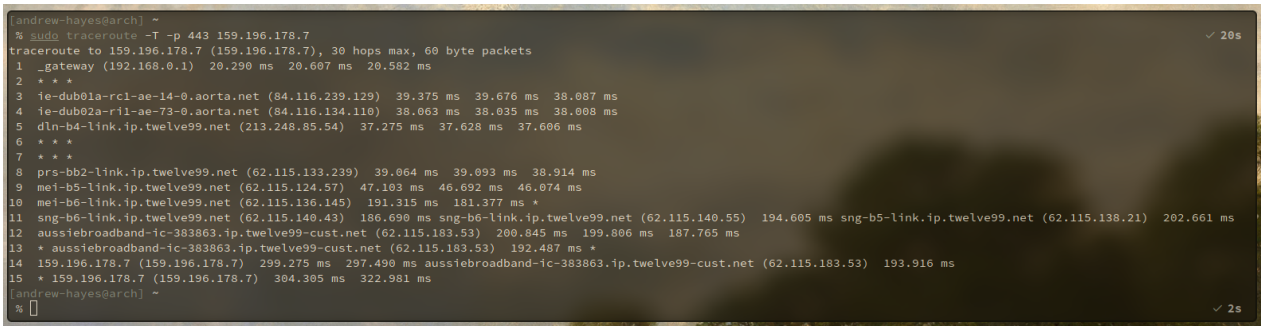

Figure 12: Output of `sudo traceroute -T -p 443 159.196.178.7`

2.6 Asia Server

The Asia server I added had `remote 202.65.114.202`.

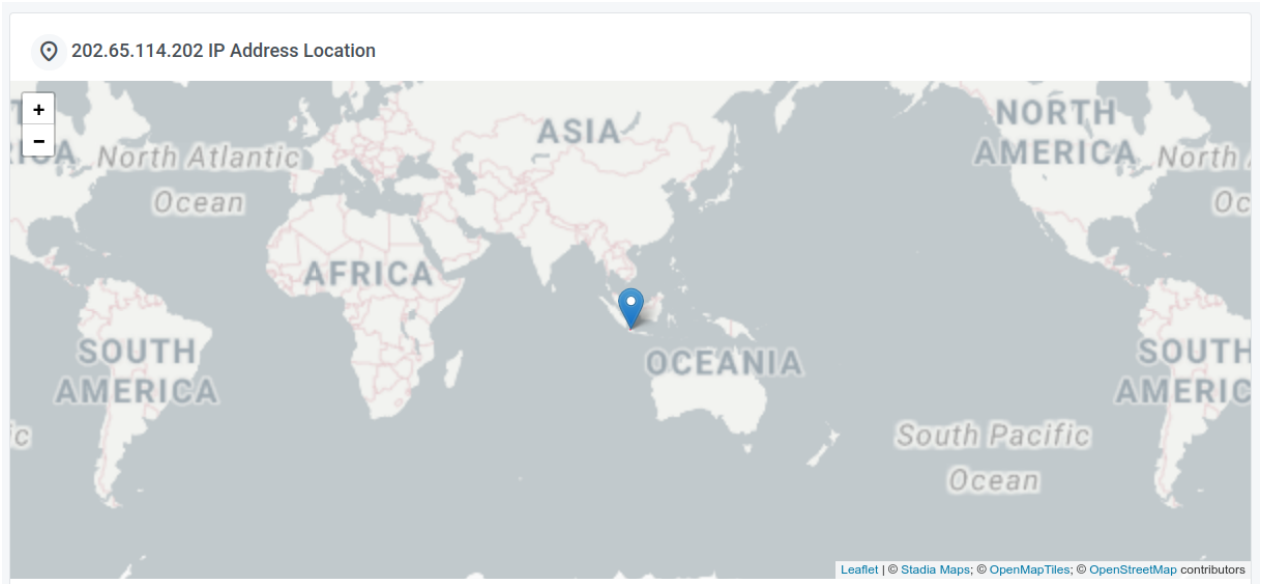

Figure 13: Location of my chosen Asia server (source: `https://www.ipaddress.com/`)

According to `https://gps-coordinates.org/distance-between-coordinates.php` the distance between the latitude and longitude of Galway (as given in the assignment specification) and the Asia Server is 12256.96 kilometres. The number of hops to the destination server was 14.

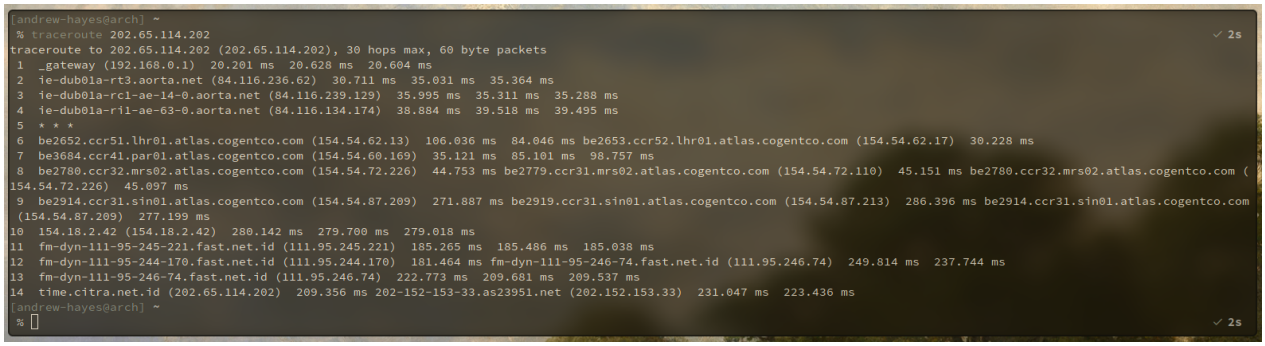

Figure 14: Output of `traceroute 202.65.114.202`

3 Collected Data

I collected the NTP peers data over a period of 8 hours with one query every 20 minutes using a shell script which would then parse the data into TSV (tab-separated value) format and append it to a file called `results.tsv`.

```
#!/bin/sh

file="results.tsv"
printf "timestamp\tremote\trefid\tst\tt\twhen\tpoll\treach\tdelay\toffset\tjitter\n" > "$file"  # add headings to results file

# every 20 minutes for 8 hours
for i in $(seq 1 24); do
    # add the ntpq peers data in TSV format to file with timestamp prepended
    ntpq --peers | awk '
        (NR > 2 ) {
            timestamp = systime();
            gsub(/ +/, "\t");
            print(timestamp "\t" $0);
        }
    ' | tee --append "$file"

```

```
    # do nothing for 20 minutes
    sleep 20m
done
```

Listing 2: `query.sh`

The `remote` column for the UK server contained a single `(` character in the output, the meaning of which I'm not quite sure as I couldn't find anything about it in the NTP documentation or manual pages, which made parsing the data more difficult so I just removed any instances of the character from the file using the command `sed -i 's/\(\t//g' results.tsv`. Then, I removed the prefix characters (`+`, `-`, `*`) from the `remote` column using Vim with visual-block editing. Finally, I wrote a short Python script to ingest the data, plot it, and perform the necessary calculations.

Server	Max	Min	Mean	Std
Asia	36.340	1.538	14.799	14.314
Australia	38.036	2.142	20.088	12.054
Europe	31.494	0.735	5.296	6.040
Ireland	32.574	0.882	12.049	12.067
UK	48.932	0.587	6.474	9.322
US	40.647	0.434	6.249	8.860

Table 1: Jitter statistics

Server	Max	Min	Mean	Std
Asia	222.677	207.773	213.492	4.114
Australia	335.595	295.743	308.813	10.419
Europe	79.569	57.901	67.093	6.319
Ireland	41.311	22.422	28.672	5.045
UK	46.231	28.801	34.843	5.228
US	201.211	180.389	186.829	5.196

Table 2: Delay statistics

Server	Max	Min	Mean	Std
Asia	6.475	-10.676	-5.678	3.500
Australia	-1.570	-31.768	-17.999	5.977
Europe	46.757	-7.301	0.464	10.393
Ireland	8.914	-2.956	2.186	4.099
UK	5.197	-14.073	-1.955	4.641
US	-7.888	-24.577	-18.804	4.837

Table 3: Offset statistics

I think that the results indicate a strong correlation between delay, jitter, & offset with geographical distance and number of packet hops. As we saw previously, the number of packet hops was higher the further away the server was geographically from my computer. The Irish server needed only 11 hops, the UK server 12, the European server 14, the Australian server 15, and the Asian server 14. We estimated that the American server could've been accessed in just 10 hops, but really there's no good way of knowing since the packet was blocked every time. This pattern continues with the jitter, delay, and offset statistics: looking at the mean column for each table above, the Australian and US servers consistently have the highest absolute value, being the furthest away geographically. This is to be expected, as the packets have to take more time to physically travel across the world to those locations. Interestingly, the Irish server has consistently high jitter: one key reason for this might be that the data was collected across afternoon and evening time in Ireland, which are likely to peak times for load on Irish NTP servers and therefore introduce more jitter. Another interesting observation is that the Irish mean offset is actually more than the European mean offset; however, I think this can be explained by the fact that European offset had a much higher standard deviation, and a much wider range of offset values, which average out to be closer to zero despite being significantly worse.

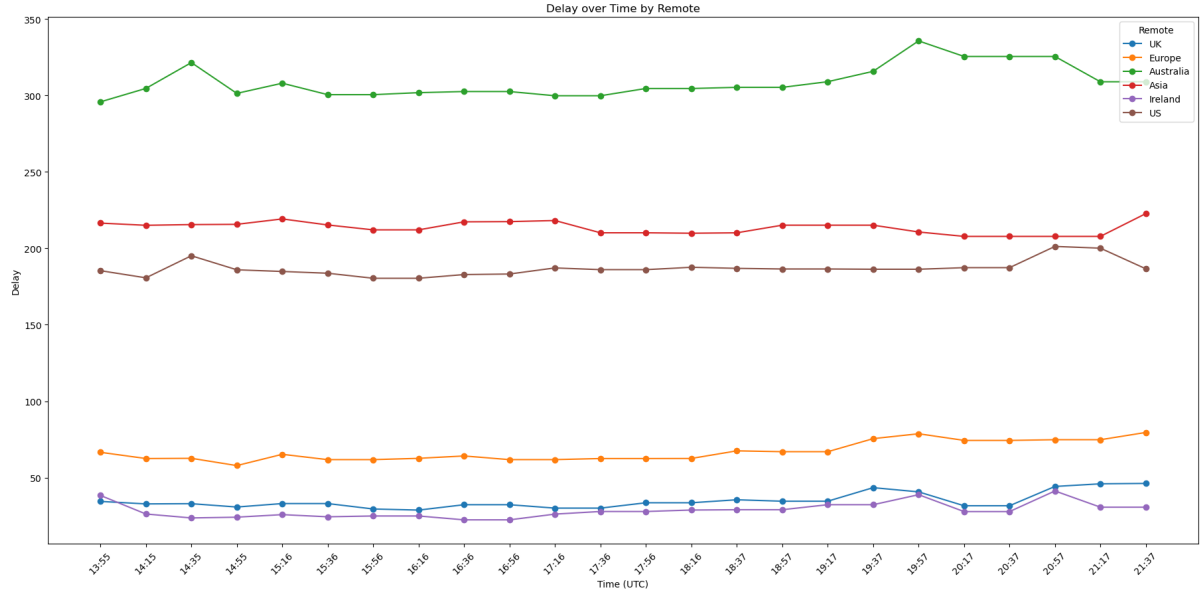

Figure 15: Delay over Time

The results of plotting delay against time are exactly as one would expect: the further away a server is, the higher the offset. Asutralia has consistently the highest offset, followed by Asia, followed by US, followed by Europe, UK, & Ireland. We can see that the Irish server's delay follows the UK's server delay very closely: this is likely due to the closeness in time zones – both servers would face peak hours at roughly the same times. The delay for these servers peaks in the evening time, when people are off work and home from school and thus using Internet-connected devices. However, for the most part, even with the temporal variation in the delay values, they stay remarkably consistent, which indicates that while they are somewhat dependent on the time of day, the delay values are primarily determined by geographical distance.

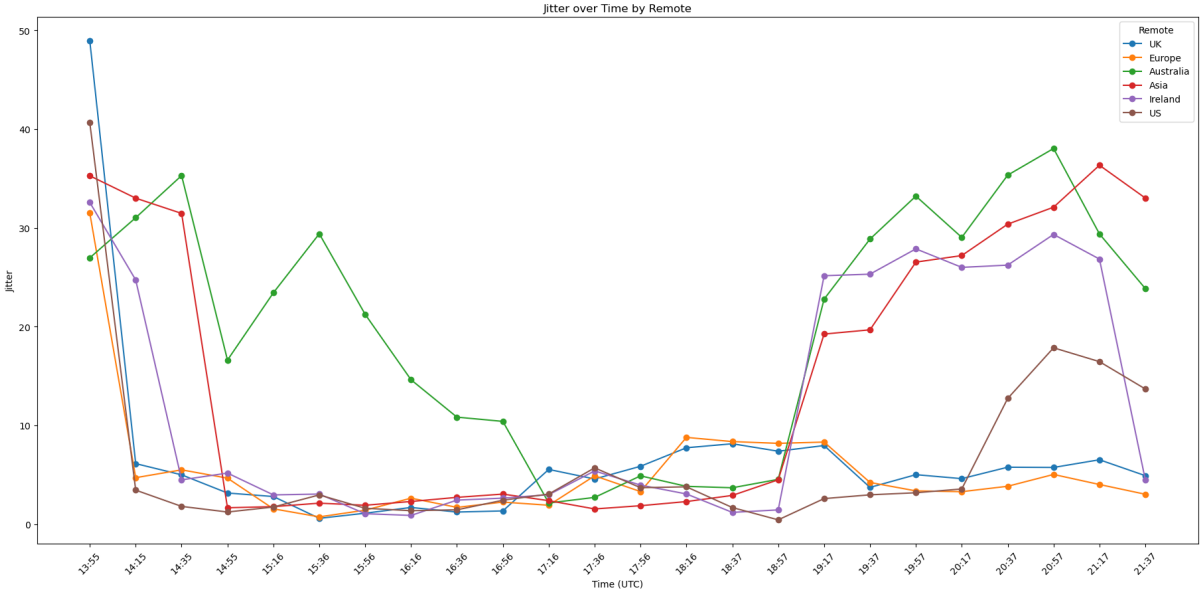

Figure 16: Jitter over Time

The jitter over time varies a great deal more. Of course, since jitter is a measure of the variance in delay, we can see that the jitter values peak for around the same times that there are small peaks in the delay data. Again, the Irish server's jitter peaks in the evening time, as one would expect. We can also see that despite varying more than the offset, the jitter values across different servers seem to be more aligned, being low around the same times and high around the same times, giving strong evidence that jitter is influenced by the time of day.

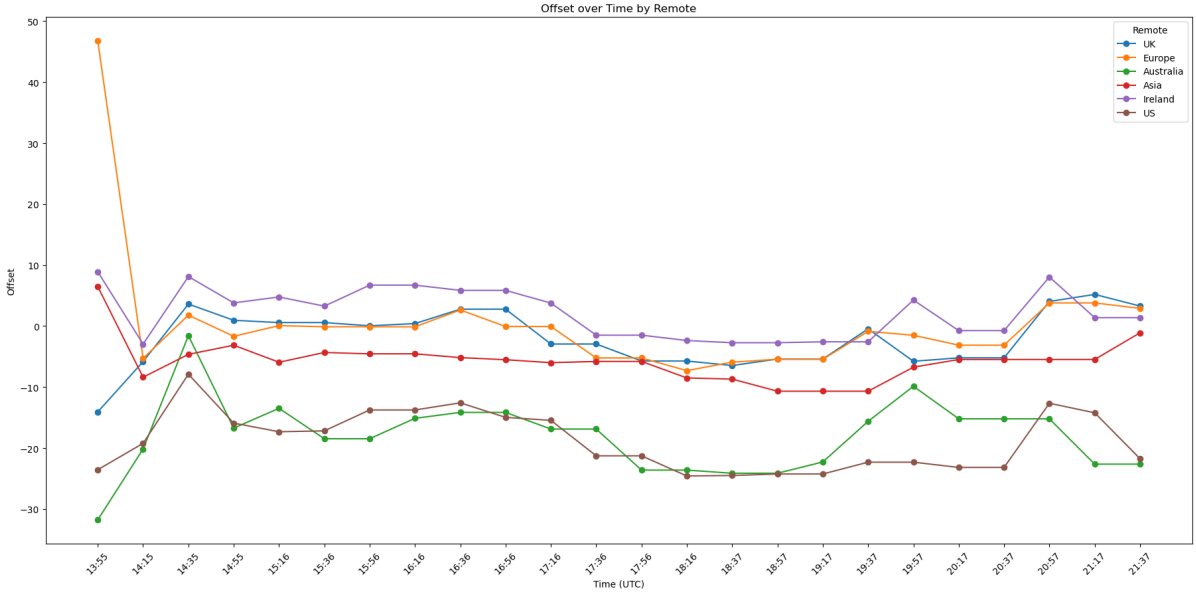

Figure 17: Offset over Time

We can see that offset also varies over time, more wildly than the delay but less so than the jitter. We can also see that despite offset varying less than jitter, the offset curves tend to go up when the jitter curves go up, which makes sense, as greater variance and inconsistency in the amount of time a packet takes to get to its destination will necessarily impact the offset.