Observations for Each Part:

a. Creating Two IP Subnets

Observation:

- Upon setting up two IP subnets—one for the WiFi network (e.g., `192.168.1.0/24`) and another for the point-to-point (p2p) network (e.g., `10.1.1.0/24`)—we observe that the WiFi clients and the server are on separate networks.

- The Access Point (AP) functions as a router between the two subnets, facilitating communication between the clients and the server.

- Routing tables are automatically configured or manually set to ensure proper packet forwarding between subnets.

Explanation:

- Separating the networks into different subnets isolates the WiFi clients from the p2p link, which is a common practice to manage network traffic.

- The AP's role as a router is crucial for enabling communication across subnets. Without proper routing, packets from the clients would not reach the server.

b. Clients Downloading a 5MB File from the Server

Observation:

- All clients start downloading a 5MB file simultaneously from the server.

- The completion time for each client—the time from sending the request to receiving the last byte—varies slightly among clients but generally increases with the number of clients (N).

- Plotting the completion times shows a linear increase as the number of clients increases.

Explanation:

- Since all clients share the same WiFi channel, the available bandwidth is divided among them.

- Using a fixed Modulation and Coding Scheme (MCS) index of 4 ensures a consistent data rate for all clients (e.g., approximately 26 Mbps for MCS 4 in 802.11n with a 20 MHz channel).

- As more clients share the medium, contention increases, leading to higher delays and reduced per-client throughput.

- The slight variations in completion times are due to random access delays inherent in the Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) mechanism used by WiFi.

c. Simultaneous Download and Upload Applications

Observation:

- When clients run an upload application at 100-200 Kbps alongside the download, the completion times for downloading the 5MB file increase compared to part b.

- The increase in completion time is more pronounced as the number of clients increases.

- The network experiences higher contention and possibly increased collision rates.

Explanation:

- WiFi is a half-duplex medium, meaning that upload (uplink) and download (downlink) transmissions share the same channel.

- Introducing uplink traffic adds more contention for the medium, as clients now compete to send and receive data.

- The additional upload traffic, though relatively low per client, aggregates to a significant amount when multiple clients are involved.

- This increased contention leads to longer delays in medium access, reducing the effective throughput for both uploads and downloads.

d. Introducing Path Loss, Fading, and Rate Adaptation (MinstrelHTManager)

Observation:

- With the path loss and fading model enabled and using MinstrelHTManager for rate adaptation, the completion times for downloading the 5MB file increase further compared to part c.

- There is greater variability in completion times among clients.

- Clients located farther from the AP experience longer completion times due to lower data rates.

Explanation:

- The path loss and fading models simulate realistic wireless channel conditions, introducing factors like signal attenuation and multipath effects.

- MinstrelHTManager dynamically adjusts the MCS based on current channel conditions, aiming to optimize throughput.

- Clients experiencing poor channel conditions (e.g., due to distance from the AP) will downgrade to lower MCS indices, reducing their data rates.

- The adaptive nature of MinstrelHTManager leads to heterogeneous data rates among clients, causing variations in completion times.

- Overall network performance is affected by the lower data rates of distant clients, as they occupy the channel for longer periods during transmissions.

e. Enabling RTS/CTS Mechanism

Observation:

- With Request to Send/Clear to Send (RTS/CTS) enabled, the completion times for downloading increase compared to part d.

- The increase in completion time is noticeable across all clients, regardless of their position relative to the AP.

Explanation:

- RTS/CTS introduces an additional handshake before data transmission, which helps mitigate the hidden node problem by reserving the channel.

- In environments without significant hidden nodes (e.g., all clients are within range of each other), the RTS/CTS mechanism adds unnecessary overhead without substantial benefits.

- The additional control frames consume time on the channel, reducing the effective throughput available for data transmission.

- While RTS/CTS can reduce collisions in certain scenarios, in this simulation with stationary nodes and no mobility, the overhead outweighs the benefits.

Summary of Observations:

- Part b vs. Part c: Introducing uplink traffic increases contention, leading to longer download completion times.

- Part c vs. Part d: Realistic channel conditions and rate adaptation introduce variability in data rates, affecting clients differently based on their location – but it tends to increase download completion time due to path loss, fading effects and due to the rate adaptation by MinstrelHTManager.

- Part d vs. Part e: Enabling RTS/CTS adds overhead, increasing completion times, especially when the number of clients are limited and there's no hidden node problem as far the positioning of the clients is concerned.

Conclusion:

Through these simulations, we observe how different network configurations and conditions impact the performance of WiFi networks. Factors such as medium contention, channel conditions, rate adaptation mechanisms, and access protocols like RTS/CTS play significant roles in determining throughput and latency experienced by clients.

Screenshots:

a.

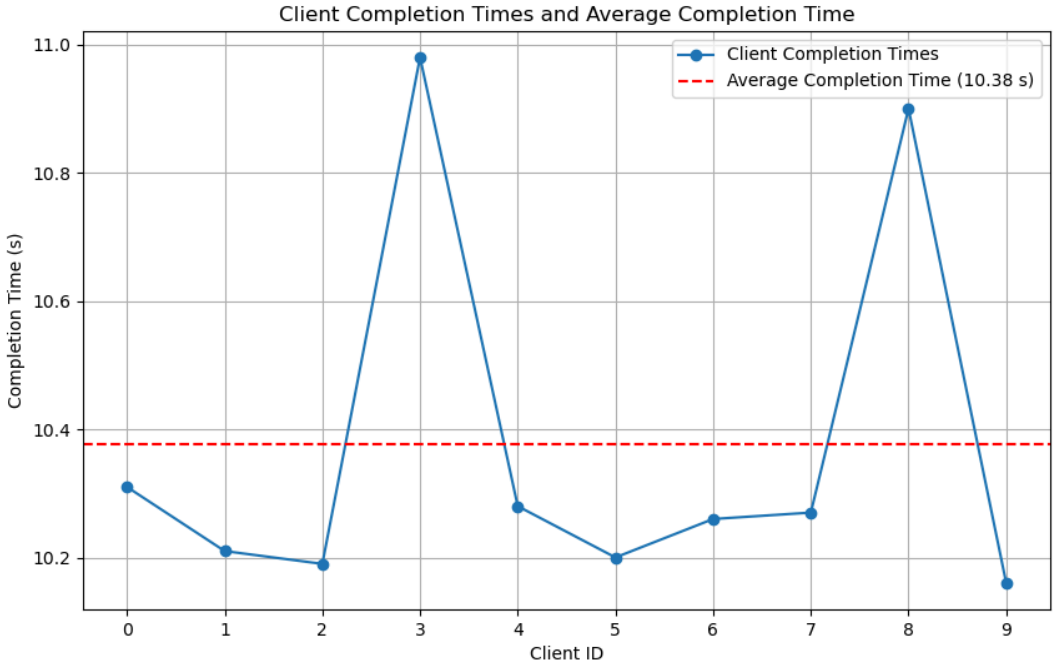
```
nikhil-suri@codecrusader247:~/ns-allinone-3.42/ns-3.42$ ./ns3 run "scratch/a --numClients=10"
[0/2] Re-checking globbed directories...
ninja: no work to do.
node=0x5975476c6420, mob=0x5975476c70a0
node=0x5975476629c0, mob=0x5975476c67a0
node=0x597547645a50, mob=0x5975476c6810
node=0x5975476c0b40, mob=0x5975476c6d20
node=0x597547577ed0, mob=0x5975476c6d90
node=0x5975476c5b30, mob=0x5975476c6e00
node=0x5975476c5ca0, mob=0x5975476c6e70
node=0x5975476c5e60, mob=0x5975476c6ee0
node=0x5975476c5fd0, mob=0x5975476c6f50
node=0x5975476c6140, mob=0x5975476c6fc0
node=0x5975476c62b0, mob=0x5975476c7030
nikhil-suri@codecrusader247:~/ns-allinone-3.42/ns-3.42$
```

b.

```
nikhil-suri@codecrusader247:~/ns-allinone-3.42/ns-3.42$ ./ns3 run "scratch/b2 --numClients=3"
[0/2] Re-checking globbed directories...
ninja: no work to do.
Client 0 completed at time 10.07 seconds
Client 1 completed at time 10.11 seconds
Client 2 completed at time 10.11 seconds
```

```
nikhil-suri@codecrusader247:~/ns-allinone-3.42/ns-3.42$ ./ns3 run "scratch/b2 --numClients=10"
[0/2] Re-checking globbed directories...
ninja: no work to do.
Client 9 completed at time 10.16 seconds
Client 2 completed at time 10.19 seconds
Client 5 completed at time 10.2 seconds
Client 1 completed at time 10.21 seconds
Client 6 completed at time 10.26 seconds
Client 7 completed at time 10.27 seconds
Client 4 completed at time 10.28 seconds
Client 0 completed at time 10.31 seconds
Client 8 completed at time 10.9 seconds
Client 3 completed at time 10.98 seconds
nikhil-suri@codecrusader247:~/ns-allinone-3.42/ns-3.42$
```

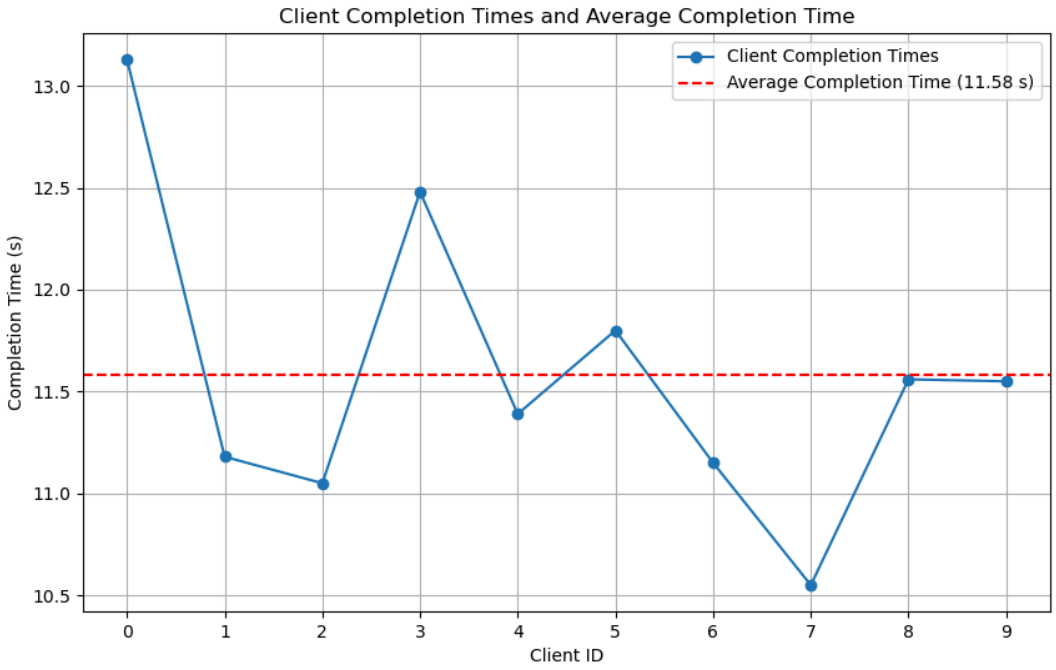
```
nikhil-suri@codecrusader247:~/ns-allinone-3.42/ns-3.42$ ./ns3 run "scratch/b2 --numClients=5"
[0/2] Re-checking globbed directories...
ninja: no work to do.
Client 0 completed at time 10.05 seconds
Client 1 completed at time 10.14 seconds
Client 4 completed at time 10.14 seconds
Client 3 completed at time 10.15 seconds
Client 2 completed at time 10.17 seconds
```



c.

Final Outputs:

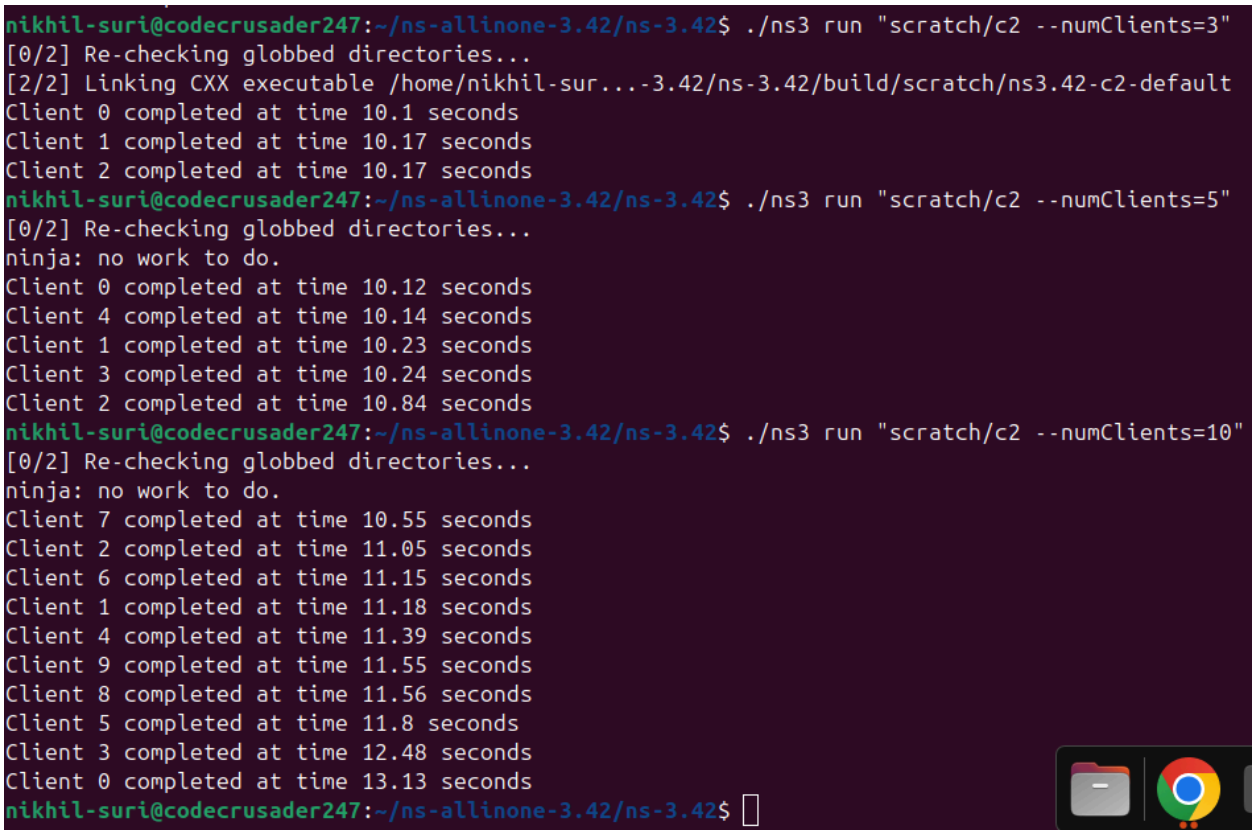
```
nikhil-suri@codecrusader247:~/ns-allinone-3.42/ns-3.42$ ./ns3 run "scratch/c2 --numClients=10"
[0/2] Re-checking globbed directories...
[2/2] Linking CXX executable /home/nikhil-suri/ns-allinone-3.42/ns-3.42/build/scratch/ns3.42-c2-default
Client 7 completed at time 10.7 seconds
Client 5 completed at time 10.73 seconds
Client 2 completed at time 10.75 seconds
Client 4 completed at time 10.82 seconds
Client 8 completed at time 11.13 seconds
Client 9 completed at time 11.4 seconds
Client 0 completed at time 12.08 seconds
Client 1 completed at time 12.36 seconds
Client 6 completed at time 12.52 seconds
Client 3 completed at time 12.78 seconds
nikhil-suri@codecrusader247:~/ns-allinone-3.42/ns-3.42$ ./ns3 run "scratch/c2 --numClients=5"
[0/2] Re-checking globbed directories...
ninja: no work to do.
Client 3 completed at time 10.14 seconds
Client 1 completed at time 10.15 seconds
Client 2 completed at time 10.2 seconds
Client 4 completed at time 10.23 seconds
Client 0 completed at time 11.13 seconds
nikhil-suri@codecrusader247:~/ns-allinone-3.42/ns-3.42$ ./ns3 run "scratch/c2 --numClients=3"
[0/2] Re-checking globbed directories...
ninja: no work to do.
Client 0 completed at time 10.14 seconds
Client 1 completed at time 10.15 seconds
Client 2 completed at time 11.09 seconds
nikhil-suri@codecrusader247:~/ns-allinone-3.42/ns-3.42$
```



Earlier Output1:

```
nikhil-suri@codecrusader247:~/ns-allinone-3.42/ns-3.42$ ./ns3 run "scratch/c2 --numClients=3"
[0/2] Re-checking globbed directories...
ninja: no work to do.
Client 1 completed at time 10.12 seconds
Client 0 completed at time 10.14 seconds
Client 2 completed at time 10.15 seconds
nikhil-suri@codecrusader247:~/ns-allinone-3.42/ns-3.42$ ./ns3 run "scratch/c2 --numClients=5"
[0/2] Re-checking globbed directories...
ninja: no work to do.
Client 2 completed at time 10.12 seconds
Client 3 completed at time 10.14 seconds
Client 1 completed at time 10.16 seconds
Client 0 completed at time 10.21 seconds
Client 4 completed at time 10.28 seconds
nikhil-suri@codecrusader247:~/ns-allinone-3.42/ns-3.42$ ./ns3 run "scratch/c2 --numClients=10"
[0/2] Re-checking globbed directories...
ninja: no work to do.
Client 5 completed at time 10.59 seconds
Client 9 completed at time 10.74 seconds
Client 1 completed at time 10.78 seconds
Client 2 completed at time 10.83 seconds
Client 8 completed at time 11.23 seconds
Client 4 completed at time 11.31 seconds
Client 7 completed at time 11.31 seconds
Client 6 completed at time 11.42 seconds
Client 0 completed at time 11.79 seconds
Client 3 completed at time 12.72 seconds
nikhil-suri@codecrusader247:~/ns-allinone-3.42/ns-3.42$
```

Earlier Output2:



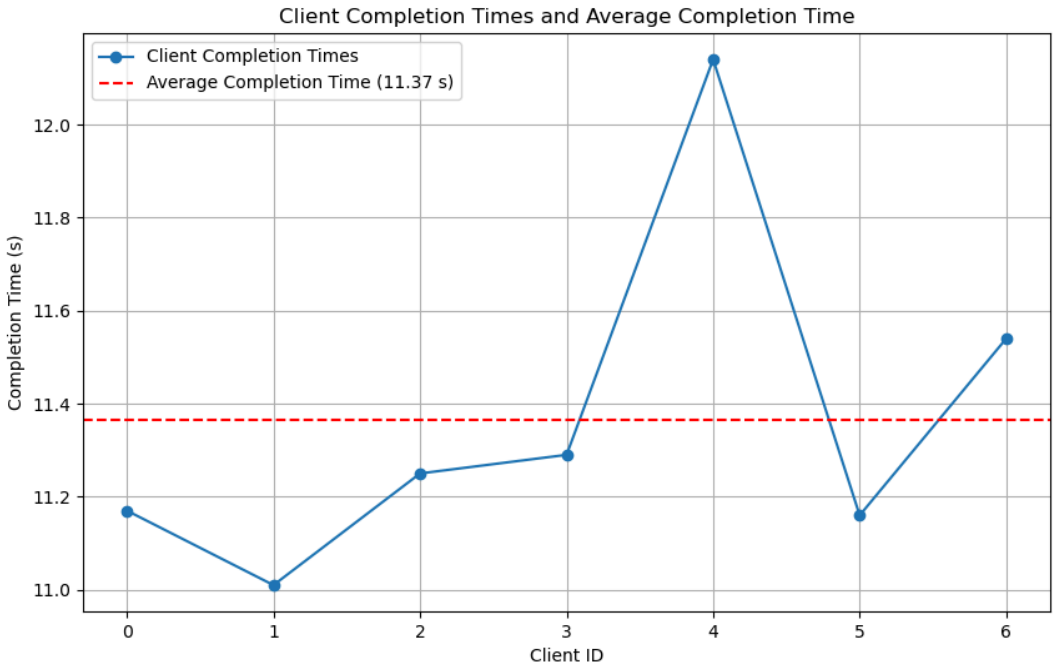
d.

```
nikhil-suri@codecrusader247:~/ns-allinone-3.42/ns-3.42$ ./ns3 run "scratch/d2 --numClients=3"
[0/2] Re-checking globbed directories...
ninja: no work to do.
Client 0 completed at time 10.31 seconds
Client 2 completed at time 10.42 seconds
Client 1 completed at time 11.34 seconds
nikhil-suri@codecrusader247:~/ns-allinone-3.42/ns-3.42$ ./ns3 run "scratch/d2 --numClients=5"
[0/2] Re-checking globbed directories...
ninja: no work to do.
Client 4 completed at time 10.57 seconds
Client 0 completed at time 10.59 seconds
Client 2 completed at time 10.61 seconds
Client 3 completed at time 10.69 seconds
Client 1 completed at time 11.59 seconds
nikhil-suri@codecrusader247:~/ns-allinone-3.42/ns-3.42$ ./ns3 run "scratch/d2 --numClients=10"
[0/2] Re-checking globbed directories...
ninja: no work to do.
Client 1 completed at time 12.47 seconds
Client 0 completed at time 12.69 seconds
Client 6 completed at time 12.77 seconds
Client 7 completed at time 12.79 seconds
Client 5 completed at time 13.15 seconds
Client 8 completed at time 13.35 seconds
Client 4 completed at time 14.23 seconds
Client 2 completed at time 14.64 seconds
Client 9 completed at time 14.76 seconds
Client 3 completed at time 15.22 seconds
nikhil-suri@codecrusader247:~/ns-allinone-3.42/ns-3.42$
```

Again adding screenshots for part d with upload packet data size 10 bytes each – to simulate ideal upload data content that is primarily for syncing emails, Whatsapp, and other apps. Earlier the packet size was kept relatively large at 100 bytes during uploads – but to observe the impact and the potential overhead caused by RTS/CTS for sync purposes, we reduce the packet size to 10 bytes each.

d.

```
nikhil-suri@codecrusader247:~/ns-allinone-3.42/ns-3.42$ ./ns3 run "scratch/d2 --numClients=3"
[0/2] Re-checking globbed directories...
ninja: no work to do.
Client 1 completed at time 10.4 seconds
Client 0 completed at time 11.35 seconds
Client 2 completed at time 11.43 seconds
nikhil-suri@codecrusader247:~/ns-allinone-3.42/ns-3.42$ ./ns3 run "scratch/d2 --numClients=5"
[0/2] Re-checking globbed directories...
ninja: no work to do.
Client 2 completed at time 10.92 seconds
Client 4 completed at time 11 seconds
Client 0 completed at time 11.13 seconds
Client 3 completed at time 11.14 seconds
Client 1 completed at time 11.96 seconds
nikhil-suri@codecrusader247:~/ns-allinone-3.42/ns-3.42$ ./ns3 run "scratch/d2 --numClients=7"
[0/2] Re-checking globbed directories...
ninja: no work to do.
Client 1 completed at time 11.01 seconds
Client 5 completed at time 11.16 seconds
Client 0 completed at time 11.17 seconds
Client 2 completed at time 11.25 seconds
Client 3 completed at time 11.29 seconds
Client 6 completed at time 11.54 seconds
Client 4 completed at time 12.14 seconds
```



e.

```
nikhil-suri@codecrusader247:~/ns-allinone-3.42/ns-3.42$ ./ns3 run "scratch/e --numClients=3"
[0/2] Re-checking globbed directories...
[2/2] Linking CXX executable /home/nikhil-suri/ns-allinone-3.42/ns-3.42/build/scratch/ns3.42-e-defaul
Client 0 completed at time 10.5 seconds
Client 1 completed at time 11.18 seconds
Client 2 completed at time 11.2 seconds
nikhil-suri@codecrusader247:~/ns-allinone-3.42/ns-3.42$ ./ns3 run "scratch/e --numClients=5"
[0/2] Re-checking globbed directories...
ninja: no work to do.
Client 1 completed at time 10.8 seconds
Client 3 completed at time 10.81 seconds
Client 2 completed at time 11.11 seconds
Client 0 completed at time 11.57 seconds
Client 4 completed at time 12.83 seconds
nikhil-suri@codecrusader247:~/ns-allinone-3.42/ns-3.42$ ./ns3 run "scratch/e --numClients=7"
[0/2] Re-checking globbed directories...
ninja: no work to do.
Client 6 completed at time 11.48 seconds
Client 1 completed at time 11.66 seconds
Client 2 completed at time 11.69 seconds
Client 0 completed at time 11.83 seconds
Client 4 completed at time 12.27 seconds
Client 5 completed at time 12.4 seconds
Client 3 completed at time 13.06 seconds
nikhil-suri@codecrusader247:~/ns-allinone-3.42/ns-3.42$
```