CZ4052 Cloud Computing Assignment 1

1. Introduction

Additive Increase Multiplicative Decrease (AIMD)

AIMD is a feedback control algorithm which is used by TCP protocols in the transport layer of the TCP/IP stack. The AI phase is responsible for the linear growth of the sender's congestion window where there is no congestion detected. The MD phase is responsible for the exponential cut-down of the sender's congestion window when congestion is detected.

In this project, we aim to explore the tuning of parameters for AIMD and see the behaviours of the increase/decrease in congestion window size(CWND) over Round-Trip Time(RTT), in order to set the optimal AIMD parameters in a data centre environment.

2. Experiment

Do note that the initial CWND is constant among the experiment for no. of users = 2 and 20.

Experiment 1: Traditional AIMD Implementation(Linear Approach)

In this experiment, we demonstrated the basic AIMD implementation, a linear approach where the incremental function in additive increase phase is linear. This is served as our baseline in this assignment. We also investigated on how does each parameter affect the rate of speed of convergence over the time(RTT).

The following parameters have been used and the convergence time(RTT) is shown as below:

α	β	No. of users	Congestion Window Size(CWND)	Convergence RTT	Packet loss
1	0.5	2	100	161	6
1	0.5	2	500	961	6
1	0.5	20	500	68	4
1	0.5	20	1000	184	6

(Packet loss is counted by the no. of times of Multiplicative Decrease phase occurred before convergence)

The result graph can be seen in **Appendix I**.

Observation:

1. When the congestion window size increases, the required RTT is also increased, however with a trade-off of lower packet loss.
2. When total no. of users increases, the required RTT will decrease because more users is sharing the same congestion window, but it increased the rate of speed of having packet loss (No. of packet loss/RTT).

Experiment 2: AIMD with Logarithmic Increase

Next, we changed the linear incremental function to logarithmic incremental function with base 2 where,

$$x_n = x_n + \log_2(CWND)$$

which is a non-linear incremental function providing a more responsive adjustment to the congestion window size instead of linear function. The result of convergence RTT is shown as below:

Log Base	No. of Users	Congestion Window Size(CWND)	Convergence RTT	Packet loss
2	2	100	37	6
2	20	1000	47	7

The result graph can be seen in **Appendix II**.

Observation:

1. Changing incremental function to logarithmic function greatly reduced the no. of required RTT for the AIMD to converge.
2. The number of packet loss increases slightly compared to the baseline(experiment 1), possible reason is that the alpha value we used in experiment 1 is small and constant over the RTT, but in the logarithmic incremental function, the alpha value added is depends on the previous CWND size hence we will have a much more aggressive increase in CWND.

Experiment 3: AIMD with Exponential Increase

In this experiment, we changed the alpha value/function which is used in the additive increase phase from a constant addition to exponential incremental function which is,

$$x_n = x_n + (CWND)^{0.5}$$

to see the behavioural changes. The result of convergence RTT is shown as below:

No. of Users	Congestion Window Size(CWND)	Convergence RTT	Packet loss
2	100	45	8
20	1000	71	9

The result graph can be seen in **Appendix III**.

Observation:

1. It required lower RTT to converge but with a trade-off of increasing packet loss.
2. It has a moderate result compared to experiment 2 which used logarithmic incremental function.

Experiment 4: AIMD with User Priority

In this experiment, we differentiate user priorities by modifying the incremental function, where,

$$x_n = x_n + n$$

, to simulate who has a higher bandwidth using their index no.. For consistency, user 2 is the premium user tier and thus has a larger share of the network bandwidth, compared to user 1.

The result of convergence RTT is shown as below:

User 1 Initial CWND	User 2 Initial CWND	Congestion Window Size(CWND)	Convergence RTT	Packet loss
30	70	100	55	3
70	30	100	109	6

The result graph can be seen in **Appendix IV**.

Observation:

1. By having different incremental value for each users in additive phase, we are able to skew the bandwidth to certain users.
2. The initial CWND size is one of the important factors that will affect the RTT and the packet loss.

Alternatively, we can also implement user priority by modifying the decremental function, where user with higher priority get higher beta values.

The result of convergence RTT is shown as below:

User 1 Initial CWND	User 2 Initial CWND	Congestion Window Size(CWND)	Convergence RTT	Packet loss
30	70	100	81	3
70	30	100	174	6

The result graph can be seen in **Appendix IV**.

Summary of all Experiments:

1. A less aggressive incremental function helps to decrease packet loss before the TCP/user flows converged, but with a trade-off of increasing RTT.

2. The initial CWND is one of the important factors that will affect the convergence RTT, and the increase of RTT will result in the increase of packet loss.

3. When other parameters remain constant, the larger the congestion windows size, the larger the convergence RTT, but since it becomes less aggressive(due to the increase of the CWND) the packet loss will also decrease.

4. When other parameters remain constant, the larger the number of TCP/user flows, the larger the packet loss, but since it becomes more aggressive(due to the increase in number of TCP/user flows) the required RTT to converge decreased.

5. By having a dynamic incremental/decremental function, user priority can be implemented, which in real life situation, some premium users get to have higher bandwith.

6. Logarithmic Incremental function we implemented($\log_2 x$) has a better result than exponential Incremental function ($x^{0.5}$).

3. Remy: TCP ex Machina (computer-generated congestion control)

Remy is an optimization tool to develop new TCP congestion-control schemes, given prior knowledge about the network it will encounter and an objective to optimize for. By having these models as input, namely:

1. model that specifies the protocol's prior assumptions about the network (e.g. upper, lower limits on the bottleneck link speeds, non-queueing delays, queue sizes, and degrees of multiplexing),
2. a traffic model for the offered load given to endpoints,

Remy is able to design a congestion-control algorithm that tries to maximize the total expected value of the objective function, measured over the set of network and traffic models.

Discussion about the usage of AI/ChatGPT to engineer a TCP ex Machina

I think ideally, it is possible to use AI techniques and incorporate ChatGPT assistance to engineer a TCP ex Machina. We can first identify the requirements and challenges in our data center, which might include factors such as scalability, performance, congestion control, fault tolerance etc., and followed by gathering enough data from our data center environment for

training AI models. ChatGPT can be used to assist in our AI model selection, data analysis, troubleshooting and refinement of models, etc.

However, there are several factors that may be holding us back from doing so:

1. **Data Availability and Quality**:
   Data centers may not always capture all relevant TCP connection information, and the data available may be noisy or incomplete.

2. **Scalability**:
   Data centers typically handle a large number of concurrent TCP connections, and for TCP ex machina to scale to handle this load efficiently, we required to have both the computational resources for analysis and the ability to manage a large number of connections in real-time.

3. **Complexity of TCP**:
   TCP is a complex protocol with many parameters and behaviors that interact in non-trivial ways. Developing accurate models that capture the nuances of TCP behavior can be challenging.

So, in order to incorporate this idea into real life situation, we either need to have a very large server like ChatGPT that have enough computer resources for getting a scalable models that can handle different kinds of situations or we need to develop a much more efficient AI models that is able to solve this problem.

4. Conclusion

From the above experiments and discussion, we understand the trade-off between convergence RTT and the packet loss, and the importance of both incremental function and the initial CWND. Instead of linear approach, we introduced non-linearity to the incremental function in order to have a much more dynamic increase in congestion window size, however that is still not good enough. Hence, by the ideas from the TCP ex Machina, we can introduce the dynamic adjustment of congestion window growth rate based on the network conditions. By extracting data from the network daily, we can use them as the dataset for training a machine learning models which can adaptively change the additive increase factor according to the observed network parameters such as available bandwidth, latency, packet loss etc. which allows the algorithm to scale more efficiently across diverse network environment.
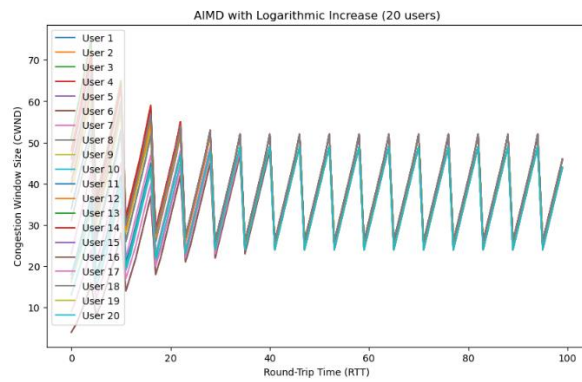
5. Appendix

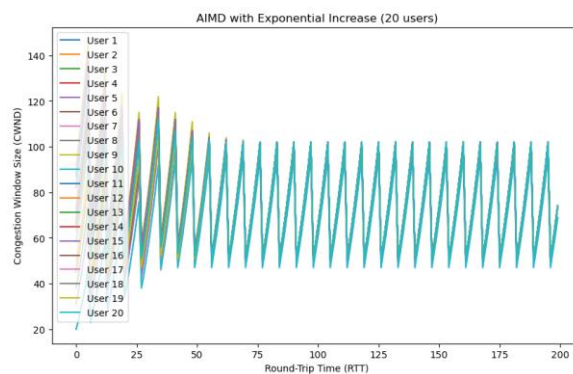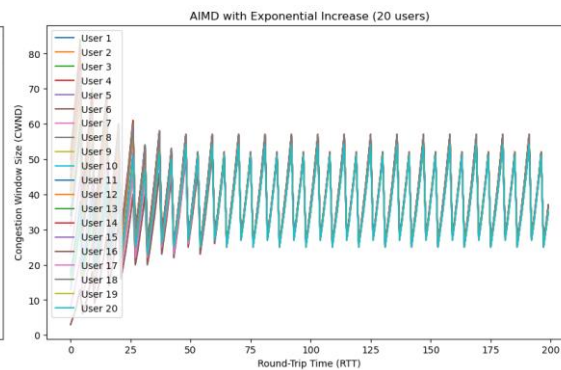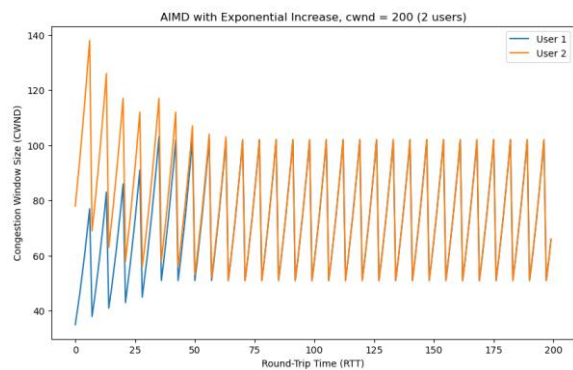## Appendix I: Result Graph of Experiment 1(Baseline)
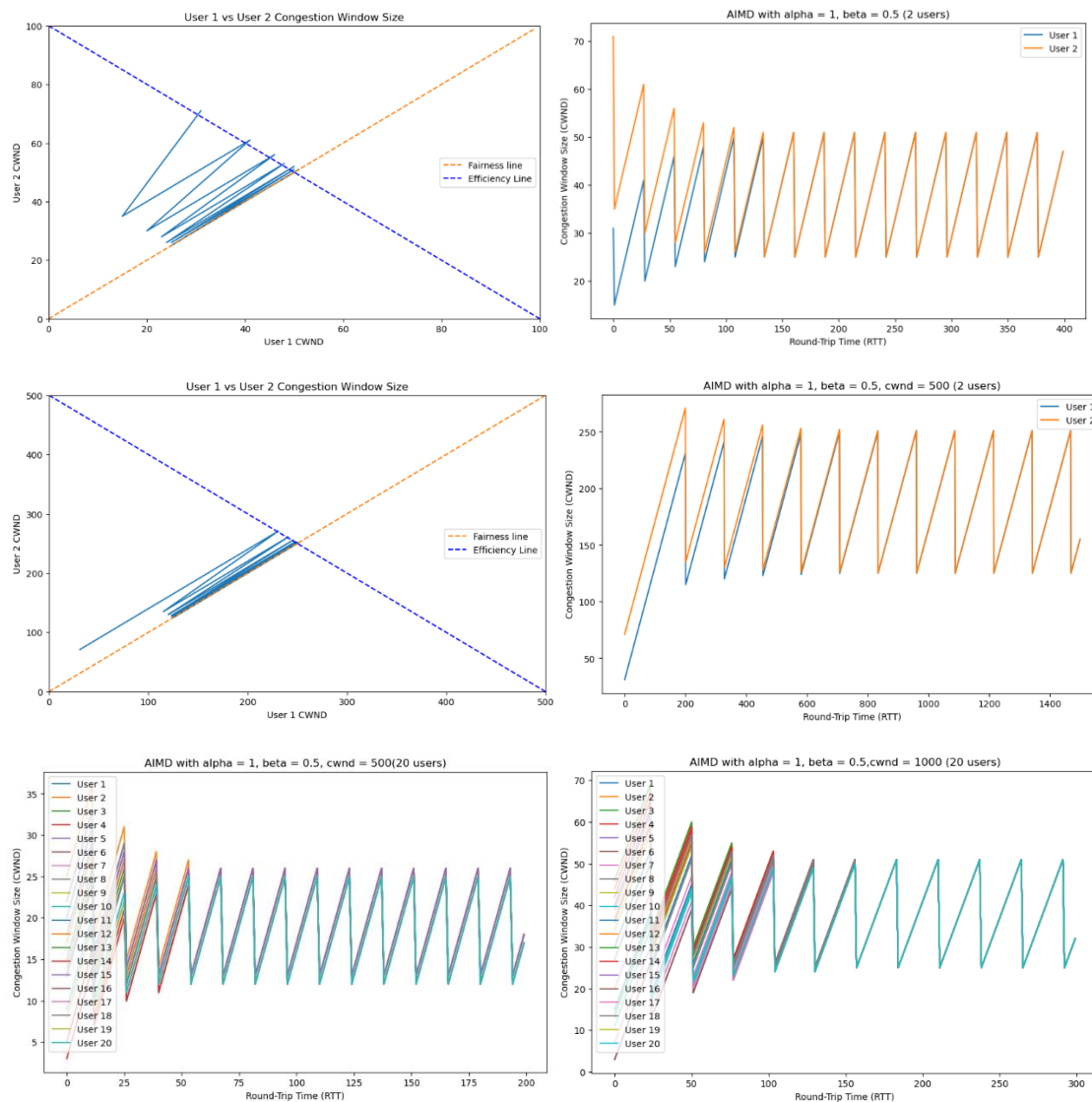
Appendix II: Result Graph of Experiment 2(Logarithmic Incremental)

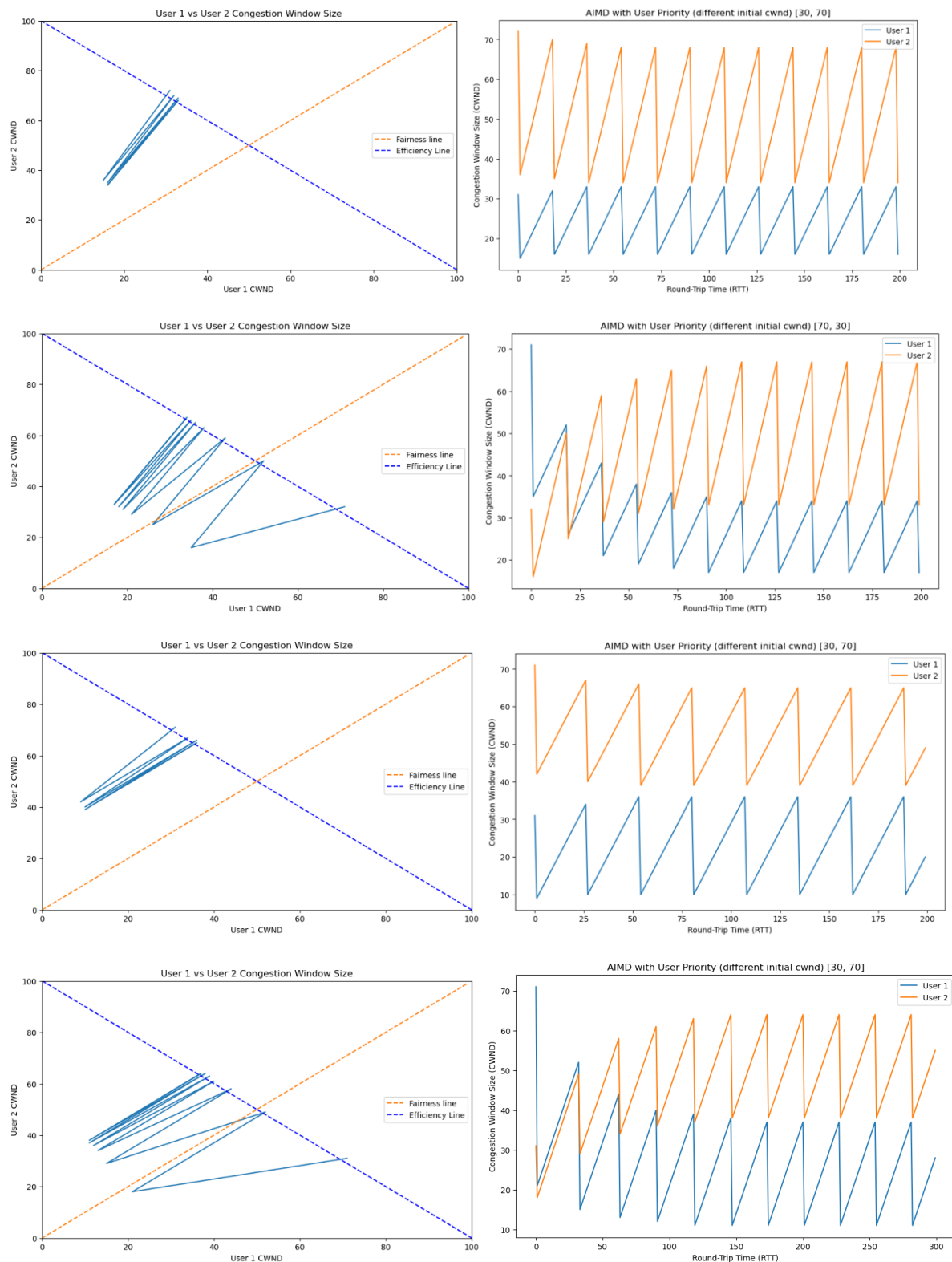AIMD with Logarithmic Increase (20 users)
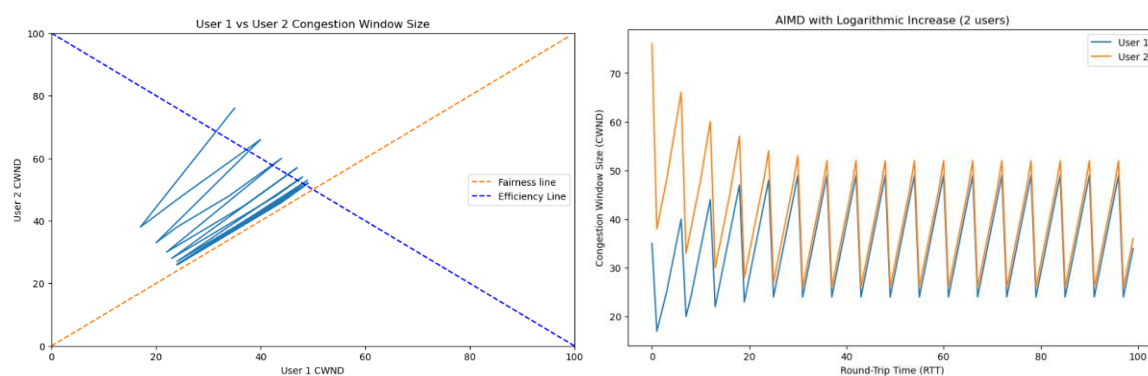
Appendix III: Result Graph of Experiment 3(Exponential Incremental)
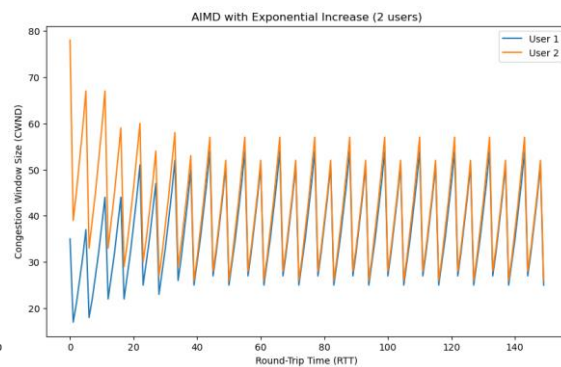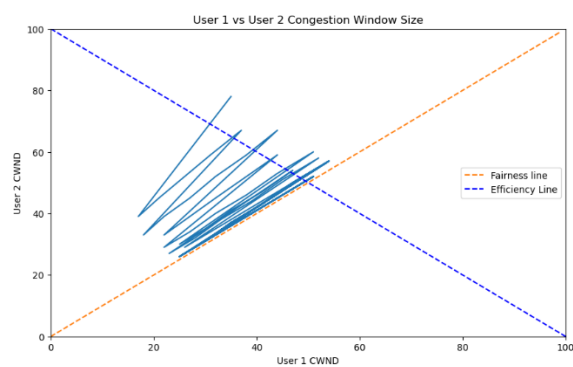
Appendix IV: Result Graph of Experiment 4(User Priority)

Appendix V: Jupyter Notebook of the Experiment

https://github.com/zijian99/CZ4052_CloudComputing_Assignment1

Appendix V: Jupyter Notebook of Experiments

CZ4052 Cloud Computing Assignment

Exploring TCP Algorithm AIMD(Additive Increase Multiplicative Decrease)

The additive-increase/multiplicative-decrease (AIMD) algorithm is a feedback control algorithm best known for its use in TCP congestion control. AIMD combines linear growth of the congestion window when there is no congestion with an exponential reduction when congestion is detected. Multiple flows using AIMD congestion control will eventually converge to an equal usage of a shared link.

The approach taken is to increase the transmission rate (window size), probing for usable bandwidth, until loss occurs. The policy of additive increase may, for instance, increase the congestion window by a fixed amount every round-trip time. When congestion is detected, the transmitter decreases the transmission rate by a multiplicative factor; for example, cut the congestion window in half after loss. The result is a saw-tooth behavior that represents the process of bandwidth probing.

AIMD requires a binary congestion signal. Most frequently, packet loss serves as the signal; the multiplicative decrease is triggered when a timeout or an acknowledgement message indicates a packet lost. It is also possible for in-network switches/routers to mark congestion (without discarding packets) as in Explicit Congestion Notification (ECN).

Import Library

```
In [1]:   import math
          import numpy as np
          import matplotlib.pyplot as plt
```

```
In [2]:   # To make sure repeated random initial cwnd array for every run
          np.random.seed(20)
```

Graph Plotting Functions

```
In [3]:   def visualize_fairness(x,y, max_cwnd_size):
              plt.figure(figsize=(10,6))
              # Set ranges for x and y axes
              plt.xlim(0, max_cwnd_size)
              plt.ylim(0, max_cwnd_size)
              plt.plot(x,y)
              plt.plot([i for i in range(0,max_cwnd_size)], [i for i in range(0,max_cwnd_size
              plt.plot([max_cwnd_size,0], [0,max_cwnd_size], color='blue',linestyle='--', lat
              plt.xlabel('User 1 CWND')
              plt.ylabel('User 2 CWND')
              plt.title("User 1 vs User 2 Congestion Window Size")
              plt.legend()
              plt.show()

          # Define a function to plot graph of RTT over congestion window size to visualize t
```

```
    """
        Plot graph of RTT over CWND


        Parameter:
        ==========
            num_users: The number of users
            cwnd_tracker: The array of users and its cwnd for each RTT
            plot_title: The title of the graph

        Return Value:
        =============
            The calculated cwnd size of current user
    """
    def plot_graph(num_users, cwnd_tracker, plot_title):

        plt.figure(figsize=(10, 6))
        for user in range(num_users):
            plt.plot(cwnd_tracker[user], label=f'User {user + 1}')

        plt.title(plot_title)
        plt.xlabel('Round-Trip Time (RTT)')
        plt.ylabel('Congestion Window Size (CWND)')

        plt.legend()
        plt.show()
```

Define function used for simulation of AIMD algorithm

In [4]:
```python
# Define the AIMD function that simulates the AIMD behavior for a single user.
"""
    Calculates the AIMD for current user


    Parameter:
    ==========
        user: The index of the current user (unused except for user priority functi
        alpha: Alpha function for current experiment
        beta: Beta function for current experiment
        cwnd: Current congestion window size.
        status: Status of current congestion window size (Transfer/Drop)

    Return Value:
    =============
        The calculated cwnd size of current user
"""
def AIMD(user, alpha, beta, cwnd, status):

    # Additive Increase Phase
    if status == "Transfer":
        cwnd += alpha(user, cwnd)
    # Multiplicative Decrease Phase
    elif status == "Drop":
        cwnd *= beta(user,cwnd)
        # Convert cwnd to integer to avoid fractional values for window sizes.
        cwnd = int(cwnd)
        # Ensure cwnd does not fall below 1 as there is always something to send by
        cwnd = max(1, cwnd)


    return cwnd


# Define the main simulation function.
```

```python
"""
    Simulation of AIMD process


    Parameter:
    ==========
        no_RTT: The total numbers of Round-Trip Time
        num_users: The total numbers of users
        alpha_func: Alpha function for current experiment
        beta_func: Beta function for current experiment
        initial_cwnd: The array of initial cwnd for all users
        max_cwnd_size: The threshold of congestion window size

    Return Value:
    =============
        The array of users and its cwnd for each RTT
"""
def simulate_aimd(no_RTT, num_users, alpha_func, beta_func, initial_cwnd, max_cwnd_

    # Initialize the total congestion window size.
    total_cwnd = 0

    # Initialize a tracker for all users flows for congestion window sizes over tim
    cwnd_tracker = np.zeros((num_users, no_RTT))


    for i, initial_cwnd_size in enumerate(initial_cwnd):
        cwnd_tracker[i, 0] = initial_cwnd_size


    for rtt in range(no_RTT):

        # Used for tracking total cwnd size for each Round-Trip Time
        cur = 0

        # Check if window size exceed the max window size
        if total_cwnd > max_cwnd_size:
            status = "Drop"
            print(f"\n")
            print('(Packet Loss)Multiplicative Decrease at:', rtt)
            cur_peak_cwnd = np.zeros(num_users)
        else:
            status = "Transfer"



        # Loop thru all users flows
        for user in range(num_users):

            if status =="Drop":
                cwnd = cwnd_tracker[user, rtt-1]
                print(f"Peak congestion window size for user {user}: {cwnd}")
            # Get cwnd values from prev RTT
            if rtt == 0:
                cwnd = cwnd_tracker[user, 0]
                print(f"Initial cwnd for user {user}: {cwnd}")
            else:
                cwnd = cwnd_tracker[user, rtt-1]

            # Perform AIMD
            cwnd = AIMD(user, alpha_func, beta_func, cwnd, status)

            # Update current window size for current user
            cwnd_tracker[user, rtt] = cwnd
```

```
            cur += cwnd  # Update total cwnd after each user's increase
        total_cwnd = cur
    if len(initial_cwnd)==2:
        visualize_fairness(cwnd_tracker[0],cwnd_tracker[1], max_cwnd_size)

    #print(cwnd_tracker)

    return cwnd_tracker
```

Define different alpha and beta functions for different experiments later

In [5]:
```
# Define Alpha Functions
"""
    Calculates the additive increase value for the congestion window


    Parameter:
    ==========
        user: The index of the current user (unused except for user priority functi
        cwnd: Current congestion window size.

    Return Value:
    =============
        The amount to increase the congestion window size, based on a logarithmic f
"""
# Define the alpha function for additive increase
def alpha_func(user, cwnd):

    # A constant additive increase for all users.
    return 1


# Alpha function with log increase for cwnd
def alpha_func_log(user, cwnd):

    BASE = 2 # Base 2 logarithms are taken so that the window size will always be >
    # Make sure cwnd is at least 1 to prevent log(0)
    cwnd = max(cwnd, 1)
    # As partial window sizes are not allowed, we take the rounded integer value of
    return round(math.log(1 + cwnd, BASE))


# Alpha function with exp increase for cwnd
def alpha_func_exp(user, cwnd):

    POWER = 0.5  # Sub-linear growth rate (power < 1)
    # Ensure cwnd is at least 1 to maintain a minimum growth rate
    cwnd = max(cwnd, 1)
    # Calculate the increase as cwnd^POWER and round it to the nearest integer
    increase = round(cwnd ** POWER)
    # Ensure at least a minimum increase of 1 to maintain AIMD properties
    return max(1, increase)


# Define the alpha function with user priority
def alpha_func_priority(user, cwnd):

    # Simulating different user priorities depends on the user index
    return 1 + user
```

```python
# Define the alpha function with log increase and exp increase based on user priori
def alpha_func_exp_log(user, cwnd):

    # Make sure cwnd is at least 1 to prevent log(0)
    cwnd = max(cwnd, 1)

    # Logarithmic increase for the zeroth user
    if user == 0:
        BASE = 2  # Base of the logarithm
        return max(1, round(math.log(cwnd, BASE)))
    # Exponential increase for the first user
    elif user == 1:
        POWER = 0.5  # Power for exponential growth, less than 1 for sub-linear gro
        return max(1, round(cwnd ** POWER))



# Define the beta function for multiplicative decrease
"""
    Calculates the multiplicative decrease value for the congestion window


    Parameter:
    ==========
        cwnd: The current congestion window size.

    Return Value:
    =============
        The factor by which the cwnd should be multiplied in the multiplicative dec
"""
def beta_func(user, cwnd):

    # A constant multiplicative decrease for all users.
    return 0.5

def beta_func_low(user, cwnd):

    # A constant multiplicative decrease for all users.
    return 0.3

def beta_func_high(user, cwnd):

    # A constant multiplicative decrease for all users.
    return 0.8
```

Experiment

1. Traditional AIMD
2. AIMD with Logarithmic Incremental function
3. AIMD with Exponential Incremental function
4. AIMD with User Priority
5. AIMD with User Priority Using Logarithmic and Exponential Incremental function

Define initial cwnd for 20 users to make it constant among all experiments

```python
In [6]:  # Define the initial cwnd size for users.
         max_cwnd = 1000
         num_users = 20
         initial_cwnd_b = np.random.rand(20)
```

```
initial_cwnd_b *= max_cwnd // num_users
initial_cwnd_b = np.round(initial_cwnd_b)
```

Experiment 1: AIMD with alpha = 1, beta = 0.5

This is the baseline of our AIMD algorithm

Experiment with 2 users

In [7]:
```
# Experiment Variables
num_users = 2
max_RTT = 400
max_cwnd = 100
# Define the initial cwnd size for users.
initial_cwnd = [30, 70]


# Simulation of AIMD
cwnd_tracker = simulate_aimd(max_RTT, num_users, alpha_func, beta_func, initial_cwr

# Plot graph of RTT over CWND
plot_title = "AIMD with alpha = 1, beta = 0.5 (2 users)"
plot_graph(num_users, cwnd_tracker, plot_title)
```

Experiment 1: AIMD with alpha = 1, beta = 0.5

```
Initial cwnd for user 0: 30.0
Initial cwnd for user 1: 70.0


(Packet Loss)Multiplicative Decrease at: 1
Peak congestion window size for user 0: 31.0
Peak congestion window size for user 1: 71.0


(Packet Loss)Multiplicative Decrease at: 28
Peak congestion window size for user 0: 41.0
Peak congestion window size for user 1: 61.0


(Packet Loss)Multiplicative Decrease at: 55
Peak congestion window size for user 0: 46.0
Peak congestion window size for user 1: 56.0


(Packet Loss)Multiplicative Decrease at: 81
Peak congestion window size for user 0: 48.0
Peak congestion window size for user 1: 53.0


(Packet Loss)Multiplicative Decrease at: 108
Peak congestion window size for user 0: 50.0
Peak congestion window size for user 1: 52.0


(Packet Loss)Multiplicative Decrease at: 134
Peak congestion window size for user 0: 50.0
Peak congestion window size for user 1: 51.0


(Packet Loss)Multiplicative Decrease at: 161
Peak congestion window size for user 0: 51.0
Peak congestion window size for user 1: 51.0


(Packet Loss)Multiplicative Decrease at: 188
Peak congestion window size for user 0: 51.0
Peak congestion window size for user 1: 51.0


(Packet Loss)Multiplicative Decrease at: 215
Peak congestion window size for user 0: 51.0
Peak congestion window size for user 1: 51.0


(Packet Loss)Multiplicative Decrease at: 242
Peak congestion window size for user 0: 51.0
Peak congestion window size for user 1: 51.0


(Packet Loss)Multiplicative Decrease at: 269
Peak congestion window size for user 0: 51.0
Peak congestion window size for user 1: 51.0


(Packet Loss)Multiplicative Decrease at: 296
Peak congestion window size for user 0: 51.0
Peak congestion window size for user 1: 51.0
```
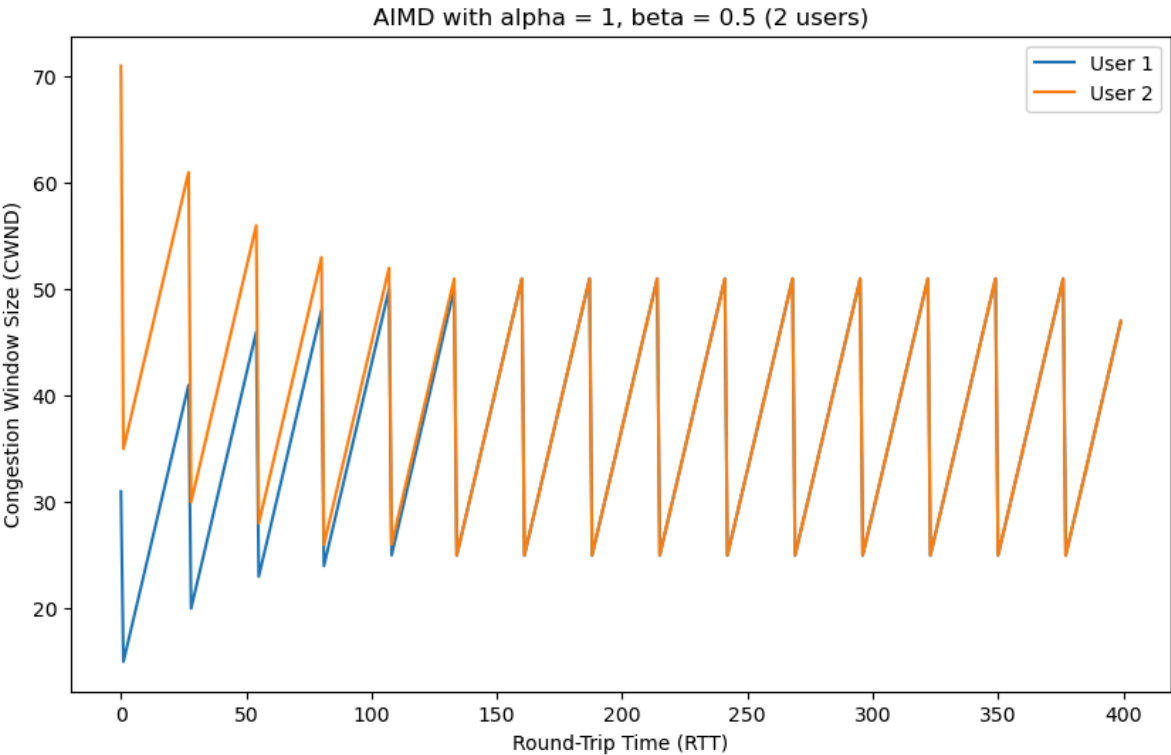
```
(Packet Loss)Multiplicative Decrease at: 323
Peak congestion window size for user 0: 51.0
Peak congestion window size for user 1: 51.0


(Packet Loss)Multiplicative Decrease at: 350
Peak congestion window size for user 0: 51.0
Peak congestion window size for user 1: 51.0


(Packet Loss)Multiplicative Decrease at: 377
Peak congestion window size for user 0: 51.0
Peak congestion window size for user 1: 51.0
```
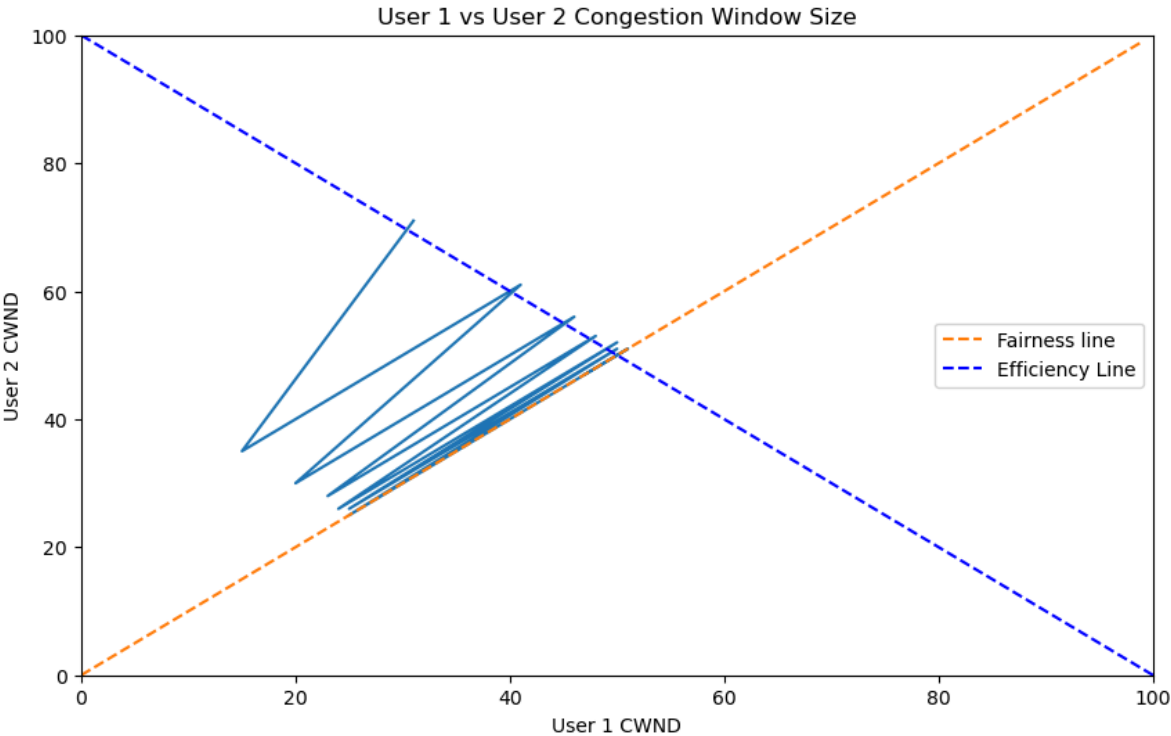
User 1 vs User 2 Congestion Window Size

AIMD with alpha = 1, beta = 0.5 (2 users)

Observation:

Converged at around RTT 161, packet loss count 6

Experiment with 2 users (cwnd = 500)

In [8]:

```python
# Experiment Variables
num_users = 2
max_RTT = 1500
max_cwnd = 500
# Define the initial cwnd size for users.
initial_cwnd = [30, 70]


# Simulation of AIMD
cwnd_tracker = simulate_aimd(max_RTT, num_users, alpha_func, beta_func, initial_cwn

# Plot graph of RTT over CWND
plot_title = "AIMD with alpha = 1, beta = 0.5, cwnd = 500 (2 users)"
plot_graph(num_users, cwnd_tracker, plot_title)
```

```
Initial cwnd for user 0: 30.0
Initial cwnd for user 1: 70.0


(Packet Loss)Multiplicative Decrease at: 201
Peak congestion window size for user 0: 231.0
Peak congestion window size for user 1: 271.0


(Packet Loss)Multiplicative Decrease at: 328
Peak congestion window size for user 0: 241.0
Peak congestion window size for user 1: 261.0


(Packet Loss)Multiplicative Decrease at: 455
Peak congestion window size for user 0: 246.0
Peak congestion window size for user 1: 256.0


(Packet Loss)Multiplicative Decrease at: 581
Peak congestion window size for user 0: 248.0
Peak congestion window size for user 1: 253.0


(Packet Loss)Multiplicative Decrease at: 708
Peak congestion window size for user 0: 250.0
Peak congestion window size for user 1: 252.0


(Packet Loss)Multiplicative Decrease at: 834
Peak congestion window size for user 0: 250.0
Peak congestion window size for user 1: 251.0


(Packet Loss)Multiplicative Decrease at: 961
Peak congestion window size for user 0: 251.0
Peak congestion window size for user 1: 251.0


(Packet Loss)Multiplicative Decrease at: 1088
Peak congestion window size for user 0: 251.0
Peak congestion window size for user 1: 251.0


(Packet Loss)Multiplicative Decrease at: 1215
Peak congestion window size for user 0: 251.0
Peak congestion window size for user 1: 251.0


(Packet Loss)Multiplicative Decrease at: 1342
Peak congestion window size for user 0: 251.0
Peak congestion window size for user 1: 251.0


(Packet Loss)Multiplicative Decrease at: 1469
Peak congestion window size for user 0: 251.0
Peak congestion window size for user 1: 251.0
```
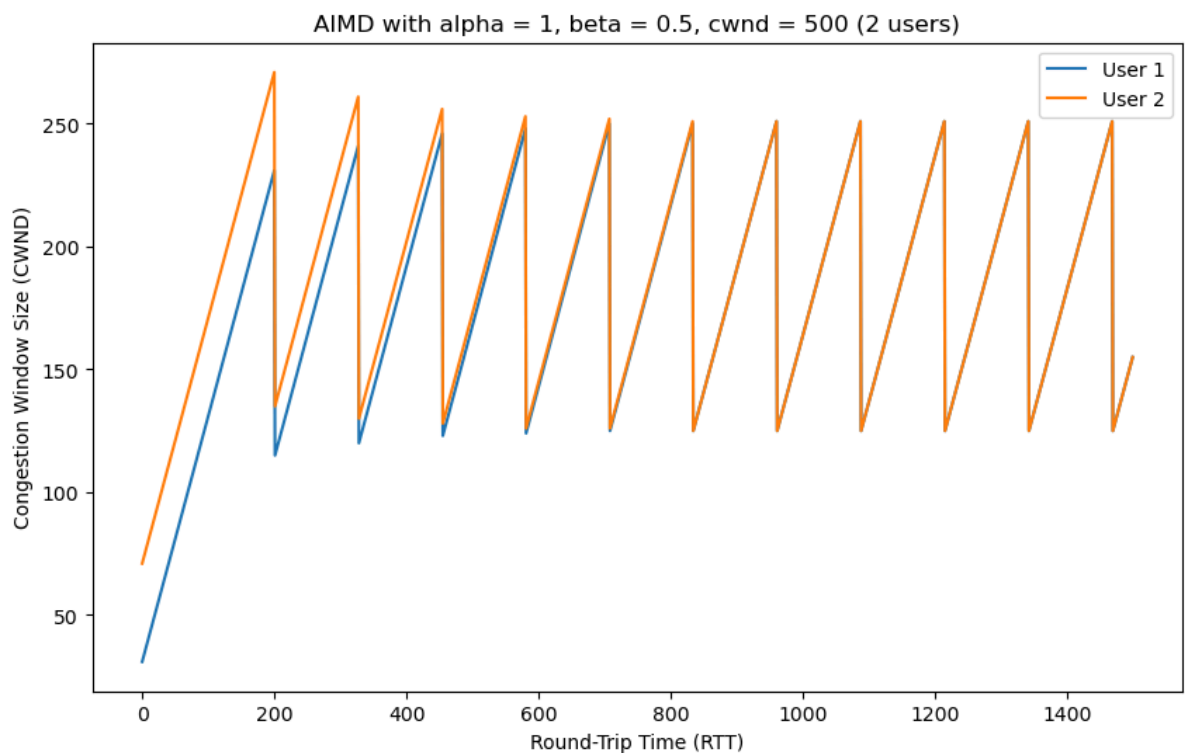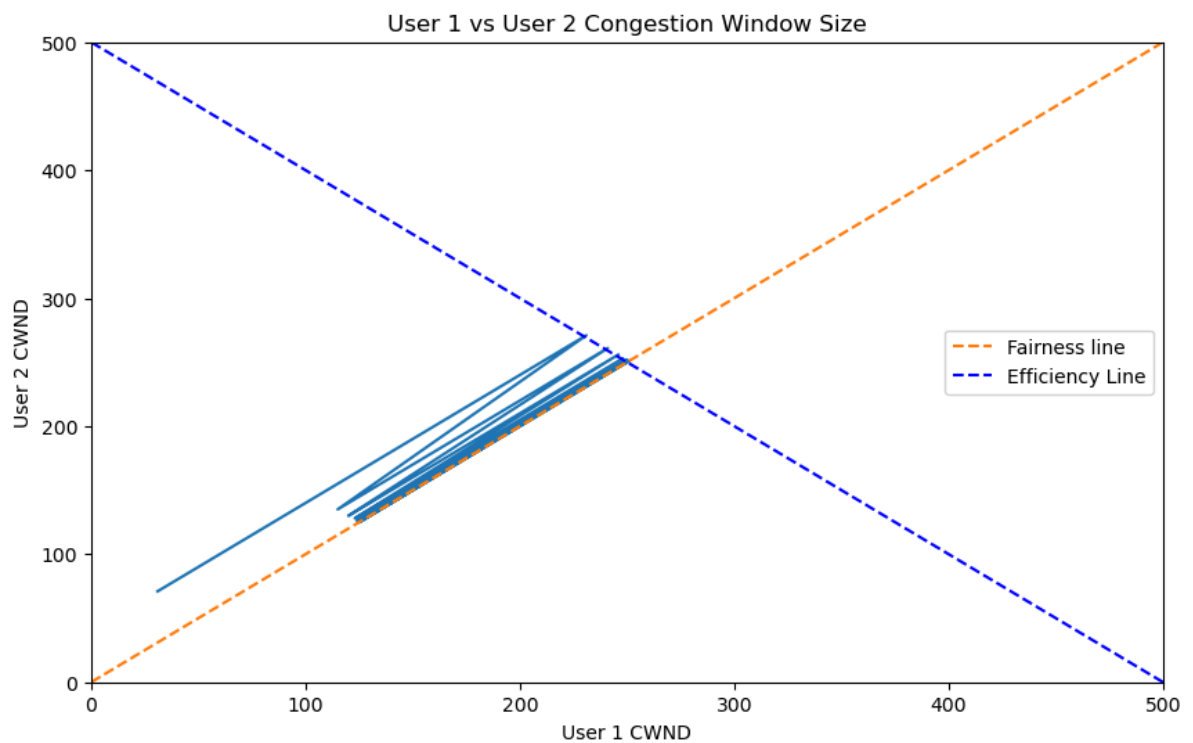
User 1 vs User 2 Congestion Window Size

AIMD with alpha = 1, beta = 0.5, cwnd = 500 (2 users)

Observation:

Converged at 961,Packet loss count 6

Experiment with 20 users (cwnd = 500)

```
In [ ]:

In [9]:  # Experiment Variables
         num_users = 20
         max_RTT = 200
         max_cwnd = 500
         # Define the initial cwnd size for users.
         initial_cwnd = np.random.rand(20)
```

```python
initial_cwnd *= max_cwnd // num_users
initial_cwnd = np.round(initial_cwnd)

# Simulation of AIMD
cwnd_tracker = simulate_aimd(max_RTT, num_users, alpha_func, beta_func,initial_cwnd

# Plot graph of RTT over CWND
plot_title = "AIMD with alpha = 1, beta = 0.5, cwnd = 500(20 users)"
plot_graph(num_users, cwnd_tracker, plot_title)
```

```python
initial_cwnd *= max_cwnd // num_users
initial_cwnd = np.round(initial_cwnd)

# Simulation of AIMD
cwnd_tracker = simulate_aimd(max_RTT, num_users, alpha_func, beta_func,initial_cwnd
```

```
Initial cwnd for user 0: 21.0
Initial cwnd for user 1: 24.0
Initial cwnd for user 2: 14.0
Initial cwnd for user 3: 4.0
Initial cwnd for user 4: 19.0
Initial cwnd for user 5: 12.0
Initial cwnd for user 6: 16.0
Initial cwnd for user 7: 21.0
Initial cwnd for user 8: 12.0
Initial cwnd for user 9: 12.0
Initial cwnd for user 10: 17.0
Initial cwnd for user 11: 16.0
Initial cwnd for user 12: 7.0
Initial cwnd for user 13: 2.0
Initial cwnd for user 14: 19.0
Initial cwnd for user 15: 12.0
Initial cwnd for user 16: 8.0
Initial cwnd for user 17: 13.0
Initial cwnd for user 18: 7.0
Initial cwnd for user 19: 8.0


(Packet Loss)Multiplicative Decrease at: 12
Peak congestion window size for user 0: 33.0
Peak congestion window size for user 1: 36.0
Peak congestion window size for user 2: 26.0
Peak congestion window size for user 3: 16.0
Peak congestion window size for user 4: 31.0
Peak congestion window size for user 5: 24.0
Peak congestion window size for user 6: 28.0
Peak congestion window size for user 7: 33.0
Peak congestion window size for user 8: 24.0
Peak congestion window size for user 9: 24.0
Peak congestion window size for user 10: 29.0
Peak congestion window size for user 11: 28.0
Peak congestion window size for user 12: 19.0
Peak congestion window size for user 13: 14.0
Peak congestion window size for user 14: 31.0
Peak congestion window size for user 15: 24.0
Peak congestion window size for user 16: 20.0
Peak congestion window size for user 17: 25.0
Peak congestion window size for user 18: 19.0
Peak congestion window size for user 19: 20.0


(Packet Loss)Multiplicative Decrease at: 26
Peak congestion window size for user 0: 29.0
Peak congestion window size for user 1: 31.0
Peak congestion window size for user 2: 26.0
Peak congestion window size for user 3: 21.0
Peak congestion window size for user 4: 28.0
Peak congestion window size for user 5: 25.0
Peak congestion window size for user 6: 27.0
Peak congestion window size for user 7: 29.0
Peak congestion window size for user 8: 25.0
Peak congestion window size for user 9: 25.0
Peak congestion window size for user 10: 27.0
Peak congestion window size for user 11: 27.0
Peak congestion window size for user 12: 22.0
Peak congestion window size for user 13: 20.0
Peak congestion window size for user 14: 28.0
Peak congestion window size for user 15: 25.0
Peak congestion window size for user 16: 23.0
Peak congestion window size for user 17: 25.0
```

```
Peak congestion window size for user 18: 22.0
Peak congestion window size for user 19: 23.0


(Packet Loss)Multiplicative Decrease at: 40
Peak congestion window size for user 0: 27.0
Peak congestion window size for user 1: 28.0
Peak congestion window size for user 2: 26.0
Peak congestion window size for user 3: 23.0
Peak congestion window size for user 4: 27.0
Peak congestion window size for user 5: 25.0
Peak congestion window size for user 6: 26.0
Peak congestion window size for user 7: 27.0
Peak congestion window size for user 8: 25.0
Peak congestion window size for user 9: 25.0
Peak congestion window size for user 10: 26.0
Peak congestion window size for user 11: 26.0
Peak congestion window size for user 12: 24.0
Peak congestion window size for user 13: 23.0
Peak congestion window size for user 14: 27.0
Peak congestion window size for user 15: 25.0
Peak congestion window size for user 16: 24.0
Peak congestion window size for user 17: 25.0
Peak congestion window size for user 18: 24.0
Peak congestion window size for user 19: 24.0


(Packet Loss)Multiplicative Decrease at: 54
Peak congestion window size for user 0: 26.0
Peak congestion window size for user 1: 27.0
Peak congestion window size for user 2: 26.0
Peak congestion window size for user 3: 24.0
Peak congestion window size for user 4: 26.0
Peak congestion window size for user 5: 25.0
Peak congestion window size for user 6: 26.0
Peak congestion window size for user 7: 26.0
Peak congestion window size for user 8: 25.0
Peak congestion window size for user 9: 25.0
Peak congestion window size for user 10: 26.0
Peak congestion window size for user 11: 26.0
Peak congestion window size for user 12: 25.0
Peak congestion window size for user 13: 24.0
Peak congestion window size for user 14: 26.0
Peak congestion window size for user 15: 25.0
Peak congestion window size for user 16: 25.0
Peak congestion window size for user 17: 25.0
Peak congestion window size for user 18: 25.0
Peak congestion window size for user 19: 25.0


(Packet Loss)Multiplicative Decrease at: 68
Peak congestion window size for user 0: 26.0
Peak congestion window size for user 1: 26.0
Peak congestion window size for user 2: 26.0
Peak congestion window size for user 3: 25.0
Peak congestion window size for user 4: 26.0
Peak congestion window size for user 5: 25.0
Peak congestion window size for user 6: 26.0
Peak congestion window size for user 7: 26.0
Peak congestion window size for user 8: 25.0
Peak congestion window size for user 9: 25.0
Peak congestion window size for user 10: 26.0
Peak congestion window size for user 11: 26.0
Peak congestion window size for user 12: 25.0
```

```
Peak congestion window size for user 13: 25.0
Peak congestion window size for user 14: 26.0
Peak congestion window size for user 15: 25.0
Peak congestion window size for user 16: 25.0
Peak congestion window size for user 17: 25.0
Peak congestion window size for user 18: 25.0
Peak congestion window size for user 19: 25.0


(Packet Loss)Multiplicative Decrease at: 82
Peak congestion window size for user 0: 26.0
Peak congestion window size for user 1: 26.0
Peak congestion window size for user 2: 26.0
Peak congestion window size for user 3: 25.0
Peak congestion window size for user 4: 26.0
Peak congestion window size for user 5: 25.0
Peak congestion window size for user 6: 26.0
Peak congestion window size for user 7: 26.0
Peak congestion window size for user 8: 25.0
Peak congestion window size for user 9: 25.0
Peak congestion window size for user 10: 26.0
Peak congestion window size for user 11: 26.0
Peak congestion window size for user 12: 25.0
Peak congestion window size for user 13: 25.0
Peak congestion window size for user 14: 26.0
Peak congestion window size for user 15: 25.0
Peak congestion window size for user 16: 25.0
Peak congestion window size for user 17: 25.0
Peak congestion window size for user 18: 25.0
Peak congestion window size for user 19: 25.0


(Packet Loss)Multiplicative Decrease at: 96
Peak congestion window size for user 0: 26.0
Peak congestion window size for user 1: 26.0
Peak congestion window size for user 2: 26.0
Peak congestion window size for user 3: 25.0
Peak congestion window size for user 4: 26.0
Peak congestion window size for user 5: 25.0
Peak congestion window size for user 6: 26.0
Peak congestion window size for user 7: 26.0
Peak congestion window size for user 8: 25.0
Peak congestion window size for user 9: 25.0
Peak congestion window size for user 10: 26.0
Peak congestion window size for user 11: 26.0
Peak congestion window size for user 12: 25.0
Peak congestion window size for user 13: 25.0
Peak congestion window size for user 14: 26.0
Peak congestion window size for user 15: 25.0
Peak congestion window size for user 16: 25.0
Peak congestion window size for user 17: 25.0
Peak congestion window size for user 18: 25.0
Peak congestion window size for user 19: 25.0


(Packet Loss)Multiplicative Decrease at: 110
Peak congestion window size for user 0: 26.0
Peak congestion window size for user 1: 26.0
Peak congestion window size for user 2: 26.0
Peak congestion window size for user 3: 25.0
Peak congestion window size for user 4: 26.0
Peak congestion window size for user 5: 25.0
Peak congestion window size for user 6: 26.0
Peak congestion window size for user 7: 26.0
```

```
Peak congestion window size for user 8: 25.0
Peak congestion window size for user 9: 25.0
Peak congestion window size for user 10: 26.0
Peak congestion window size for user 11: 26.0
Peak congestion window size for user 12: 25.0
Peak congestion window size for user 13: 25.0
Peak congestion window size for user 14: 26.0
Peak congestion window size for user 15: 25.0
Peak congestion window size for user 16: 25.0
Peak congestion window size for user 17: 25.0
Peak congestion window size for user 18: 25.0
Peak congestion window size for user 19: 25.0


(Packet Loss)Multiplicative Decrease at: 124
Peak congestion window size for user 0: 26.0
Peak congestion window size for user 1: 26.0
Peak congestion window size for user 2: 26.0
Peak congestion window size for user 3: 25.0
Peak congestion window size for user 4: 26.0
Peak congestion window size for user 5: 25.0
Peak congestion window size for user 6: 26.0
Peak congestion window size for user 7: 26.0
Peak congestion window size for user 8: 25.0
Peak congestion window size for user 9: 25.0
Peak congestion window size for user 10: 26.0
Peak congestion window size for user 11: 26.0
Peak congestion window size for user 12: 25.0
Peak congestion window size for user 13: 25.0
Peak congestion window size for user 14: 26.0
Peak congestion window size for user 15: 25.0
Peak congestion window size for user 16: 25.0
Peak congestion window size for user 17: 25.0
Peak congestion window size for user 18: 25.0
Peak congestion window size for user 19: 25.0


(Packet Loss)Multiplicative Decrease at: 138
Peak congestion window size for user 0: 26.0
Peak congestion window size for user 1: 26.0
Peak congestion window size for user 2: 26.0
Peak congestion window size for user 3: 25.0
Peak congestion window size for user 4: 26.0
Peak congestion window size for user 5: 25.0
Peak congestion window size for user 6: 26.0
Peak congestion window size for user 7: 26.0
Peak congestion window size for user 8: 25.0
Peak congestion window size for user 9: 25.0
Peak congestion window size for user 10: 26.0
Peak congestion window size for user 11: 26.0
Peak congestion window size for user 12: 25.0
Peak congestion window size for user 13: 25.0
Peak congestion window size for user 14: 26.0
Peak congestion window size for user 15: 25.0
Peak congestion window size for user 16: 25.0
Peak congestion window size for user 17: 25.0
Peak congestion window size for user 18: 25.0
Peak congestion window size for user 19: 25.0


(Packet Loss)Multiplicative Decrease at: 152
Peak congestion window size for user 0: 26.0
Peak congestion window size for user 1: 26.0
Peak congestion window size for user 2: 26.0
```

```
Peak congestion window size for user 3: 25.0
Peak congestion window size for user 4: 26.0
Peak congestion window size for user 5: 25.0
Peak congestion window size for user 6: 26.0
Peak congestion window size for user 7: 26.0
Peak congestion window size for user 8: 25.0
Peak congestion window size for user 9: 25.0
Peak congestion window size for user 10: 26.0
Peak congestion window size for user 11: 26.0
Peak congestion window size for user 12: 25.0
Peak congestion window size for user 13: 25.0
Peak congestion window size for user 14: 26.0
Peak congestion window size for user 15: 25.0
Peak congestion window size for user 16: 25.0
Peak congestion window size for user 17: 25.0
Peak congestion window size for user 18: 25.0
Peak congestion window size for user 19: 25.0


(Packet Loss)Multiplicative Decrease at: 166
Peak congestion window size for user 0: 26.0
Peak congestion window size for user 1: 26.0
Peak congestion window size for user 2: 26.0
Peak congestion window size for user 3: 25.0
Peak congestion window size for user 4: 26.0
Peak congestion window size for user 5: 25.0
Peak congestion window size for user 6: 26.0
Peak congestion window size for user 7: 26.0
Peak congestion window size for user 8: 25.0
Peak congestion window size for user 9: 25.0
Peak congestion window size for user 10: 26.0
Peak congestion window size for user 11: 26.0
Peak congestion window size for user 12: 25.0
Peak congestion window size for user 13: 25.0
Peak congestion window size for user 14: 26.0
Peak congestion window size for user 15: 25.0
Peak congestion window size for user 16: 25.0
Peak congestion window size for user 17: 25.0
Peak congestion window size for user 18: 25.0
Peak congestion window size for user 19: 25.0


(Packet Loss)Multiplicative Decrease at: 180
Peak congestion window size for user 0: 26.0
Peak congestion window size for user 1: 26.0
Peak congestion window size for user 2: 26.0
Peak congestion window size for user 3: 25.0
Peak congestion window size for user 4: 26.0
Peak congestion window size for user 5: 25.0
Peak congestion window size for user 6: 26.0
Peak congestion window size for user 7: 26.0
Peak congestion window size for user 8: 25.0
Peak congestion window size for user 9: 25.0
Peak congestion window size for user 10: 26.0
Peak congestion window size for user 11: 26.0
Peak congestion window size for user 12: 25.0
Peak congestion window size for user 13: 25.0
Peak congestion window size for user 14: 26.0
Peak congestion window size for user 15: 25.0
Peak congestion window size for user 16: 25.0
Peak congestion window size for user 17: 25.0
Peak congestion window size for user 18: 25.0
Peak congestion window size for user 19: 25.0
```
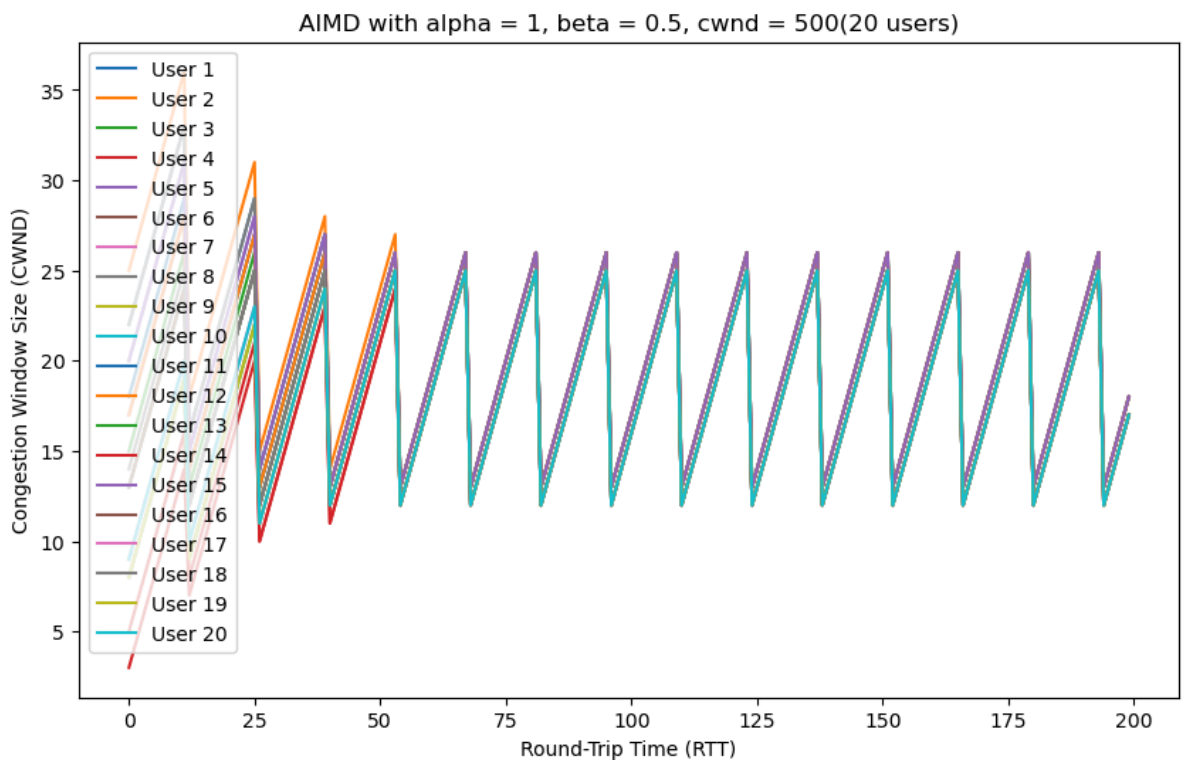
```
(Packet Loss)Multiplicative Decrease at: 194
Peak congestion window size for user 0: 26.0
Peak congestion window size for user 1: 26.0
Peak congestion window size for user 2: 26.0
Peak congestion window size for user 3: 25.0
Peak congestion window size for user 4: 26.0
Peak congestion window size for user 5: 25.0
Peak congestion window size for user 6: 26.0
Peak congestion window size for user 7: 26.0
Peak congestion window size for user 8: 25.0
Peak congestion window size for user 9: 25.0
Peak congestion window size for user 10: 26.0
Peak congestion window size for user 11: 26.0
Peak congestion window size for user 12: 25.0
Peak congestion window size for user 13: 25.0
Peak congestion window size for user 14: 26.0
Peak congestion window size for user 15: 25.0
Peak congestion window size for user 16: 25.0
Peak congestion window size for user 17: 25.0
Peak congestion window size for user 18: 25.0
Peak congestion window size for user 19: 25.0
```


Observation:

Converged at 68, loss packet count 4

Experiment with 20 users (cwnd = 1000)

```
In [10]:  # Experiment Variables
          num_users = 20
          max_RTT = 300
          max_cwnd = 1000


          # Simulation of AIMD
          cwnd_tracker = simulate_aimd(max_RTT, num_users, alpha_func, beta_func,initial_cwnd

          # Plot graph of RTT over CWND
```

```python
plot_title = "AIMD with alpha = 1, beta = 0.5,cwnd = 1000 (20 users)"
plot_graph(num_users, cwnd_tracker, plot_title)
```

```python
plot_title = "AIMD with alpha = 1, beta = 0.5,cwnd = 1000 (20 users)"
plot_graph(num_users, cwnd_tracker, plot_title)
```

```
Initial cwnd for user 0: 29.0
Initial cwnd for user 1: 45.0
Initial cwnd for user 2: 45.0
Initial cwnd for user 3: 41.0
Initial cwnd for user 4: 2.0
Initial cwnd for user 5: 35.0
Initial cwnd for user 6: 19.0
Initial cwnd for user 7: 26.0
Initial cwnd for user 8: 33.0
Initial cwnd for user 9: 10.0
Initial cwnd for user 10: 14.0
Initial cwnd for user 11: 36.0
Initial cwnd for user 12: 39.0
Initial cwnd for user 13: 43.0
Initial cwnd for user 14: 39.0
Initial cwnd for user 15: 2.0
Initial cwnd for user 16: 6.0
Initial cwnd for user 17: 38.0
Initial cwnd for user 18: 12.0
Initial cwnd for user 19: 13.0


(Packet Loss)Multiplicative Decrease at: 24
Peak congestion window size for user 0: 53.0
Peak congestion window size for user 1: 69.0
Peak congestion window size for user 2: 69.0
Peak congestion window size for user 3: 65.0
Peak congestion window size for user 4: 26.0
Peak congestion window size for user 5: 59.0
Peak congestion window size for user 6: 43.0
Peak congestion window size for user 7: 50.0
Peak congestion window size for user 8: 57.0
Peak congestion window size for user 9: 34.0
Peak congestion window size for user 10: 38.0
Peak congestion window size for user 11: 60.0
Peak congestion window size for user 12: 63.0
Peak congestion window size for user 13: 67.0
Peak congestion window size for user 14: 63.0
Peak congestion window size for user 15: 26.0
Peak congestion window size for user 16: 30.0
Peak congestion window size for user 17: 62.0
Peak congestion window size for user 18: 36.0
Peak congestion window size for user 19: 37.0


(Packet Loss)Multiplicative Decrease at: 51
Peak congestion window size for user 0: 52.0
Peak congestion window size for user 1: 60.0
Peak congestion window size for user 2: 60.0
Peak congestion window size for user 3: 58.0
Peak congestion window size for user 4: 39.0
Peak congestion window size for user 5: 55.0
Peak congestion window size for user 6: 47.0
Peak congestion window size for user 7: 51.0
Peak congestion window size for user 8: 54.0
Peak congestion window size for user 9: 43.0
Peak congestion window size for user 10: 45.0
Peak congestion window size for user 11: 56.0
Peak congestion window size for user 12: 57.0
Peak congestion window size for user 13: 59.0
Peak congestion window size for user 14: 57.0
Peak congestion window size for user 15: 39.0
Peak congestion window size for user 16: 41.0
Peak congestion window size for user 17: 57.0
```

```
Peak congestion window size for user 18: 44.0
Peak congestion window size for user 19: 44.0


(Packet Loss)Multiplicative Decrease at: 77
Peak congestion window size for user 0: 51.0
Peak congestion window size for user 1: 55.0
Peak congestion window size for user 2: 55.0
Peak congestion window size for user 3: 54.0
Peak congestion window size for user 4: 44.0
Peak congestion window size for user 5: 52.0
Peak congestion window size for user 6: 48.0
Peak congestion window size for user 7: 50.0
Peak congestion window size for user 8: 52.0
Peak congestion window size for user 9: 46.0
Peak congestion window size for user 10: 47.0
Peak congestion window size for user 11: 53.0
Peak congestion window size for user 12: 53.0
Peak congestion window size for user 13: 54.0
Peak congestion window size for user 14: 53.0
Peak congestion window size for user 15: 44.0
Peak congestion window size for user 16: 45.0
Peak congestion window size for user 17: 53.0
Peak congestion window size for user 18: 47.0
Peak congestion window size for user 19: 47.0


(Packet Loss)Multiplicative Decrease at: 104
Peak congestion window size for user 0: 51.0
Peak congestion window size for user 1: 53.0
Peak congestion window size for user 2: 53.0
Peak congestion window size for user 3: 53.0
Peak congestion window size for user 4: 48.0
Peak congestion window size for user 5: 52.0
Peak congestion window size for user 6: 50.0
Peak congestion window size for user 7: 51.0
Peak congestion window size for user 8: 52.0
Peak congestion window size for user 9: 49.0
Peak congestion window size for user 10: 49.0
Peak congestion window size for user 11: 52.0
Peak congestion window size for user 12: 52.0
Peak congestion window size for user 13: 53.0
Peak congestion window size for user 14: 52.0
Peak congestion window size for user 15: 48.0
Peak congestion window size for user 16: 48.0
Peak congestion window size for user 17: 52.0
Peak congestion window size for user 18: 49.0
Peak congestion window size for user 19: 49.0


(Packet Loss)Multiplicative Decrease at: 130
Peak congestion window size for user 0: 50.0
Peak congestion window size for user 1: 51.0
Peak congestion window size for user 2: 51.0
Peak congestion window size for user 3: 51.0
Peak congestion window size for user 4: 49.0
Peak congestion window size for user 5: 51.0
Peak congestion window size for user 6: 50.0
Peak congestion window size for user 7: 50.0
Peak congestion window size for user 8: 51.0
Peak congestion window size for user 9: 49.0
Peak congestion window size for user 10: 49.0
Peak congestion window size for user 11: 51.0
Peak congestion window size for user 12: 51.0
```

```
Peak congestion window size for user 13: 51.0
Peak congestion window size for user 14: 51.0
Peak congestion window size for user 15: 49.0
Peak congestion window size for user 16: 49.0
Peak congestion window size for user 17: 51.0
Peak congestion window size for user 18: 49.0
Peak congestion window size for user 19: 49.0


(Packet Loss)Multiplicative Decrease at: 157
Peak congestion window size for user 0: 51.0
Peak congestion window size for user 1: 51.0
Peak congestion window size for user 2: 51.0
Peak congestion window size for user 3: 51.0
Peak congestion window size for user 4: 50.0
Peak congestion window size for user 5: 51.0
Peak congestion window size for user 6: 51.0
Peak congestion window size for user 7: 51.0
Peak congestion window size for user 8: 51.0
Peak congestion window size for user 9: 50.0
Peak congestion window size for user 10: 50.0
Peak congestion window size for user 11: 51.0
Peak congestion window size for user 12: 51.0
Peak congestion window size for user 13: 51.0
Peak congestion window size for user 14: 51.0
Peak congestion window size for user 15: 50.0
Peak congestion window size for user 16: 50.0
Peak congestion window size for user 17: 51.0
Peak congestion window size for user 18: 50.0
Peak congestion window size for user 19: 50.0


(Packet Loss)Multiplicative Decrease at: 184
Peak congestion window size for user 0: 51.0
Peak congestion window size for user 1: 51.0
Peak congestion window size for user 2: 51.0
Peak congestion window size for user 3: 51.0
Peak congestion window size for user 4: 51.0
Peak congestion window size for user 5: 51.0
Peak congestion window size for user 6: 51.0
Peak congestion window size for user 7: 51.0
Peak congestion window size for user 8: 51.0
Peak congestion window size for user 9: 51.0
Peak congestion window size for user 10: 51.0
Peak congestion window size for user 11: 51.0
Peak congestion window size for user 12: 51.0
Peak congestion window size for user 13: 51.0
Peak congestion window size for user 14: 51.0
Peak congestion window size for user 15: 51.0
Peak congestion window size for user 16: 51.0
Peak congestion window size for user 17: 51.0
Peak congestion window size for user 18: 51.0
Peak congestion window size for user 19: 51.0


(Packet Loss)Multiplicative Decrease at: 211
Peak congestion window size for user 0: 51.0
Peak congestion window size for user 1: 51.0
Peak congestion window size for user 2: 51.0
Peak congestion window size for user 3: 51.0
Peak congestion window size for user 4: 51.0
Peak congestion window size for user 5: 51.0
Peak congestion window size for user 6: 51.0
Peak congestion window size for user 7: 51.0
```

```
Peak congestion window size for user 8: 51.0
Peak congestion window size for user 9: 51.0
Peak congestion window size for user 10: 51.0
Peak congestion window size for user 11: 51.0
Peak congestion window size for user 12: 51.0
Peak congestion window size for user 13: 51.0
Peak congestion window size for user 14: 51.0
Peak congestion window size for user 15: 51.0
Peak congestion window size for user 16: 51.0
Peak congestion window size for user 17: 51.0
Peak congestion window size for user 18: 51.0
Peak congestion window size for user 19: 51.0


(Packet Loss)Multiplicative Decrease at: 238
Peak congestion window size for user 0: 51.0
Peak congestion window size for user 1: 51.0
Peak congestion window size for user 2: 51.0
Peak congestion window size for user 3: 51.0
Peak congestion window size for user 4: 51.0
Peak congestion window size for user 5: 51.0
Peak congestion window size for user 6: 51.0
Peak congestion window size for user 7: 51.0
Peak congestion window size for user 8: 51.0
Peak congestion window size for user 9: 51.0
Peak congestion window size for user 10: 51.0
Peak congestion window size for user 11: 51.0
Peak congestion window size for user 12: 51.0
Peak congestion window size for user 13: 51.0
Peak congestion window size for user 14: 51.0
Peak congestion window size for user 15: 51.0
Peak congestion window size for user 16: 51.0
Peak congestion window size for user 17: 51.0
Peak congestion window size for user 18: 51.0
Peak congestion window size for user 19: 51.0


(Packet Loss)Multiplicative Decrease at: 265
Peak congestion window size for user 0: 51.0
Peak congestion window size for user 1: 51.0
Peak congestion window size for user 2: 51.0
Peak congestion window size for user 3: 51.0
Peak congestion window size for user 4: 51.0
Peak congestion window size for user 5: 51.0
Peak congestion window size for user 6: 51.0
Peak congestion window size for user 7: 51.0
Peak congestion window size for user 8: 51.0
Peak congestion window size for user 9: 51.0
Peak congestion window size for user 10: 51.0
Peak congestion window size for user 11: 51.0
Peak congestion window size for user 12: 51.0
Peak congestion window size for user 13: 51.0
Peak congestion window size for user 14: 51.0
Peak congestion window size for user 15: 51.0
Peak congestion window size for user 16: 51.0
Peak congestion window size for user 17: 51.0
Peak congestion window size for user 18: 51.0
Peak congestion window size for user 19: 51.0


(Packet Loss)Multiplicative Decrease at: 292
Peak congestion window size for user 0: 51.0
Peak congestion window size for user 1: 51.0
Peak congestion window size for user 2: 51.0
```
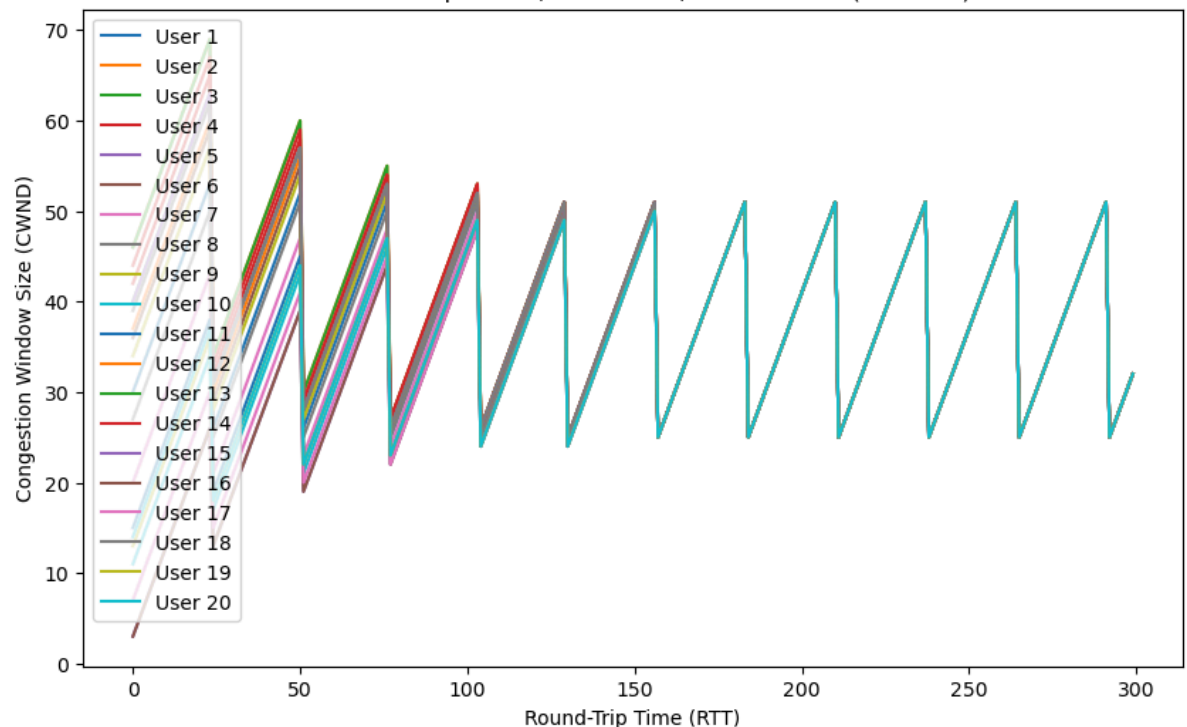
```
Peak congestion window size for user 3: 51.0
Peak congestion window size for user 4: 51.0
Peak congestion window size for user 5: 51.0
Peak congestion window size for user 6: 51.0
Peak congestion window size for user 7: 51.0
Peak congestion window size for user 8: 51.0
Peak congestion window size for user 9: 51.0
Peak congestion window size for user 10: 51.0
Peak congestion window size for user 11: 51.0
Peak congestion window size for user 12: 51.0
Peak congestion window size for user 13: 51.0
Peak congestion window size for user 14: 51.0
Peak congestion window size for user 15: 51.0
Peak congestion window size for user 16: 51.0
Peak congestion window size for user 17: 51.0
Peak congestion window size for user 18: 51.0
Peak congestion window size for user 19: 51.0
```


Observation:

Converged at 184, Packet loss count 6

```
In [ ]:
```

Experiment 2: AIMD with Logarithmic Increase

Experiment with 2 users

```
In [11]:   # Experiment Variables
           num_users = 2
           max_RTT = 100
           max_cwnd = 100
           # Define the initial cwnd size for users.
           initial_cwnd = [30, 70]


           # Simulation of AIMD
```

```python
cwnd_tracker = simulate_aimd(max_RTT, num_users, alpha_func_log, beta_func, initial

# Plot graph of RTT over CWND
plot_title = "AIMD with Logarithmic Increase (2 users)"
plot_graph(num_users, cwnd_tracker, plot_title)
```

```python
cwnd_tracker = simulate_aimd(max_RTT, num_users, alpha_func_log, beta_func, initial


# Plot graph of RTT over CWND
plot_title = "AIMD with Logarithmic Increase (2 users)"
plot_graph(num_users, cwnd_tracker, plot_title)
```

```
Initial cwnd for user 0: 30.0
Initial cwnd for user 1: 70.0


(Packet Loss)Multiplicative Decrease at: 1
Peak congestion window size for user 0: 35.0
Peak congestion window size for user 1: 76.0


(Packet Loss)Multiplicative Decrease at: 7
Peak congestion window size for user 0: 40.0
Peak congestion window size for user 1: 66.0


(Packet Loss)Multiplicative Decrease at: 13
Peak congestion window size for user 0: 44.0
Peak congestion window size for user 1: 60.0


(Packet Loss)Multiplicative Decrease at: 19
Peak congestion window size for user 0: 47.0
Peak congestion window size for user 1: 57.0


(Packet Loss)Multiplicative Decrease at: 25
Peak congestion window size for user 0: 48.0
Peak congestion window size for user 1: 54.0


(Packet Loss)Multiplicative Decrease at: 31
Peak congestion window size for user 0: 49.0
Peak congestion window size for user 1: 53.0


(Packet Loss)Multiplicative Decrease at: 37
Peak congestion window size for user 0: 49.0
Peak congestion window size for user 1: 52.0


(Packet Loss)Multiplicative Decrease at: 43
Peak congestion window size for user 0: 49.0
Peak congestion window size for user 1: 52.0


(Packet Loss)Multiplicative Decrease at: 49
Peak congestion window size for user 0: 49.0
Peak congestion window size for user 1: 52.0


(Packet Loss)Multiplicative Decrease at: 55
Peak congestion window size for user 0: 49.0
Peak congestion window size for user 1: 52.0


(Packet Loss)Multiplicative Decrease at: 61
Peak congestion window size for user 0: 49.0
Peak congestion window size for user 1: 52.0


(Packet Loss)Multiplicative Decrease at: 67
Peak congestion window size for user 0: 49.0
Peak congestion window size for user 1: 52.0
```

(Packet Loss)Multiplicative Decrease at: 73
Peak congestion window size for user 0: 49.0
Peak congestion window size for user 1: 52.0

(Packet Loss)Multiplicative Decrease at: 79
Peak congestion window size for user 0: 49.0
Peak congestion window size for user 1: 52.0

(Packet Loss)Multiplicative Decrease at: 85
Peak congestion window size for user 0: 49.0
Peak congestion window size for user 1: 52.0

(Packet Loss)Multiplicative Decrease at: 91
Peak congestion window size for user 0: 49.0
Peak congestion window size for user 1: 52.0

(Packet Loss)Multiplicative Decrease at: 97
Peak congestion window size for user 0: 49.0
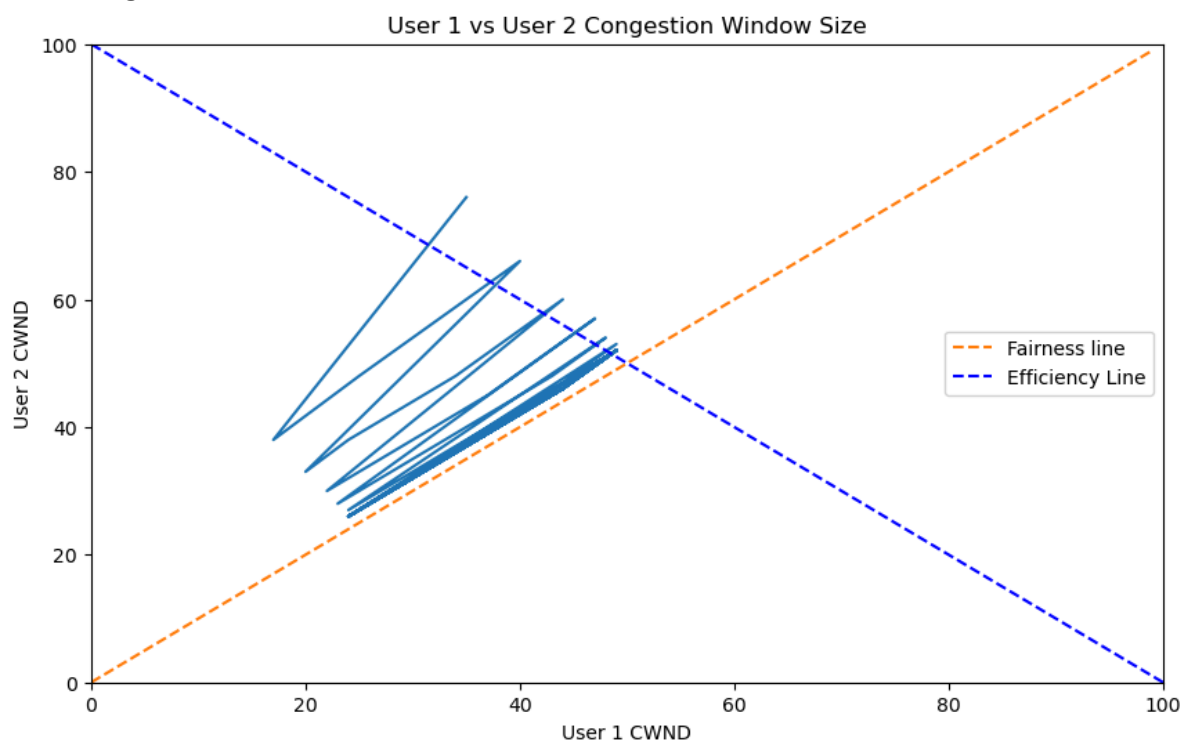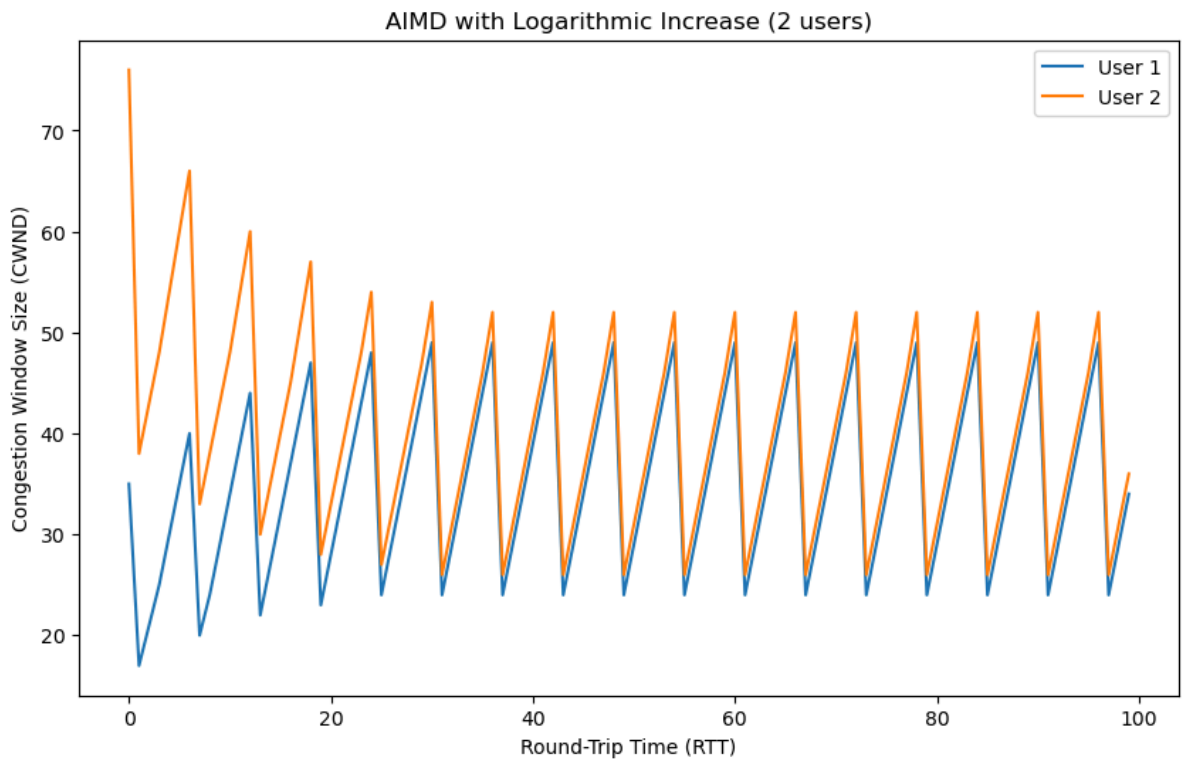Peak congestion window size for user 1: 52.0

AIMD with Logarithmic Increase (2 users)

Observation:

Converged at 37, Packet loss count 6

We can see that it converges faster as compared to the experiment with 2 users in experiment 1, possible reason is because that the logarithmic increase function will increase the speed of congestion window to reach its threshold as compared to normal alpha increase function, and we can see that due to the higher rate of increase in cwnd size because of log function, the multiplicative decrease occurs more often compared to experiment 1.

Experiment with 20 users

```
In [12]:  # Experiment Variables
          num_users = 20
          max_RTT = 100
          max_cwnd = 1000



          # Simulation of AIMD
          cwnd_tracker = simulate_aimd(max_RTT, num_users, alpha_func_log, beta_func, initial

          # Plot graph of RTT over CWND
          plot_title = "AIMD with Logarithmic Increase (20 users)"
          plot_graph(num_users, cwnd_tracker, plot_title)
```

```
Initial cwnd for user 0: 29.0
Initial cwnd for user 1: 45.0
Initial cwnd for user 2: 45.0
Initial cwnd for user 3: 41.0
Initial cwnd for user 4: 2.0
Initial cwnd for user 5: 35.0
Initial cwnd for user 6: 19.0
Initial cwnd for user 7: 26.0
Initial cwnd for user 8: 33.0
Initial cwnd for user 9: 10.0
Initial cwnd for user 10: 14.0
Initial cwnd for user 11: 36.0
Initial cwnd for user 12: 39.0
Initial cwnd for user 13: 43.0
Initial cwnd for user 14: 39.0
Initial cwnd for user 15: 2.0
Initial cwnd for user 16: 6.0
Initial cwnd for user 17: 38.0
Initial cwnd for user 18: 12.0
Initial cwnd for user 19: 13.0


(Packet Loss)Multiplicative Decrease at: 5
Peak congestion window size for user 0: 55.0
Peak congestion window size for user 1: 75.0
Peak congestion window size for user 2: 75.0
Peak congestion window size for user 3: 70.0
Peak congestion window size for user 4: 16.0
Peak congestion window size for user 5: 63.0
Peak congestion window size for user 6: 43.0
Peak congestion window size for user 7: 52.0
Peak congestion window size for user 8: 60.0
Peak congestion window size for user 9: 30.0
Peak congestion window size for user 10: 37.0
Peak congestion window size for user 11: 64.0
Peak congestion window size for user 12: 67.0
Peak congestion window size for user 13: 72.0
Peak congestion window size for user 14: 67.0
Peak congestion window size for user 15: 16.0
Peak congestion window size for user 16: 24.0
Peak congestion window size for user 17: 66.0
Peak congestion window size for user 18: 34.0
Peak congestion window size for user 19: 35.0


(Packet Loss)Multiplicative Decrease at: 11
Peak congestion window size for user 0: 53.0
Peak congestion window size for user 1: 65.0
Peak congestion window size for user 2: 65.0
Peak congestion window size for user 3: 63.0
Peak congestion window size for user 4: 28.0
Peak congestion window size for user 5: 58.0
Peak congestion window size for user 6: 45.0
Peak congestion window size for user 7: 52.0
Peak congestion window size for user 8: 57.0
Peak congestion window size for user 9: 38.0
Peak congestion window size for user 10: 42.0
Peak congestion window size for user 11: 59.0
Peak congestion window size for user 12: 60.0
Peak congestion window size for user 13: 64.0
Peak congestion window size for user 14: 60.0
Peak congestion window size for user 15: 28.0
Peak congestion window size for user 16: 34.0
Peak congestion window size for user 17: 60.0
```

```
Peak congestion window size for user 18: 40.0
Peak congestion window size for user 19: 40.0


(Packet Loss)Multiplicative Decrease at: 17
Peak congestion window size for user 0: 52.0
Peak congestion window size for user 1: 59.0
Peak congestion window size for user 2: 59.0
Peak congestion window size for user 3: 58.0
Peak congestion window size for user 4: 37.0
Peak congestion window size for user 5: 55.0
Peak congestion window size for user 6: 47.0
Peak congestion window size for user 7: 52.0
Peak congestion window size for user 8: 54.0
Peak congestion window size for user 9: 43.0
Peak congestion window size for user 10: 45.0
Peak congestion window size for user 11: 55.0
Peak congestion window size for user 12: 57.0
Peak congestion window size for user 13: 59.0
Peak congestion window size for user 14: 57.0
Peak congestion window size for user 15: 37.0
Peak congestion window size for user 16: 40.0
Peak congestion window size for user 17: 57.0
Peak congestion window size for user 18: 44.0
Peak congestion window size for user 19: 44.0


(Packet Loss)Multiplicative Decrease at: 23
Peak congestion window size for user 0: 52.0
Peak congestion window size for user 1: 55.0
Peak congestion window size for user 2: 55.0
Peak congestion window size for user 3: 55.0
Peak congestion window size for user 4: 42.0
Peak congestion window size for user 5: 53.0
Peak congestion window size for user 6: 48.0
Peak congestion window size for user 7: 52.0
Peak congestion window size for user 8: 53.0
Peak congestion window size for user 9: 45.0
Peak congestion window size for user 10: 47.0
Peak congestion window size for user 11: 53.0
Peak congestion window size for user 12: 54.0
Peak congestion window size for user 13: 55.0
Peak congestion window size for user 14: 54.0
Peak congestion window size for user 15: 42.0
Peak congestion window size for user 16: 44.0
Peak congestion window size for user 17: 54.0
Peak congestion window size for user 18: 47.0
Peak congestion window size for user 19: 47.0


(Packet Loss)Multiplicative Decrease at: 29
Peak congestion window size for user 0: 52.0
Peak congestion window size for user 1: 53.0
Peak congestion window size for user 2: 53.0
Peak congestion window size for user 3: 53.0
Peak congestion window size for user 4: 45.0
Peak congestion window size for user 5: 52.0
Peak congestion window size for user 6: 49.0
Peak congestion window size for user 7: 52.0
Peak congestion window size for user 8: 52.0
Peak congestion window size for user 9: 47.0
Peak congestion window size for user 10: 48.0
Peak congestion window size for user 11: 52.0
Peak congestion window size for user 12: 53.0
```

```
Peak congestion window size for user 13: 53.0
Peak congestion window size for user 14: 53.0
Peak congestion window size for user 15: 45.0
Peak congestion window size for user 16: 47.0
Peak congestion window size for user 17: 53.0
Peak congestion window size for user 18: 48.0
Peak congestion window size for user 19: 48.0


(Packet Loss)Multiplicative Decrease at: 35
Peak congestion window size for user 0: 52.0
Peak congestion window size for user 1: 52.0
Peak congestion window size for user 2: 52.0
Peak congestion window size for user 3: 52.0
Peak congestion window size for user 4: 47.0
Peak congestion window size for user 5: 52.0
Peak congestion window size for user 6: 49.0
Peak congestion window size for user 7: 52.0
Peak congestion window size for user 8: 52.0
Peak congestion window size for user 9: 48.0
Peak congestion window size for user 10: 49.0
Peak congestion window size for user 11: 52.0
Peak congestion window size for user 12: 52.0
Peak congestion window size for user 13: 52.0
Peak congestion window size for user 14: 52.0
Peak congestion window size for user 15: 47.0
Peak congestion window size for user 16: 48.0
Peak congestion window size for user 17: 52.0
Peak congestion window size for user 18: 49.0
Peak congestion window size for user 19: 49.0


(Packet Loss)Multiplicative Decrease at: 41
Peak congestion window size for user 0: 52.0
Peak congestion window size for user 1: 52.0
Peak congestion window size for user 2: 52.0
Peak congestion window size for user 3: 52.0
Peak congestion window size for user 4: 48.0
Peak congestion window size for user 5: 52.0
Peak congestion window size for user 6: 49.0
Peak congestion window size for user 7: 52.0
Peak congestion window size for user 8: 52.0
Peak congestion window size for user 9: 49.0
Peak congestion window size for user 10: 49.0
Peak congestion window size for user 11: 52.0
Peak congestion window size for user 12: 52.0
Peak congestion window size for user 13: 52.0
Peak congestion window size for user 14: 52.0
Peak congestion window size for user 15: 48.0
Peak congestion window size for user 16: 49.0
Peak congestion window size for user 17: 52.0
Peak congestion window size for user 18: 49.0
Peak congestion window size for user 19: 49.0


(Packet Loss)Multiplicative Decrease at: 47
Peak congestion window size for user 0: 52.0
Peak congestion window size for user 1: 52.0
Peak congestion window size for user 2: 52.0
Peak congestion window size for user 3: 52.0
Peak congestion window size for user 4: 49.0
Peak congestion window size for user 5: 52.0
Peak congestion window size for user 6: 49.0
Peak congestion window size for user 7: 52.0
```

```
Peak congestion window size for user 8: 52.0
Peak congestion window size for user 9: 49.0
Peak congestion window size for user 10: 49.0
Peak congestion window size for user 11: 52.0
Peak congestion window size for user 12: 52.0
Peak congestion window size for user 13: 52.0
Peak congestion window size for user 14: 52.0
Peak congestion window size for user 15: 49.0
Peak congestion window size for user 16: 49.0
Peak congestion window size for user 17: 52.0
Peak congestion window size for user 18: 49.0
Peak congestion window size for user 19: 49.0


(Packet Loss)Multiplicative Decrease at: 53
Peak congestion window size for user 0: 52.0
Peak congestion window size for user 1: 52.0
Peak congestion window size for user 2: 52.0
Peak congestion window size for user 3: 52.0
Peak congestion window size for user 4: 49.0
Peak congestion window size for user 5: 52.0
Peak congestion window size for user 6: 49.0
Peak congestion window size for user 7: 52.0
Peak congestion window size for user 8: 52.0
Peak congestion window size for user 9: 49.0
Peak congestion window size for user 10: 49.0
Peak congestion window size for user 11: 52.0
Peak congestion window size for user 12: 52.0
Peak congestion window size for user 13: 52.0
Peak congestion window size for user 14: 52.0
Peak congestion window size for user 15: 49.0
Peak congestion window size for user 16: 49.0
Peak congestion window size for user 17: 52.0
Peak congestion window size for user 18: 49.0
Peak congestion window size for user 19: 49.0


(Packet Loss)Multiplicative Decrease at: 59
Peak congestion window size for user 0: 52.0
Peak congestion window size for user 1: 52.0
Peak congestion window size for user 2: 52.0
Peak congestion window size for user 3: 52.0
Peak congestion window size for user 4: 49.0
Peak congestion window size for user 5: 52.0
Peak congestion window size for user 6: 49.0
Peak congestion window size for user 7: 52.0
Peak congestion window size for user 8: 52.0
Peak congestion window size for user 9: 49.0
Peak congestion window size for user 10: 49.0
Peak congestion window size for user 11: 52.0
Peak congestion window size for user 12: 52.0
Peak congestion window size for user 13: 52.0
Peak congestion window size for user 14: 52.0
Peak congestion window size for user 15: 49.0
Peak congestion window size for user 16: 49.0
Peak congestion window size for user 17: 52.0
Peak congestion window size for user 18: 49.0
Peak congestion window size for user 19: 49.0


(Packet Loss)Multiplicative Decrease at: 65
Peak congestion window size for user 0: 52.0
Peak congestion window size for user 1: 52.0
Peak congestion window size for user 2: 52.0
```

```
Peak congestion window size for user 3: 52.0
Peak congestion window size for user 4: 49.0
Peak congestion window size for user 5: 52.0
Peak congestion window size for user 6: 49.0
Peak congestion window size for user 7: 52.0
Peak congestion window size for user 8: 52.0
Peak congestion window size for user 9: 49.0
Peak congestion window size for user 10: 49.0
Peak congestion window size for user 11: 52.0
Peak congestion window size for user 12: 52.0
Peak congestion window size for user 13: 52.0
Peak congestion window size for user 14: 52.0
Peak congestion window size for user 15: 49.0
Peak congestion window size for user 16: 49.0
Peak congestion window size for user 17: 52.0
Peak congestion window size for user 18: 49.0
Peak congestion window size for user 19: 49.0


(Packet Loss)Multiplicative Decrease at: 71
Peak congestion window size for user 0: 52.0
Peak congestion window size for user 1: 52.0
Peak congestion window size for user 2: 52.0
Peak congestion window size for user 3: 52.0
Peak congestion window size for user 4: 49.0
Peak congestion window size for user 5: 52.0
Peak congestion window size for user 6: 49.0
Peak congestion window size for user 7: 52.0
Peak congestion window size for user 8: 52.0
Peak congestion window size for user 9: 49.0
Peak congestion window size for user 10: 49.0
Peak congestion window size for user 11: 52.0
Peak congestion window size for user 12: 52.0
Peak congestion window size for user 13: 52.0
Peak congestion window size for user 14: 52.0
Peak congestion window size for user 15: 49.0
Peak congestion window size for user 16: 49.0
Peak congestion window size for user 17: 52.0
Peak congestion window size for user 18: 49.0
Peak congestion window size for user 19: 49.0


(Packet Loss)Multiplicative Decrease at: 77
Peak congestion window size for user 0: 52.0
Peak congestion window size for user 1: 52.0
Peak congestion window size for user 2: 52.0
Peak congestion window size for user 3: 52.0
Peak congestion window size for user 4: 49.0
Peak congestion window size for user 5: 52.0
Peak congestion window size for user 6: 49.0
Peak congestion window size for user 7: 52.0
Peak congestion window size for user 8: 52.0
Peak congestion window size for user 9: 49.0
Peak congestion window size for user 10: 49.0
Peak congestion window size for user 11: 52.0
Peak congestion window size for user 12: 52.0
Peak congestion window size for user 13: 52.0
Peak congestion window size for user 14: 52.0
Peak congestion window size for user 15: 49.0
Peak congestion window size for user 16: 49.0
Peak congestion window size for user 17: 52.0
Peak congestion window size for user 18: 49.0
Peak congestion window size for user 19: 49.0
```
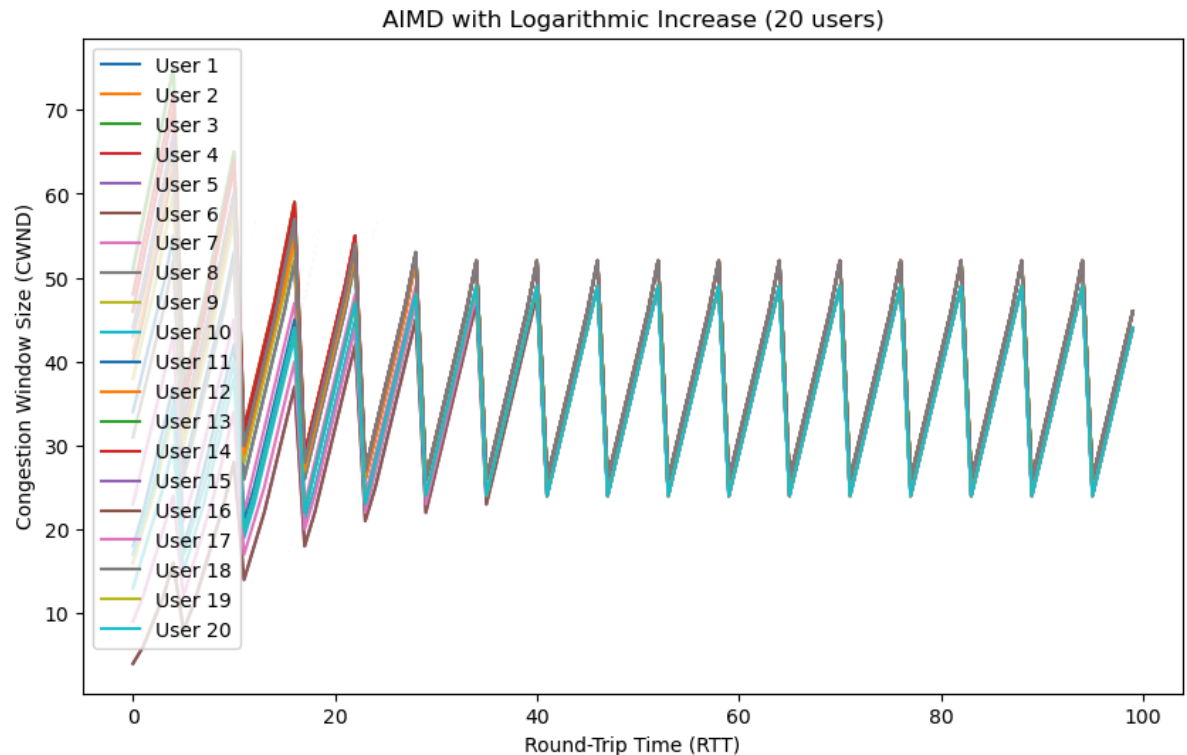
```
(Packet Loss)Multiplicative Decrease at: 83
Peak congestion window size for user 0: 52.0
Peak congestion window size for user 1: 52.0
Peak congestion window size for user 2: 52.0
Peak congestion window size for user 3: 52.0
Peak congestion window size for user 4: 49.0
Peak congestion window size for user 5: 52.0
Peak congestion window size for user 6: 49.0
Peak congestion window size for user 7: 52.0
Peak congestion window size for user 8: 52.0
Peak congestion window size for user 9: 49.0
Peak congestion window size for user 10: 49.0
Peak congestion window size for user 11: 52.0
Peak congestion window size for user 12: 52.0
Peak congestion window size for user 13: 52.0
Peak congestion window size for user 14: 52.0
Peak congestion window size for user 15: 49.0
Peak congestion window size for user 16: 49.0
Peak congestion window size for user 17: 52.0
Peak congestion window size for user 18: 49.0
Peak congestion window size for user 19: 49.0


(Packet Loss)Multiplicative Decrease at: 89
Peak congestion window size for user 0: 52.0
Peak congestion window size for user 1: 52.0
Peak congestion window size for user 2: 52.0
Peak congestion window size for user 3: 52.0
Peak congestion window size for user 4: 49.0
Peak congestion window size for user 5: 52.0
Peak congestion window size for user 6: 49.0
Peak congestion window size for user 7: 52.0
Peak congestion window size for user 8: 52.0
Peak congestion window size for user 9: 49.0
Peak congestion window size for user 10: 49.0
Peak congestion window size for user 11: 52.0
Peak congestion window size for user 12: 52.0
Peak congestion window size for user 13: 52.0
Peak congestion window size for user 14: 52.0
Peak congestion window size for user 15: 49.0
Peak congestion window size for user 16: 49.0
Peak congestion window size for user 17: 52.0
Peak congestion window size for user 18: 49.0
Peak congestion window size for user 19: 49.0


(Packet Loss)Multiplicative Decrease at: 95
Peak congestion window size for user 0: 52.0
Peak congestion window size for user 1: 52.0
Peak congestion window size for user 2: 52.0
Peak congestion window size for user 3: 52.0
Peak congestion window size for user 4: 49.0
Peak congestion window size for user 5: 52.0
Peak congestion window size for user 6: 49.0
Peak congestion window size for user 7: 52.0
Peak congestion window size for user 8: 52.0
Peak congestion window size for user 9: 49.0
Peak congestion window size for user 10: 49.0
Peak congestion window size for user 11: 52.0
Peak congestion window size for user 12: 52.0
Peak congestion window size for user 13: 52.0
Peak congestion window size for user 14: 52.0
Peak congestion window size for user 15: 49.0
```

```
Peak congestion window size for user 16: 49.0
Peak congestion window size for user 17: 52.0
Peak congestion window size for user 18: 49.0
Peak congestion window size for user 19: 49.0
```


Observation:

Converge at RTT 47, Packet loss count 7

In [ ]:

Experiment 3: AIMD with Exponential Increase

Experiment with 2 users

```
In [13]:   # Experiment Variables
           num_users = 2
           max_RTT = 150
           max_cwnd = 100
           # Define the initial cwnd size for users.
           initial_cwnd = [30, 70]


           # Simulation of AIMD
           cwnd_tracker = simulate_aimd(max_RTT, num_users, alpha_func_exp, beta_func, initial

           # Plot graph of RTT over CWND
           plot_title = "AIMD with Exponential Increase (2 users)"
           plot_graph(num_users, cwnd_tracker, plot_title)
```

```
Initial cwnd for user 0: 30.0
Initial cwnd for user 1: 70.0


(Packet Loss)Multiplicative Decrease at: 1
Peak congestion window size for user 0: 35.0
Peak congestion window size for user 1: 78.0


(Packet Loss)Multiplicative Decrease at: 6
Peak congestion window size for user 0: 37.0
Peak congestion window size for user 1: 67.0


(Packet Loss)Multiplicative Decrease at: 12
Peak congestion window size for user 0: 44.0
Peak congestion window size for user 1: 67.0


(Packet Loss)Multiplicative Decrease at: 17
Peak congestion window size for user 0: 44.0
Peak congestion window size for user 1: 59.0


(Packet Loss)Multiplicative Decrease at: 23
Peak congestion window size for user 0: 51.0
Peak congestion window size for user 1: 60.0


(Packet Loss)Multiplicative Decrease at: 28
Peak congestion window size for user 0: 47.0
Peak congestion window size for user 1: 54.0


(Packet Loss)Multiplicative Decrease at: 34
Peak congestion window size for user 0: 52.0
Peak congestion window size for user 1: 58.0


(Packet Loss)Multiplicative Decrease at: 39
Peak congestion window size for user 0: 50.0
Peak congestion window size for user 1: 53.0


(Packet Loss)Multiplicative Decrease at: 45
Peak congestion window size for user 0: 54.0
Peak congestion window size for user 1: 57.0


(Packet Loss)Multiplicative Decrease at: 50
Peak congestion window size for user 0: 51.0
Peak congestion window size for user 1: 52.0


(Packet Loss)Multiplicative Decrease at: 56
Peak congestion window size for user 0: 54.0
Peak congestion window size for user 1: 57.0


(Packet Loss)Multiplicative Decrease at: 61
Peak congestion window size for user 0: 51.0
Peak congestion window size for user 1: 52.0
```

```
(Packet Loss)Multiplicative Decrease at: 67
Peak congestion window size for user 0: 54.0
Peak congestion window size for user 1: 57.0


(Packet Loss)Multiplicative Decrease at: 72
Peak congestion window size for user 0: 51.0
Peak congestion window size for user 1: 52.0


(Packet Loss)Multiplicative Decrease at: 78
Peak congestion window size for user 0: 54.0
Peak congestion window size for user 1: 57.0


(Packet Loss)Multiplicative Decrease at: 83
Peak congestion window size for user 0: 51.0
Peak congestion window size for user 1: 52.0


(Packet Loss)Multiplicative Decrease at: 89
Peak congestion window size for user 0: 54.0
Peak congestion window size for user 1: 57.0


(Packet Loss)Multiplicative Decrease at: 94
Peak congestion window size for user 0: 51.0
Peak congestion window size for user 1: 52.0


(Packet Loss)Multiplicative Decrease at: 100
Peak congestion window size for user 0: 54.0
Peak congestion window size for user 1: 57.0


(Packet Loss)Multiplicative Decrease at: 105
Peak congestion window size for user 0: 51.0
Peak congestion window size for user 1: 52.0


(Packet Loss)Multiplicative Decrease at: 111
Peak congestion window size for user 0: 54.0
Peak congestion window size for user 1: 57.0


(Packet Loss)Multiplicative Decrease at: 116
Peak congestion window size for user 0: 51.0
Peak congestion window size for user 1: 52.0


(Packet Loss)Multiplicative Decrease at: 122
Peak congestion window size for user 0: 54.0
Peak congestion window size for user 1: 57.0


(Packet Loss)Multiplicative Decrease at: 127
Peak congestion window size for user 0: 51.0
Peak congestion window size for user 1: 52.0


(Packet Loss)Multiplicative Decrease at: 133
Peak congestion window size for user 0: 54.0
Peak congestion window size for user 1: 57.0
```

```
(Packet Loss)Multiplicative Decrease at: 138
Peak congestion window size for user 0: 51.0
Peak congestion window size for user 1: 52.0


(Packet Loss)Multiplicative Decrease at: 144
Peak congestion window size for user 0: 54.0
Peak congestion window size for user 1: 57.0


(Packet Loss)Multiplicative Decrease at: 149
Peak congestion window size for user 0: 51.0
Peak congestion window size for user 1: 52.0
```
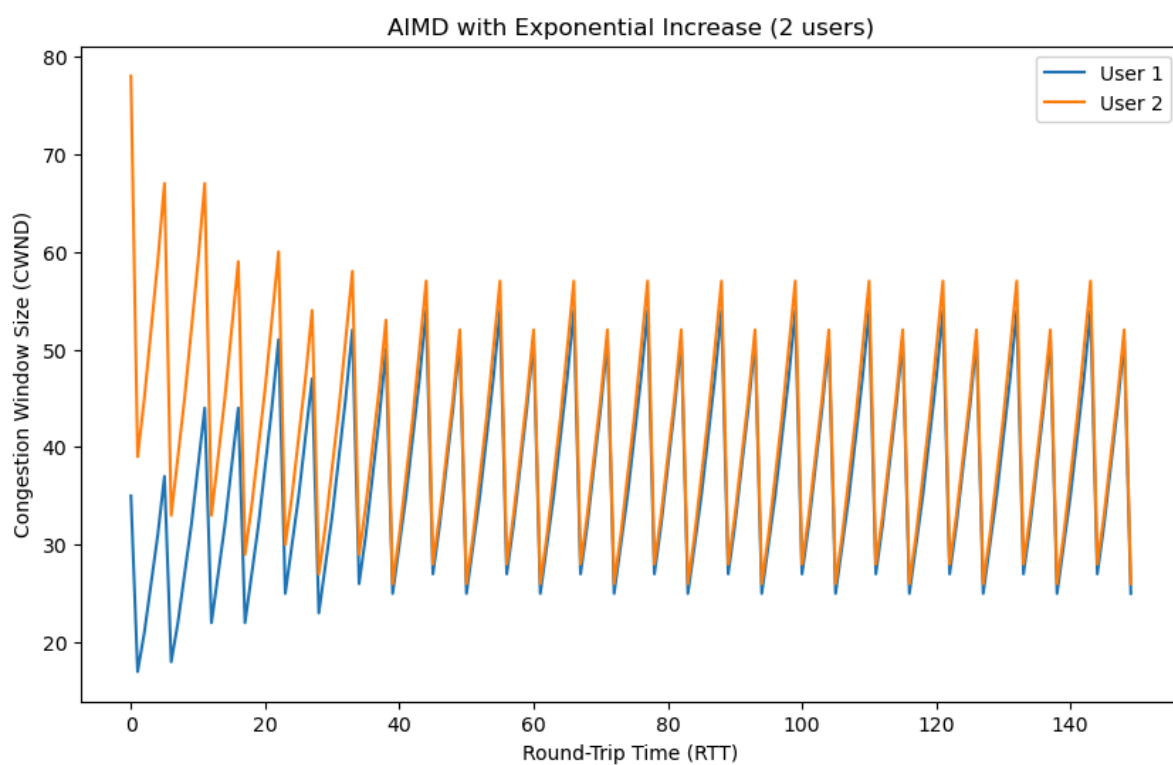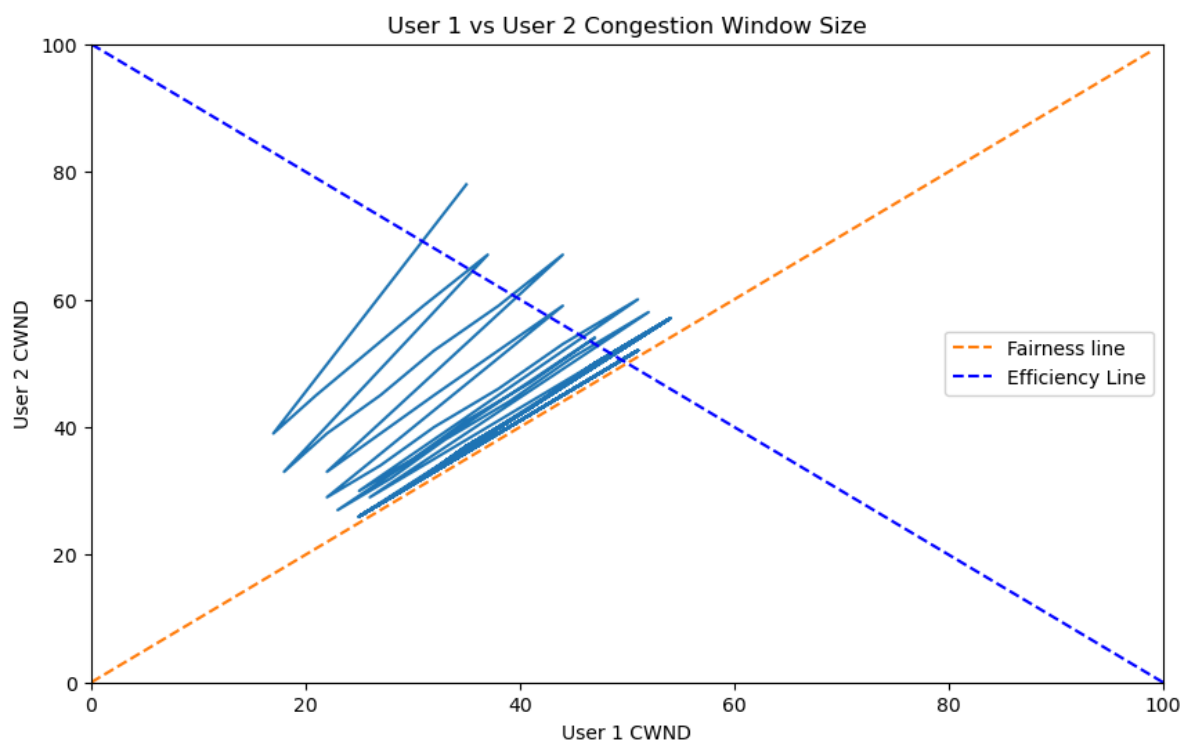
Observation:

Converged at 45, Packet loss count 8

We can see that it converges slightly slower as compared to logarithmic increase function, however we can see that after it converges, we will have a lower peak and higher peak for every 2 peaks, possible reason is because that the higher rate of increase in cwnd size compared to logarithmic increase function and because of the lower cwnd size.

Experiment with 2 users (cwnd = 200)

In [14]:
```python
# Experiment Variables
num_users = 2
max_RTT = 200
max_cwnd = 200
# Define the initial cwnd size for users.
initial_cwnd = [30, 70]


# Simulation of AIMD
cwnd_tracker = simulate_aimd(max_RTT, num_users, alpha_func_exp, beta_func, initial

# Plot graph of RTT over CWND
plot_title = "AIMD with Exponential Increase, cwnd = 200 (2 users)"
plot_graph(num_users, cwnd_tracker, plot_title)
```

```
Initial cwnd for user 0: 30.0
Initial cwnd for user 1: 70.0


(Packet Loss)Multiplicative Decrease at: 7
Peak congestion window size for user 0: 77.0
Peak congestion window size for user 1: 138.0


(Packet Loss)Multiplicative Decrease at: 14
Peak congestion window size for user 0: 83.0
Peak congestion window size for user 1: 126.0


(Packet Loss)Multiplicative Decrease at: 21
Peak congestion window size for user 0: 86.0
Peak congestion window size for user 1: 117.0


(Packet Loss)Multiplicative Decrease at: 28
Peak congestion window size for user 0: 91.0
Peak congestion window size for user 1: 112.0


(Packet Loss)Multiplicative Decrease at: 36
Peak congestion window size for user 0: 103.0
Peak congestion window size for user 1: 117.0


(Packet Loss)Multiplicative Decrease at: 43
Peak congestion window size for user 0: 102.0
Peak congestion window size for user 1: 112.0


(Packet Loss)Multiplicative Decrease at: 50
Peak congestion window size for user 0: 102.0
Peak congestion window size for user 1: 107.0


(Packet Loss)Multiplicative Decrease at: 57
Peak congestion window size for user 0: 102.0
Peak congestion window size for user 1: 104.0


(Packet Loss)Multiplicative Decrease at: 64
Peak congestion window size for user 0: 102.0
Peak congestion window size for user 1: 103.0


(Packet Loss)Multiplicative Decrease at: 71
Peak congestion window size for user 0: 102.0
Peak congestion window size for user 1: 102.0


(Packet Loss)Multiplicative Decrease at: 78
Peak congestion window size for user 0: 102.0
Peak congestion window size for user 1: 102.0


(Packet Loss)Multiplicative Decrease at: 85
Peak congestion window size for user 0: 102.0
Peak congestion window size for user 1: 102.0
```

```
(Packet Loss)Multiplicative Decrease at: 92
Peak congestion window size for user 0: 102.0
Peak congestion window size for user 1: 102.0


(Packet Loss)Multiplicative Decrease at: 99
Peak congestion window size for user 0: 102.0
Peak congestion window size for user 1: 102.0


(Packet Loss)Multiplicative Decrease at: 106
Peak congestion window size for user 0: 102.0
Peak congestion window size for user 1: 102.0


(Packet Loss)Multiplicative Decrease at: 113
Peak congestion window size for user 0: 102.0
Peak congestion window size for user 1: 102.0


(Packet Loss)Multiplicative Decrease at: 120
Peak congestion window size for user 0: 102.0
Peak congestion window size for user 1: 102.0


(Packet Loss)Multiplicative Decrease at: 127
Peak congestion window size for user 0: 102.0
Peak congestion window size for user 1: 102.0


(Packet Loss)Multiplicative Decrease at: 134
Peak congestion window size for user 0: 102.0
Peak congestion window size for user 1: 102.0


(Packet Loss)Multiplicative Decrease at: 141
Peak congestion window size for user 0: 102.0
Peak congestion window size for user 1: 102.0


(Packet Loss)Multiplicative Decrease at: 148
Peak congestion window size for user 0: 102.0
Peak congestion window size for user 1: 102.0


(Packet Loss)Multiplicative Decrease at: 155
Peak congestion window size for user 0: 102.0
Peak congestion window size for user 1: 102.0


(Packet Loss)Multiplicative Decrease at: 162
Peak congestion window size for user 0: 102.0
Peak congestion window size for user 1: 102.0


(Packet Loss)Multiplicative Decrease at: 169
Peak congestion window size for user 0: 102.0
Peak congestion window size for user 1: 102.0


(Packet Loss)Multiplicative Decrease at: 176
Peak congestion window size for user 0: 102.0
Peak congestion window size for user 1: 102.0
```

(Packet Loss)Multiplicative Decrease at: 183
Peak congestion window size for user 0: 102.0
Peak congestion window size for user 1: 102.0
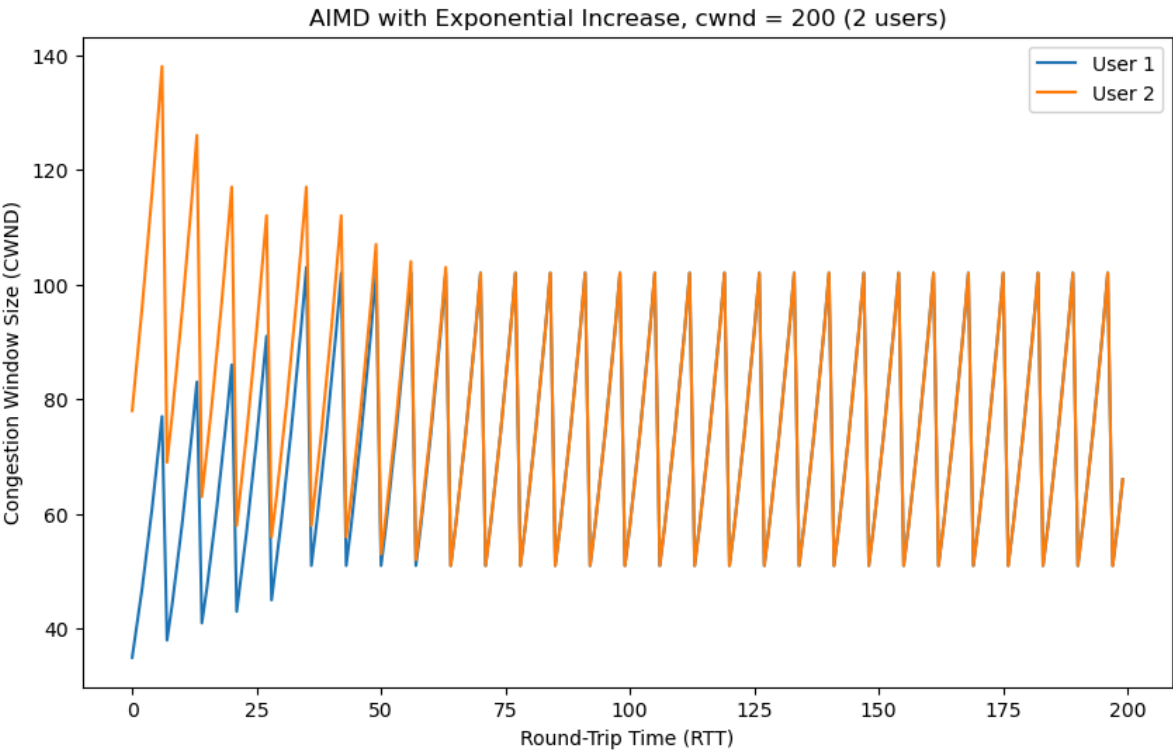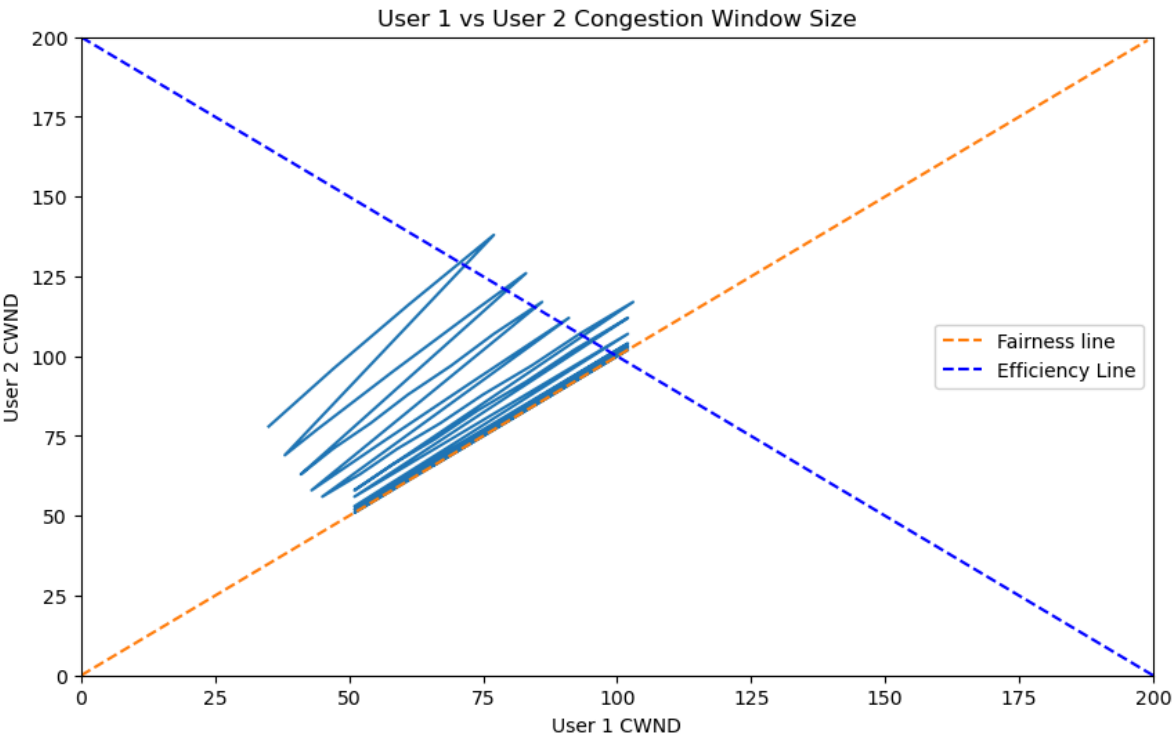

(Packet Loss)Multiplicative Decrease at: 190
Peak congestion window size for user 0: 102.0
Peak congestion window size for user 1: 102.0

(Packet Loss)Multiplicative Decrease at: 197
Peak congestion window size for user 0: 102.0
Peak congestion window size for user 1: 102.0

User 1 vs User 2 Congestion Window Size

AIMD with Exponential Increase, cwnd = 200 (2 users)

Observation:

Converged at RTT 71, packet loss count 9

We can see that this proves our reason in the previous experiment, as now when cwnd size has increase, after the cwnd has converged, we will not have a low and high peak in the graph

Experiment with 20 users

In [ ]:

In [15]:
```python
# Experiment Variables
num_users = 20
max_RTT = 200
max_cwnd = 1000

# Simulation of AIMD
cwnd_tracker = simulate_aimd(max_RTT, num_users, alpha_func_exp, beta_func, initial

# Plot graph of RTT over CWND
plot_title = "AIMD with Exponential Increase (20 users)"
plot_graph(num_users, cwnd_tracker, plot_title)
```

```
Initial cwnd for user 0: 29.0
Initial cwnd for user 1: 45.0
Initial cwnd for user 2: 45.0
Initial cwnd for user 3: 41.0
Initial cwnd for user 4: 2.0
Initial cwnd for user 5: 35.0
Initial cwnd for user 6: 19.0
Initial cwnd for user 7: 26.0
Initial cwnd for user 8: 33.0
Initial cwnd for user 9: 10.0
Initial cwnd for user 10: 14.0
Initial cwnd for user 11: 36.0
Initial cwnd for user 12: 39.0
Initial cwnd for user 13: 43.0
Initial cwnd for user 14: 39.0
Initial cwnd for user 15: 2.0
Initial cwnd for user 16: 6.0
Initial cwnd for user 17: 38.0
Initial cwnd for user 18: 12.0
Initial cwnd for user 19: 13.0


(Packet Loss)Multiplicative Decrease at: 5
Peak congestion window size for user 0: 60.0
Peak congestion window size for user 1: 84.0
Peak congestion window size for user 2: 84.0
Peak congestion window size for user 3: 77.0
Peak congestion window size for user 4: 13.0
Peak congestion window size for user 5: 69.0
Peak congestion window size for user 6: 45.0
Peak congestion window size for user 7: 57.0
Peak congestion window size for user 8: 67.0
Peak congestion window size for user 9: 31.0
Peak congestion window size for user 10: 38.0
Peak congestion window size for user 11: 70.0
Peak congestion window size for user 12: 75.0
Peak congestion window size for user 13: 82.0
Peak congestion window size for user 14: 75.0
Peak congestion window size for user 15: 13.0
Peak congestion window size for user 16: 22.0
Peak congestion window size for user 17: 74.0
Peak congestion window size for user 18: 33.0
Peak congestion window size for user 19: 37.0


(Packet Loss)Multiplicative Decrease at: 10
Peak congestion window size for user 0: 54.0
Peak congestion window size for user 1: 70.0
Peak congestion window size for user 2: 70.0
Peak congestion window size for user 3: 66.0
Peak congestion window size for user 4: 18.0
Peak congestion window size for user 5: 60.0
Peak congestion window size for user 6: 44.0
Peak congestion window size for user 7: 52.0
Peak congestion window size for user 8: 59.0
Peak congestion window size for user 9: 33.0
Peak congestion window size for user 10: 39.0
Peak congestion window size for user 11: 61.0
Peak congestion window size for user 12: 65.0
Peak congestion window size for user 13: 69.0
Peak congestion window size for user 14: 65.0
Peak congestion window size for user 15: 18.0
Peak congestion window size for user 16: 27.0
Peak congestion window size for user 17: 65.0
```

```
Peak congestion window size for user 18: 34.0
Peak congestion window size for user 19: 38.0


(Packet Loss)Multiplicative Decrease at: 16
Peak congestion window size for user 0: 58.0
Peak congestion window size for user 1: 69.0
Peak congestion window size for user 2: 69.0
Peak congestion window size for user 3: 67.0
Peak congestion window size for user 4: 28.0
Peak congestion window size for user 5: 61.0
Peak congestion window size for user 6: 51.0
Peak congestion window size for user 7: 57.0
Peak congestion window size for user 8: 60.0
Peak congestion window size for user 9: 40.0
Peak congestion window size for user 10: 45.0
Peak congestion window size for user 11: 61.0
Peak congestion window size for user 12: 66.0
Peak congestion window size for user 13: 68.0
Peak congestion window size for user 14: 66.0
Peak congestion window size for user 15: 28.0
Peak congestion window size for user 16: 37.0
Peak congestion window size for user 17: 66.0
Peak congestion window size for user 18: 43.0
Peak congestion window size for user 19: 45.0


(Packet Loss)Multiplicative Decrease at: 21
Peak congestion window size for user 0: 53.0
Peak congestion window size for user 1: 60.0
Peak congestion window size for user 2: 60.0
Peak congestion window size for user 3: 59.0
Peak congestion window size for user 4: 32.0
Peak congestion window size for user 5: 54.0
Peak congestion window size for user 6: 47.0
Peak congestion window size for user 7: 52.0
Peak congestion window size for user 8: 54.0
Peak congestion window size for user 9: 40.0
Peak congestion window size for user 10: 44.0
Peak congestion window size for user 11: 54.0
Peak congestion window size for user 12: 59.0
Peak congestion window size for user 13: 60.0
Peak congestion window size for user 14: 59.0
Peak congestion window size for user 15: 32.0
Peak congestion window size for user 16: 38.0
Peak congestion window size for user 17: 59.0
Peak congestion window size for user 18: 43.0
Peak congestion window size for user 19: 44.0


(Packet Loss)Multiplicative Decrease at: 27
Peak congestion window size for user 0: 57.0
Peak congestion window size for user 1: 61.0
Peak congestion window size for user 2: 61.0
Peak congestion window size for user 3: 60.0
Peak congestion window size for user 4: 40.0
Peak congestion window size for user 5: 58.0
Peak congestion window size for user 6: 52.0
Peak congestion window size for user 7: 57.0
Peak congestion window size for user 8: 58.0
Peak congestion window size for user 9: 46.0
Peak congestion window size for user 10: 51.0
Peak congestion window size for user 11: 58.0
Peak congestion window size for user 12: 60.0
```

```
Peak congestion window size for user 13: 61.0
Peak congestion window size for user 14: 60.0
Peak congestion window size for user 15: 40.0
Peak congestion window size for user 16: 45.0
Peak congestion window size for user 17: 60.0
Peak congestion window size for user 18: 50.0
Peak congestion window size for user 19: 51.0


(Packet Loss)Multiplicative Decrease at: 32
Peak congestion window size for user 0: 52.0
Peak congestion window size for user 1: 54.0
Peak congestion window size for user 2: 54.0
Peak congestion window size for user 3: 54.0
Peak congestion window size for user 4: 40.0
Peak congestion window size for user 5: 53.0
Peak congestion window size for user 6: 50.0
Peak congestion window size for user 7: 52.0
Peak congestion window size for user 8: 53.0
Peak congestion window size for user 9: 45.0
Peak congestion window size for user 10: 47.0
Peak congestion window size for user 11: 53.0
Peak congestion window size for user 12: 54.0
Peak congestion window size for user 13: 54.0
Peak congestion window size for user 14: 54.0
Peak congestion window size for user 15: 40.0
Peak congestion window size for user 16: 44.0
Peak congestion window size for user 17: 54.0
Peak congestion window size for user 18: 47.0
Peak congestion window size for user 19: 47.0


(Packet Loss)Multiplicative Decrease at: 38
Peak congestion window size for user 0: 57.0
Peak congestion window size for user 1: 58.0
Peak congestion window size for user 2: 58.0
Peak congestion window size for user 3: 58.0
Peak congestion window size for user 4: 46.0
Peak congestion window size for user 5: 57.0
Peak congestion window size for user 6: 54.0
Peak congestion window size for user 7: 57.0
Peak congestion window size for user 8: 57.0
Peak congestion window size for user 9: 51.0
Peak congestion window size for user 10: 52.0
Peak congestion window size for user 11: 57.0
Peak congestion window size for user 12: 58.0
Peak congestion window size for user 13: 58.0
Peak congestion window size for user 14: 58.0
Peak congestion window size for user 15: 46.0
Peak congestion window size for user 16: 51.0
Peak congestion window size for user 17: 58.0
Peak congestion window size for user 18: 52.0
Peak congestion window size for user 19: 52.0


(Packet Loss)Multiplicative Decrease at: 43
Peak congestion window size for user 0: 52.0
Peak congestion window size for user 1: 53.0
Peak congestion window size for user 2: 53.0
Peak congestion window size for user 3: 53.0
Peak congestion window size for user 4: 45.0
Peak congestion window size for user 5: 52.0
Peak congestion window size for user 6: 51.0
Peak congestion window size for user 7: 52.0
```

```
Peak congestion window size for user 8: 52.0
Peak congestion window size for user 9: 47.0
Peak congestion window size for user 10: 50.0
Peak congestion window size for user 11: 52.0
Peak congestion window size for user 12: 53.0
Peak congestion window size for user 13: 53.0
Peak congestion window size for user 14: 53.0
Peak congestion window size for user 15: 45.0
Peak congestion window size for user 16: 47.0
Peak congestion window size for user 17: 53.0
Peak congestion window size for user 18: 50.0
Peak congestion window size for user 19: 50.0


(Packet Loss)Multiplicative Decrease at: 49
Peak congestion window size for user 0: 57.0
Peak congestion window size for user 1: 57.0
Peak congestion window size for user 2: 57.0
Peak congestion window size for user 3: 57.0
Peak congestion window size for user 4: 51.0
Peak congestion window size for user 5: 57.0
Peak congestion window size for user 6: 54.0
Peak congestion window size for user 7: 57.0
Peak congestion window size for user 8: 57.0
Peak congestion window size for user 9: 52.0
Peak congestion window size for user 10: 54.0
Peak congestion window size for user 11: 57.0
Peak congestion window size for user 12: 57.0
Peak congestion window size for user 13: 57.0
Peak congestion window size for user 14: 57.0
Peak congestion window size for user 15: 51.0
Peak congestion window size for user 16: 52.0
Peak congestion window size for user 17: 57.0
Peak congestion window size for user 18: 54.0
Peak congestion window size for user 19: 54.0


(Packet Loss)Multiplicative Decrease at: 54
Peak congestion window size for user 0: 52.0
Peak congestion window size for user 1: 52.0
Peak congestion window size for user 2: 52.0
Peak congestion window size for user 3: 52.0
Peak congestion window size for user 4: 47.0
Peak congestion window size for user 5: 52.0
Peak congestion window size for user 6: 51.0
Peak congestion window size for user 7: 52.0
Peak congestion window size for user 8: 52.0
Peak congestion window size for user 9: 50.0
Peak congestion window size for user 10: 51.0
Peak congestion window size for user 11: 52.0
Peak congestion window size for user 12: 52.0
Peak congestion window size for user 13: 52.0
Peak congestion window size for user 14: 52.0
Peak congestion window size for user 15: 47.0
Peak congestion window size for user 16: 50.0
Peak congestion window size for user 17: 52.0
Peak congestion window size for user 18: 51.0
Peak congestion window size for user 19: 51.0


(Packet Loss)Multiplicative Decrease at: 60
Peak congestion window size for user 0: 57.0
Peak congestion window size for user 1: 57.0
Peak congestion window size for user 2: 57.0
```

```
Peak congestion window size for user 3: 57.0
Peak congestion window size for user 4: 52.0
Peak congestion window size for user 5: 57.0
Peak congestion window size for user 6: 54.0
Peak congestion window size for user 7: 57.0
Peak congestion window size for user 8: 57.0
Peak congestion window size for user 9: 54.0
Peak congestion window size for user 10: 54.0
Peak congestion window size for user 11: 57.0
Peak congestion window size for user 12: 57.0
Peak congestion window size for user 13: 57.0
Peak congestion window size for user 14: 57.0
Peak congestion window size for user 15: 52.0
Peak congestion window size for user 16: 54.0
Peak congestion window size for user 17: 57.0
Peak congestion window size for user 18: 54.0
Peak congestion window size for user 19: 54.0


(Packet Loss)Multiplicative Decrease at: 65
Peak congestion window size for user 0: 52.0
Peak congestion window size for user 1: 52.0
Peak congestion window size for user 2: 52.0
Peak congestion window size for user 3: 52.0
Peak congestion window size for user 4: 50.0
Peak congestion window size for user 5: 52.0
Peak congestion window size for user 6: 51.0
Peak congestion window size for user 7: 52.0
Peak congestion window size for user 8: 52.0
Peak congestion window size for user 9: 51.0
Peak congestion window size for user 10: 51.0
Peak congestion window size for user 11: 52.0
Peak congestion window size for user 12: 52.0
Peak congestion window size for user 13: 52.0
Peak congestion window size for user 14: 52.0
Peak congestion window size for user 15: 50.0
Peak congestion window size for user 16: 51.0
Peak congestion window size for user 17: 52.0
Peak congestion window size for user 18: 51.0
Peak congestion window size for user 19: 51.0


(Packet Loss)Multiplicative Decrease at: 71
Peak congestion window size for user 0: 57.0
Peak congestion window size for user 1: 57.0
Peak congestion window size for user 2: 57.0
Peak congestion window size for user 3: 57.0
Peak congestion window size for user 4: 54.0
Peak congestion window size for user 5: 57.0
Peak congestion window size for user 6: 54.0
Peak congestion window size for user 7: 57.0
Peak congestion window size for user 8: 57.0
Peak congestion window size for user 9: 54.0
Peak congestion window size for user 10: 54.0
Peak congestion window size for user 11: 57.0
Peak congestion window size for user 12: 57.0
Peak congestion window size for user 13: 57.0
Peak congestion window size for user 14: 57.0
Peak congestion window size for user 15: 54.0
Peak congestion window size for user 16: 54.0
Peak congestion window size for user 17: 57.0
Peak congestion window size for user 18: 54.0
Peak congestion window size for user 19: 54.0
```

```
(Packet Loss)Multiplicative Decrease at: 76
Peak congestion window size for user 0: 52.0
Peak congestion window size for user 1: 52.0
Peak congestion window size for user 2: 52.0
Peak congestion window size for user 3: 52.0
Peak congestion window size for user 4: 51.0
Peak congestion window size for user 5: 52.0
Peak congestion window size for user 6: 51.0
Peak congestion window size for user 7: 52.0
Peak congestion window size for user 8: 52.0
Peak congestion window size for user 9: 51.0
Peak congestion window size for user 10: 51.0
Peak congestion window size for user 11: 52.0
Peak congestion window size for user 12: 52.0
Peak congestion window size for user 13: 52.0
Peak congestion window size for user 14: 52.0
Peak congestion window size for user 15: 51.0
Peak congestion window size for user 16: 51.0
Peak congestion window size for user 17: 52.0
Peak congestion window size for user 18: 51.0
Peak congestion window size for user 19: 51.0


(Packet Loss)Multiplicative Decrease at: 82
Peak congestion window size for user 0: 57.0
Peak congestion window size for user 1: 57.0
Peak congestion window size for user 2: 57.0
Peak congestion window size for user 3: 57.0
Peak congestion window size for user 4: 54.0
Peak congestion window size for user 5: 57.0
Peak congestion window size for user 6: 54.0
Peak congestion window size for user 7: 57.0
Peak congestion window size for user 8: 57.0
Peak congestion window size for user 9: 54.0
Peak congestion window size for user 10: 54.0
Peak congestion window size for user 11: 57.0
Peak congestion window size for user 12: 57.0
Peak congestion window size for user 13: 57.0
Peak congestion window size for user 14: 57.0
Peak congestion window size for user 15: 54.0
Peak congestion window size for user 16: 54.0
Peak congestion window size for user 17: 57.0
Peak congestion window size for user 18: 54.0
Peak congestion window size for user 19: 54.0


(Packet Loss)Multiplicative Decrease at: 87
Peak congestion window size for user 0: 52.0
Peak congestion window size for user 1: 52.0
Peak congestion window size for user 2: 52.0
Peak congestion window size for user 3: 52.0
Peak congestion window size for user 4: 51.0
Peak congestion window size for user 5: 52.0
Peak congestion window size for user 6: 51.0
Peak congestion window size for user 7: 52.0
Peak congestion window size for user 8: 52.0
Peak congestion window size for user 9: 51.0
Peak congestion window size for user 10: 51.0
Peak congestion window size for user 11: 52.0
Peak congestion window size for user 12: 52.0
Peak congestion window size for user 13: 52.0
Peak congestion window size for user 14: 52.0
Peak congestion window size for user 15: 51.0
```

```
Peak congestion window size for user 16: 51.0
Peak congestion window size for user 17: 52.0
Peak congestion window size for user 18: 51.0
Peak congestion window size for user 19: 51.0


(Packet Loss)Multiplicative Decrease at: 93
Peak congestion window size for user 0: 57.0
Peak congestion window size for user 1: 57.0
Peak congestion window size for user 2: 57.0
Peak congestion window size for user 3: 57.0
Peak congestion window size for user 4: 54.0
Peak congestion window size for user 5: 57.0
Peak congestion window size for user 6: 54.0
Peak congestion window size for user 7: 57.0
Peak congestion window size for user 8: 57.0
Peak congestion window size for user 9: 54.0
Peak congestion window size for user 10: 54.0
Peak congestion window size for user 11: 57.0
Peak congestion window size for user 12: 57.0
Peak congestion window size for user 13: 57.0
Peak congestion window size for user 14: 57.0
Peak congestion window size for user 15: 54.0
Peak congestion window size for user 16: 54.0
Peak congestion window size for user 17: 57.0
Peak congestion window size for user 18: 54.0
Peak congestion window size for user 19: 54.0


(Packet Loss)Multiplicative Decrease at: 98
Peak congestion window size for user 0: 52.0
Peak congestion window size for user 1: 52.0
Peak congestion window size for user 2: 52.0
Peak congestion window size for user 3: 52.0
Peak congestion window size for user 4: 51.0
Peak congestion window size for user 5: 52.0
Peak congestion window size for user 6: 51.0
Peak congestion window size for user 7: 52.0
Peak congestion window size for user 8: 52.0
Peak congestion window size for user 9: 51.0
Peak congestion window size for user 10: 51.0
Peak congestion window size for user 11: 52.0
Peak congestion window size for user 12: 52.0
Peak congestion window size for user 13: 52.0
Peak congestion window size for user 14: 52.0
Peak congestion window size for user 15: 51.0
Peak congestion window size for user 16: 51.0
Peak congestion window size for user 17: 52.0
Peak congestion window size for user 18: 51.0
Peak congestion window size for user 19: 51.0


(Packet Loss)Multiplicative Decrease at: 104
Peak congestion window size for user 0: 57.0
Peak congestion window size for user 1: 57.0
Peak congestion window size for user 2: 57.0
Peak congestion window size for user 3: 57.0
Peak congestion window size for user 4: 54.0
Peak congestion window size for user 5: 57.0
Peak congestion window size for user 6: 54.0
Peak congestion window size for user 7: 57.0
Peak congestion window size for user 8: 57.0
Peak congestion window size for user 9: 54.0
Peak congestion window size for user 10: 54.0
```

```
Peak congestion window size for user 11: 57.0
Peak congestion window size for user 12: 57.0
Peak congestion window size for user 13: 57.0
Peak congestion window size for user 14: 57.0
Peak congestion window size for user 15: 54.0
Peak congestion window size for user 16: 54.0
Peak congestion window size for user 17: 57.0
Peak congestion window size for user 18: 54.0
Peak congestion window size for user 19: 54.0


(Packet Loss)Multiplicative Decrease at: 109
Peak congestion window size for user 0: 52.0
Peak congestion window size for user 1: 52.0
Peak congestion window size for user 2: 52.0
Peak congestion window size for user 3: 52.0
Peak congestion window size for user 4: 51.0
Peak congestion window size for user 5: 52.0
Peak congestion window size for user 6: 51.0
Peak congestion window size for user 7: 52.0
Peak congestion window size for user 8: 52.0
Peak congestion window size for user 9: 51.0
Peak congestion window size for user 10: 51.0
Peak congestion window size for user 11: 52.0
Peak congestion window size for user 12: 52.0
Peak congestion window size for user 13: 52.0
Peak congestion window size for user 14: 52.0
Peak congestion window size for user 15: 51.0
Peak congestion window size for user 16: 51.0
Peak congestion window size for user 17: 52.0
Peak congestion window size for user 18: 51.0
Peak congestion window size for user 19: 51.0


(Packet Loss)Multiplicative Decrease at: 115
Peak congestion window size for user 0: 57.0
Peak congestion window size for user 1: 57.0
Peak congestion window size for user 2: 57.0
Peak congestion window size for user 3: 57.0
Peak congestion window size for user 4: 54.0
Peak congestion window size for user 5: 57.0
Peak congestion window size for user 6: 54.0
Peak congestion window size for user 7: 57.0
Peak congestion window size for user 8: 57.0
Peak congestion window size for user 9: 54.0
Peak congestion window size for user 10: 54.0
Peak congestion window size for user 11: 57.0
Peak congestion window size for user 12: 57.0
Peak congestion window size for user 13: 57.0
Peak congestion window size for user 14: 57.0
Peak congestion window size for user 15: 54.0
Peak congestion window size for user 16: 54.0
Peak congestion window size for user 17: 57.0
Peak congestion window size for user 18: 54.0
Peak congestion window size for user 19: 54.0


(Packet Loss)Multiplicative Decrease at: 120
Peak congestion window size for user 0: 52.0
Peak congestion window size for user 1: 52.0
Peak congestion window size for user 2: 52.0
Peak congestion window size for user 3: 52.0
Peak congestion window size for user 4: 51.0
Peak congestion window size for user 5: 52.0
```

```
Peak congestion window size for user 6: 51.0
Peak congestion window size for user 7: 52.0
Peak congestion window size for user 8: 52.0
Peak congestion window size for user 9: 51.0
Peak congestion window size for user 10: 51.0
Peak congestion window size for user 11: 52.0
Peak congestion window size for user 12: 52.0
Peak congestion window size for user 13: 52.0
Peak congestion window size for user 14: 52.0
Peak congestion window size for user 15: 51.0
Peak congestion window size for user 16: 51.0
Peak congestion window size for user 17: 52.0
Peak congestion window size for user 18: 51.0
Peak congestion window size for user 19: 51.0


(Packet Loss)Multiplicative Decrease at: 126
Peak congestion window size for user 0: 57.0
Peak congestion window size for user 1: 57.0
Peak congestion window size for user 2: 57.0
Peak congestion window size for user 3: 57.0
Peak congestion window size for user 4: 54.0
Peak congestion window size for user 5: 57.0
Peak congestion window size for user 6: 54.0
Peak congestion window size for user 7: 57.0
Peak congestion window size for user 8: 57.0
Peak congestion window size for user 9: 54.0
Peak congestion window size for user 10: 54.0
Peak congestion window size for user 11: 57.0
Peak congestion window size for user 12: 57.0
Peak congestion window size for user 13: 57.0
Peak congestion window size for user 14: 57.0
Peak congestion window size for user 15: 54.0
Peak congestion window size for user 16: 54.0
Peak congestion window size for user 17: 57.0
Peak congestion window size for user 18: 54.0
Peak congestion window size for user 19: 54.0


(Packet Loss)Multiplicative Decrease at: 131
Peak congestion window size for user 0: 52.0
Peak congestion window size for user 1: 52.0
Peak congestion window size for user 2: 52.0
Peak congestion window size for user 3: 52.0
Peak congestion window size for user 4: 51.0
Peak congestion window size for user 5: 52.0
Peak congestion window size for user 6: 51.0
Peak congestion window size for user 7: 52.0
Peak congestion window size for user 8: 52.0
Peak congestion window size for user 9: 51.0
Peak congestion window size for user 10: 51.0
Peak congestion window size for user 11: 52.0
Peak congestion window size for user 12: 52.0
Peak congestion window size for user 13: 52.0
Peak congestion window size for user 14: 52.0
Peak congestion window size for user 15: 51.0
Peak congestion window size for user 16: 51.0
Peak congestion window size for user 17: 52.0
Peak congestion window size for user 18: 51.0
Peak congestion window size for user 19: 51.0


(Packet Loss)Multiplicative Decrease at: 137
Peak congestion window size for user 0: 57.0
```

```
Peak congestion window size for user 1: 57.0
Peak congestion window size for user 2: 57.0
Peak congestion window size for user 3: 57.0
Peak congestion window size for user 4: 54.0
Peak congestion window size for user 5: 57.0
Peak congestion window size for user 6: 54.0
Peak congestion window size for user 7: 57.0
Peak congestion window size for user 8: 57.0
Peak congestion window size for user 9: 54.0
Peak congestion window size for user 10: 54.0
Peak congestion window size for user 11: 57.0
Peak congestion window size for user 12: 57.0
Peak congestion window size for user 13: 57.0
Peak congestion window size for user 14: 57.0
Peak congestion window size for user 15: 54.0
Peak congestion window size for user 16: 54.0
Peak congestion window size for user 17: 57.0
Peak congestion window size for user 18: 54.0
Peak congestion window size for user 19: 54.0


(Packet Loss)Multiplicative Decrease at: 142
Peak congestion window size for user 0: 52.0
Peak congestion window size for user 1: 52.0
Peak congestion window size for user 2: 52.0
Peak congestion window size for user 3: 52.0
Peak congestion window size for user 4: 51.0
Peak congestion window size for user 5: 52.0
Peak congestion window size for user 6: 51.0
Peak congestion window size for user 7: 52.0
Peak congestion window size for user 8: 52.0
Peak congestion window size for user 9: 51.0
Peak congestion window size for user 10: 51.0
Peak congestion window size for user 11: 52.0
Peak congestion window size for user 12: 52.0
Peak congestion window size for user 13: 52.0
Peak congestion window size for user 14: 52.0
Peak congestion window size for user 15: 51.0
Peak congestion window size for user 16: 51.0
Peak congestion window size for user 17: 52.0
Peak congestion window size for user 18: 51.0
Peak congestion window size for user 19: 51.0


(Packet Loss)Multiplicative Decrease at: 148
Peak congestion window size for user 0: 57.0
Peak congestion window size for user 1: 57.0
Peak congestion window size for user 2: 57.0
Peak congestion window size for user 3: 57.0
Peak congestion window size for user 4: 54.0
Peak congestion window size for user 5: 57.0
Peak congestion window size for user 6: 54.0
Peak congestion window size for user 7: 57.0
Peak congestion window size for user 8: 57.0
Peak congestion window size for user 9: 54.0
Peak congestion window size for user 10: 54.0
Peak congestion window size for user 11: 57.0
Peak congestion window size for user 12: 57.0
Peak congestion window size for user 13: 57.0
Peak congestion window size for user 14: 57.0
Peak congestion window size for user 15: 54.0
Peak congestion window size for user 16: 54.0
Peak congestion window size for user 17: 57.0
Peak congestion window size for user 18: 54.0
```

```
                    Peak congestion window size for user 19: 54.0


                    (Packet Loss)Multiplicative Decrease at: 153
                    Peak congestion window size for user 0: 52.0
                    Peak congestion window size for user 1: 52.0
                    Peak congestion window size for user 2: 52.0
                    Peak congestion window size for user 3: 52.0
                    Peak congestion window size for user 4: 51.0
                    Peak congestion window size for user 5: 52.0
                    Peak congestion window size for user 6: 51.0
                    Peak congestion window size for user 7: 52.0
                    Peak congestion window size for user 8: 52.0
                    Peak congestion window size for user 9: 51.0
                    Peak congestion window size for user 10: 51.0
                    Peak congestion window size for user 11: 52.0
                    Peak congestion window size for user 12: 52.0
                    Peak congestion window size for user 13: 52.0
                    Peak congestion window size for user 14: 52.0
                    Peak congestion window size for user 15: 51.0
                    Peak congestion window size for user 16: 51.0
                    Peak congestion window size for user 17: 52.0
                    Peak congestion window size for user 18: 51.0
                    Peak congestion window size for user 19: 51.0


                    (Packet Loss)Multiplicative Decrease at: 159
                    Peak congestion window size for user 0: 57.0
                    Peak congestion window size for user 1: 57.0
                    Peak congestion window size for user 2: 57.0
                    Peak congestion window size for user 3: 57.0
                    Peak congestion window size for user 4: 54.0
                    Peak congestion window size for user 5: 57.0
                    Peak congestion window size for user 6: 54.0
                    Peak congestion window size for user 7: 57.0
                    Peak congestion window size for user 8: 57.0
                    Peak congestion window size for user 9: 54.0
                    Peak congestion window size for user 10: 54.0
                    Peak congestion window size for user 11: 57.0
                    Peak congestion window size for user 12: 57.0
                    Peak congestion window size for user 13: 57.0
                    Peak congestion window size for user 14: 57.0
                    Peak congestion window size for user 15: 54.0
                    Peak congestion window size for user 16: 54.0
                    Peak congestion window size for user 17: 57.0
                    Peak congestion window size for user 18: 54.0
                    Peak congestion window size for user 19: 54.0


                    (Packet Loss)Multiplicative Decrease at: 164
                    Peak congestion window size for user 0: 52.0
                    Peak congestion window size for user 1: 52.0
                    Peak congestion window size for user 2: 52.0
                    Peak congestion window size for user 3: 52.0
                    Peak congestion window size for user 4: 51.0
                    Peak congestion window size for user 5: 52.0
                    Peak congestion window size for user 6: 51.0
                    Peak congestion window size for user 7: 52.0
                    Peak congestion window size for user 8: 52.0
                    Peak congestion window size for user 9: 51.0
                    Peak congestion window size for user 10: 51.0
                    Peak congestion window size for user 11: 52.0
                    Peak congestion window size for user 12: 52.0
                    Peak congestion window size for user 13: 52.0
```

```
Peak congestion window size for user 14: 52.0
Peak congestion window size for user 15: 51.0
Peak congestion window size for user 16: 51.0
Peak congestion window size for user 17: 52.0
Peak congestion window size for user 18: 51.0
Peak congestion window size for user 19: 51.0


(Packet Loss)Multiplicative Decrease at: 170
Peak congestion window size for user 0: 57.0
Peak congestion window size for user 1: 57.0
Peak congestion window size for user 2: 57.0
Peak congestion window size for user 3: 57.0
Peak congestion window size for user 4: 54.0
Peak congestion window size for user 5: 57.0
Peak congestion window size for user 6: 54.0
Peak congestion window size for user 7: 57.0
Peak congestion window size for user 8: 57.0
Peak congestion window size for user 9: 54.0
Peak congestion window size for user 10: 54.0
Peak congestion window size for user 11: 57.0
Peak congestion window size for user 12: 57.0
Peak congestion window size for user 13: 57.0
Peak congestion window size for user 14: 57.0
Peak congestion window size for user 15: 54.0
Peak congestion window size for user 16: 54.0
Peak congestion window size for user 17: 57.0
Peak congestion window size for user 18: 54.0
Peak congestion window size for user 19: 54.0


(Packet Loss)Multiplicative Decrease at: 175
Peak congestion window size for user 0: 52.0
Peak congestion window size for user 1: 52.0
Peak congestion window size for user 2: 52.0
Peak congestion window size for user 3: 52.0
Peak congestion window size for user 4: 51.0
Peak congestion window size for user 5: 52.0
Peak congestion window size for user 6: 51.0
Peak congestion window size for user 7: 52.0
Peak congestion window size for user 8: 52.0
Peak congestion window size for user 9: 51.0
Peak congestion window size for user 10: 51.0
Peak congestion window size for user 11: 52.0
Peak congestion window size for user 12: 52.0
Peak congestion window size for user 13: 52.0
Peak congestion window size for user 14: 52.0
Peak congestion window size for user 15: 51.0
Peak congestion window size for user 16: 51.0
Peak congestion window size for user 17: 52.0
Peak congestion window size for user 18: 51.0
Peak congestion window size for user 19: 51.0


(Packet Loss)Multiplicative Decrease at: 181
Peak congestion window size for user 0: 57.0
Peak congestion window size for user 1: 57.0
Peak congestion window size for user 2: 57.0
Peak congestion window size for user 3: 57.0
Peak congestion window size for user 4: 54.0
Peak congestion window size for user 5: 57.0
Peak congestion window size for user 6: 54.0
Peak congestion window size for user 7: 57.0
Peak congestion window size for user 8: 57.0
```
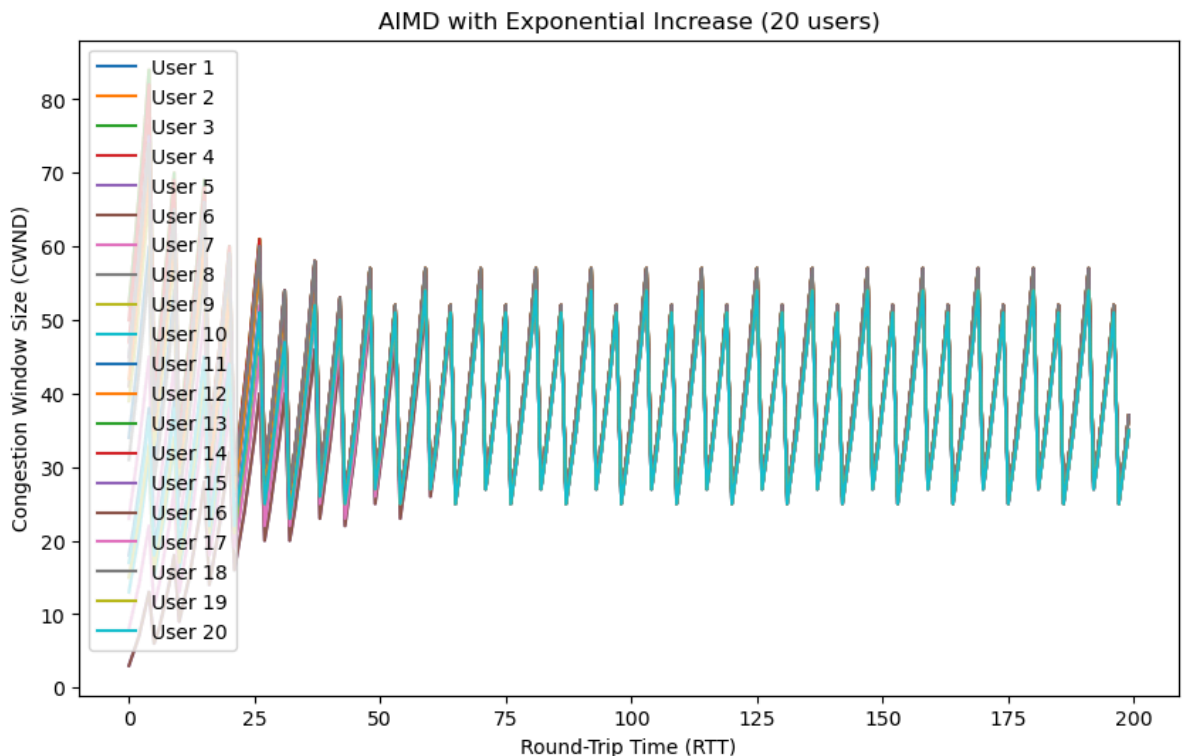
```
Peak congestion window size for user 9: 54.0
Peak congestion window size for user 10: 54.0
Peak congestion window size for user 11: 57.0
Peak congestion window size for user 12: 57.0
Peak congestion window size for user 13: 57.0
Peak congestion window size for user 14: 57.0
Peak congestion window size for user 15: 54.0
Peak congestion window size for user 16: 54.0
Peak congestion window size for user 17: 57.0
Peak congestion window size for user 18: 54.0
Peak congestion window size for user 19: 54.0


(Packet Loss)Multiplicative Decrease at: 186
Peak congestion window size for user 0: 52.0
Peak congestion window size for user 1: 52.0
Peak congestion window size for user 2: 52.0
Peak congestion window size for user 3: 52.0
Peak congestion window size for user 4: 51.0
Peak congestion window size for user 5: 52.0
Peak congestion window size for user 6: 51.0
Peak congestion window size for user 7: 52.0
Peak congestion window size for user 8: 52.0
Peak congestion window size for user 9: 51.0
Peak congestion window size for user 10: 51.0
Peak congestion window size for user 11: 52.0
Peak congestion window size for user 12: 52.0
Peak congestion window size for user 13: 52.0
Peak congestion window size for user 14: 52.0
Peak congestion window size for user 15: 51.0
Peak congestion window size for user 16: 51.0
Peak congestion window size for user 17: 52.0
Peak congestion window size for user 18: 51.0
Peak congestion window size for user 19: 51.0


(Packet Loss)Multiplicative Decrease at: 192
Peak congestion window size for user 0: 57.0
Peak congestion window size for user 1: 57.0
Peak congestion window size for user 2: 57.0
Peak congestion window size for user 3: 57.0
Peak congestion window size for user 4: 54.0
Peak congestion window size for user 5: 57.0
Peak congestion window size for user 6: 54.0
Peak congestion window size for user 7: 57.0
Peak congestion window size for user 8: 57.0
Peak congestion window size for user 9: 54.0
Peak congestion window size for user 10: 54.0
Peak congestion window size for user 11: 57.0
Peak congestion window size for user 12: 57.0
Peak congestion window size for user 13: 57.0
Peak congestion window size for user 14: 57.0
Peak congestion window size for user 15: 54.0
Peak congestion window size for user 16: 54.0
Peak congestion window size for user 17: 57.0
Peak congestion window size for user 18: 54.0
Peak congestion window size for user 19: 54.0


(Packet Loss)Multiplicative Decrease at: 197
Peak congestion window size for user 0: 52.0
Peak congestion window size for user 1: 52.0
Peak congestion window size for user 2: 52.0
Peak congestion window size for user 3: 52.0
```

```
Peak congestion window size for user 4: 51.0
Peak congestion window size for user 5: 52.0
Peak congestion window size for user 6: 51.0
Peak congestion window size for user 7: 52.0
Peak congestion window size for user 8: 52.0
Peak congestion window size for user 9: 51.0
Peak congestion window size for user 10: 51.0
Peak congestion window size for user 11: 52.0
Peak congestion window size for user 12: 52.0
Peak congestion window size for user 13: 52.0
Peak congestion window size for user 14: 52.0
Peak congestion window size for user 15: 51.0
Peak congestion window size for user 16: 51.0
Peak congestion window size for user 17: 52.0
Peak congestion window size for user 18: 51.0
Peak congestion window size for user 19: 51.0
```


AIMD with Exponential Increase (20 users)

Observation:

Converged at RTT 49, Packet loss count 8

Experiment with 20 users (cwnd = 2000)

```
In [16]:   # Experiment Variables
           num_users = 20
           max_RTT = 200
           max_cwnd = 2000
           # Define the initial cwnd size for users.
           initial_cwnd = np.random.rand(20)
           initial_cwnd *= max_cwnd // num_users
           initial_cwnd = np.round(initial_cwnd)

           # Simulation of AIMD
           cwnd_tracker = simulate_aimd(max_RTT, num_users, alpha_func_exp, beta_func, initial

           # Plot graph of RTT over CWND
           plot_title = "AIMD with Exponential Increase (20 users)"
           plot_graph(num_users, cwnd_tracker, plot_title)
```

```
Initial cwnd for user 0: 63.0
Initial cwnd for user 1: 56.0
Initial cwnd for user 2: 32.0
Initial cwnd for user 3: 39.0
Initial cwnd for user 4: 26.0
Initial cwnd for user 5: 58.0
Initial cwnd for user 6: 16.0
Initial cwnd for user 7: 60.0
Initial cwnd for user 8: 83.0
Initial cwnd for user 9: 16.0
Initial cwnd for user 10: 73.0
Initial cwnd for user 11: 41.0
Initial cwnd for user 12: 78.0
Initial cwnd for user 13: 80.0
Initial cwnd for user 14: 79.0
Initial cwnd for user 15: 59.0
Initial cwnd for user 16: 66.0
Initial cwnd for user 17: 65.0
Initial cwnd for user 18: 43.0
Initial cwnd for user 19: 51.0


(Packet Loss)Multiplicative Decrease at: 6
Peak congestion window size for user 0: 117.0
Peak congestion window size for user 1: 107.0
Peak congestion window size for user 2: 74.0
Peak congestion window size for user 3: 84.0
Peak congestion window size for user 4: 65.0
Peak congestion window size for user 5: 112.0
Peak congestion window size for user 6: 46.0
Peak congestion window size for user 7: 114.0
Peak congestion window size for user 8: 146.0
Peak congestion window size for user 9: 46.0
Peak congestion window size for user 10: 133.0
Peak congestion window size for user 11: 86.0
Peak congestion window size for user 12: 138.0
Peak congestion window size for user 13: 140.0
Peak congestion window size for user 14: 139.0
Peak congestion window size for user 15: 113.0
Peak congestion window size for user 16: 123.0
Peak congestion window size for user 17: 122.0
Peak congestion window size for user 18: 91.0
Peak congestion window size for user 19: 102.0


(Packet Loss)Multiplicative Decrease at: 13
Peak congestion window size for user 0: 112.0
Peak congestion window size for user 1: 104.0
Peak congestion window size for user 2: 82.0
Peak congestion window size for user 3: 87.0
Peak congestion window size for user 4: 74.0
Peak congestion window size for user 5: 107.0
Peak congestion window size for user 6: 59.0
Peak congestion window size for user 7: 111.0
Peak congestion window size for user 8: 133.0
Peak congestion window size for user 9: 59.0
Peak congestion window size for user 10: 123.0
Peak congestion window size for user 11: 91.0
Peak congestion window size for user 12: 126.0
Peak congestion window size for user 13: 127.0
Peak congestion window size for user 14: 126.0
Peak congestion window size for user 15: 107.0
Peak congestion window size for user 16: 115.0
Peak congestion window size for user 17: 115.0
```

```
        Peak congestion window size for user 18: 93.0
        Peak congestion window size for user 19: 102.0


        (Packet Loss)Multiplicative Decrease at: 20
        Peak congestion window size for user 0: 107.0
        Peak congestion window size for user 1: 103.0
        Peak congestion window size for user 2: 86.0
        Peak congestion window size for user 3: 91.0
        Peak congestion window size for user 4: 82.0
        Peak congestion window size for user 5: 104.0
        Peak congestion window size for user 6: 68.0
        Peak congestion window size for user 7: 106.0
        Peak congestion window size for user 8: 123.0
        Peak congestion window size for user 9: 68.0
        Peak congestion window size for user 10: 115.0
        Peak congestion window size for user 11: 93.0
        Peak congestion window size for user 12: 117.0
        Peak congestion window size for user 13: 117.0
        Peak congestion window size for user 14: 117.0
        Peak congestion window size for user 15: 104.0
        Peak congestion window size for user 16: 111.0
        Peak congestion window size for user 17: 111.0
        Peak congestion window size for user 18: 94.0
        Peak congestion window size for user 19: 102.0


        (Packet Loss)Multiplicative Decrease at: 27
        Peak congestion window size for user 0: 104.0
        Peak congestion window size for user 1: 102.0
        Peak congestion window size for user 2: 91.0
        Peak congestion window size for user 3: 93.0
        Peak congestion window size for user 4: 86.0
        Peak congestion window size for user 5: 103.0
        Peak congestion window size for user 6: 76.0
        Peak congestion window size for user 7: 104.0
        Peak congestion window size for user 8: 115.0
        Peak congestion window size for user 9: 76.0
        Peak congestion window size for user 10: 111.0
        Peak congestion window size for user 11: 94.0
        Peak congestion window size for user 12: 112.0
        Peak congestion window size for user 13: 112.0
        Peak congestion window size for user 14: 112.0
        Peak congestion window size for user 15: 103.0
        Peak congestion window size for user 16: 106.0
        Peak congestion window size for user 17: 106.0
        Peak congestion window size for user 18: 95.0
        Peak congestion window size for user 19: 102.0


        (Packet Loss)Multiplicative Decrease at: 35
        Peak congestion window size for user 0: 113.0
        Peak congestion window size for user 1: 112.0
        Peak congestion window size for user 2: 103.0
        Peak congestion window size for user 3: 104.0
        Peak congestion window size for user 4: 101.0
        Peak congestion window size for user 5: 112.0
        Peak congestion window size for user 6: 92.0
        Peak congestion window size for user 7: 113.0
        Peak congestion window size for user 8: 122.0
        Peak congestion window size for user 9: 92.0
        Peak congestion window size for user 10: 116.0
        Peak congestion window size for user 11: 105.0
        Peak congestion window size for user 12: 117.0
```

```
Peak congestion window size for user 13: 117.0
Peak congestion window size for user 14: 117.0
Peak congestion window size for user 15: 112.0
Peak congestion window size for user 16: 114.0
Peak congestion window size for user 17: 114.0
Peak congestion window size for user 18: 105.0
Peak congestion window size for user 19: 112.0


(Packet Loss)Multiplicative Decrease at: 42
Peak congestion window size for user 0: 107.0
Peak congestion window size for user 1: 107.0
Peak congestion window size for user 2: 102.0
Peak congestion window size for user 3: 103.0
Peak congestion window size for user 4: 101.0
Peak congestion window size for user 5: 107.0
Peak congestion window size for user 6: 94.0
Peak congestion window size for user 7: 107.0
Peak congestion window size for user 8: 115.0
Peak congestion window size for user 9: 94.0
Peak congestion window size for user 10: 112.0
Peak congestion window size for user 11: 103.0
Peak congestion window size for user 12: 112.0
Peak congestion window size for user 13: 112.0
Peak congestion window size for user 14: 112.0
Peak congestion window size for user 15: 107.0
Peak congestion window size for user 16: 111.0
Peak congestion window size for user 17: 111.0
Peak congestion window size for user 18: 103.0
Peak congestion window size for user 19: 107.0


(Packet Loss)Multiplicative Decrease at: 49
Peak congestion window size for user 0: 104.0
Peak congestion window size for user 1: 104.0
Peak congestion window size for user 2: 102.0
Peak congestion window size for user 3: 102.0
Peak congestion window size for user 4: 101.0
Peak congestion window size for user 5: 104.0
Peak congestion window size for user 6: 95.0
Peak congestion window size for user 7: 104.0
Peak congestion window size for user 8: 111.0
Peak congestion window size for user 9: 95.0
Peak congestion window size for user 10: 107.0
Peak congestion window size for user 11: 102.0
Peak congestion window size for user 12: 107.0
Peak congestion window size for user 13: 107.0
Peak congestion window size for user 14: 107.0
Peak congestion window size for user 15: 104.0
Peak congestion window size for user 16: 106.0
Peak congestion window size for user 17: 106.0
Peak congestion window size for user 18: 102.0
Peak congestion window size for user 19: 104.0


(Packet Loss)Multiplicative Decrease at: 56
Peak congestion window size for user 0: 103.0
Peak congestion window size for user 1: 103.0
Peak congestion window size for user 2: 102.0
Peak congestion window size for user 3: 102.0
Peak congestion window size for user 4: 101.0
Peak congestion window size for user 5: 103.0
Peak congestion window size for user 6: 95.0
Peak congestion window size for user 7: 103.0
```

```
Peak congestion window size for user 8: 106.0
Peak congestion window size for user 9: 95.0
Peak congestion window size for user 10: 104.0
Peak congestion window size for user 11: 102.0
Peak congestion window size for user 12: 104.0
Peak congestion window size for user 13: 104.0
Peak congestion window size for user 14: 104.0
Peak congestion window size for user 15: 103.0
Peak congestion window size for user 16: 104.0
Peak congestion window size for user 17: 104.0
Peak congestion window size for user 18: 102.0
Peak congestion window size for user 19: 103.0


(Packet Loss)Multiplicative Decrease at: 63
Peak congestion window size for user 0: 102.0
Peak congestion window size for user 1: 102.0
Peak congestion window size for user 2: 102.0
Peak congestion window size for user 3: 102.0
Peak congestion window size for user 4: 101.0
Peak congestion window size for user 5: 102.0
Peak congestion window size for user 6: 95.0
Peak congestion window size for user 7: 102.0
Peak congestion window size for user 8: 104.0
Peak congestion window size for user 9: 95.0
Peak congestion window size for user 10: 103.0
Peak congestion window size for user 11: 102.0
Peak congestion window size for user 12: 103.0
Peak congestion window size for user 13: 103.0
Peak congestion window size for user 14: 103.0
Peak congestion window size for user 15: 102.0
Peak congestion window size for user 16: 103.0
Peak congestion window size for user 17: 103.0
Peak congestion window size for user 18: 102.0
Peak congestion window size for user 19: 102.0


(Packet Loss)Multiplicative Decrease at: 70
Peak congestion window size for user 0: 102.0
Peak congestion window size for user 1: 102.0
Peak congestion window size for user 2: 102.0
Peak congestion window size for user 3: 102.0
Peak congestion window size for user 4: 101.0
Peak congestion window size for user 5: 102.0
Peak congestion window size for user 6: 95.0
Peak congestion window size for user 7: 102.0
Peak congestion window size for user 8: 103.0
Peak congestion window size for user 9: 95.0
Peak congestion window size for user 10: 102.0
Peak congestion window size for user 11: 102.0
Peak congestion window size for user 12: 102.0
Peak congestion window size for user 13: 102.0
Peak congestion window size for user 14: 102.0
Peak congestion window size for user 15: 102.0
Peak congestion window size for user 16: 102.0
Peak congestion window size for user 17: 102.0
Peak congestion window size for user 18: 102.0
Peak congestion window size for user 19: 102.0


(Packet Loss)Multiplicative Decrease at: 77
Peak congestion window size for user 0: 102.0
Peak congestion window size for user 1: 102.0
Peak congestion window size for user 2: 102.0
```

```
Peak congestion window size for user 3: 102.0
Peak congestion window size for user 4: 101.0
Peak congestion window size for user 5: 102.0
Peak congestion window size for user 6: 95.0
Peak congestion window size for user 7: 102.0
Peak congestion window size for user 8: 102.0
Peak congestion window size for user 9: 95.0
Peak congestion window size for user 10: 102.0
Peak congestion window size for user 11: 102.0
Peak congestion window size for user 12: 102.0
Peak congestion window size for user 13: 102.0
Peak congestion window size for user 14: 102.0
Peak congestion window size for user 15: 102.0
Peak congestion window size for user 16: 102.0
Peak congestion window size for user 17: 102.0
Peak congestion window size for user 18: 102.0
Peak congestion window size for user 19: 102.0


(Packet Loss)Multiplicative Decrease at: 84
Peak congestion window size for user 0: 102.0
Peak congestion window size for user 1: 102.0
Peak congestion window size for user 2: 102.0
Peak congestion window size for user 3: 102.0
Peak congestion window size for user 4: 101.0
Peak congestion window size for user 5: 102.0
Peak congestion window size for user 6: 95.0
Peak congestion window size for user 7: 102.0
Peak congestion window size for user 8: 102.0
Peak congestion window size for user 9: 95.0
Peak congestion window size for user 10: 102.0
Peak congestion window size for user 11: 102.0
Peak congestion window size for user 12: 102.0
Peak congestion window size for user 13: 102.0
Peak congestion window size for user 14: 102.0
Peak congestion window size for user 15: 102.0
Peak congestion window size for user 16: 102.0
Peak congestion window size for user 17: 102.0
Peak congestion window size for user 18: 102.0
Peak congestion window size for user 19: 102.0


(Packet Loss)Multiplicative Decrease at: 91
Peak congestion window size for user 0: 102.0
Peak congestion window size for user 1: 102.0
Peak congestion window size for user 2: 102.0
Peak congestion window size for user 3: 102.0
Peak congestion window size for user 4: 101.0
Peak congestion window size for user 5: 102.0
Peak congestion window size for user 6: 95.0
Peak congestion window size for user 7: 102.0
Peak congestion window size for user 8: 102.0
Peak congestion window size for user 9: 95.0
Peak congestion window size for user 10: 102.0
Peak congestion window size for user 11: 102.0
Peak congestion window size for user 12: 102.0
Peak congestion window size for user 13: 102.0
Peak congestion window size for user 14: 102.0
Peak congestion window size for user 15: 102.0
Peak congestion window size for user 16: 102.0
Peak congestion window size for user 17: 102.0
Peak congestion window size for user 18: 102.0
Peak congestion window size for user 19: 102.0
```

```
(Packet Loss)Multiplicative Decrease at: 98
Peak congestion window size for user 0: 102.0
Peak congestion window size for user 1: 102.0
Peak congestion window size for user 2: 102.0
Peak congestion window size for user 3: 102.0
Peak congestion window size for user 4: 101.0
Peak congestion window size for user 5: 102.0
Peak congestion window size for user 6: 95.0
Peak congestion window size for user 7: 102.0
Peak congestion window size for user 8: 102.0
Peak congestion window size for user 9: 95.0
Peak congestion window size for user 10: 102.0
Peak congestion window size for user 11: 102.0
Peak congestion window size for user 12: 102.0
Peak congestion window size for user 13: 102.0
Peak congestion window size for user 14: 102.0
Peak congestion window size for user 15: 102.0
Peak congestion window size for user 16: 102.0
Peak congestion window size for user 17: 102.0
Peak congestion window size for user 18: 102.0
Peak congestion window size for user 19: 102.0


(Packet Loss)Multiplicative Decrease at: 105
Peak congestion window size for user 0: 102.0
Peak congestion window size for user 1: 102.0
Peak congestion window size for user 2: 102.0
Peak congestion window size for user 3: 102.0
Peak congestion window size for user 4: 101.0
Peak congestion window size for user 5: 102.0
Peak congestion window size for user 6: 95.0
Peak congestion window size for user 7: 102.0
Peak congestion window size for user 8: 102.0
Peak congestion window size for user 9: 95.0
Peak congestion window size for user 10: 102.0
Peak congestion window size for user 11: 102.0
Peak congestion window size for user 12: 102.0
Peak congestion window size for user 13: 102.0
Peak congestion window size for user 14: 102.0
Peak congestion window size for user 15: 102.0
Peak congestion window size for user 16: 102.0
Peak congestion window size for user 17: 102.0
Peak congestion window size for user 18: 102.0
Peak congestion window size for user 19: 102.0


(Packet Loss)Multiplicative Decrease at: 112
Peak congestion window size for user 0: 102.0
Peak congestion window size for user 1: 102.0
Peak congestion window size for user 2: 102.0
Peak congestion window size for user 3: 102.0
Peak congestion window size for user 4: 101.0
Peak congestion window size for user 5: 102.0
Peak congestion window size for user 6: 95.0
Peak congestion window size for user 7: 102.0
Peak congestion window size for user 8: 102.0
Peak congestion window size for user 9: 95.0
Peak congestion window size for user 10: 102.0
Peak congestion window size for user 11: 102.0
Peak congestion window size for user 12: 102.0
Peak congestion window size for user 13: 102.0
Peak congestion window size for user 14: 102.0
Peak congestion window size for user 15: 102.0
```

```
Peak congestion window size for user 16: 102.0
Peak congestion window size for user 17: 102.0
Peak congestion window size for user 18: 102.0
Peak congestion window size for user 19: 102.0


(Packet Loss)Multiplicative Decrease at: 119
Peak congestion window size for user 0: 102.0
Peak congestion window size for user 1: 102.0
Peak congestion window size for user 2: 102.0
Peak congestion window size for user 3: 102.0
Peak congestion window size for user 4: 101.0
Peak congestion window size for user 5: 102.0
Peak congestion window size for user 6: 95.0
Peak congestion window size for user 7: 102.0
Peak congestion window size for user 8: 102.0
Peak congestion window size for user 9: 95.0
Peak congestion window size for user 10: 102.0
Peak congestion window size for user 11: 102.0
Peak congestion window size for user 12: 102.0
Peak congestion window size for user 13: 102.0
Peak congestion window size for user 14: 102.0
Peak congestion window size for user 15: 102.0
Peak congestion window size for user 16: 102.0
Peak congestion window size for user 17: 102.0
Peak congestion window size for user 18: 102.0
Peak congestion window size for user 19: 102.0


(Packet Loss)Multiplicative Decrease at: 126
Peak congestion window size for user 0: 102.0
Peak congestion window size for user 1: 102.0
Peak congestion window size for user 2: 102.0
Peak congestion window size for user 3: 102.0
Peak congestion window size for user 4: 101.0
Peak congestion window size for user 5: 102.0
Peak congestion window size for user 6: 95.0
Peak congestion window size for user 7: 102.0
Peak congestion window size for user 8: 102.0
Peak congestion window size for user 9: 95.0
Peak congestion window size for user 10: 102.0
Peak congestion window size for user 11: 102.0
Peak congestion window size for user 12: 102.0
Peak congestion window size for user 13: 102.0
Peak congestion window size for user 14: 102.0
Peak congestion window size for user 15: 102.0
Peak congestion window size for user 16: 102.0
Peak congestion window size for user 17: 102.0
Peak congestion window size for user 18: 102.0
Peak congestion window size for user 19: 102.0


(Packet Loss)Multiplicative Decrease at: 133
Peak congestion window size for user 0: 102.0
Peak congestion window size for user 1: 102.0
Peak congestion window size for user 2: 102.0
Peak congestion window size for user 3: 102.0
Peak congestion window size for user 4: 101.0
Peak congestion window size for user 5: 102.0
Peak congestion window size for user 6: 95.0
Peak congestion window size for user 7: 102.0
Peak congestion window size for user 8: 102.0
Peak congestion window size for user 9: 95.0
Peak congestion window size for user 10: 102.0
```

```
Peak congestion window size for user 11: 102.0
Peak congestion window size for user 12: 102.0
Peak congestion window size for user 13: 102.0
Peak congestion window size for user 14: 102.0
Peak congestion window size for user 15: 102.0
Peak congestion window size for user 16: 102.0
Peak congestion window size for user 17: 102.0
Peak congestion window size for user 18: 102.0
Peak congestion window size for user 19: 102.0


(Packet Loss)Multiplicative Decrease at: 140
Peak congestion window size for user 0: 102.0
Peak congestion window size for user 1: 102.0
Peak congestion window size for user 2: 102.0
Peak congestion window size for user 3: 102.0
Peak congestion window size for user 4: 101.0
Peak congestion window size for user 5: 102.0
Peak congestion window size for user 6: 95.0
Peak congestion window size for user 7: 102.0
Peak congestion window size for user 8: 102.0
Peak congestion window size for user 9: 95.0
Peak congestion window size for user 10: 102.0
Peak congestion window size for user 11: 102.0
Peak congestion window size for user 12: 102.0
Peak congestion window size for user 13: 102.0
Peak congestion window size for user 14: 102.0
Peak congestion window size for user 15: 102.0
Peak congestion window size for user 16: 102.0
Peak congestion window size for user 17: 102.0
Peak congestion window size for user 18: 102.0
Peak congestion window size for user 19: 102.0


(Packet Loss)Multiplicative Decrease at: 147
Peak congestion window size for user 0: 102.0
Peak congestion window size for user 1: 102.0
Peak congestion window size for user 2: 102.0
Peak congestion window size for user 3: 102.0
Peak congestion window size for user 4: 101.0
Peak congestion window size for user 5: 102.0
Peak congestion window size for user 6: 95.0
Peak congestion window size for user 7: 102.0
Peak congestion window size for user 8: 102.0
Peak congestion window size for user 9: 95.0
Peak congestion window size for user 10: 102.0
Peak congestion window size for user 11: 102.0
Peak congestion window size for user 12: 102.0
Peak congestion window size for user 13: 102.0
Peak congestion window size for user 14: 102.0
Peak congestion window size for user 15: 102.0
Peak congestion window size for user 16: 102.0
Peak congestion window size for user 17: 102.0
Peak congestion window size for user 18: 102.0
Peak congestion window size for user 19: 102.0


(Packet Loss)Multiplicative Decrease at: 154
Peak congestion window size for user 0: 102.0
Peak congestion window size for user 1: 102.0
Peak congestion window size for user 2: 102.0
Peak congestion window size for user 3: 102.0
Peak congestion window size for user 4: 101.0
Peak congestion window size for user 5: 102.0
```

```
Peak congestion window size for user 6: 95.0
Peak congestion window size for user 7: 102.0
Peak congestion window size for user 8: 102.0
Peak congestion window size for user 9: 95.0
Peak congestion window size for user 10: 102.0
Peak congestion window size for user 11: 102.0
Peak congestion window size for user 12: 102.0
Peak congestion window size for user 13: 102.0
Peak congestion window size for user 14: 102.0
Peak congestion window size for user 15: 102.0
Peak congestion window size for user 16: 102.0
Peak congestion window size for user 17: 102.0
Peak congestion window size for user 18: 102.0
Peak congestion window size for user 19: 102.0


(Packet Loss)Multiplicative Decrease at: 161
Peak congestion window size for user 0: 102.0
Peak congestion window size for user 1: 102.0
Peak congestion window size for user 2: 102.0
Peak congestion window size for user 3: 102.0
Peak congestion window size for user 4: 101.0
Peak congestion window size for user 5: 102.0
Peak congestion window size for user 6: 95.0
Peak congestion window size for user 7: 102.0
Peak congestion window size for user 8: 102.0
Peak congestion window size for user 9: 95.0
Peak congestion window size for user 10: 102.0
Peak congestion window size for user 11: 102.0
Peak congestion window size for user 12: 102.0
Peak congestion window size for user 13: 102.0
Peak congestion window size for user 14: 102.0
Peak congestion window size for user 15: 102.0
Peak congestion window size for user 16: 102.0
Peak congestion window size for user 17: 102.0
Peak congestion window size for user 18: 102.0
Peak congestion window size for user 19: 102.0


(Packet Loss)Multiplicative Decrease at: 168
Peak congestion window size for user 0: 102.0
Peak congestion window size for user 1: 102.0
Peak congestion window size for user 2: 102.0
Peak congestion window size for user 3: 102.0
Peak congestion window size for user 4: 101.0
Peak congestion window size for user 5: 102.0
Peak congestion window size for user 6: 95.0
Peak congestion window size for user 7: 102.0
Peak congestion window size for user 8: 102.0
Peak congestion window size for user 9: 95.0
Peak congestion window size for user 10: 102.0
Peak congestion window size for user 11: 102.0
Peak congestion window size for user 12: 102.0
Peak congestion window size for user 13: 102.0
Peak congestion window size for user 14: 102.0
Peak congestion window size for user 15: 102.0
Peak congestion window size for user 16: 102.0
Peak congestion window size for user 17: 102.0
Peak congestion window size for user 18: 102.0
Peak congestion window size for user 19: 102.0


(Packet Loss)Multiplicative Decrease at: 175
Peak congestion window size for user 0: 102.0
```
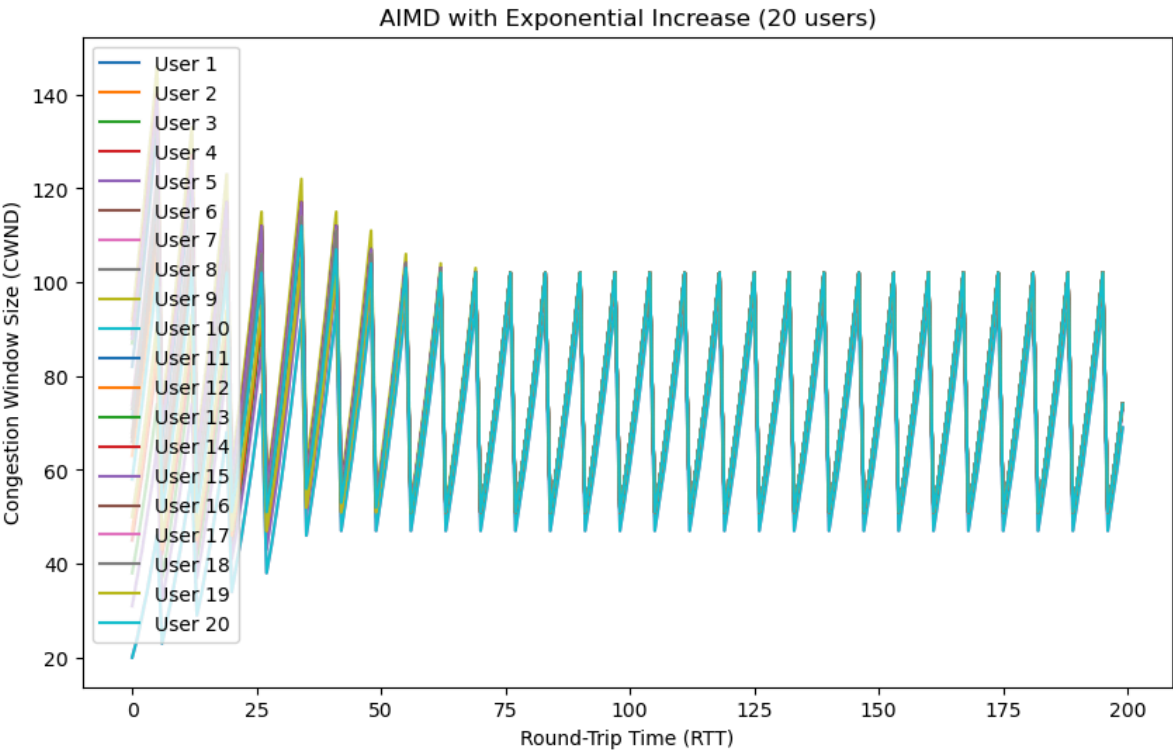
```
Peak congestion window size for user 1: 102.0
Peak congestion window size for user 2: 102.0
Peak congestion window size for user 3: 102.0
Peak congestion window size for user 4: 101.0
Peak congestion window size for user 5: 102.0
Peak congestion window size for user 6: 95.0
Peak congestion window size for user 7: 102.0
Peak congestion window size for user 8: 102.0
Peak congestion window size for user 9: 95.0
Peak congestion window size for user 10: 102.0
Peak congestion window size for user 11: 102.0
Peak congestion window size for user 12: 102.0
Peak congestion window size for user 13: 102.0
Peak congestion window size for user 14: 102.0
Peak congestion window size for user 15: 102.0
Peak congestion window size for user 16: 102.0
Peak congestion window size for user 17: 102.0
Peak congestion window size for user 18: 102.0
Peak congestion window size for user 19: 102.0


(Packet Loss)Multiplicative Decrease at: 182
Peak congestion window size for user 0: 102.0
Peak congestion window size for user 1: 102.0
Peak congestion window size for user 2: 102.0
Peak congestion window size for user 3: 102.0
Peak congestion window size for user 4: 101.0
Peak congestion window size for user 5: 102.0
Peak congestion window size for user 6: 95.0
Peak congestion window size for user 7: 102.0
Peak congestion window size for user 8: 102.0
Peak congestion window size for user 9: 95.0
Peak congestion window size for user 10: 102.0
Peak congestion window size for user 11: 102.0
Peak congestion window size for user 12: 102.0
Peak congestion window size for user 13: 102.0
Peak congestion window size for user 14: 102.0
Peak congestion window size for user 15: 102.0
Peak congestion window size for user 16: 102.0
Peak congestion window size for user 17: 102.0
Peak congestion window size for user 18: 102.0
Peak congestion window size for user 19: 102.0


(Packet Loss)Multiplicative Decrease at: 189
Peak congestion window size for user 0: 102.0
Peak congestion window size for user 1: 102.0
Peak congestion window size for user 2: 102.0
Peak congestion window size for user 3: 102.0
Peak congestion window size for user 4: 101.0
Peak congestion window size for user 5: 102.0
Peak congestion window size for user 6: 95.0
Peak congestion window size for user 7: 102.0
Peak congestion window size for user 8: 102.0
Peak congestion window size for user 9: 95.0
Peak congestion window size for user 10: 102.0
Peak congestion window size for user 11: 102.0
Peak congestion window size for user 12: 102.0
Peak congestion window size for user 13: 102.0
Peak congestion window size for user 14: 102.0
Peak congestion window size for user 15: 102.0
Peak congestion window size for user 16: 102.0
Peak congestion window size for user 17: 102.0
Peak congestion window size for user 18: 102.0
```

```
         Peak congestion window size for user 19: 102.0


         (Packet Loss)Multiplicative Decrease at: 196
         Peak congestion window size for user 0: 102.0
         Peak congestion window size for user 1: 102.0
         Peak congestion window size for user 2: 102.0
         Peak congestion window size for user 3: 102.0
         Peak congestion window size for user 4: 101.0
         Peak congestion window size for user 5: 102.0
         Peak congestion window size for user 6: 95.0
         Peak congestion window size for user 7: 102.0
         Peak congestion window size for user 8: 102.0
         Peak congestion window size for user 9: 95.0
         Peak congestion window size for user 10: 102.0
         Peak congestion window size for user 11: 102.0
         Peak congestion window size for user 12: 102.0
         Peak congestion window size for user 13: 102.0
         Peak congestion window size for user 14: 102.0
         Peak congestion window size for user 15: 102.0
         Peak congestion window size for user 16: 102.0
         Peak congestion window size for user 17: 102.0
         Peak congestion window size for user 18: 102.0
         Peak congestion window size for user 19: 102.0
```


Observation:

Converged at RTT 77, Packet loss count 10

```
In [ ]:
```

2/28/24, 9:03 PM

Experiment 4: AIMD with User Priority

In this experiment, we differentiate user priorities by modifying the alpha function. Each user's alpha value depends on their index, which results in one user's cwnd grows faster than the other's, simulating a priority system.For consistency, user 2 is the premium user tier and thus has a larger share of the network bandwidth, compared to user 1.

Experiment with different alpha values (30,70)

```
In [17]:  # Experiment Variables
          num_users = 2
          max_RTT = 200
          max_cwnd = 100
          # Define the initial cwnd size for users.
          initial_cwnd = [30, 70]


          # Simulation of AIMD
          cwnd_tracker = simulate_aimd(max_RTT, num_users, alpha_func_priority, beta_func, in

          # Plot graph of RTT over CWND
          plot_title = "AIMD with User Priority (different initial cwnd) [30, 70]"
          plot_graph(num_users, cwnd_tracker, plot_title)
```

```
Initial cwnd for user 0: 30.0
Initial cwnd for user 1: 70.0


(Packet Loss)Multiplicative Decrease at: 1
Peak congestion window size for user 0: 31.0
Peak congestion window size for user 1: 72.0


(Packet Loss)Multiplicative Decrease at: 19
Peak congestion window size for user 0: 32.0
Peak congestion window size for user 1: 70.0


(Packet Loss)Multiplicative Decrease at: 37
Peak congestion window size for user 0: 33.0
Peak congestion window size for user 1: 69.0


(Packet Loss)Multiplicative Decrease at: 55
Peak congestion window size for user 0: 33.0
Peak congestion window size for user 1: 68.0


(Packet Loss)Multiplicative Decrease at: 73
Peak congestion window size for user 0: 33.0
Peak congestion window size for user 1: 68.0


(Packet Loss)Multiplicative Decrease at: 91
Peak congestion window size for user 0: 33.0
Peak congestion window size for user 1: 68.0


(Packet Loss)Multiplicative Decrease at: 109
Peak congestion window size for user 0: 33.0
Peak congestion window size for user 1: 68.0


(Packet Loss)Multiplicative Decrease at: 127
Peak congestion window size for user 0: 33.0
Peak congestion window size for user 1: 68.0


(Packet Loss)Multiplicative Decrease at: 145
Peak congestion window size for user 0: 33.0
Peak congestion window size for user 1: 68.0


(Packet Loss)Multiplicative Decrease at: 163
Peak congestion window size for user 0: 33.0
Peak congestion window size for user 1: 68.0


(Packet Loss)Multiplicative Decrease at: 181
Peak congestion window size for user 0: 33.0
Peak congestion window size for user 1: 68.0


(Packet Loss)Multiplicative Decrease at: 199
Peak congestion window size for user 0: 33.0
Peak congestion window size for user 1: 68.0
```
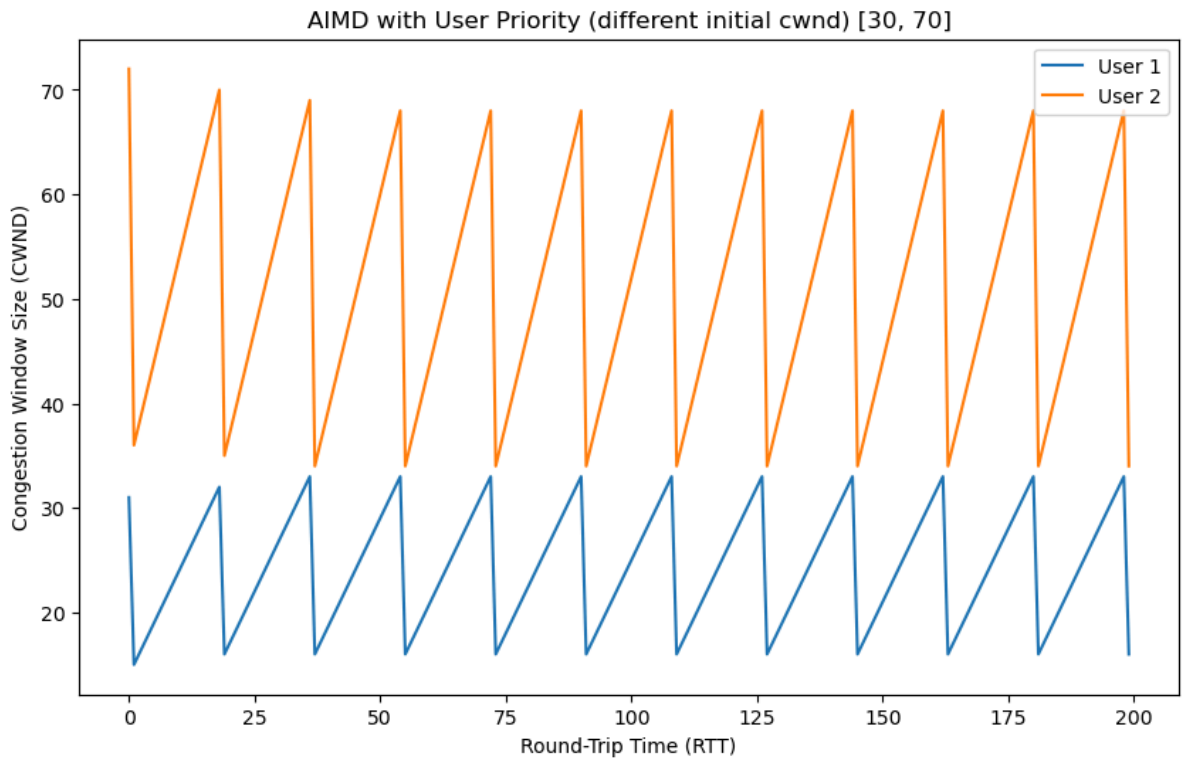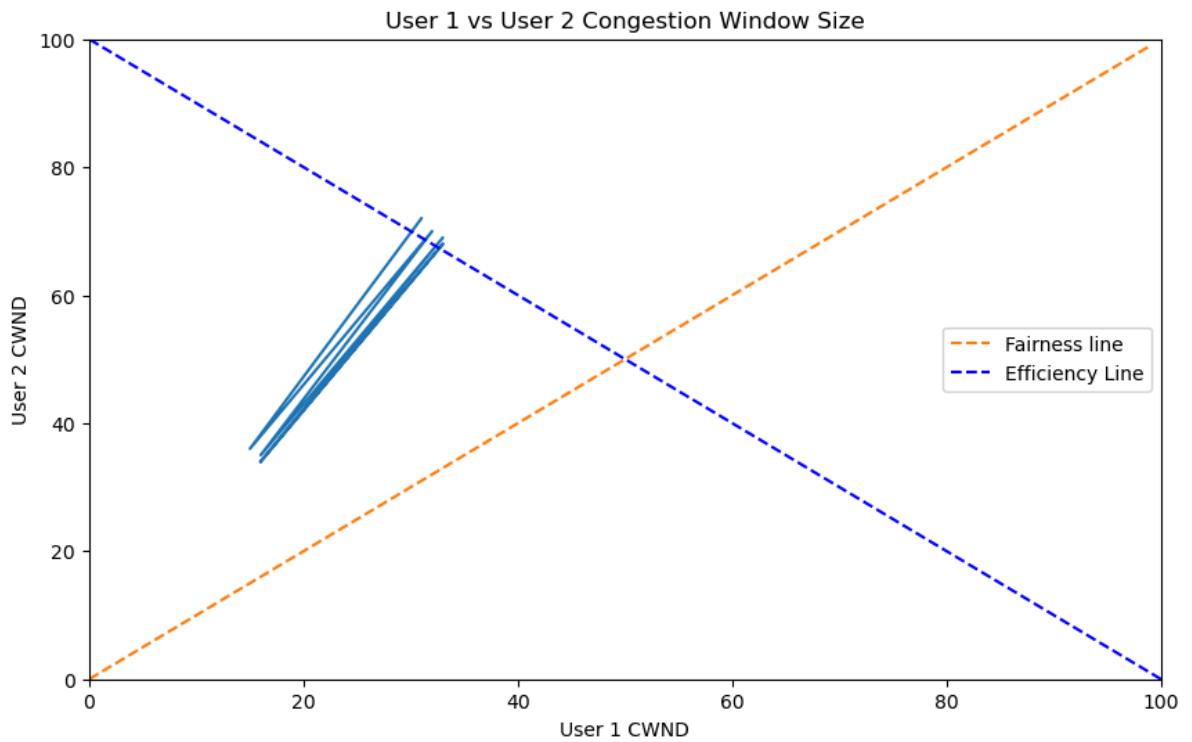
User 1 vs User 2 Congestion Window Size

AIMD with User Priority (different initial cwnd) [30, 70]

Observation:

The AIMD converge at around RTT 55, Packet loss count 3

We can see that in this experiment the zig-zag line of user 1 is not aligned with user 2 as compared to the experiment 1, this is because that we implemented user priority in this experiment and for each users we will have different increase value for additive increase phase. This experiment converges faster as compared to experiment 1, possible reason might be due to the implementation of alpha function, we implemented it by adding the user index which increase the rate of increase of cwnd size hence it will converges slightly faster.

Experiment with different alpha values (70,30)

```
In [18]:  # Experiment Variables
          num_users = 2
          max_RTT = 200
          max_cwnd = 100
          # Define the initial cwnd size for users.
          initial_cwnd = [70, 30]


          # Simulation of AIMD
          cwnd_tracker = simulate_aimd(max_RTT, num_users, alpha_func_priority, beta_func, in

          # Plot graph of RTT over CWND
          plot_title = "AIMD with User Priority (different initial cwnd) [70, 30]"
          plot_graph(num_users, cwnd_tracker, plot_title)
```

```
Initial cwnd for user 0: 70.0
Initial cwnd for user 1: 30.0


(Packet Loss)Multiplicative Decrease at: 1
Peak congestion window size for user 0: 71.0
Peak congestion window size for user 1: 32.0


(Packet Loss)Multiplicative Decrease at: 19
Peak congestion window size for user 0: 52.0
Peak congestion window size for user 1: 50.0


(Packet Loss)Multiplicative Decrease at: 37
Peak congestion window size for user 0: 43.0
Peak congestion window size for user 1: 59.0


(Packet Loss)Multiplicative Decrease at: 55
Peak congestion window size for user 0: 38.0
Peak congestion window size for user 1: 63.0


(Packet Loss)Multiplicative Decrease at: 73
Peak congestion window size for user 0: 36.0
Peak congestion window size for user 1: 65.0


(Packet Loss)Multiplicative Decrease at: 91
Peak congestion window size for user 0: 35.0
Peak congestion window size for user 1: 66.0


(Packet Loss)Multiplicative Decrease at: 109
Peak congestion window size for user 0: 34.0
Peak congestion window size for user 1: 67.0


(Packet Loss)Multiplicative Decrease at: 127
Peak congestion window size for user 0: 34.0
Peak congestion window size for user 1: 67.0


(Packet Loss)Multiplicative Decrease at: 145
Peak congestion window size for user 0: 34.0
Peak congestion window size for user 1: 67.0


(Packet Loss)Multiplicative Decrease at: 163
Peak congestion window size for user 0: 34.0
Peak congestion window size for user 1: 67.0


(Packet Loss)Multiplicative Decrease at: 181
Peak congestion window size for user 0: 34.0
Peak congestion window size for user 1: 67.0


(Packet Loss)Multiplicative Decrease at: 199
Peak congestion window size for user 0: 34.0
Peak congestion window size for user 1: 67.0
```
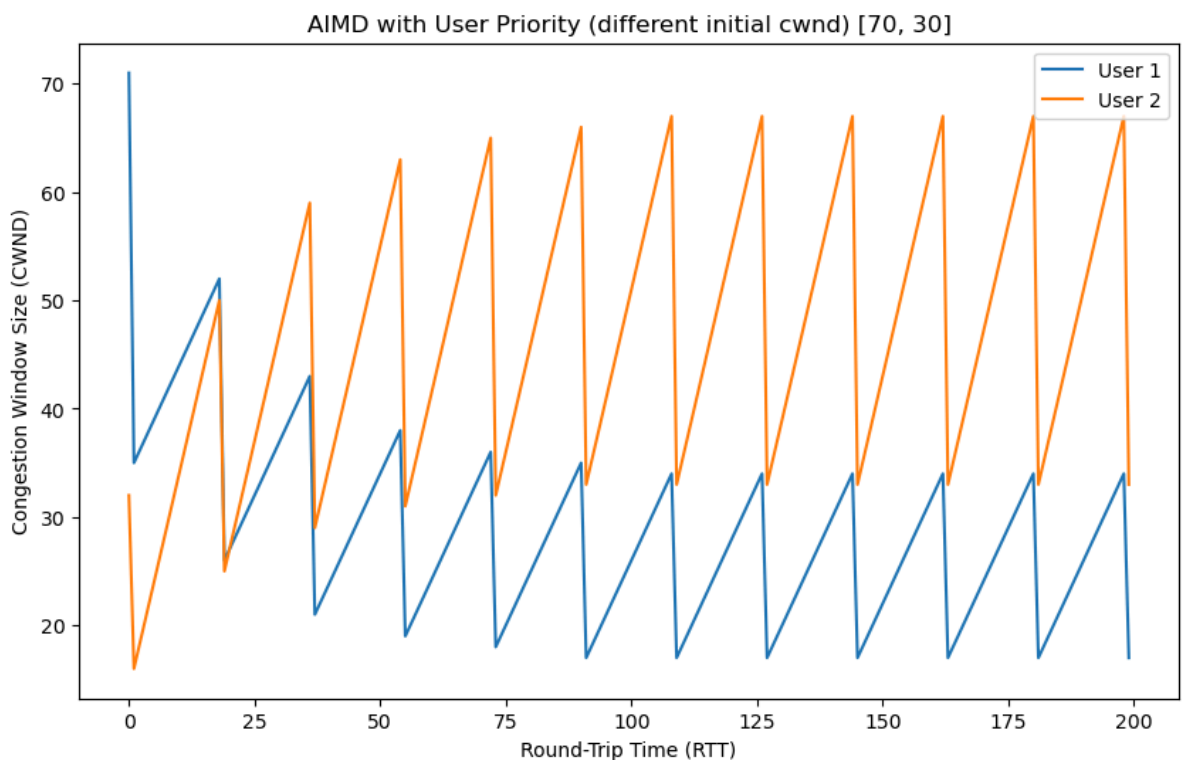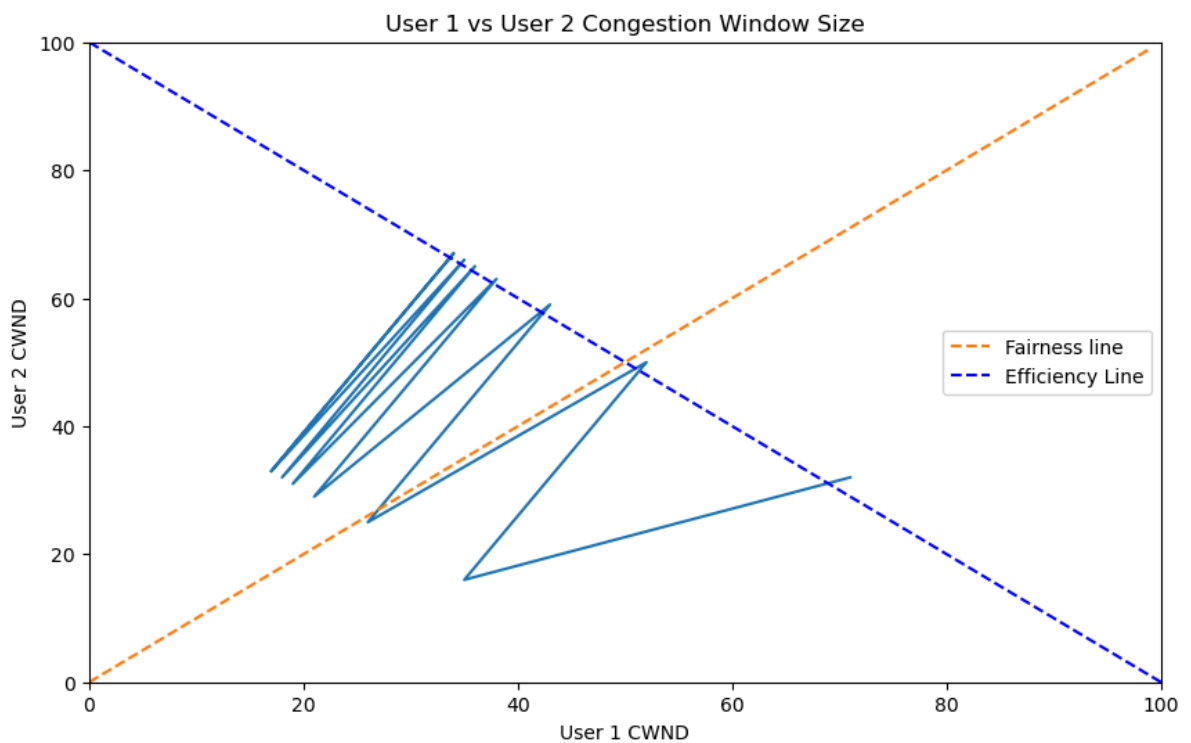
User 1 vs User 2 Congestion Window Size

AIMD with User Priority (different initial cwnd) [70, 30]

Observation:

Converged at around RTT 109, packet loss count 6

We can see that it converges slightly slower as compared to previous experiment, this is because that the priority of user 1 is lower than user 2 but the initial cwnd size of user 1 is higher than user 2, hence it slows down the convergence time of the congestion window size.

Approach by modifying beta functions (30,70)

```
In [19]:  # Experiment Variables
          num_users = 2
```

```python
max_RTT = 200
max_cwnd = 100
# Define the initial cwnd size for users.
initial_cwnd = [30, 70]

def beta_func_priority(user,cwnd):

    # A constant multiplicative decrease for all users.
    if user == 0:
        return 0.3
    else:
        return 0.6


# Simulation of AIMD
cwnd_tracker = simulate_aimd(max_RTT, num_users, alpha_func, beta_func_priority, ir

# Plot graph of RTT over CWND
plot_title = "AIMD with User Priority (different initial cwnd) [30, 70]"
plot_graph(num_users, cwnd_tracker, plot_title)
```

```
Initial cwnd for user 0: 30.0
Initial cwnd for user 1: 70.0


(Packet Loss)Multiplicative Decrease at: 1
Peak congestion window size for user 0: 31.0
Peak congestion window size for user 1: 71.0


(Packet Loss)Multiplicative Decrease at: 27
Peak congestion window size for user 0: 34.0
Peak congestion window size for user 1: 67.0


(Packet Loss)Multiplicative Decrease at: 54
Peak congestion window size for user 0: 36.0
Peak congestion window size for user 1: 66.0


(Packet Loss)Multiplicative Decrease at: 81
Peak congestion window size for user 0: 36.0
Peak congestion window size for user 1: 65.0


(Packet Loss)Multiplicative Decrease at: 108
Peak congestion window size for user 0: 36.0
Peak congestion window size for user 1: 65.0


(Packet Loss)Multiplicative Decrease at: 135
Peak congestion window size for user 0: 36.0
Peak congestion window size for user 1: 65.0


(Packet Loss)Multiplicative Decrease at: 162
Peak congestion window size for user 0: 36.0
Peak congestion window size for user 1: 65.0


(Packet Loss)Multiplicative Decrease at: 189
Peak congestion window size for user 0: 36.0
Peak congestion window size for user 1: 65.0
```
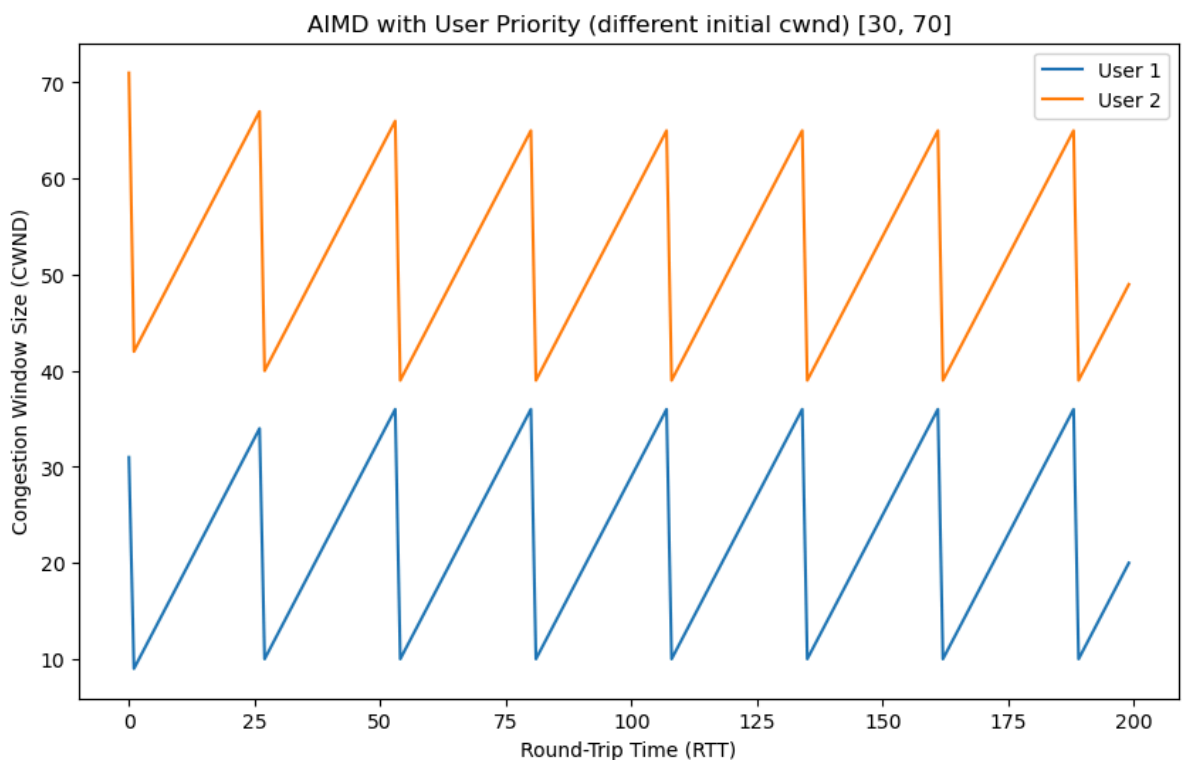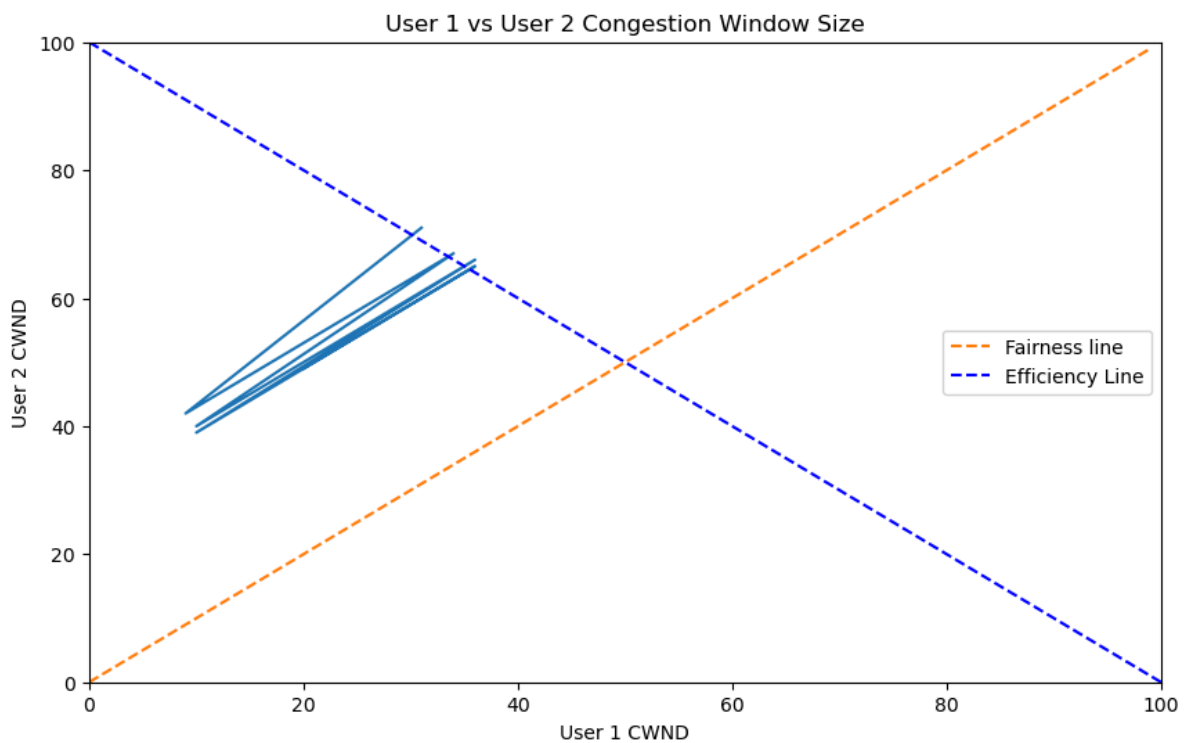
User 1 vs User 2 Congestion Window Size

AIMD with User Priority (different initial cwnd) [30, 70]

Approach by modifying beta functions (70,30)

```python
In [20]:
# Experiment Variables
num_users = 2
max_RTT = 300
max_cwnd = 100
# Define the initial cwnd size for users.
initial_cwnd = [70, 30]

def beta_func_priority(user,cwnd):

    # A constant multiplicative decrease for all users.
    if user == 0:
        return 0.3
    else:
```

```python
        return 0.6


# Simulation of AIMD
cwnd_tracker = simulate_aimd(max_RTT, num_users, alpha_func, beta_func_priority, in

# Plot graph of RTT over CWND
plot_title = "AIMD with User Priority (different initial cwnd) [30, 70]"
plot_graph(num_users, cwnd_tracker, plot_title)
```

```
Initial cwnd for user 0: 70.0
Initial cwnd for user 1: 30.0


(Packet Loss)Multiplicative Decrease at: 1
Peak congestion window size for user 0: 71.0
Peak congestion window size for user 1: 31.0


(Packet Loss)Multiplicative Decrease at: 33
Peak congestion window size for user 0: 52.0
Peak congestion window size for user 1: 49.0


(Packet Loss)Multiplicative Decrease at: 63
Peak congestion window size for user 0: 44.0
Peak congestion window size for user 1: 58.0


(Packet Loss)Multiplicative Decrease at: 91
Peak congestion window size for user 0: 40.0
Peak congestion window size for user 1: 61.0


(Packet Loss)Multiplicative Decrease at: 119
Peak congestion window size for user 0: 39.0
Peak congestion window size for user 1: 63.0


(Packet Loss)Multiplicative Decrease at: 147
Peak congestion window size for user 0: 38.0
Peak congestion window size for user 1: 64.0


(Packet Loss)Multiplicative Decrease at: 174
Peak congestion window size for user 0: 37.0
Peak congestion window size for user 1: 64.0


(Packet Loss)Multiplicative Decrease at: 201
Peak congestion window size for user 0: 37.0
Peak congestion window size for user 1: 64.0


(Packet Loss)Multiplicative Decrease at: 228
Peak congestion window size for user 0: 37.0
Peak congestion window size for user 1: 64.0


(Packet Loss)Multiplicative Decrease at: 255
Peak congestion window size for user 0: 37.0
Peak congestion window size for user 1: 64.0


(Packet Loss)Multiplicative Decrease at: 282
Peak congestion window size for user 0: 37.0
Peak congestion window size for user 1: 64.0
```
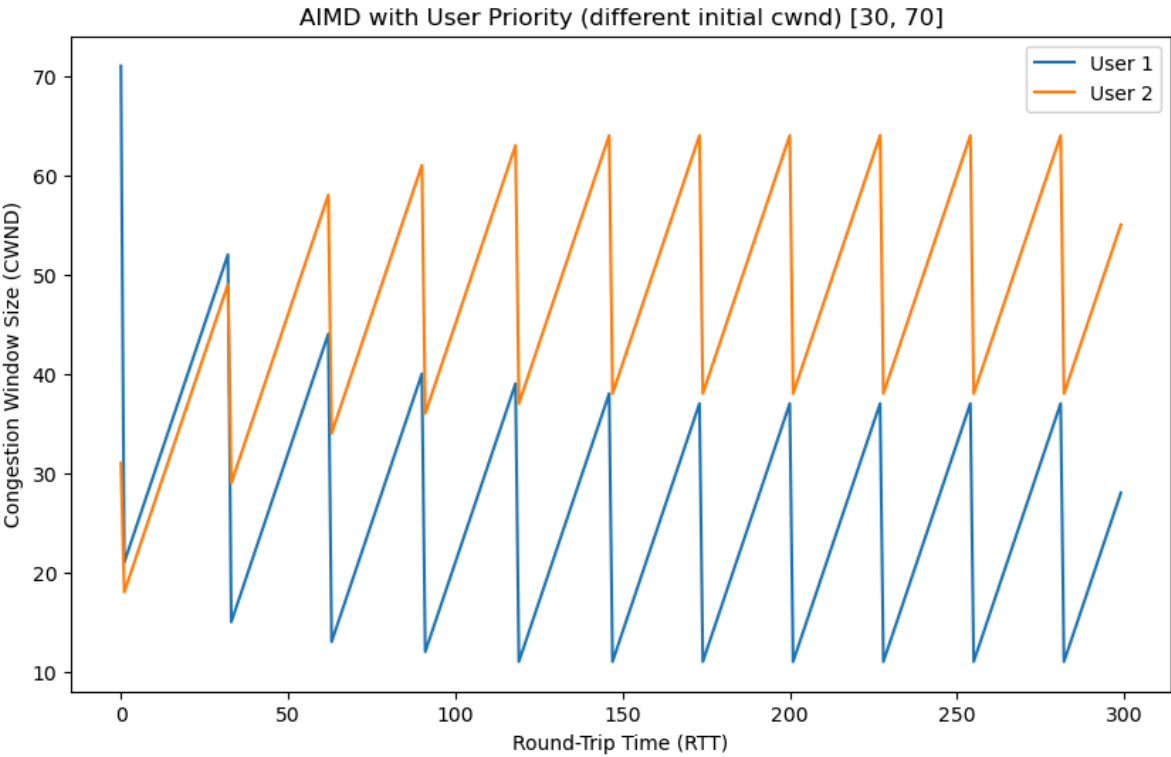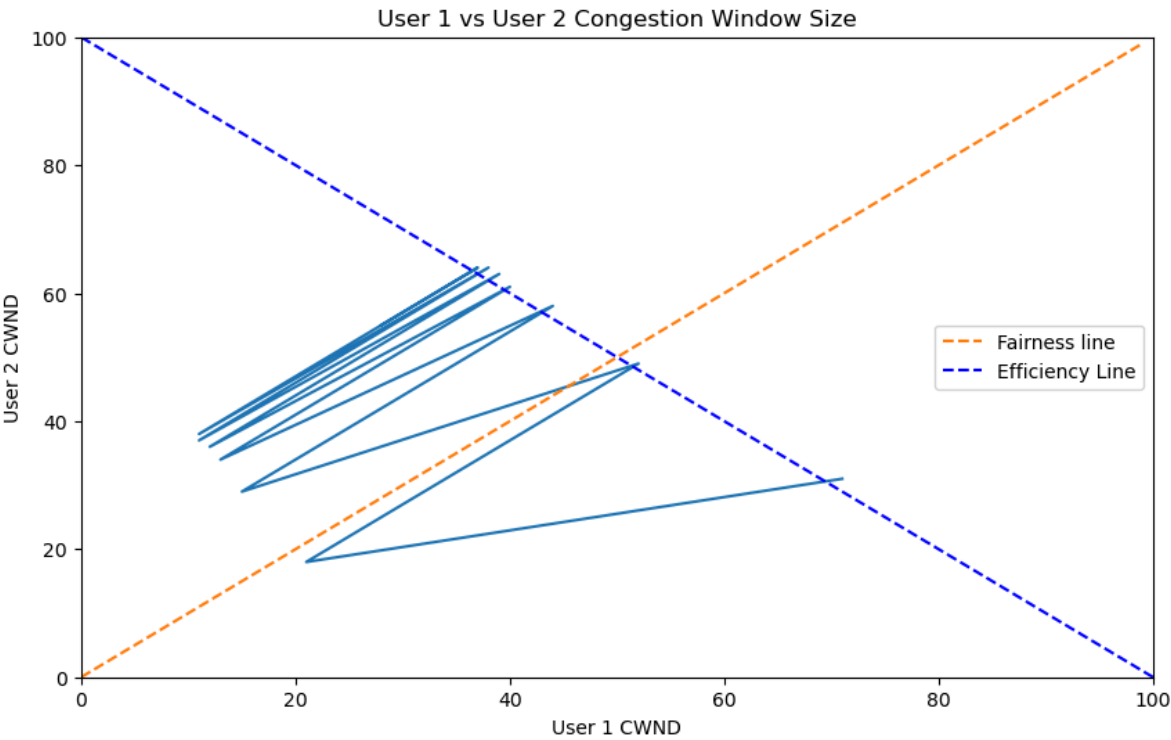
User 1 vs User 2 Congestion Window Size

AIMD with User Priority (different initial cwnd) [30, 70]

In [ ]: