

## 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:

$\alpha$	$\beta$	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)

#### 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,

$$x_n = x_n + \log_2(\text{CWND})$$

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

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,

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

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

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

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

### 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.

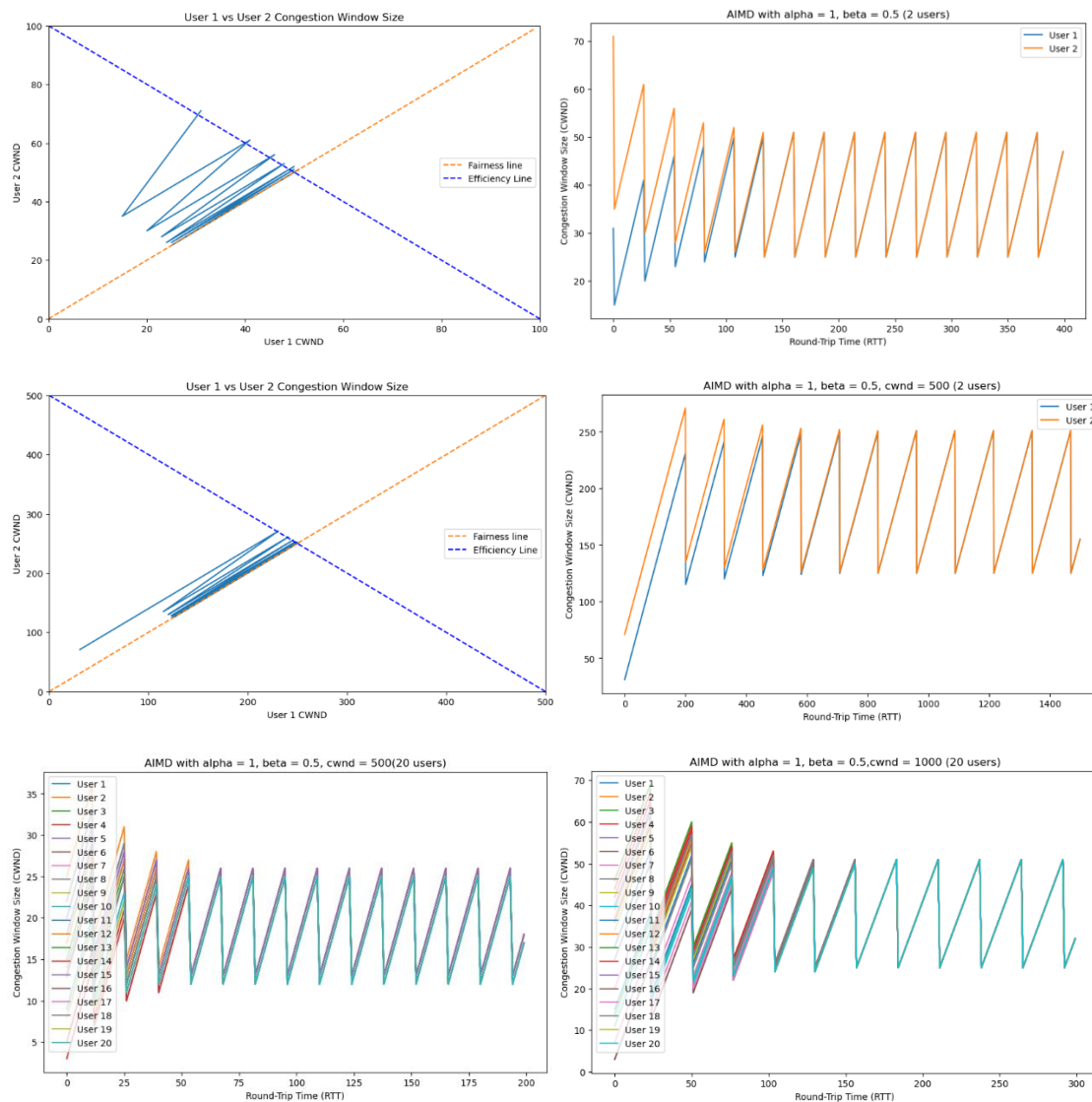
5. By having a dynamic incremental/decremental function, user priority can be implemented, which in real life situation, some premium users get to have higher bandwidth.

### **3. Conclusion**

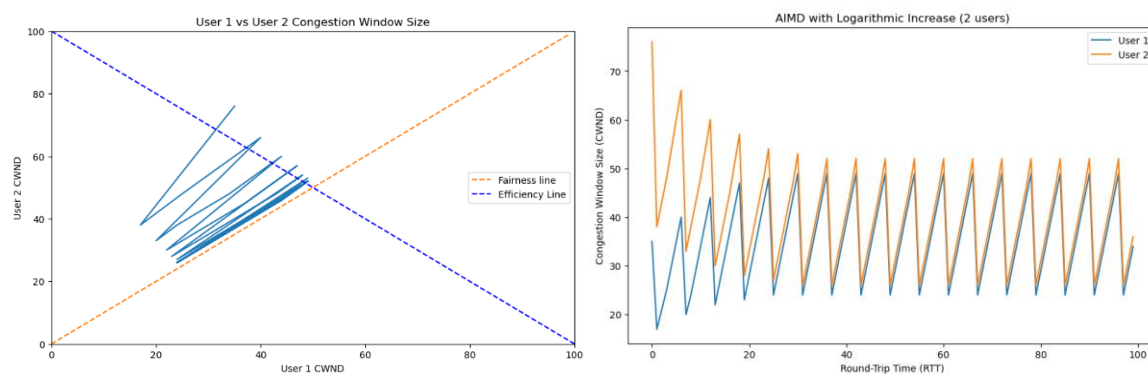
From the above experiments, we understand the trade-off between convergence RTT and the packet loss, and the importance of both incremental function and the initial CWND. Instead of linear approach, we introduced non-linearity to the incremental function in order to have a much more dynamic increase in congestion window size, however that is still not good enough. Hence, 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.

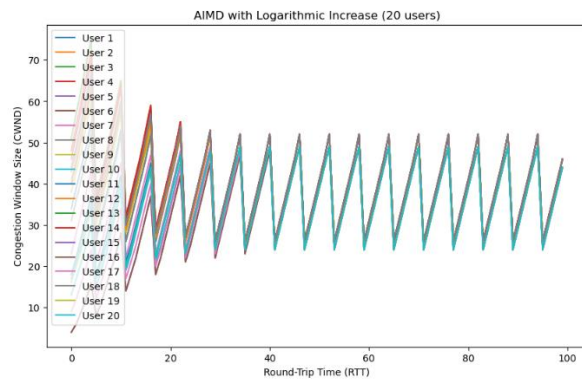
## 4. Appendix

### Appendix I: Result Graph of Experiment 1(Baseline)

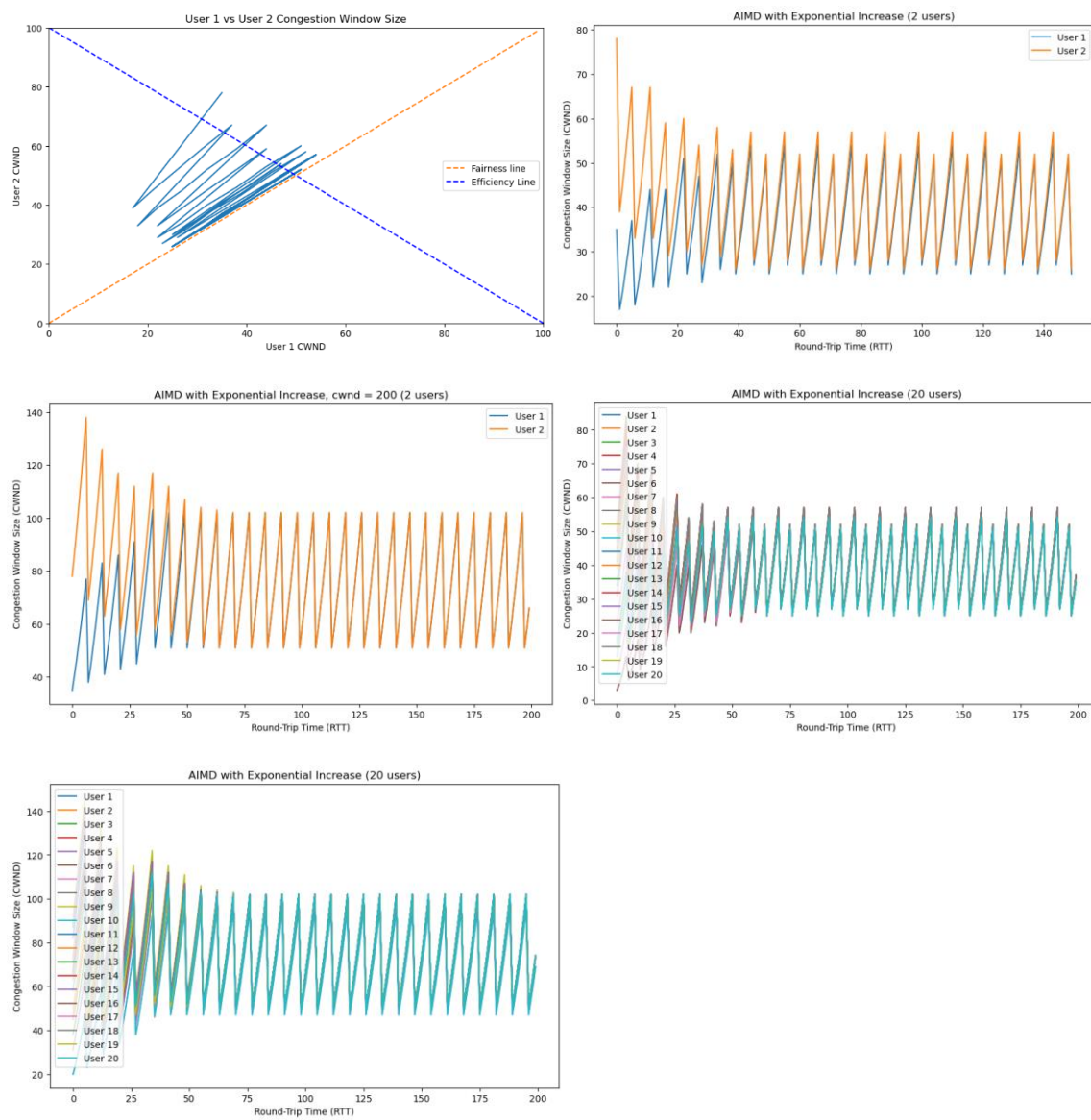


### Appendix II: Result Graph of Experiment 2(Logarithmic Incremental)

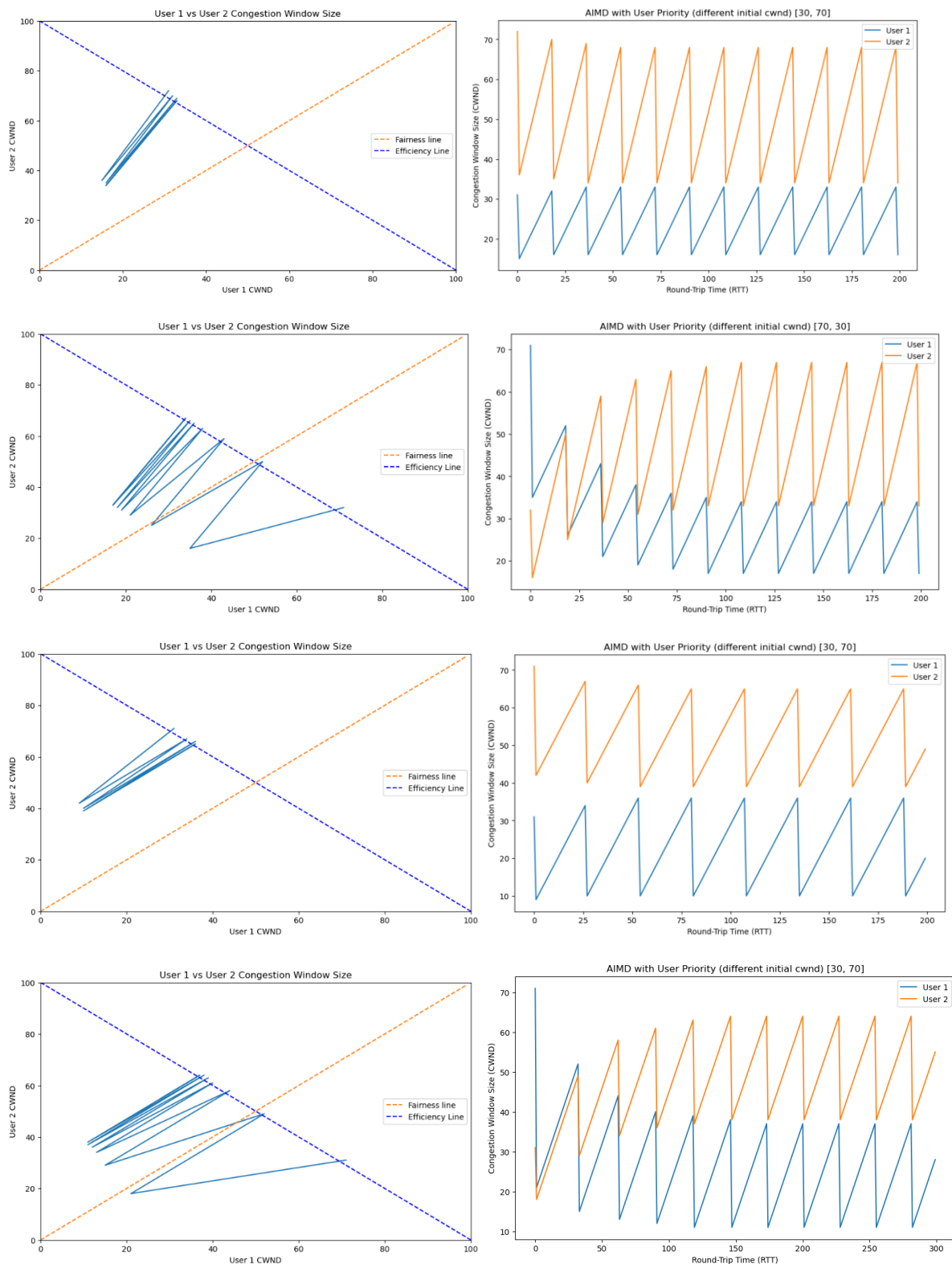




### Appendix III: Result Graph of Experiment 3(Exponential Incremental)



## Appendix IV: Result Graph of Experiment 4(User Priority)



# 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='--', label='User 1 Cwnd')
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]: # 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.

```

```

"""
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_size):
    # Initialize the total congestion window size.
    total_cwnd = 0

    # Initialize a tracker for all users flows for congestion window sizes over time
    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 function)
        cwnd: Current congestion window size.

        Return Value:
        =====
        The amount to increase the congestion window size, based on a logarithmic function
        """
        # 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 > 1
            # 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

```

```

# Define the alpha function with Log increase and exp increase based on user priority
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 growth
        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 decrease
"""
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

```

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)
```

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

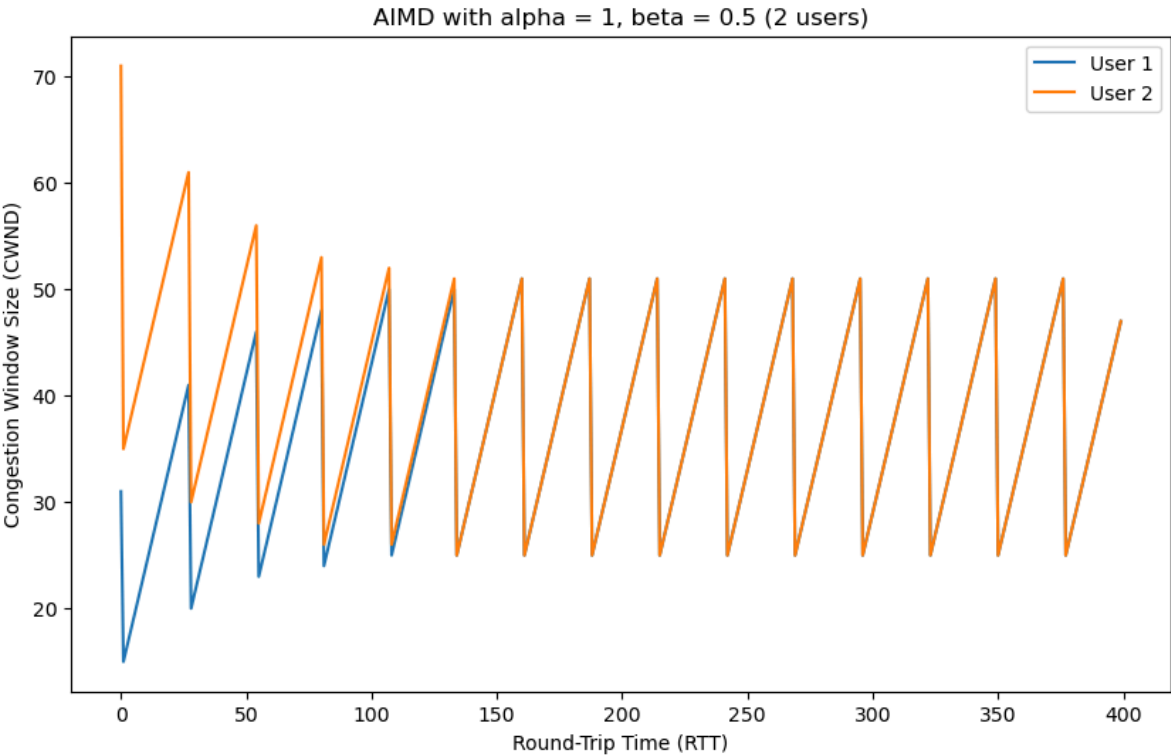
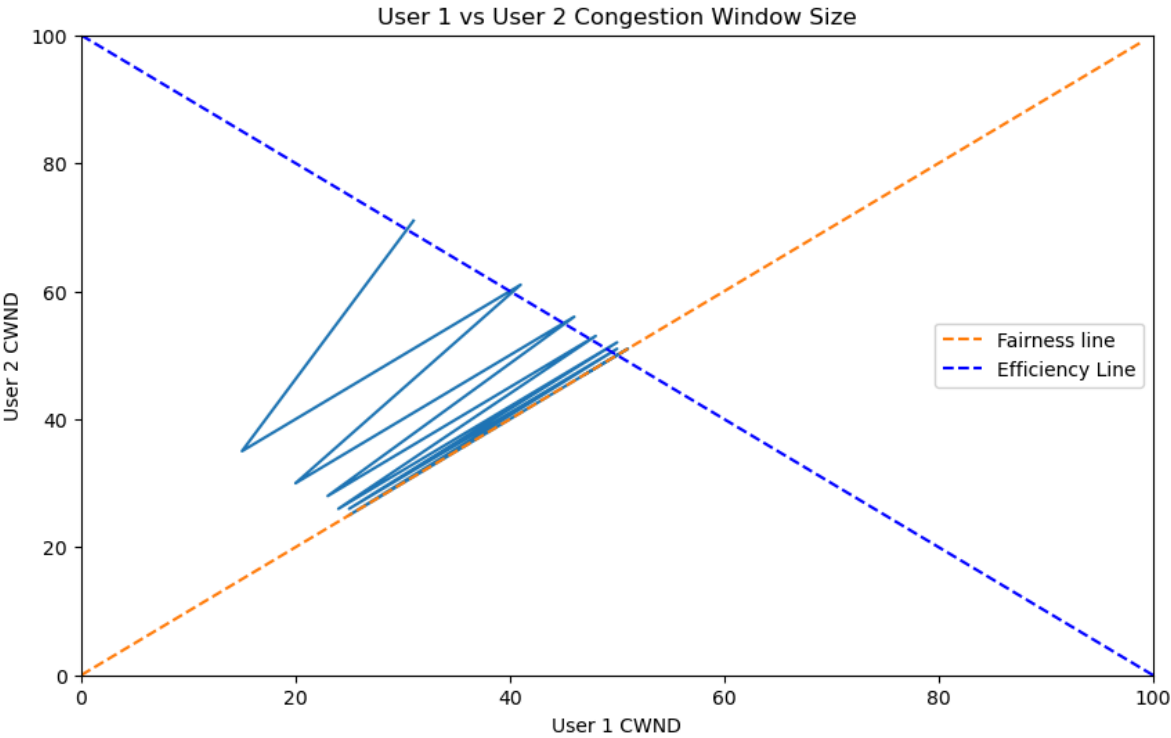
(Packet Loss)Multiplicative Decrease at: 269  
Peak congestion window size for user 0: 51.0  
Peak congestion window size for user 1: 51.0

(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



Observation:

Converged at around RTT 161, packet loss count 6

## Experiment with 2 users (cwnd = 500)

```
In [8]: # 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_cwr

# 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

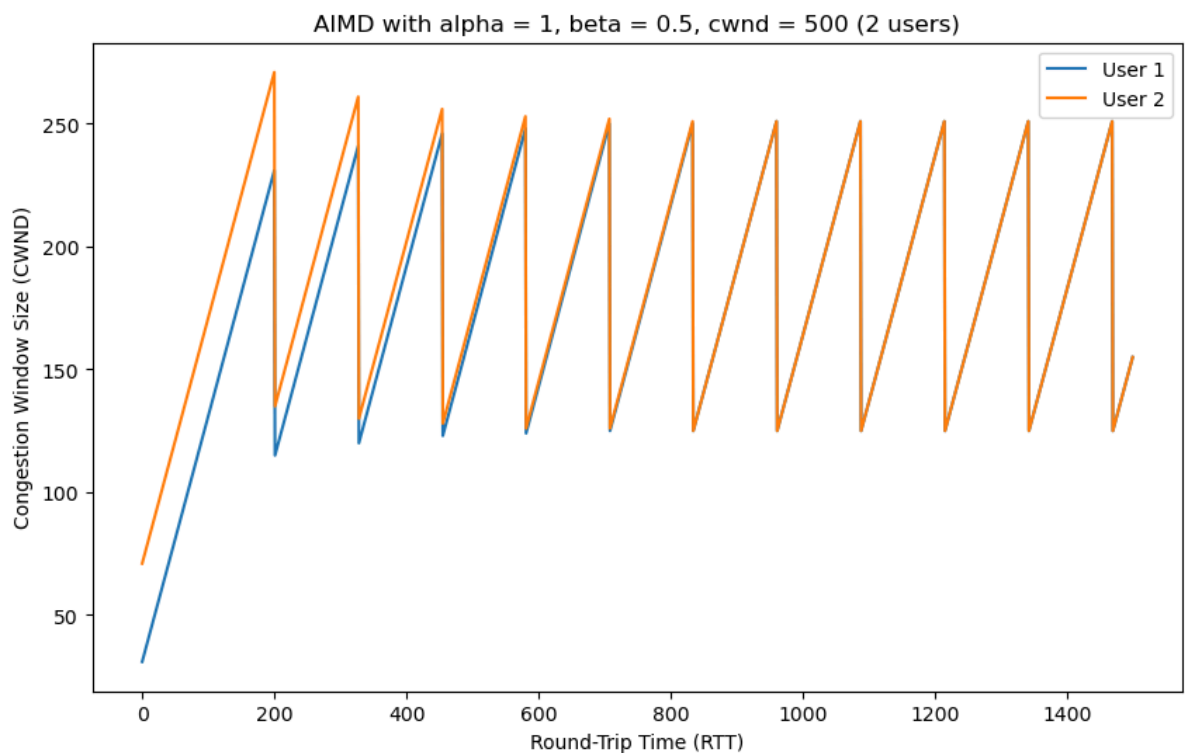
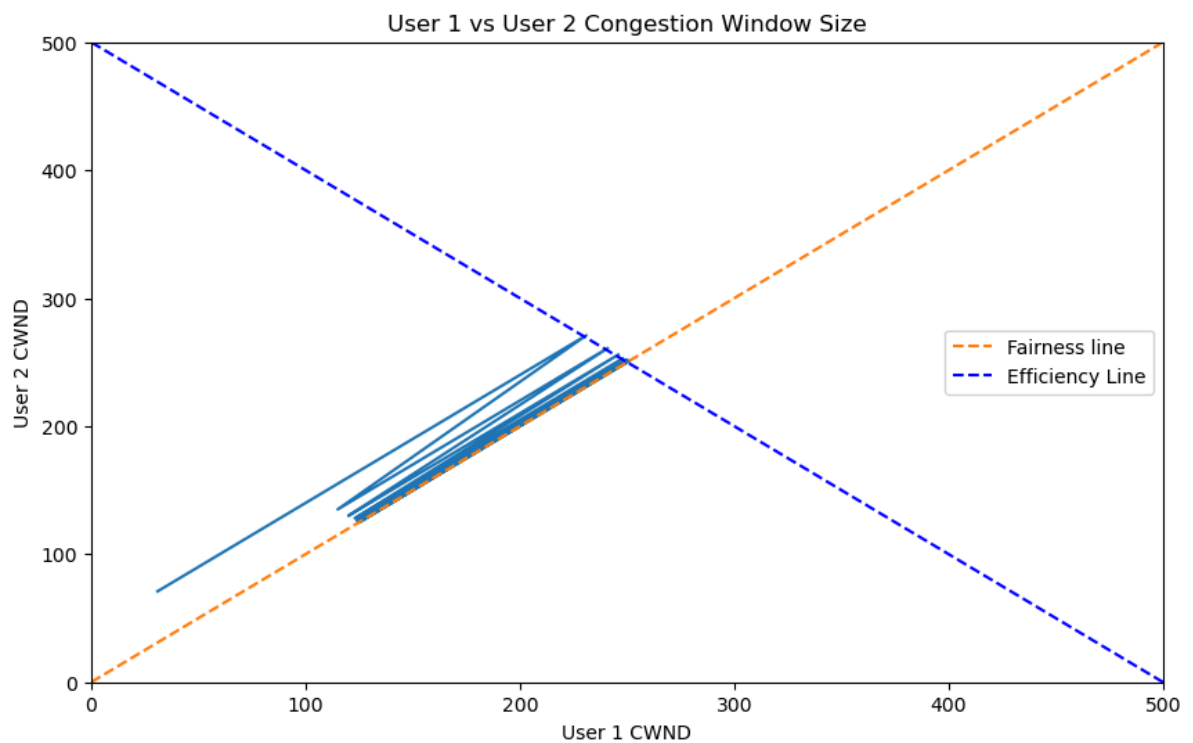
(Packet Loss)Multiplicative Decrease at: 961  
Peak congestion window size for user 0: 251.0  
Peak congestion window size for user 1: 251.0

(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



### 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)
```

```
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)
```

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

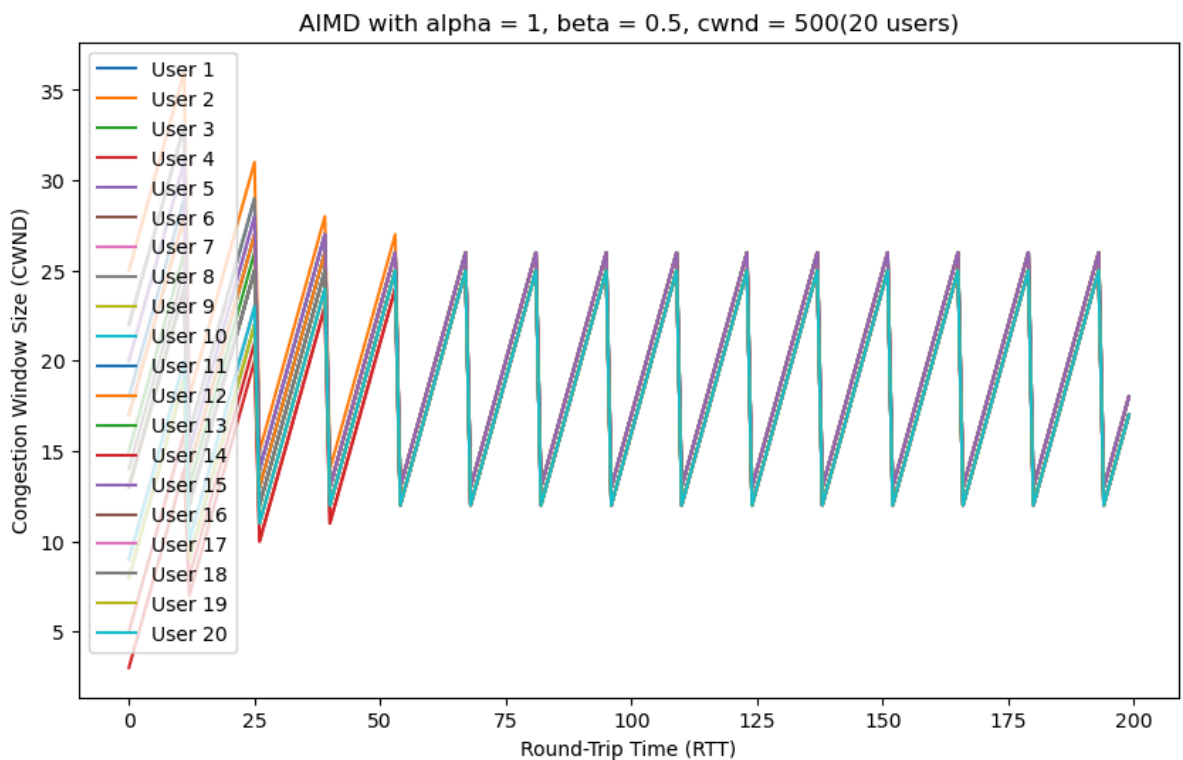
Peak congestion window size for user 3: 25.0  
Peak congestion window size for user 4: 26.0  
Peak congestion window size for user 5: 25.0  
Peak congestion window size for user 6: 26.0  
Peak congestion window size for user 7: 26.0  
Peak congestion window size for user 8: 25.0  
Peak congestion window 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
```

```
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

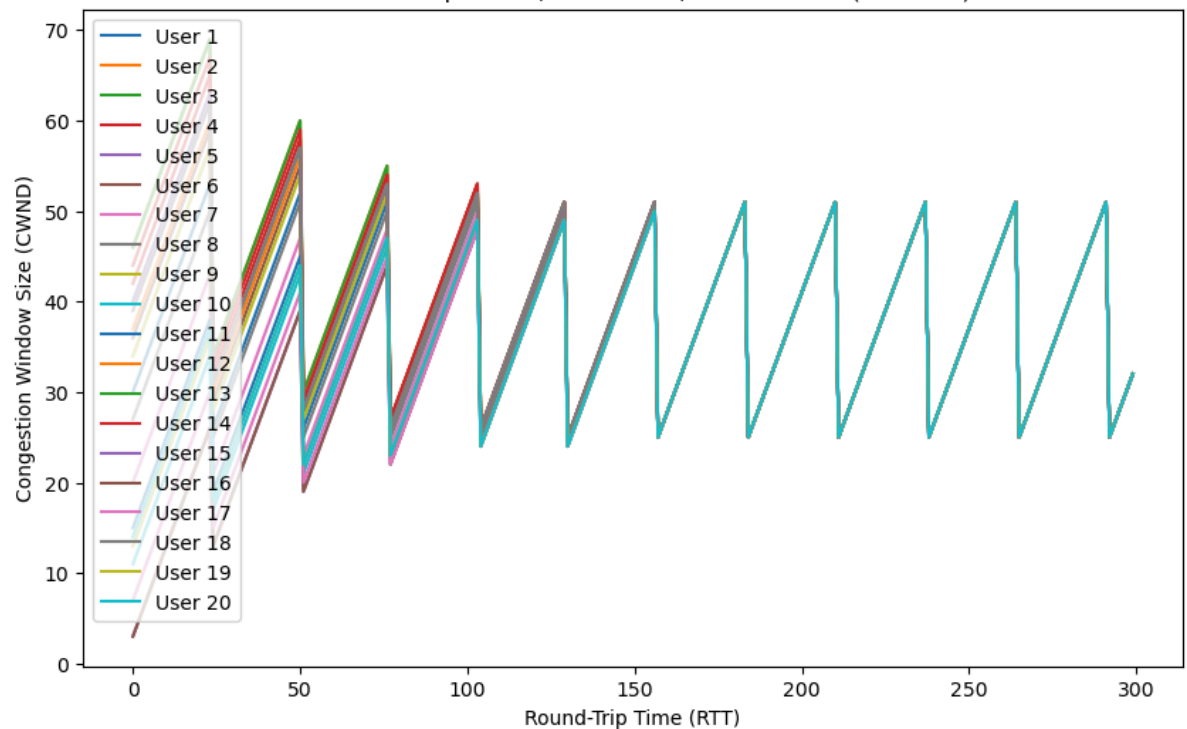
Peak congestion window size for user 8: 51.0  
Peak congestion window size for user 9: 51.0  
Peak congestion window size for user 10: 51.0  
Peak congestion window size for user 11: 51.0  
Peak congestion window size for user 12: 51.0  
Peak congestion window size for user 13: 51.0  
Peak congestion 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

AIMD with  $\alpha = 1$ ,  $\beta = 0.5$ ,  $cwnd = 1000$  (20 users)

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
```

```
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

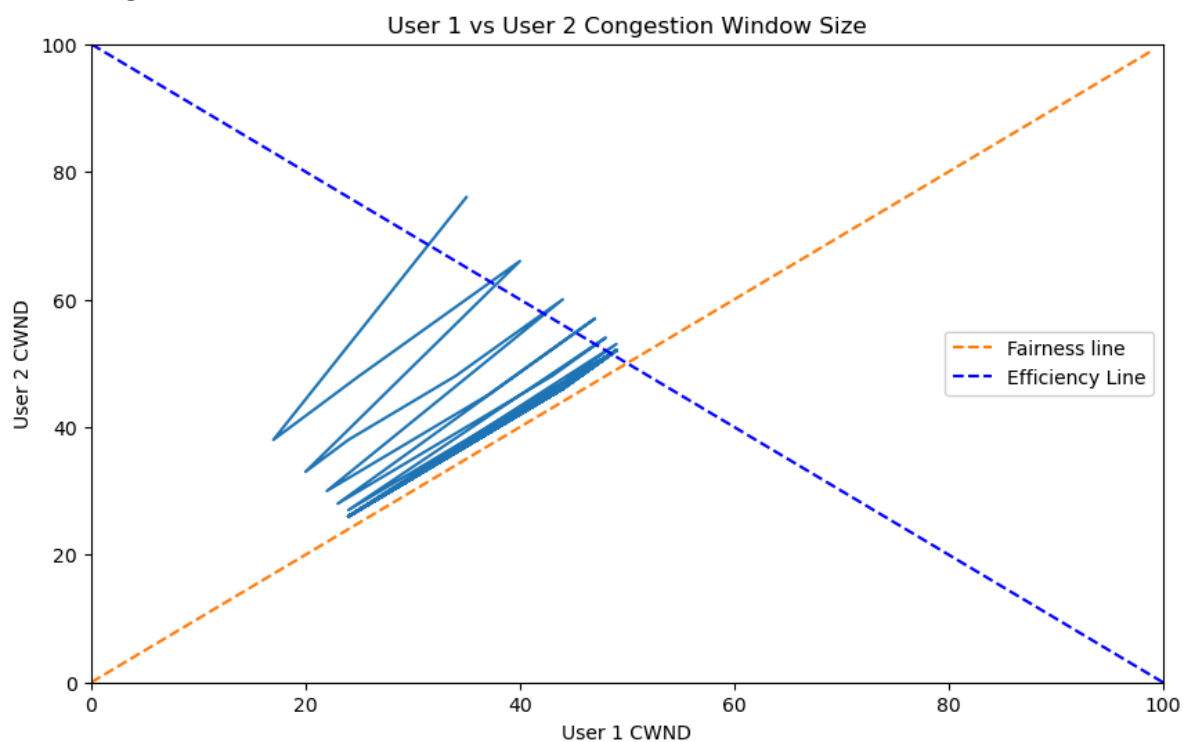
(Packet Loss)Multiplicative Decrease at: 73  
Peak congestion window size for user 0: 49.0  
Peak congestion window size for user 1: 52.0

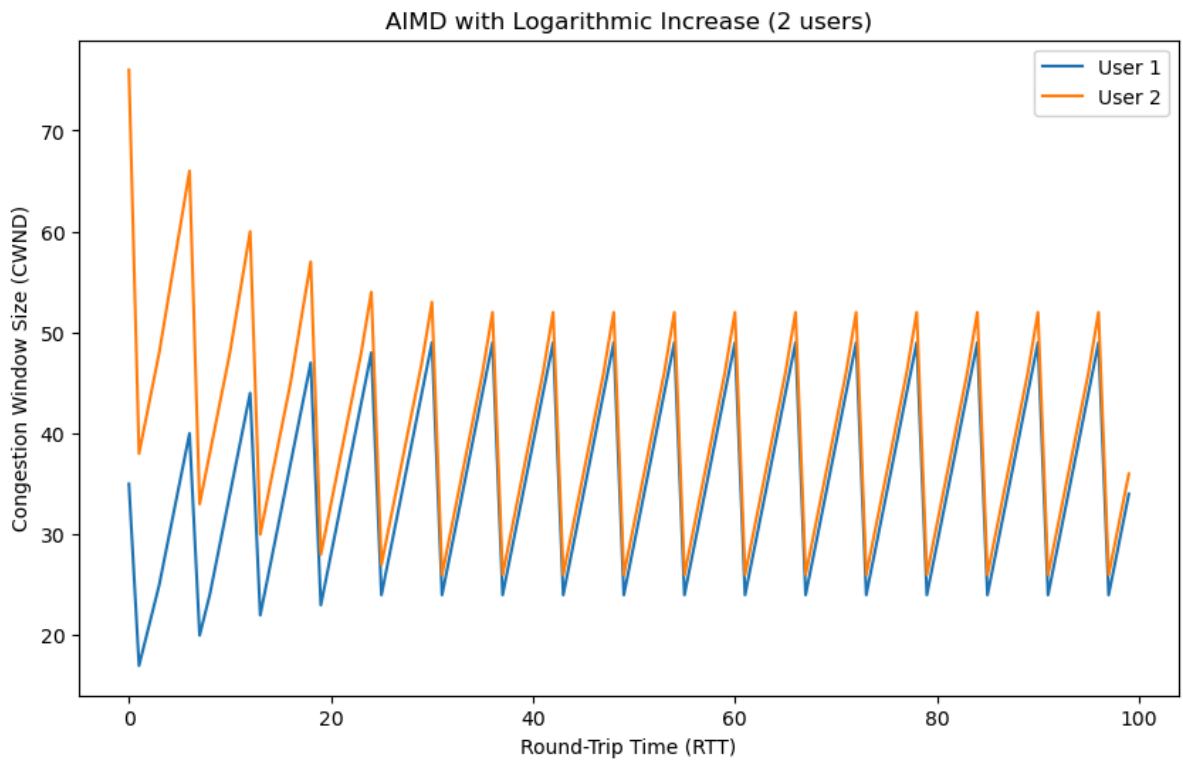
(Packet Loss)Multiplicative Decrease at: 79  
Peak congestion window size for user 0: 49.0  
Peak congestion window size for user 1: 52.0

(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





### 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

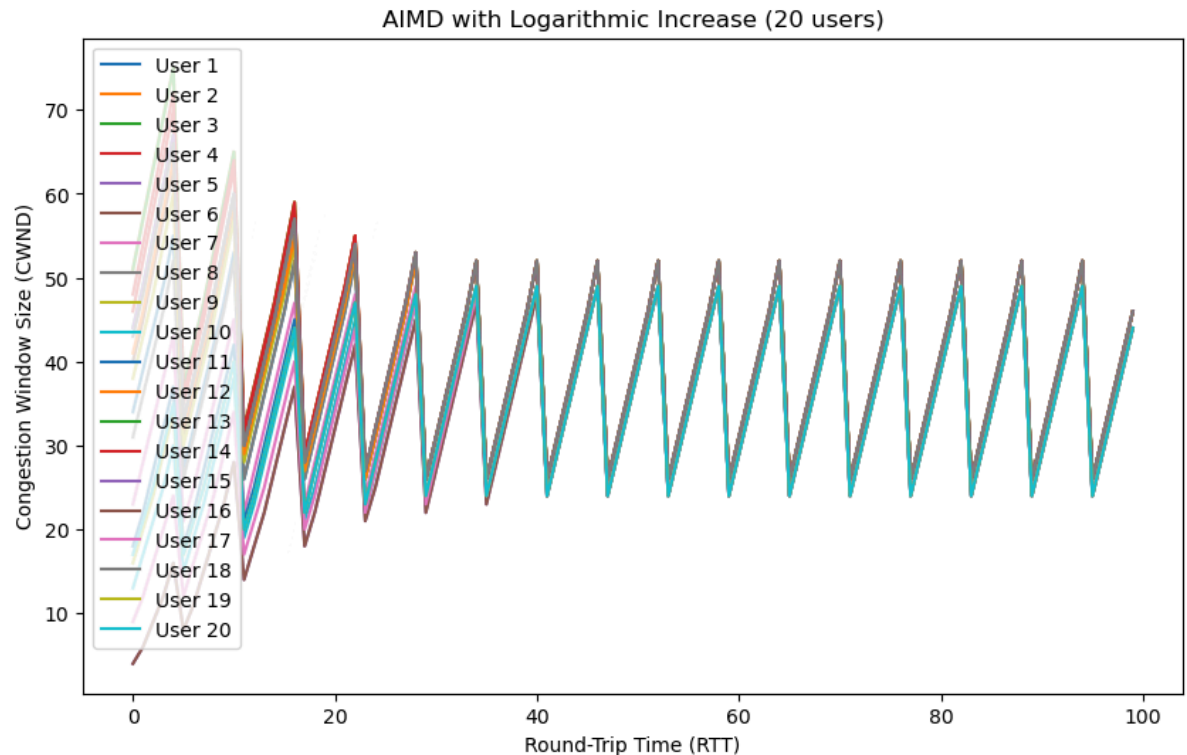


(Packet Loss)Multiplicative Decrease at: 83  
Peak congestion window size for user 0: 52.0  
Peak congestion window size for user 1: 52.0  
Peak congestion window size for user 2: 52.0  
Peak congestion window size for user 3: 52.0  
Peak congestion window size for user 4: 49.0  
Peak congestion window 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

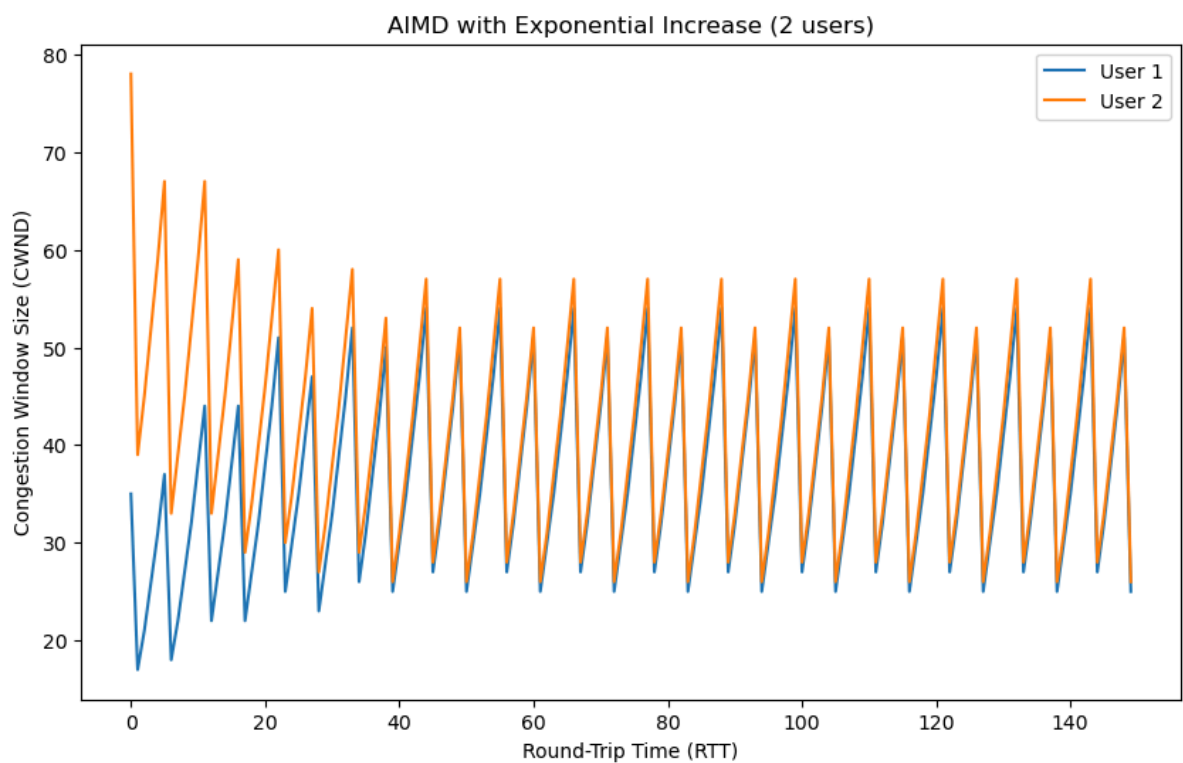
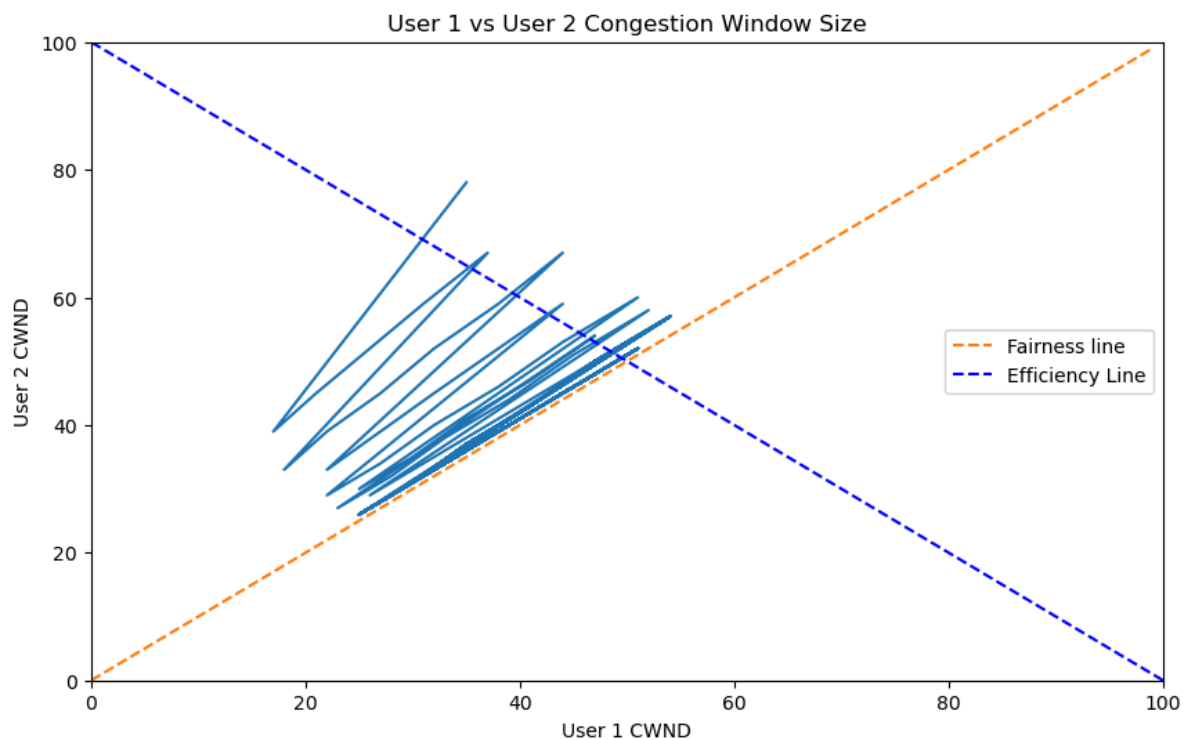
Peak congestion window size for user 0: 54.0

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]: # 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

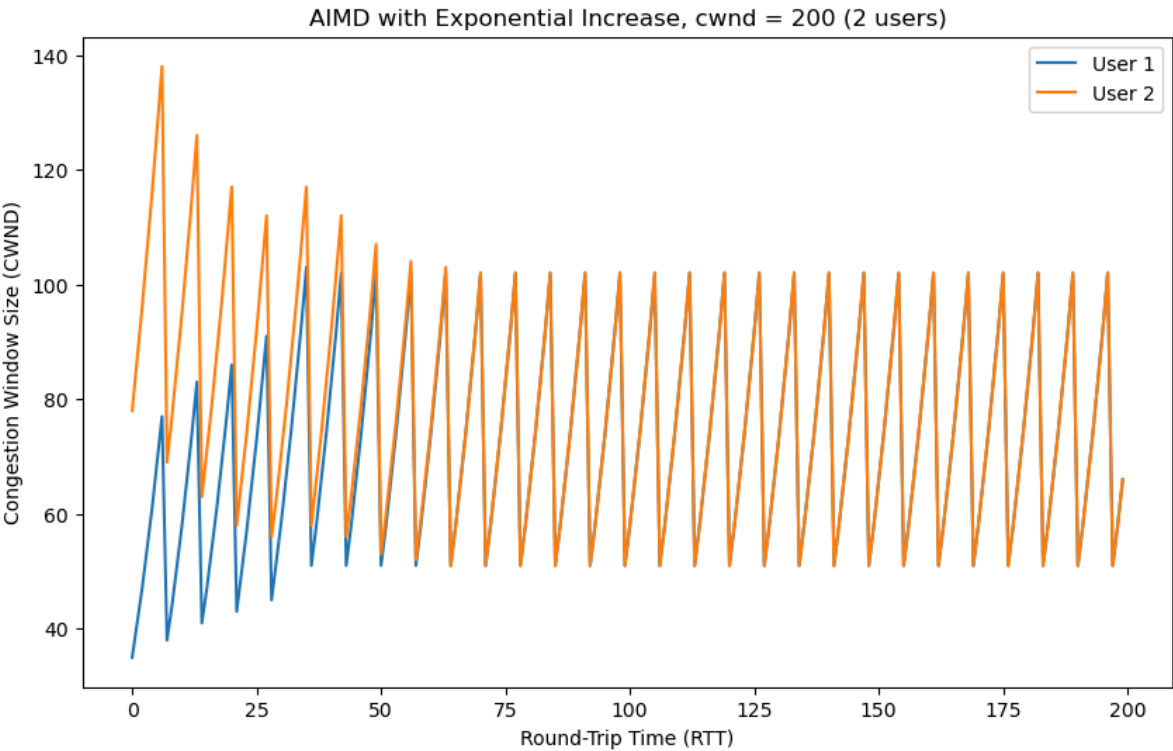
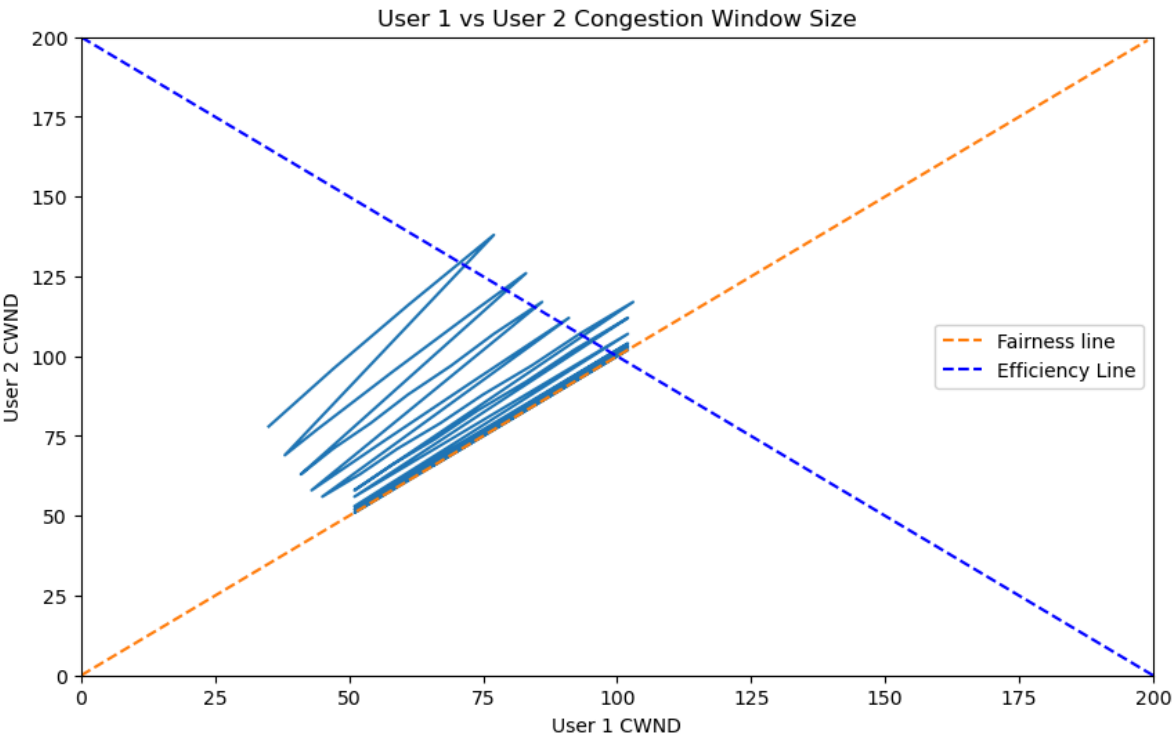
(Packet Loss)Multiplicative Decrease at: 176  
Peak congestion window size for user 0: 102.0  
Peak congestion window size for user 1: 102.0



(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



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]: # 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

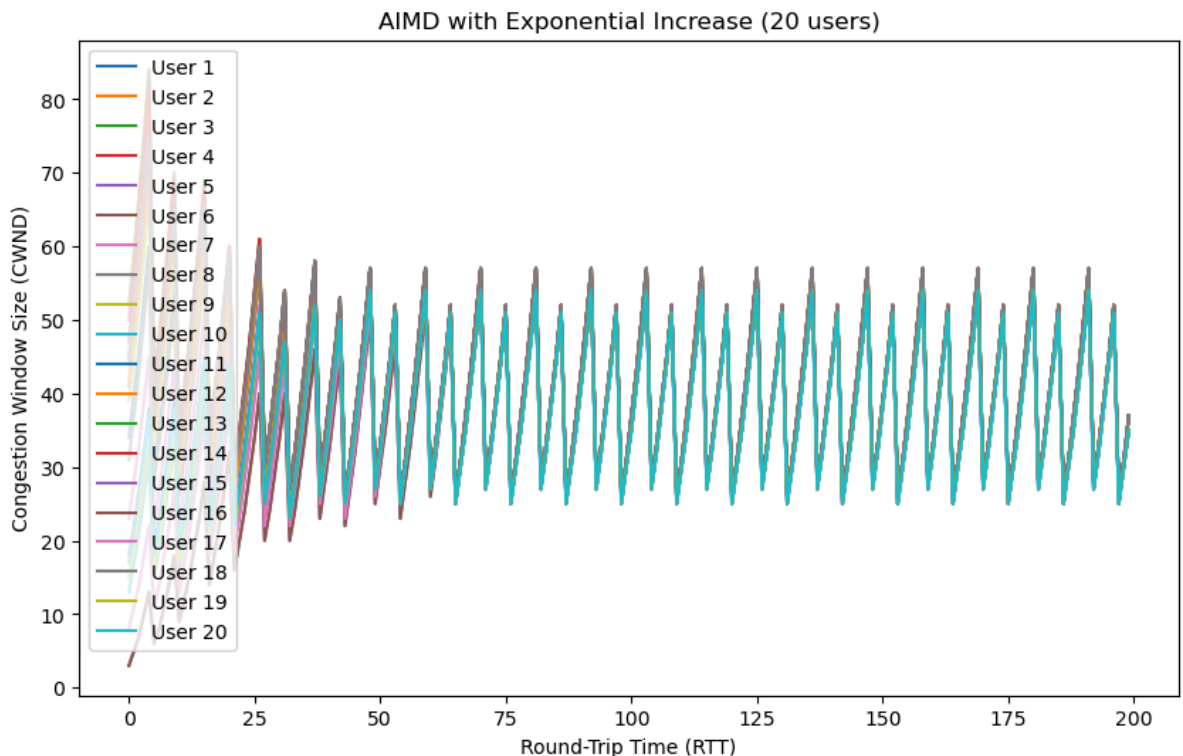
Peak congestion window size for user 9: 54.0  
Peak congestion window size for user 10: 54.0  
Peak congestion window size for user 11: 57.0  
Peak congestion window size for user 12: 57.0  
Peak congestion window size for user 13: 57.0  
Peak congestion window size for user 14: 57.0  
Peak congestion 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



### 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  
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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  
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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  
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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

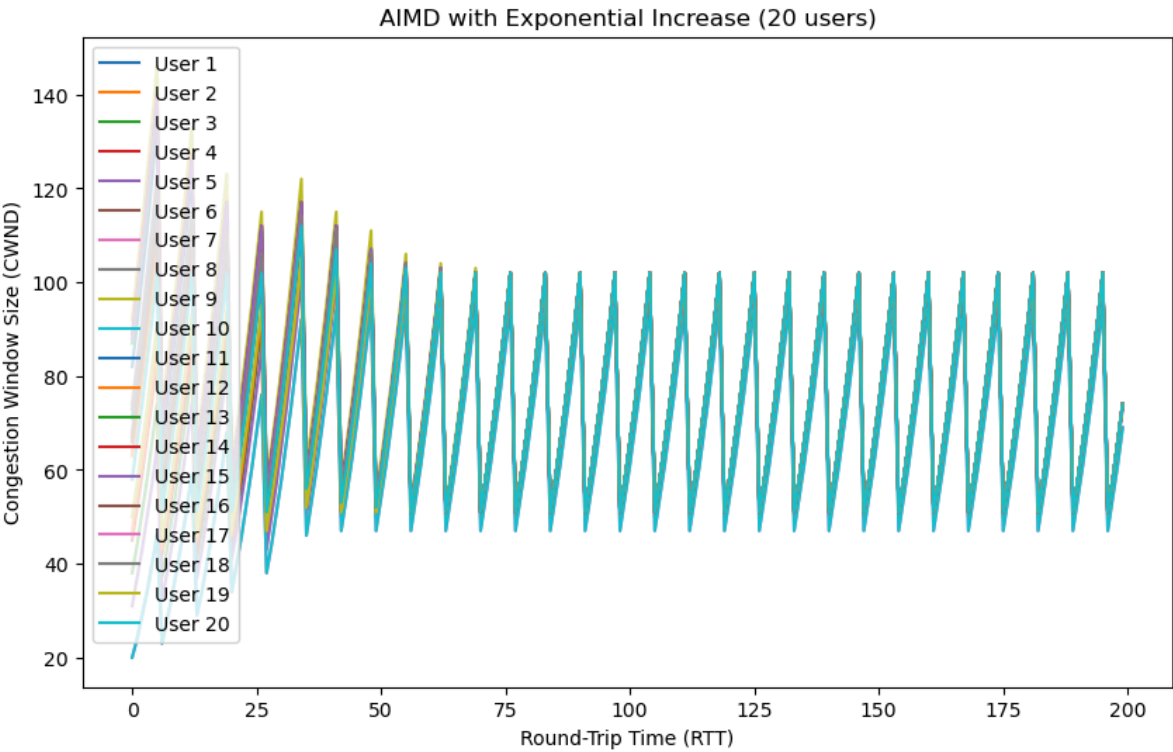
Peak congestion window size for user 1: 102.0  
Peak congestion window size for user 2: 102.0  
Peak congestion window size for user 3: 102.0  
Peak congestion window size for user 4: 101.0  
Peak congestion window size for user 5: 102.0  
Peak congestion window size for user 6: 95.0  
Peak congestion 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  
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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 [ ]:

## 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, 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: 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

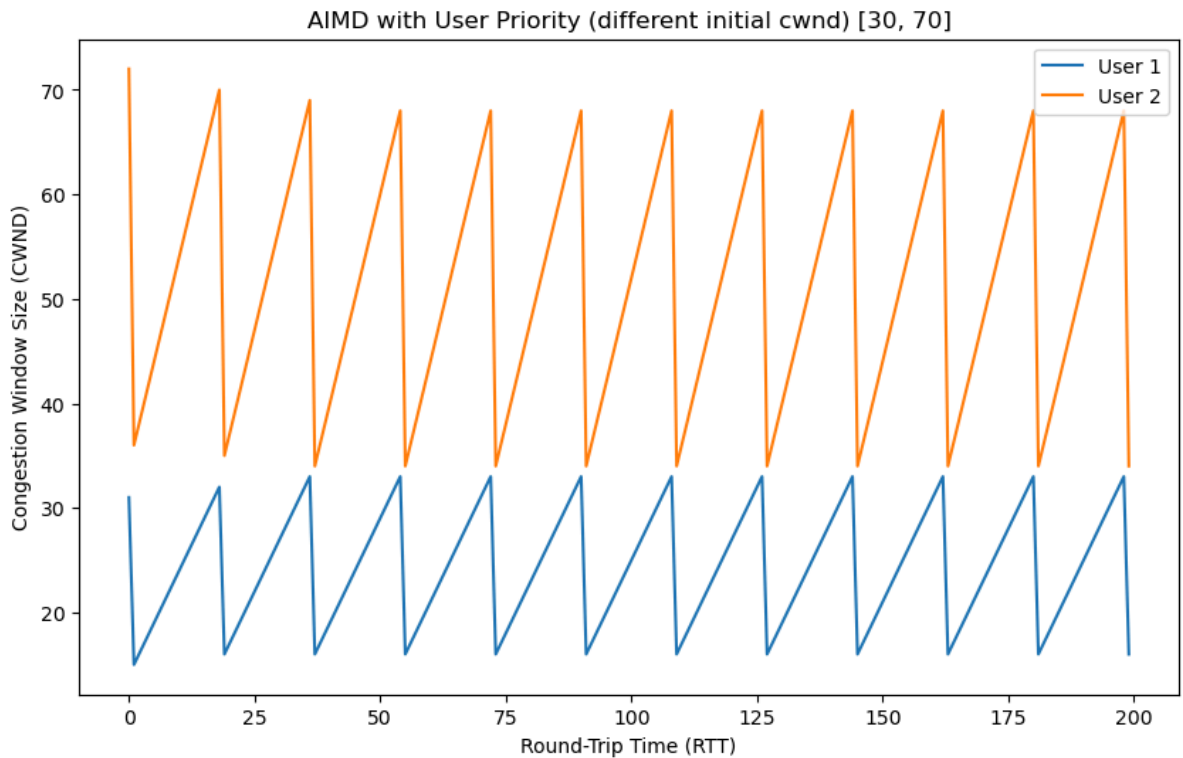
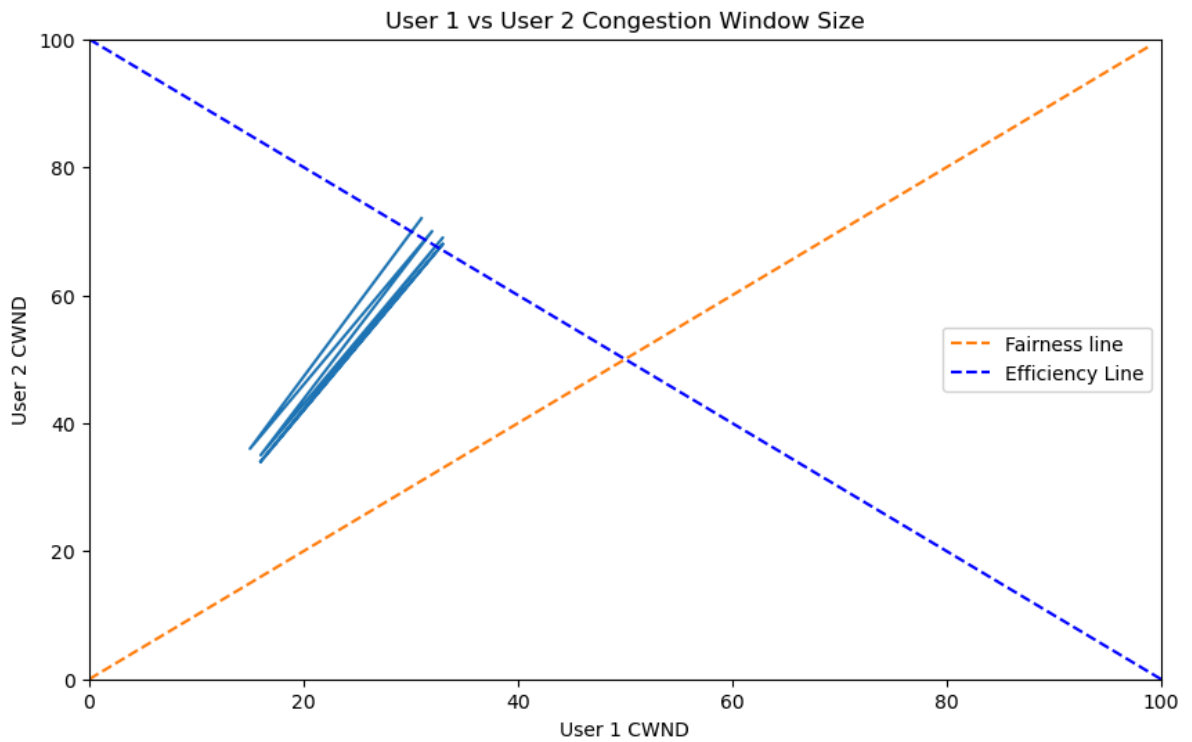
(Packet Loss)Multiplicative Decrease at: 127  
Peak congestion window size for user 0: 33.0  
Peak congestion window size for user 1: 68.0

(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



### 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, ir

# 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

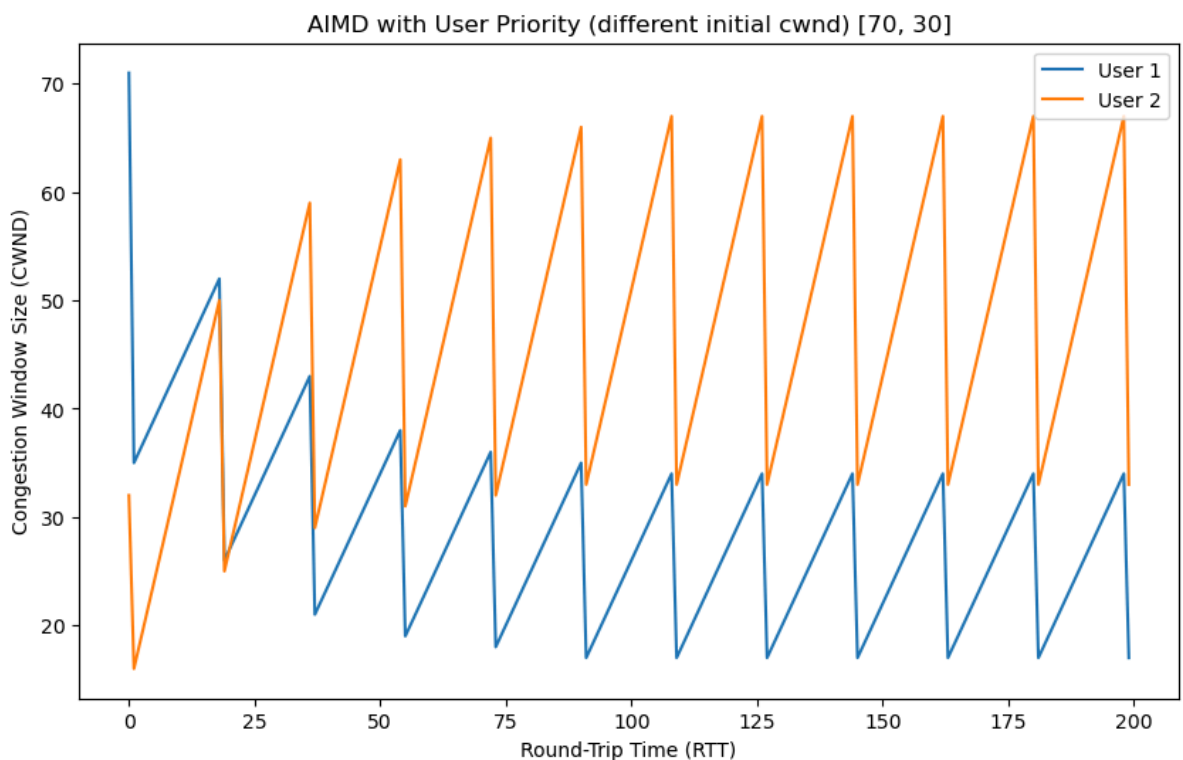
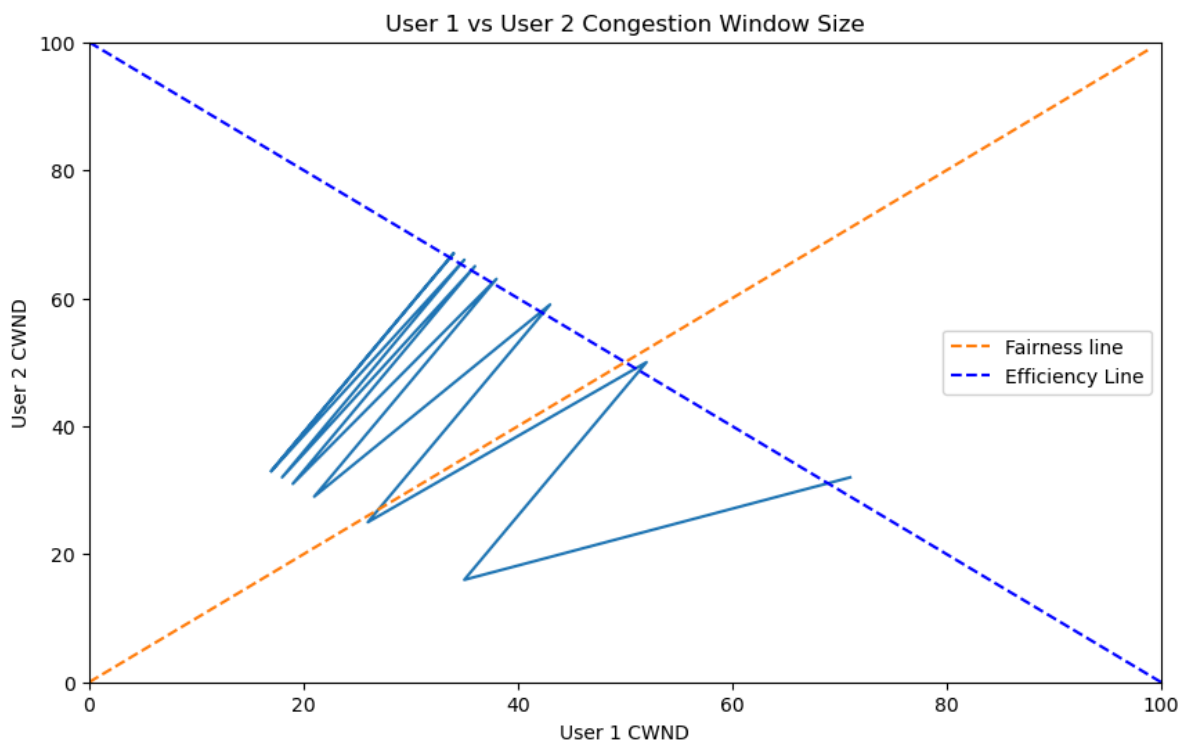
(Packet Loss)Multiplicative Decrease at: 145  
Peak congestion window size for user 0: 34.0  
Peak congestion window size for user 1: 67.0

(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





### 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
```

```

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

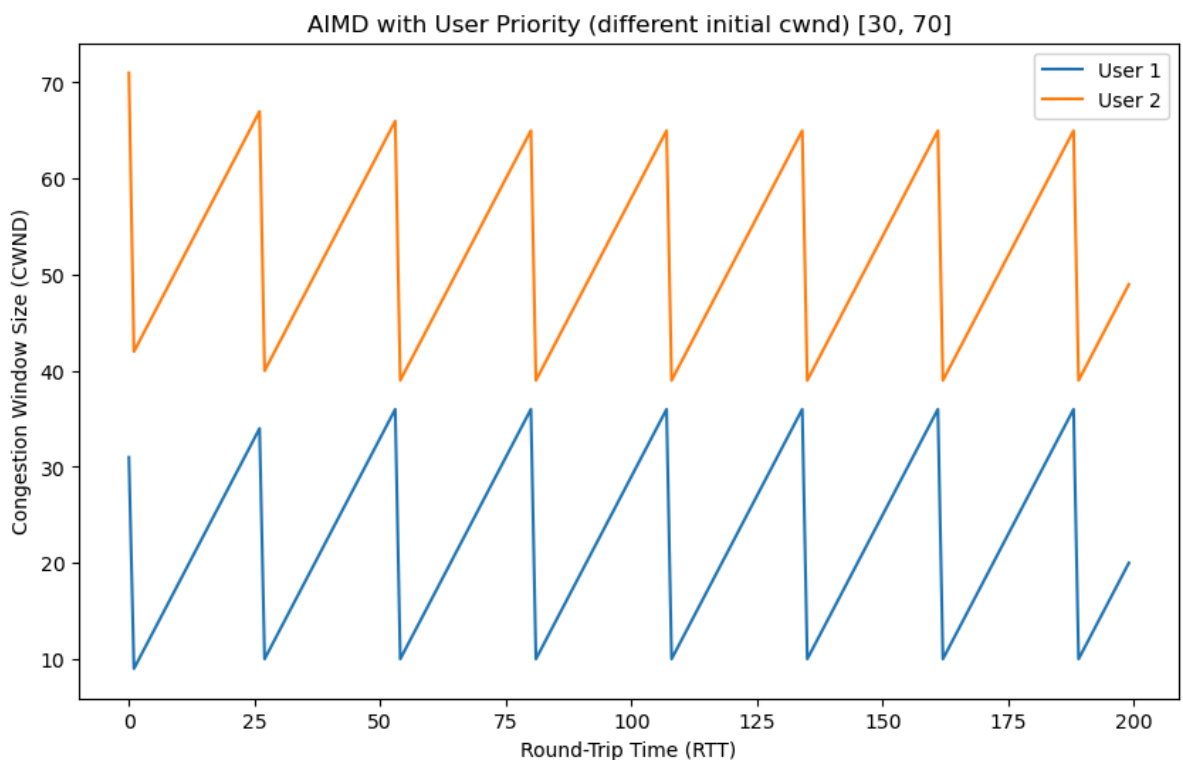
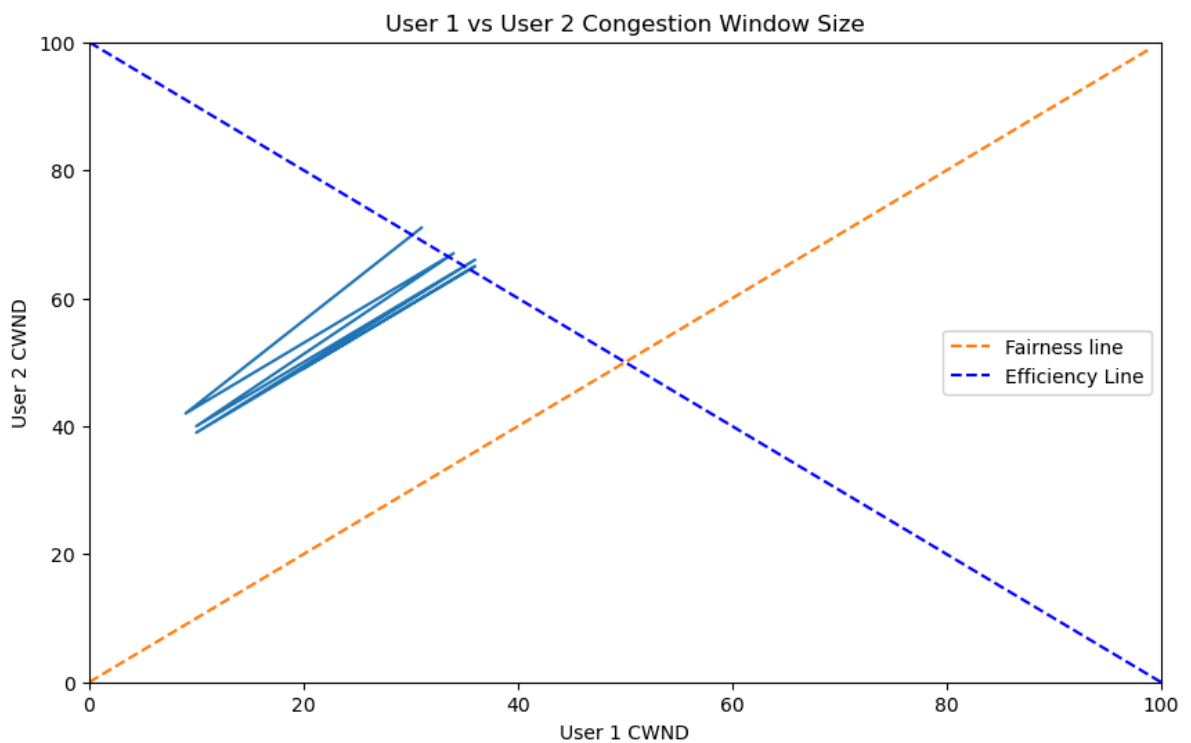
(Packet Loss)Multiplicative Decrease at: 81  
 Peak congestion window size for user 0: 36.0  
 Peak congestion window size for user 1: 65.0

(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



### Approach by modifying beta functions (70,30)

```
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:
```

```
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: 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

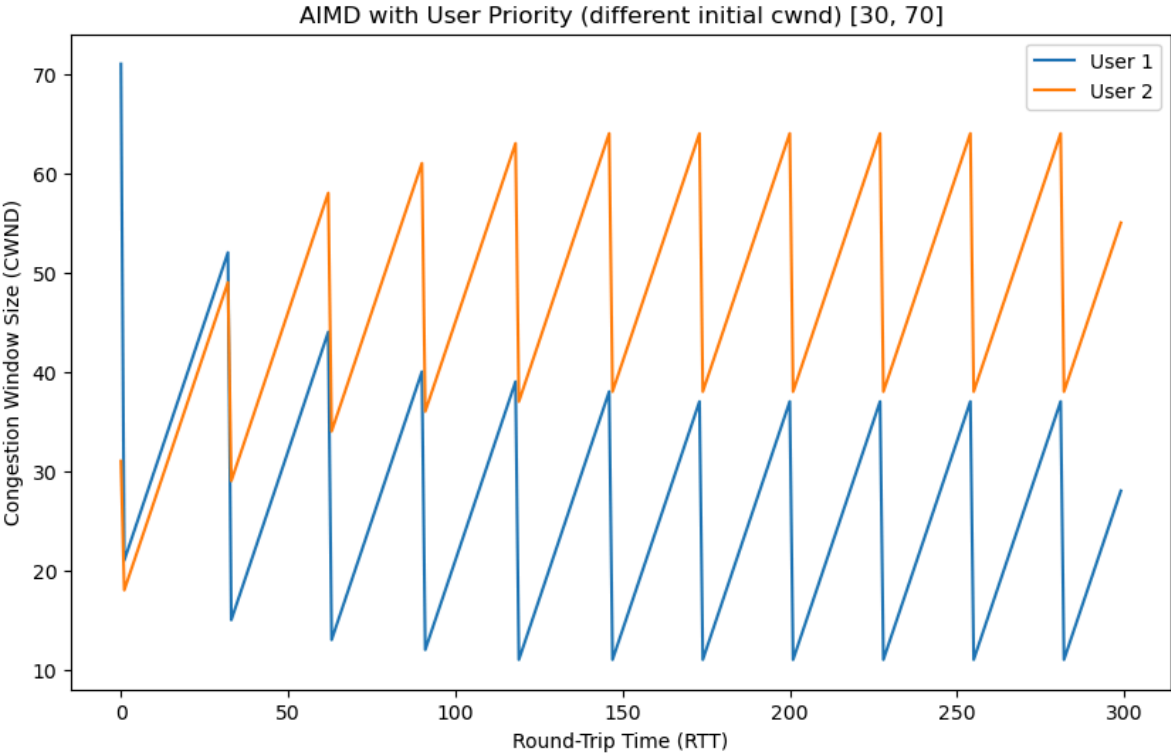
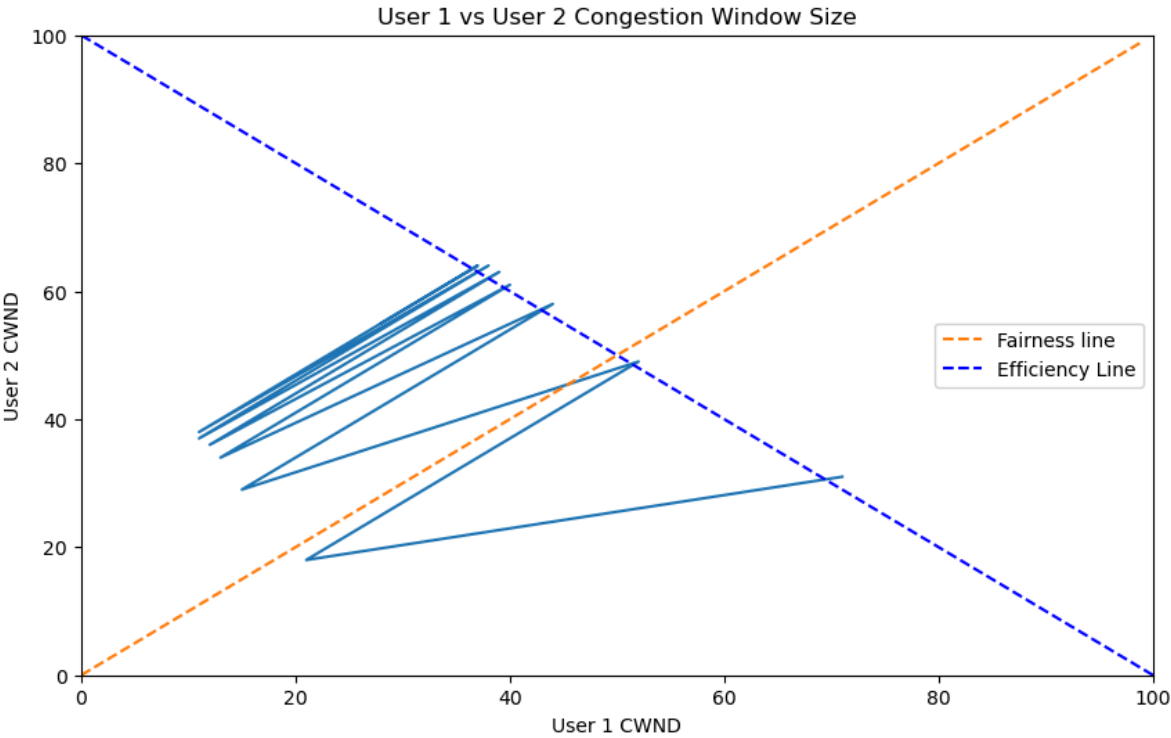
(Packet Loss)Multiplicative Decrease at: 174  
Peak congestion window size for user 0: 37.0  
Peak congestion window size for user 1: 64.0

(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



In [ ]: