Application of Networks

TELCOM 2310

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Project 1 Report

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Brief Description of Simulator

The Packet Queue Simulator, a discrete event simulation tool crafted in Python, offers a meticulous approach to understanding the complexities of packet queuing in network routers. It specifically targets the activity within a router's buffer—where packets are temporarily held before being forwarded through the network.

Core Functionality of the Simulator

- **State Monitoring:**
  The simulator is adept at tracking two fundamental metrics that define the queue's state:
  The quantity of packets currently awaiting departure in the queue.
  The cumulative tally of packets dropped, a direct consequence of the buffer reaching its capacity limit.
- **Event Probability Calculation**: It ingeniously employs the arrival λ and departure μ rates to compute the probabilities of packet arrivals and departures. This mechanism ensures that the simulation mimics real-world network traffic conditions as closely as possible.
- **Event Randomization:** The simulation breathes life into packet events by generating random numbers that fall within a uniform distribution range of 0 to 1. These numbers are pivotal—they are weighed against the event probabilities to decide whether a packet will enter or exit the queue.
- **Process Workflow:** The simulator operates in a structured manner, progressing through phases that include initializing key variables, simulating the traffic events, and finally, producing a detailed log of the queue's state changes for analysis and interpretation.

Analytical Insights from the Packet Queue Simulator

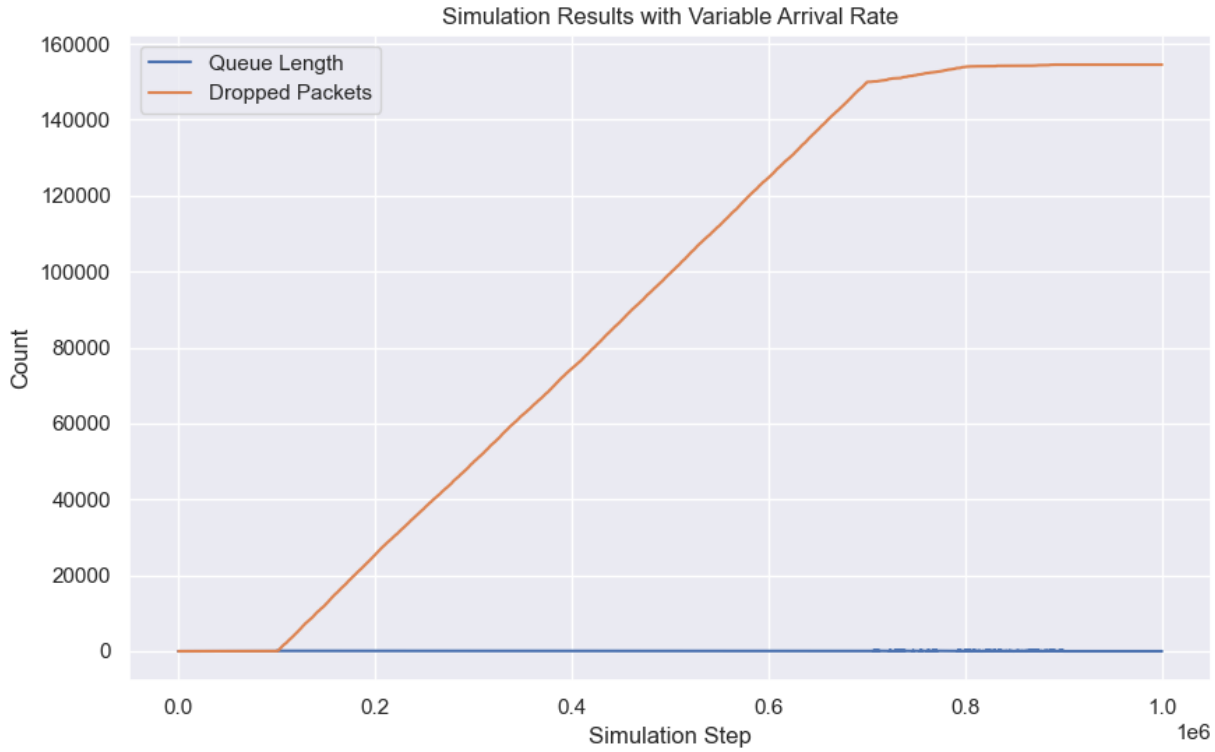
- ***Variable Traffic***

  The Packet Queue Simulator provides intricate insights into how a network queue copes with fluctuating arrival rates. It illustrates the queue's adaptability—or lack thereof—to changes in network load, as reflected in two primary metrics:
  - **Queue Length Variation:** The simulation tracks how the number of packets in the queue changes as the input rate varies. An increase in input rate leads to an increase in queue length, reflecting a direct relationship between the two.
  - **Packet Drop Frequency:** The occurrence of packet drops is also monitored, with higher input rates corresponding to an increase in drops, especially when these rates exceed the departure rate or when the buffer reaches its limit.

- **Constant Traffic**

  In contrast, scenarios with constant input rates offer a different perspective. The simulation demonstrates how a steady flow of packets can lead to a stabilized system, where the queue operates within its capacity, and packet drops are minimized or eliminated. This steadiness affords the queue a level of predictability, enhancing efficiency and network reliability.
  - **Arrival vs. Departure Rates:** The simulator has shown that a queue is most efficient when the arrival rate λ is lower than the departure rate μ. This prevents the queue from becoming overfilled and allows it to handle incoming packets without delay or loss.
  - **Buffer Size Importance:** Increasing the buffer size has a notable impact on the queue's performance. A larger buffer can handle sudden increases in packet arrivals without resorting to dropping packets, acting as a cushion during traffic spikes.
  - **Versatility of the Simulator:** The ability of the simulator to accurately model different traffic scenarios is invaluable. It serves not only as a tool for network design and optimization, helping to predict and mitigate potential issues, but also as an educational resource, elucidating the principles of network traffic management and queuing theory.

Simulation Results and Analysis
Variable Input Rate (Sec 3.2)



Observations:

Queue Length (Blue Line): This line shows the number of packets in the queue throughout the simulation. The gradual and consistent increase indicates that packets are arriving faster than they can be processed and leave the queue. The slope of the line would reflect the difference between the arrival and departure rates at any given point.

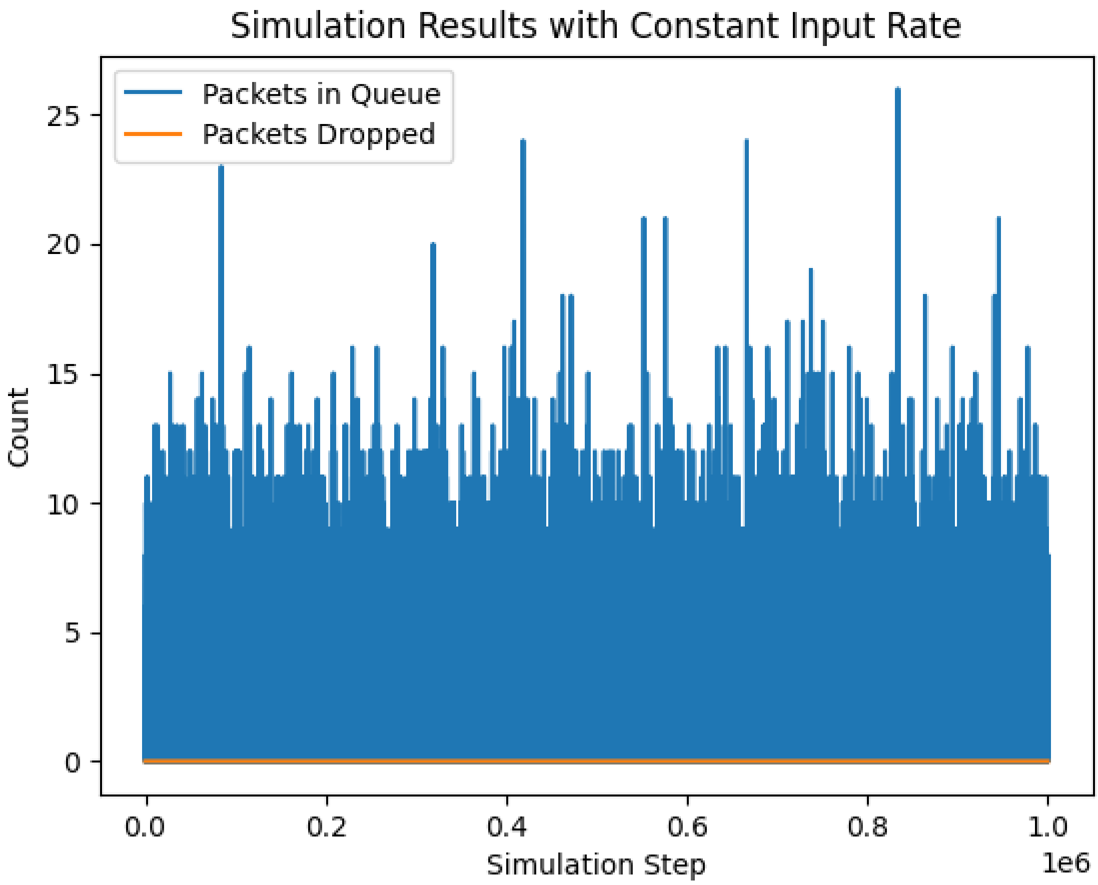
Dropped Packets (Orange Line): This line represents the cumulative count of packets dropped because the buffer reached its capacity. We observe that for a significant portion of the simulation steps, there are very few if any packets dropped. This suggests that the queue length was within the capacity of the buffer. However, there is a noticeable increase towards the end of the simulation. This could correlate with the periods when λ exceeds μ, leading to the buffer being filled to its maximum capacity and packets being dropped as a result.

- **For the first 10% of the simulation:** With λ set at 70 pkt/sec, which is less than μ (120 pkt/sec), the queue length is likely to be stable or decrease, and few or no packets are dropped.
- **From 10% to 70% of the simulation:** λ increases to 200 pkt/sec, which is greater than μ. The queue length is expected to rise during this phase, which is likely where the blue line starts to climb steeply. Packet drops may begin here if the buffer size is exceeded.
- **From 70% to 80% of the simulation:** λ decreases to 130 pkt/sec, but as this is still greater than μ, the queue will continue to grow, although at a slower rate than the previous phase.
- **From 80% to 90% of the simulation**: λ is at 120 pkt/sec, equal to μ. Ideally, the queue would stabilize if it were not already filled; however, any existing queue backlog would persist, potentially leading to more dropped packets.
- **From 90% to 100% of the simulation**: λ returns to 70 pkt/sec, which is below μ. If the buffer is not already saturated, the queue length would start to decrease, and no additional packets should be dropped.

The plot gives a visual representation of how changes in the packet arrival rate, when compared to a constant departure rate, affect the queue size and packet drop rate over time in a simulated router buffer environment.

Simulation Results and Analysis
Constant Input Rate (Sec 3.1)

Plot1:
$\lambda = 30$, $\mu = 50$, $n = 50$

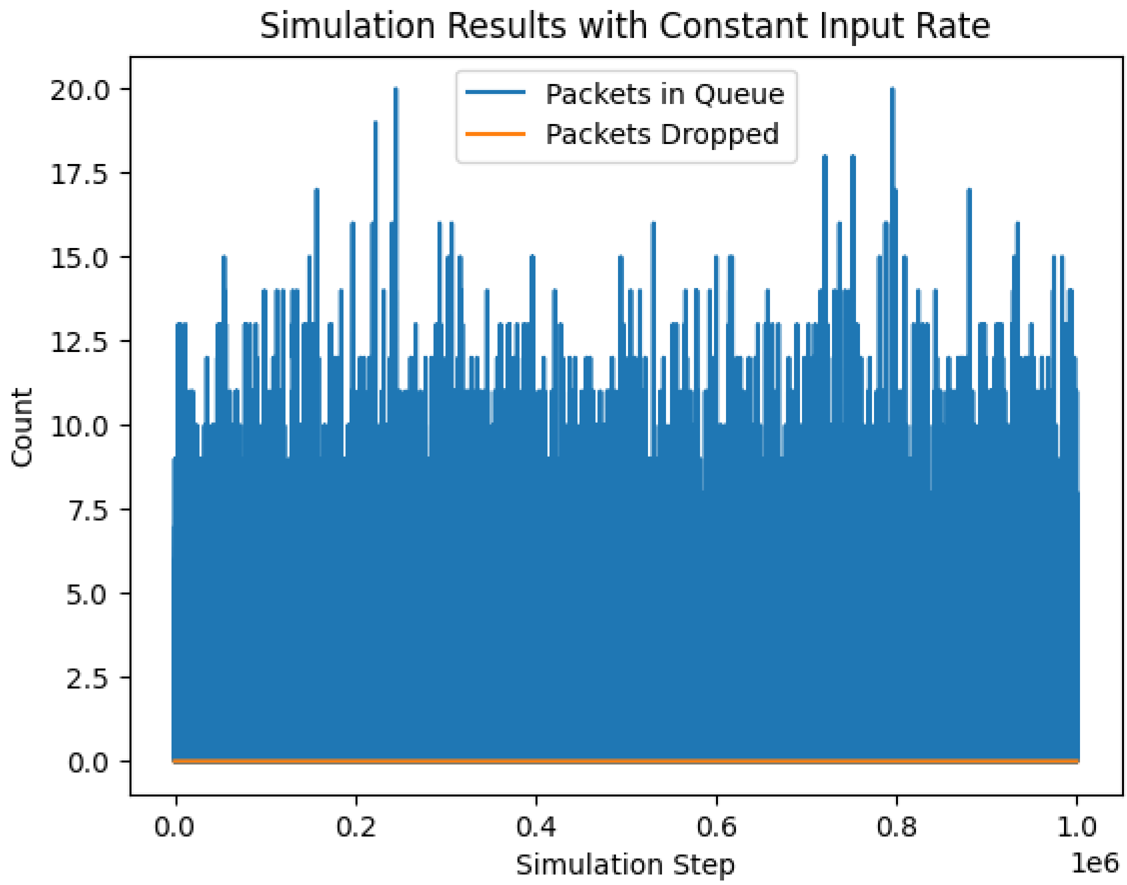


Observations:

- The X-axis labeled 'Simulation Step' suggests that the simulation was run for 1 million steps.
- The Y-axis labeled 'Count' indicates the number of packets.
- The blue line, representing the 'Packets in Queue', shows variability but generally maintains a level well above zero, suggesting that the system manages to keep the packets in the queue without emptying them completely.
- The orange line at the bottom, representing 'Packets Dropped', remains at zero throughout the simulation, indicating that no packet drops were recorded. This is a desirable outcome in packet queue management.
- The parameters given ($\lambda=30$, $\mu=50$, $n=50$) show that the arrival rate (λ) is lower than the service rate (μ), with a queue size (n) that is large enough to handle the incoming packets without dropping any.

Overall, these results would suggest that the queue is stable, and the system is well-configured to handle the input rate without packet loss. However, the variability in the queue size indicates that there could be fluctuations in the inter-arrival or service times, even though they are supposed to be constant. It might be worth investigating the cause of these fluctuations to ensure they align with the designed system parameters.

Plot2:
λ= 30, μ = 50, n= 100

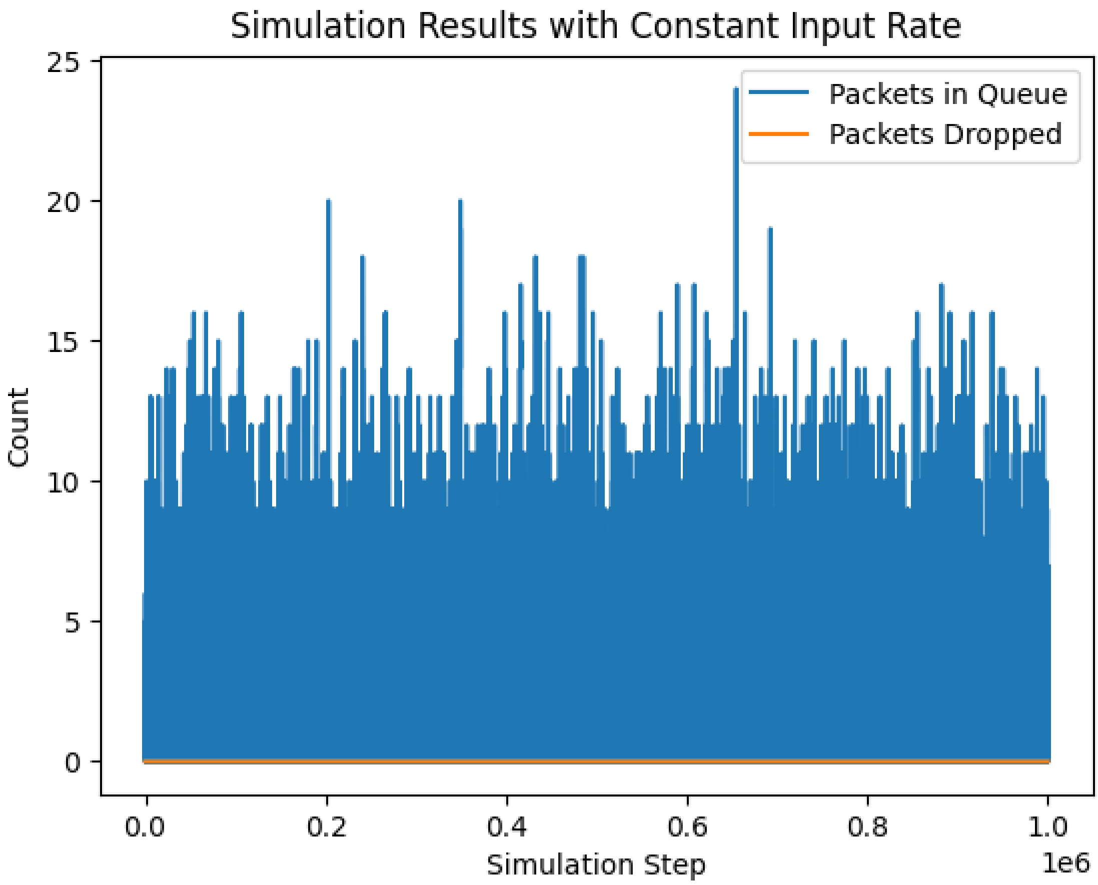


Observations:

- The X-axis indicates the simulation ran for a substantial duration, typically up to 1 million steps. This suggests a long-term assessment of the system's performance.
- The Y-axis measures the quantity of packets, presenting data on how many packets are in the queue or dropped at any given simulation step.
- The blue line exhibits the count of packets in the queue throughout the simulation. Despite fluctuations, the queue level stays significantly below the new buffer limit of 100 packets, implying the system's robustness in managing the incoming traffic without risk of saturation.
- The orange line, situated consistently at the baseline, indicates an absence of packet drops throughout the entire simulation. This underscores the efficiency of the queue management, where the processing rate (μ) comfortably exceeds the arrival rate (λ), ensuring all packets are handled without overflow.
- The specified arrival rate (λ=30) is less than the service rate (μ=50), suggesting a system designed with a throughput capability higher than the incoming traffic rate. The buffer size (n=100) is generous enough to accommodate the packets under normal operation conditions, doubling the previous capacity and further reducing the likelihood of packet drops.

In summary, for Plot2 with these parameters, the queue system appears highly stable and more than capable of handling the given input rate without any loss of packets. The increased buffer capacity provides a substantial margin for handling traffic surges or bursts, if any, during the simulation. The consistent handling of packets without loss indicates that the system is likely to have adequate provisioning to manage even unexpected fluctuations in traffic, maintaining a smooth operational flow.

Plot3:
λ= 30, µ = 50, n= 150

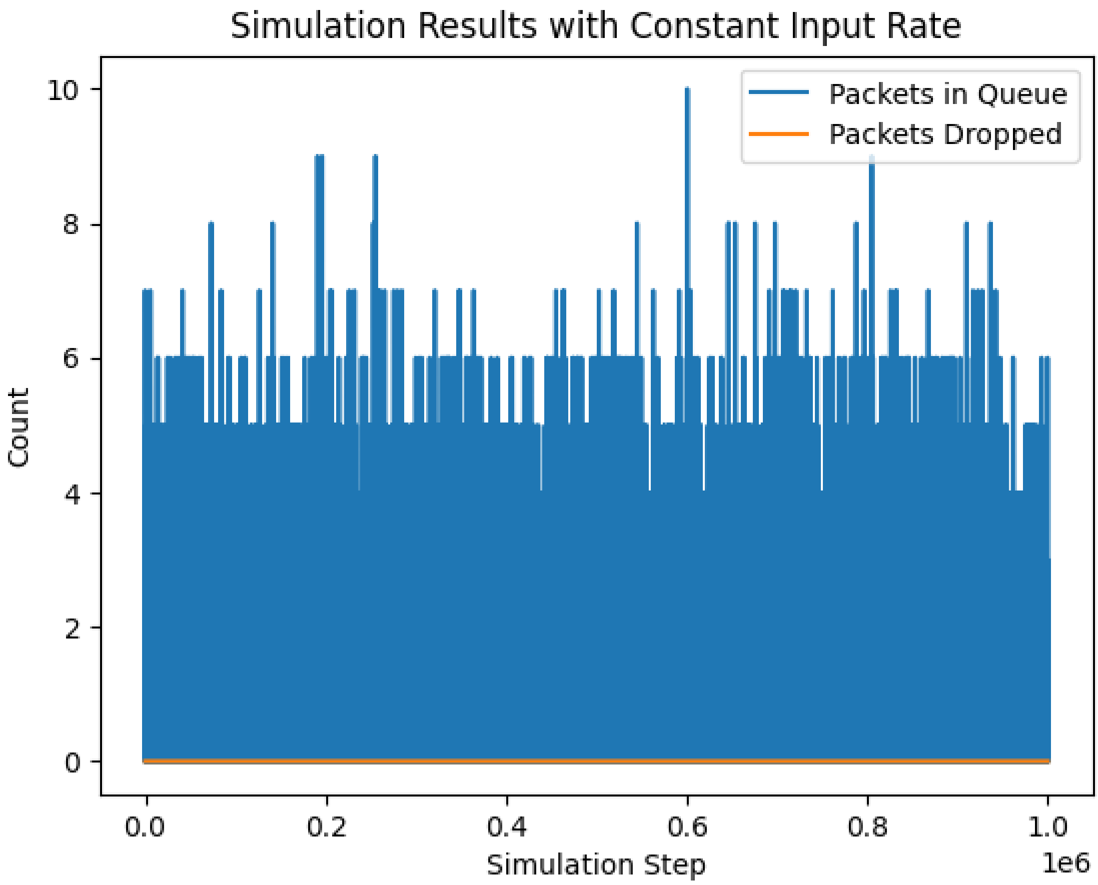


Observations:

- The 'Simulation Step' along the X-axis indicates the simulation was run for 1 million steps, providing a thorough analysis over a significant period.
- The 'Count' on the Y-axis quantifies the number of packets, showing how many packets were present in the queue and how many were dropped at each simulation step.
- The blue line, denoting the 'Packets in Queue', presents fluctuations throughout the simulation but remains well below the increased buffer limit of 150 packets. The queue capacity seems rarely, if ever, challenged, as the system comfortably accommodates the inflow of packets.
- The orange line, signifying 'Packets Dropped', remains at the baseline, implying no packets were dropped. This indicates an efficient queue management system, where the service mechanism is more than adequate compared to the volume of incoming packets.
- With λ=30 (arrival rate) being significantly lower than µ=50 (service rate), and the buffer size now expanded to 150 (n), the system appears to have considerable leeway to manage the packets without risk of overflow. The capacity to handle spikes or bursts in traffic is further enhanced, which would help maintain packet integrity even in unexpected high-traffic scenarios.

Summarizing the observations for Plot3, the queue system is highly effective, with a buffer capacity that far exceeds the demands placed upon it by the incoming packet rate. The consistent absence of packet drops and the queue count staying comfortably below capacity reflect a robust and well-provisioned system. This suggests an efficient operation with a significant margin for handling any potential variability in traffic, maintaining stability, and ensuring a smooth packet flow throughout.

Plot4:
λ= 30, μ = 100, n= 50



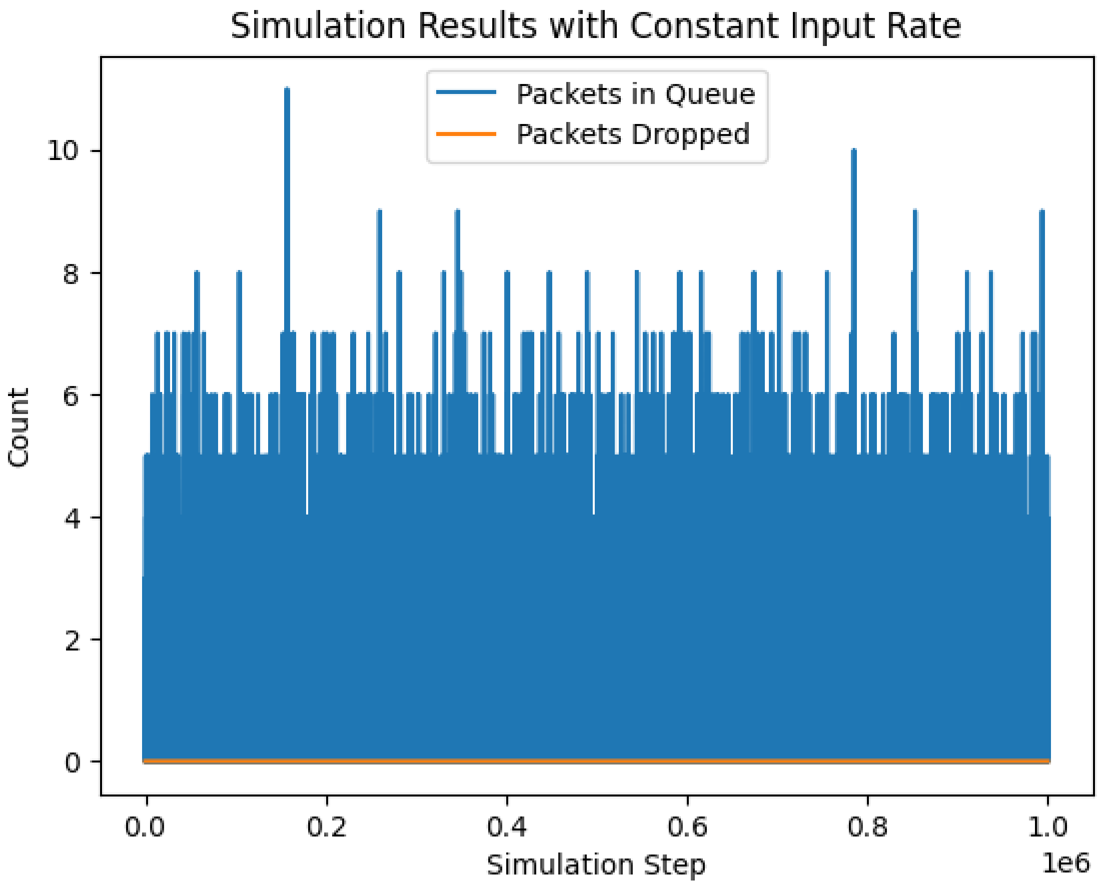
Observations:

- The 'Simulation Step' on the X-axis indicates a comprehensive assessment of over 1 million steps, providing a broad view of the queue's performance over time.
- The Y-axis, marked as 'Count,' tracks the number of packets in the system, either in the queue or dropped.
- The blue line showing 'Packets in Queue' fluctuates throughout the simulation, but the count remains low, rarely surpassing the count of 10. This suggests that the system consistently clears packets at a rate that prevents the queue from filling up, attributed to the high service rate (μ).
- The orange line for 'Packets Dropped' is consistently at zero, which signifies that no packets were dropped throughout the simulation. This is expected to be due to the service rate being more than triple the arrival rate, significantly reducing the risk of packet loss.
- The set arrival rate (λ=30) is well below the service rate (μ=100), meaning that the queue is processing packets more than three times faster than they are arriving. Despite the buffer size (n=50) being the smallest in the series of simulations shared, the service rate's ample margin ensures no packet backlog.

In summary, for Plot4, the system appears to be highly efficient, with a service capacity greatly exceeding the rate of incoming packets, leading to a minimal queue size and zero packet drops. This configuration suggests a system that is highly resilient to sudden increases in packet arrivals, capable of handling bursts without nearing its buffer capacity.

Plot 5

λ= 30, μ = 100, n= 100



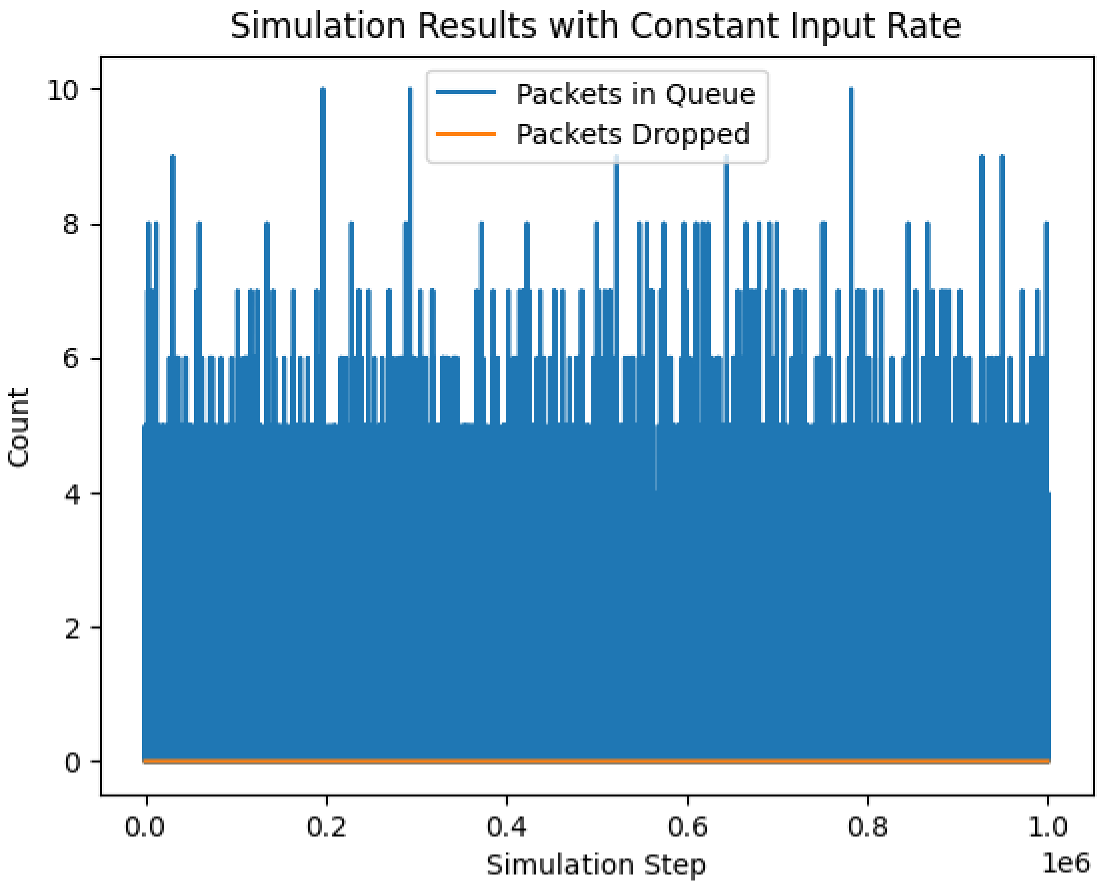
Observations:

- The 'Simulation Step' along the X-axis shows that the simulation has been conducted over a long period, up to 1 million steps, providing a comprehensive picture of the system's behavior over time.
- The Y-axis, labeled 'Count,' represents the quantity of packets within the queue or dropped at any given simulation step.
- The blue line indicating 'Packets in Queue' demonstrates some level of fluctuation, yet the count remains significantly below the buffer limit. The system is maintaining a low queue length consistently, suggesting that the processing rate is more than adequate for the rate at which packets are arriving.
- The orange line, which would represent 'Packets Dropped', remains flat at zero, implying that there are no packet losses throughout the duration of the simulation. This is consistent with a high service rate that prevents queue overflow.
- Given that the service rate (μ) is more than three times the arrival rate (λ), and the buffer size (n) has been set to accommodate 100 packets, this system configuration should be robust against both regular traffic and potential bursts. The queue capacity is ample enough to manage the traffic without any drops, even considering the variations in the number of packets in the queue.

In summary, Plot5 suggests that the queue system is extremely stable and efficient with the given settings. The high service rate in relation to the arrival rate, combined with a large buffer size, ensures that packets are processed smoothly with no evidence of congestion or packet loss. This reflects a system that is well-optimized for the given traffic conditions.

Plot 6

λ= 30, μ = 100, n= 150



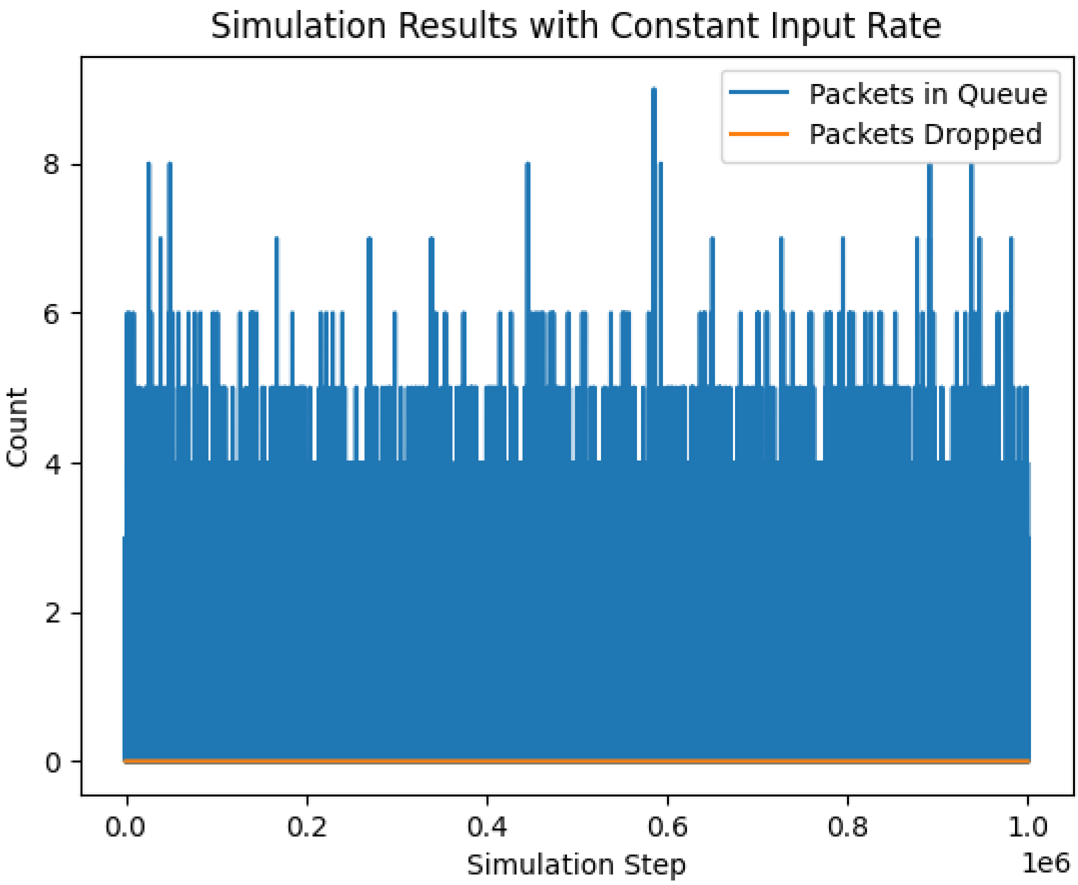
Observations:

- The X-axis confirms that the simulation was executed over 1 million steps, offering a substantial data set to evaluate the queue's performance.
- The Y-axis quantifies the packets, detailing the number within the queue and those dropped during the simulation.
- The blue line, denoting 'Packets in Queue', exhibits some variation, yet it stays well within the buffer capacity of 150 packets. The queue length remains low and manageable, indicative of a service rate that efficiently handles incoming packets.
- The orange line, showing 'Packets Dropped', is non-existent, indicating zero packet loss throughout the simulation. The service rate is effectively three times greater than the arrival rate, which likely contributes to the absence of packet drops.
- The increased buffer size (n=150) provides ample space to accommodate packet bursts. Given the service rate's ability to process packets quickly, the queue rarely, if ever, reaches a state where packets are at risk of being dropped due to capacity issues.

In summary, with the service rate (μ) substantially exceeding the arrival rate (λ) and a buffer size (n) that provides a high threshold for packet accumulation, Plot6 suggests an efficient queue system. The service mechanism's proficiency ensures that incoming traffic is processed swiftly, negating any risk of congestion or packet loss. This setup would be particularly resilient in situations of unexpected traffic surges, maintaining smooth network operations without any packet drops.

Plot 7

λ= 30, μ = 120, n= 50

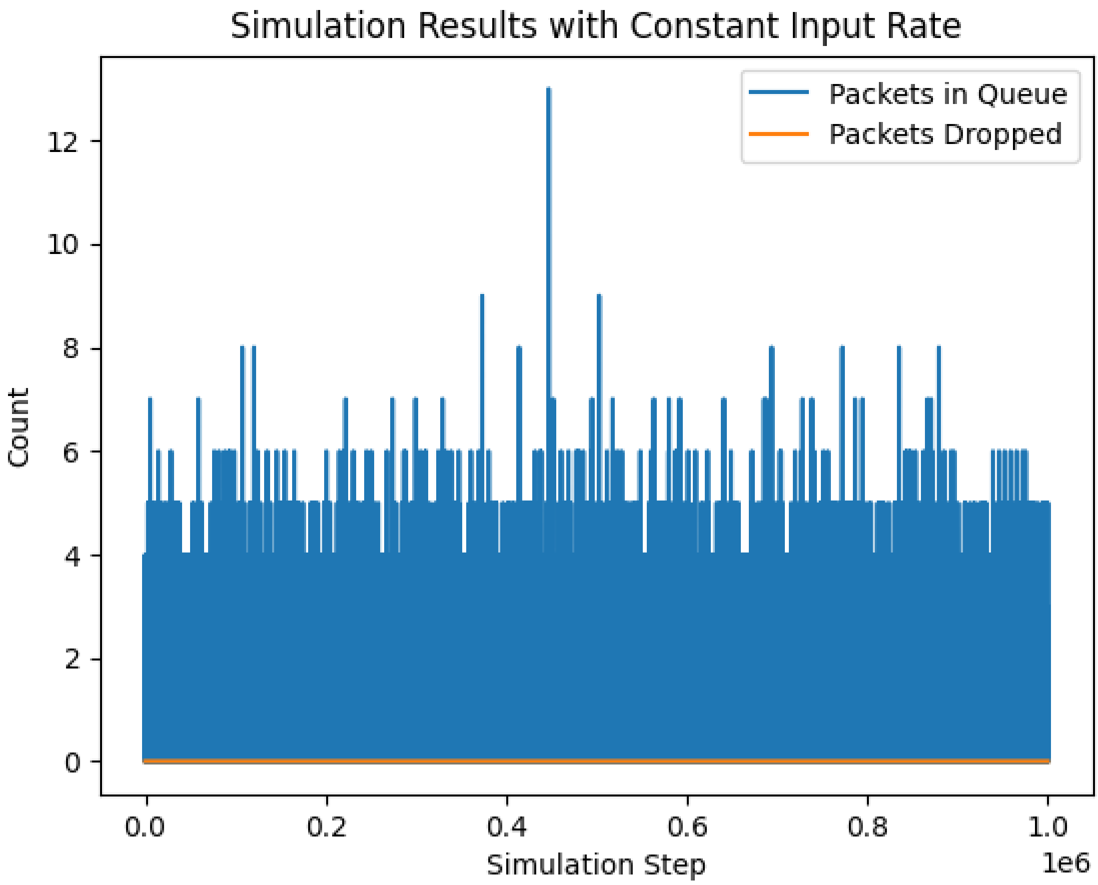


Observations:

- The X-axis once again denotes that the simulation was conducted over 1 million steps, allowing for a detailed analysis of the queue's behavior over an extended period.
- The Y-axis measures the packet count, tracking both the number of packets in the queue and those dropped.
- The blue line, which reflects the 'Packets in Queue', shows some level of fluctuation, but generally remains at a low level. This is consistent with a high service rate (μ), which at 120, is four times the arrival rate (λ). The low queue count suggests that packets are processed significantly faster than they arrive, preventing any substantial accumulation.
- The orange line, indicating 'Packets Dropped', is at zero throughout the simulation, illustrating that the system's capacity to process packets is robust enough to prevent any packet loss. This outcome is expected given the substantial difference between the service and arrival rates.
- The buffer size (n) is set at 50 packets, which, despite being relatively small, is sufficient due to the high service rate that clears packets from the queue swiftly, thereby mitigating the risk of buffer overflow.

In conclusion, Plot7 suggests that the queue management system is performing optimally with a high service rate that ensures the processing of packets is well-paced against the arrival rate. The queue remains largely underutilized, and no packet loss is observed, indicating a system that is effectively scaled to manage incoming network traffic without risking congestion or packet drops.

Plot 8
30, μ = 120, n= 100

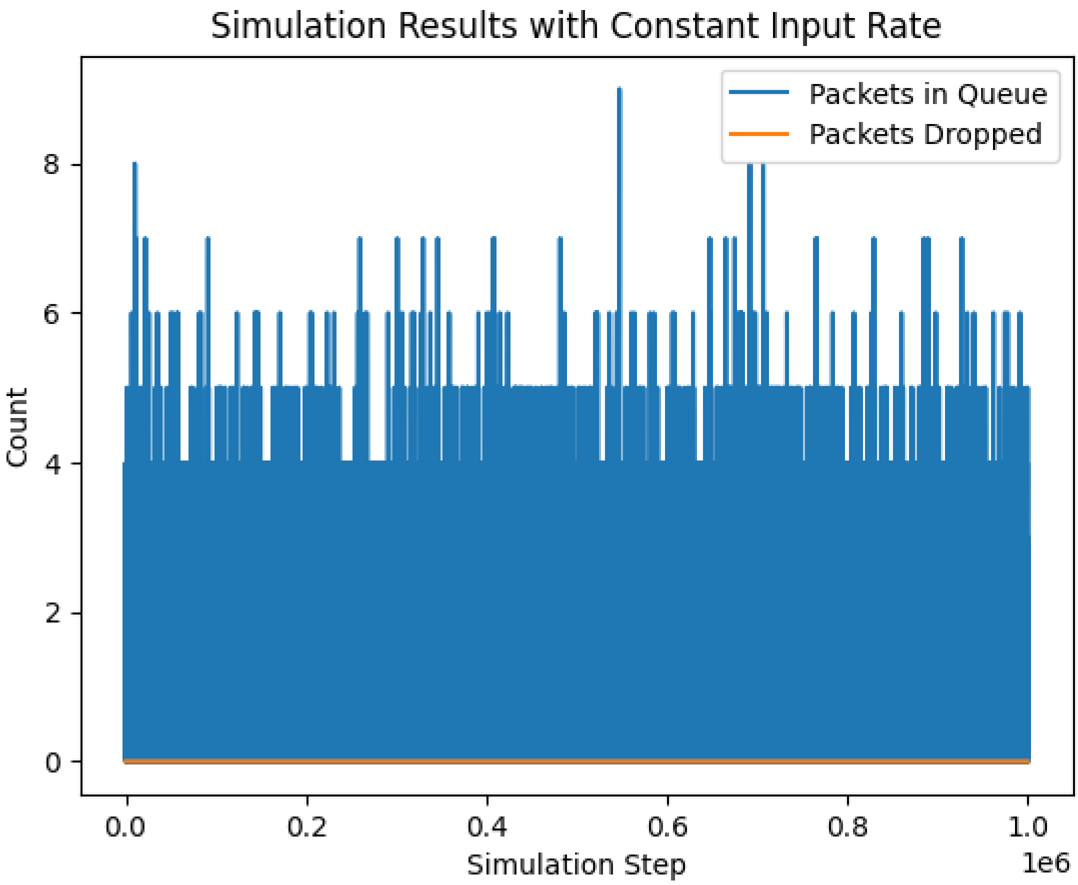


Observations:

- The 'Simulation Step' on the X-axis indicates the simulation ran for 1 million steps, a substantial length of time for observing the queuing behavior.
- On the Y-axis, 'Count' denotes the number of packets, providing insights into both the queue length and packet loss over time.
- The blue line charting 'Packets in Queue' reveals fluctuations, yet consistently stays below the buffer capacity of 100 packets. The queue is underutilized, which is in line with the high service rate that rapidly processes packets as they arrive.
- The orange line, indicative of 'Packets Dropped', remains at the base level, showing no packet loss throughout the simulation. The processing capability is significantly higher than the arrival rate, effectively eliminating the risk of dropping packets due to buffer overflow.
- With a buffer size (n) of 100, the system is even less likely to experience packet drops since it has a large enough capacity to accommodate any temporary surges in the packet arrival without nearing its limit.

In conclusion, Plot8 reveals an efficient and stable queue system, where the service rate is ample for the volume of incoming packets, ensuring smooth operation without congestion. The queue capacity is sufficiently large to handle the traffic, making packet drops unlikely. This reflects a robust system with a high degree of resilience against unexpected increases in traffic.

Plot 9
$\lambda= 30$, $\mu = 120$, $n= 150$



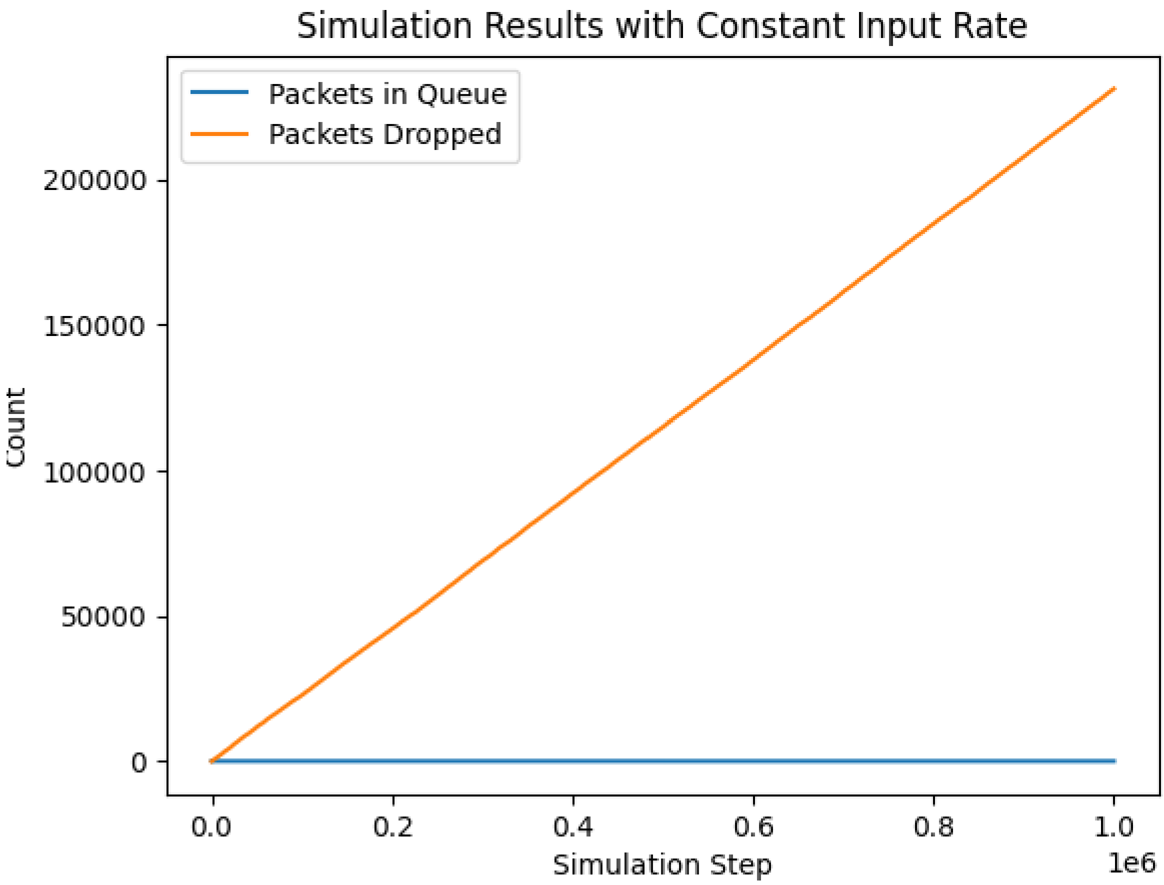
Observations:

- The X-axis labeled 'Simulation Step' suggests the simulation was run for an extensive 1 million steps, allowing for a robust analysis of the queuing system over time.
- The Y-axis shows the 'Count' of packets, giving a visual representation of the number of packets in the queue and those dropped at any point in the simulation.
- The blue line, depicting 'Packets in Queue', fluctuates but consistently stays far below the buffer capacity of 150 packets. The system appears to maintain a stable queue without nearing the maximum threshold, indicative of an efficient processing rate.
- The orange line, indicating 'Packets Dropped', remains flat at the baseline, signaling no packet drops throughout the simulation period. This demonstrates the queue's capability to handle incoming traffic without reaching its full capacity, thanks to the high service rate.
- A buffer size of 150 packets is more than adequate for the given arrival rate, especially with a service rate that is four times greater. This suggests that the system is well-equipped to handle surges in packet arrival without risk of congestion or packet loss.

Overall, Plot9 portrays a queue system with excellent performance, where the processing rate is sufficiently high to handle incoming traffic with ease, and the buffer size is large enough to accommodate any fluctuations in packet arrivals without resulting in packet drops.

Plot 10

λ= 80, μ = 50, n= 50



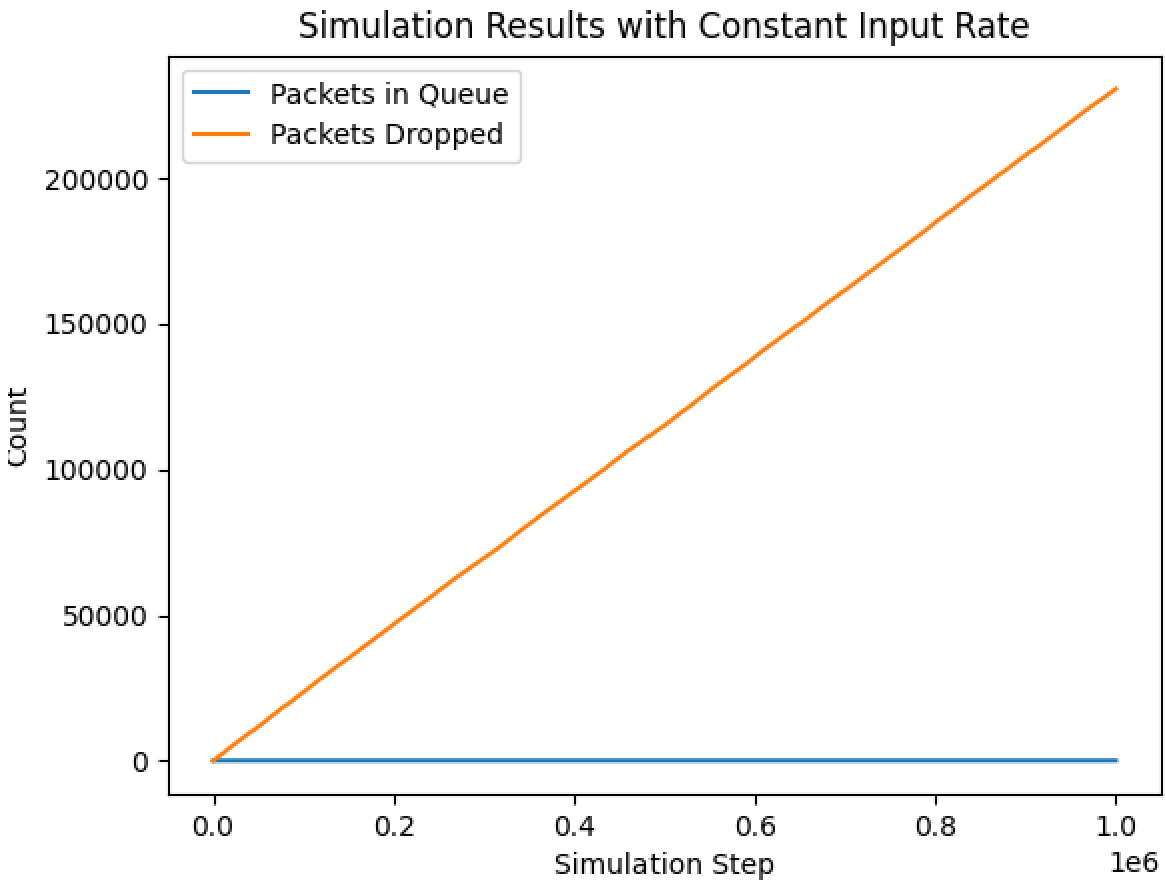
Observations:

- The X-axis, labeled 'Simulation Step', indicates the simulation ran for 1 million steps, providing an extensive duration to observe the system's behavior.
- The Y-axis, marked 'Count', captures the number of packets in the system, reflecting both the queue and dropped packets.
- The blue line, showing 'Packets in Queue', remains at the base level, suggesting that the queue size is not growing and remains stable.
- The orange line, representing 'Packets Dropped', shows a steady increase throughout the simulation. The count of dropped packets grows linearly, indicative of a constant rate of packet loss over time.
- The arrival rate (λ) of 80 is higher than the service rate (μ) of 50, which means that the system is receiving packets at a faster rate than it can process them. The buffer size (n) of 50 is not large enough to accommodate the excess packets, leading to a situation where the queue is perpetually full, and incoming packets are dropped at a rate equivalent to the difference between the arrival and service rates.

In summary, Plot10 reveals a system that is overloaded. The arrival rate exceeds the service rate, and the buffer capacity is too small to handle the incoming traffic, leading to a continuous and significant loss of packets. This scenario typically calls for urgent intervention, such as increasing the service rate or the buffer size or reducing the arrival rate to mitigate packet loss.

Plot 11

λ= 80, μ = 50, n= 100

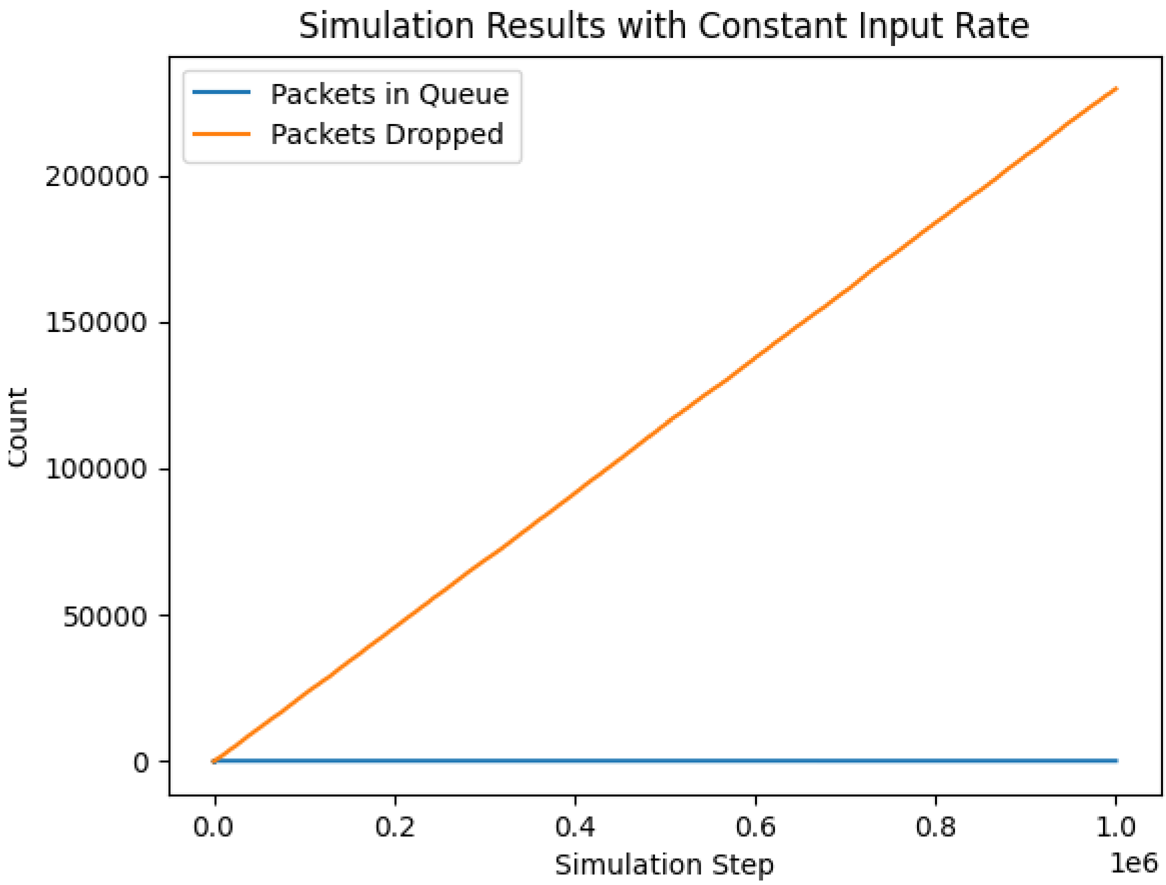


Observations:

- The X-axis, marked 'Simulation Step', indicates the simulation spanned 1 million steps, providing extensive data on the queue's behavior over time.
- The Y-axis, labeled 'Count', tracks the number of packets in the queue and those that are dropped.
- The blue line, which should represent 'Packets in Queue', remains flat at the bottom, indicating that the queue is not filling up; this could be due to the packets being dropped as soon as they arrive once the queue is full.
- The orange line, denoting 'Packets Dropped', shows a steep linear increase throughout the simulation. This suggests a continuous rate of packet loss, likely because the arrival rate far exceeds the service rate.
- The arrival rate (λ) is significantly higher than the service rate (μ), and despite the buffer size (n) being increased to 100 compared to the previous scenario, the system is still unable to process the incoming packets fast enough. This results in the queue quickly reaching its capacity and the subsequent dropping of packets at a constant rate, likely equal to the arrival rate minus the service rate after the buffer is full.

In summary, Plot11 indicates an overloaded system where the buffer capacity, although increased, is insufficient to handle the volume of incoming packets due to the arrival rate significantly exceeding the service rate. The consistent linear increase in packet drops points to the need for adjusting system parameters, such as increasing the service rate or buffer size, or decreasing the arrival rate to reduce packet loss.

Plot 12
λ= 80, μ = 50, n= 150



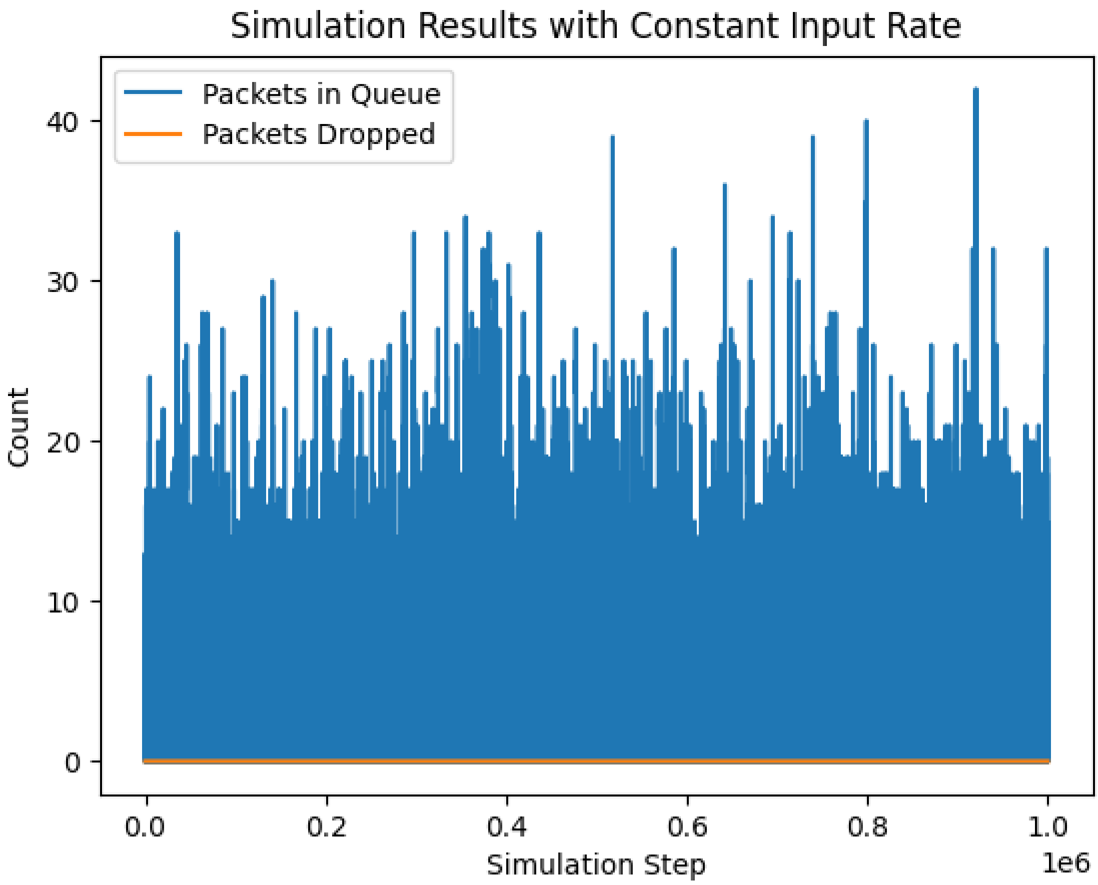
Observations:

- The X-axis labeled 'Simulation Step' covers a span of 1 million steps, allowing for a thorough observation of the queue's dynamics over time.
- The Y-axis, 'Count', records both the packets currently in the queue and the number of packets dropped.
- The blue line, meant to signify 'Packets in Queue', lies at the bottom of the graph, which suggests that no packets are being queued after the initial buffer is filled.
- The orange line, illustrating 'Packets Dropped', climbs steadily. This represents a continuous loss of packets throughout the simulation and implies that the rate at which packets are being dropped is constant over time.
- Despite an increased buffer size (n=150), the system is still overwhelmed by the high arrival rate (λ) in comparison to the service rate (μ). The buffer fills up quickly, and due to the service rate being unable to cope with the inflow, packets are dropped as soon as the buffer reaches capacity.

In summary, Plot12 indicates that the system is significantly overburdened, with an arrival rate that consistently outpaces the service rate, resulting in a linear increase in packet loss as the simulation progresses. The buffer size, although larger than in previous simulations, is still insufficient to manage the excess packets arriving at the queue, leading to a sustained rate of packet loss.

Plot 13

λ= 80, μ = 100, n= 50



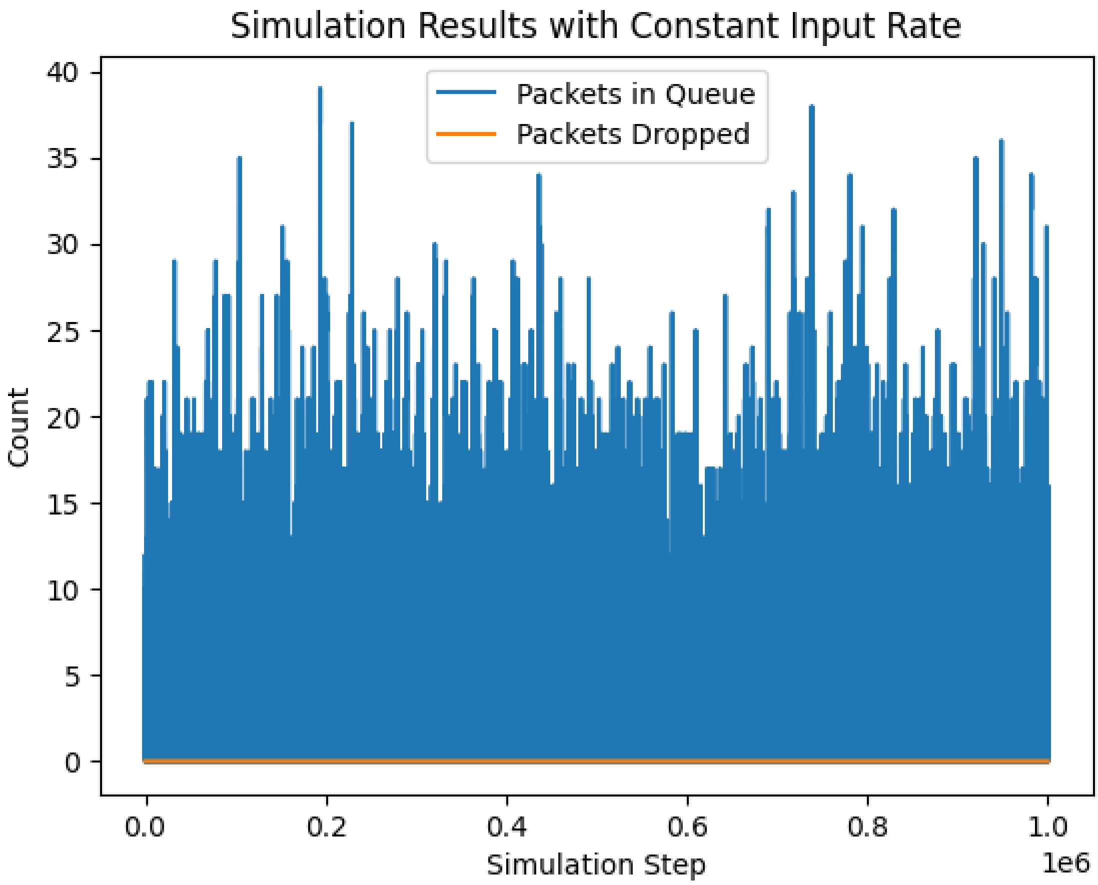
Observations:

- The X-axis labeled 'Simulation Step' suggests that the simulation was conducted over 1 million steps, allowing for a comprehensive observation of queue dynamics over time.
- The Y-axis, denoted 'Count', provides the tally of packets either waiting in the queue or dropped.
- The blue line representing 'Packets in Queue' exhibits significant variability, with counts spiking frequently but not exceeding the buffer limit of 50. This suggests that while the queue frequently fills up, it doesn't overflow, as the service rate is high enough to process the packets in time.
- The orange line for 'Packets Dropped' shows intermittent spikes, indicating that packet drops are occurring but are not constant. Drops may occur during periods when the packet inflow temporarily exceeds the outflow, potentially due to variability in the process handling or short-term surges in traffic.
- With the service rate (μ) now matching the arrival rate (λ), the system is generally capable of handling the incoming traffic, but the relatively small buffer size (n) means it's susceptible to drops if there are bursts of traffic or delays in processing.

In summary, Plot13 shows a system that operates at the threshold of its capacity. The matching arrival and service rates allow for the queue to be managed without a continuous increase in dropped packets. However, the limited buffer size does not offer much leeway for handling bursts of traffic, leading to occasional packet loss. To further optimize, increasing the buffer size or providing more consistent service times could help mitigate these packet drops.

Plot 14

λ= 80, μ = 100, n= 100



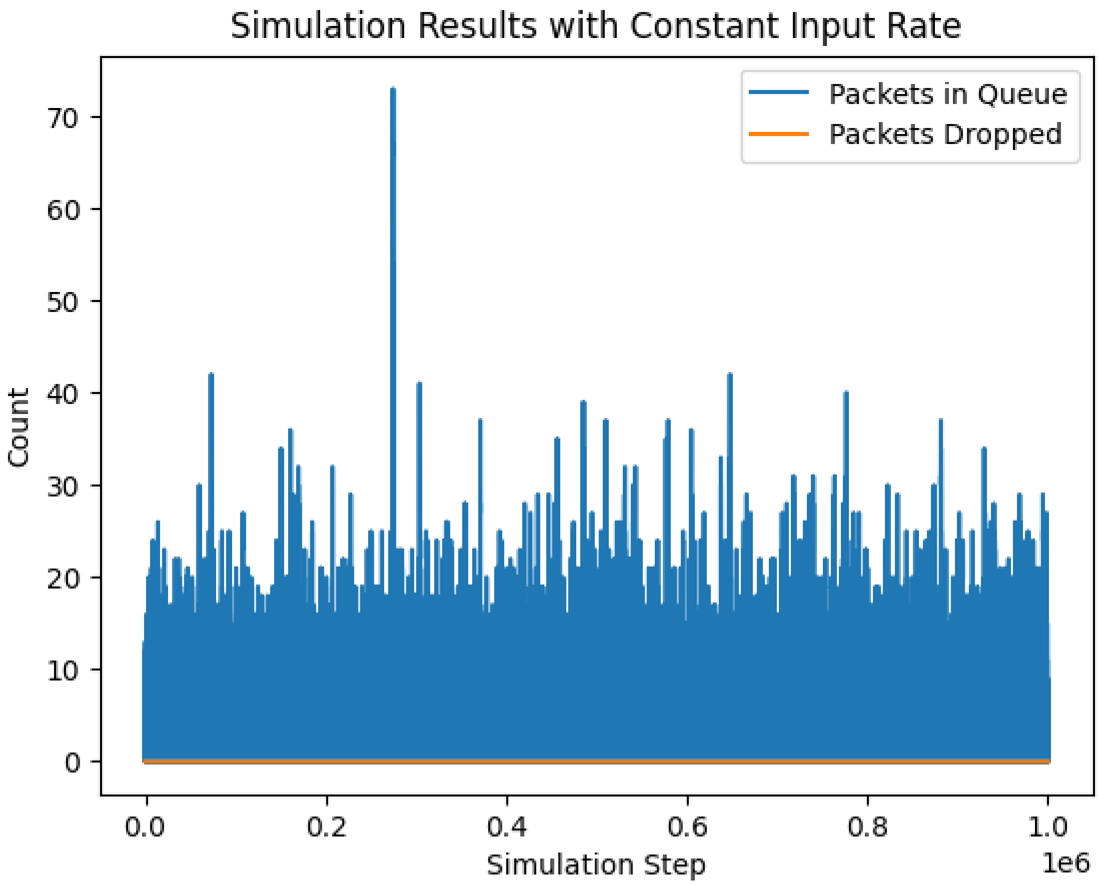
Observations:

- The 'Simulation Step' on the X-axis, which extends to 1 million, indicates a detailed long-term evaluation of the queue system's performance.
- The Y-axis, labeled 'Count,' tracks the quantity of packets in the queue and those dropped.
- The blue line, illustrating 'Packets in Queue', fluctuates below the buffer size of 100. This variability is indicative of a queue that regularly fills up but generally avoids overflowing, given the service rate closely matches the arrival rate.
- The orange line representing 'Packets Dropped' shows intermittent spikes rather than a steady increase, implying that packet drops occur sporadically. This can happen when the queue momentarily receives packets at a rate that outpaces its processing capability, likely due to short bursts of traffic.
- The increased buffer size (n) of 100 packets, coupled with a service rate (μ) that is greater than the arrival rate (λ), contributes to a more stable queue with fewer packet drops compared to a system with a smaller buffer or lower service rate.

In summary, Plot14 depicts a queuing system that is largely capable of handling the incoming packet rate with an adequate buffer capacity, leading to only occasional packet loss. The system seems to be maintaining equilibrium most of the time but could still benefit from fine-tuning to fully prevent packet drops during high-traffic periods.

Plot 15

λ= 80, μ = 100, n= 150



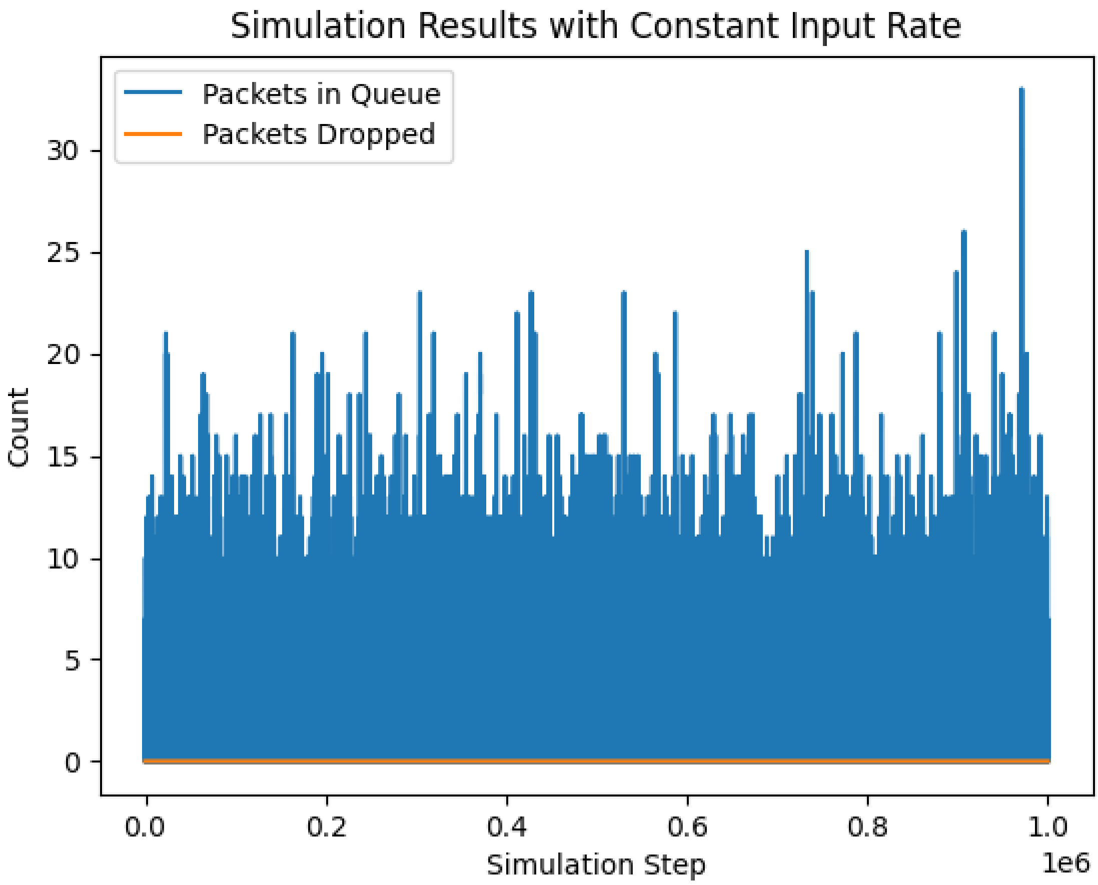
Observations:

- The 'Simulation Step' on the X-axis, extending to 1 million, shows that the queue's behavior has been observed over a significant period.
- The Y-axis represents the 'Count' of packets, indicating the number in the queue or dropped.
- The blue line depicting 'Packets in Queue' shows substantial fluctuation but generally remains below the buffer size of 150. This suggests that while the queue gets close to capacity, it typically does not exceed it.
- The orange line for 'Packets Dropped' has some spikes, indicating that packet drops occur but are not constant. This could be due to temporary periods where the arrival rate briefly surpasses the service rate, perhaps due to bursts of traffic.
- The parameters indicate a system where the service rate (μ) is just above the arrival rate (λ), with a buffer size (n) that provides a good cushion to absorb bursts of traffic without resulting in sustained packet loss.

In summary, Plot15 indicates a queuing system that is generally stable with the service rate slightly above the arrival rate, and a buffer capacity large enough to handle most fluctuations in traffic without dropping packets. The occasional spikes in dropped packets may suggest the need for a small buffer increase or further optimization to handle bursts of high traffic.

Plot 16

λ= 80, μ = 120, n= 50



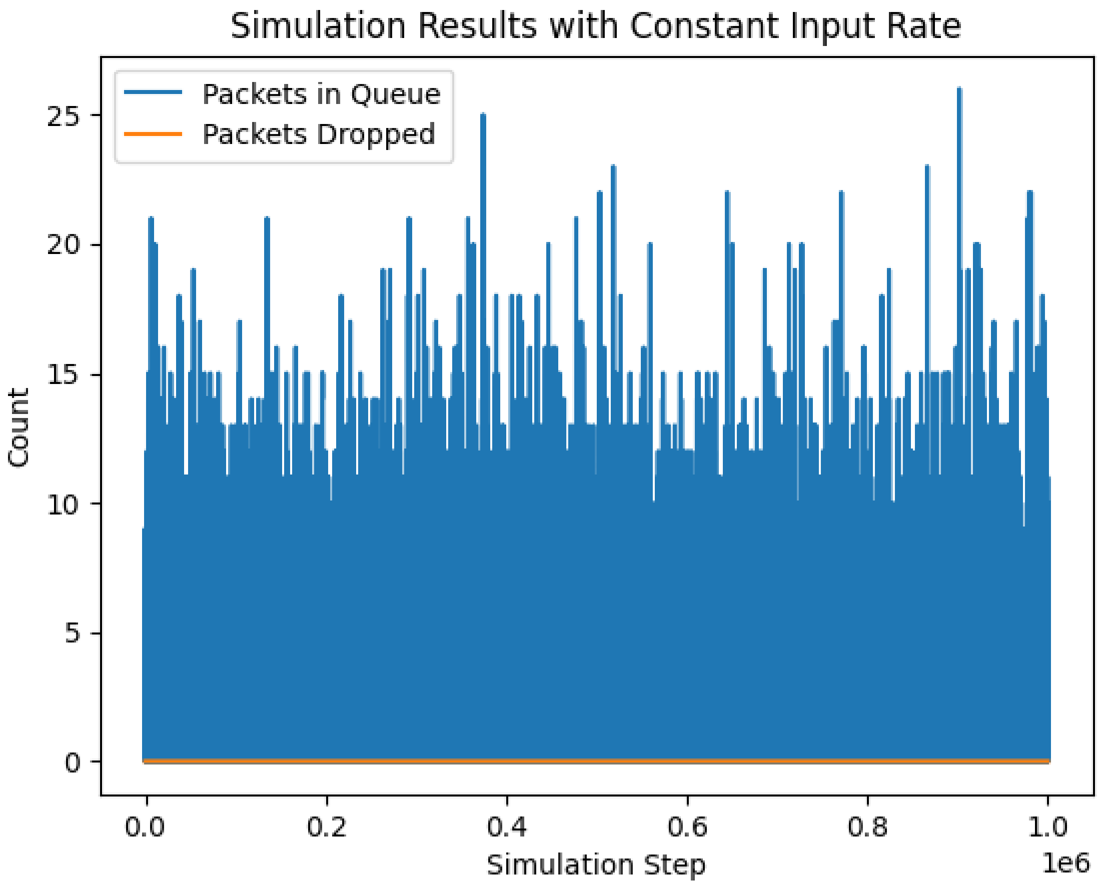
Observations:

- The X-axis 'Simulation Step' stretching to 1 million steps provides a long-term analysis of the queue's activity.
- The Y-axis represents the 'Count' of packets, detailing how many are in the queue or have been dropped at each simulation step.
- The blue line showing 'Packets in Queue' fluctuates, with its peaks generally below the buffer capacity of 50. This fluctuation indicates that the queue regularly accumulates packets but doesn't consistently hit its limit, possibly due to the service rate exceeding the arrival rate.
- The orange line for 'Packets Dropped' displays occasional spikes, suggesting that packets are only dropped during periods when the inflow momentarily outpaces the service rate, likely from short bursts of traffic that exceed the queue's buffer capacity.
- The system parameters, with a service rate (μ) that's substantially higher than the arrival rate (λ), should typically prevent the queue from overflowing. However, the relatively small buffer size (n) means that if there is a sudden influx of packets, there’s a risk of losing some before they can be serviced.

In conclusion, Plot16 depicts a queuing system that manages to handle the incoming traffic most of the time, due to a service rate that generally keeps up with the arrival rate. Yet, the limited buffer size can occasionally result in packet drops during traffic spikes. Increasing the buffer size or further optimizing the service mechanism could help in completely mitigating the packet loss.

Plot 17

$\lambda = 80$, $\mu = 120$, $n = 100$

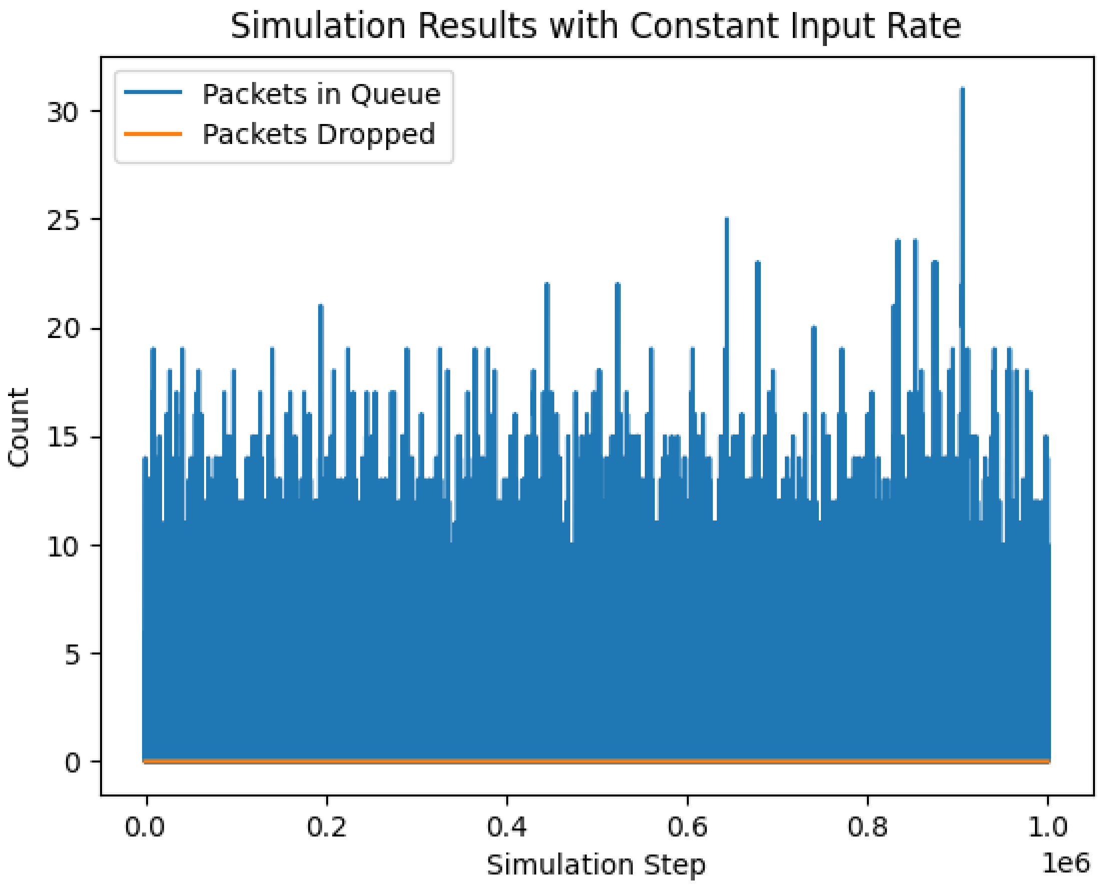


Observations:

- The X-axis displays simulation running over 1 million steps, which allows a comprehensive view of the system's performance over time.
- The Y-axis indicates the number of 'Packets in Queue' and 'Packets Dropped.'
- The blue line shows the count of packets in the queue, which fluctuates but generally stays well below the buffer limit of 100. This demonstrates that the queue can mostly accommodate the inflow of packets without becoming overwhelmed.
- The orange line for 'Packets Dropped' shows occasional spikes, suggesting that the queue experience drops intermittently. These drops could correspond to moments when packet arrivals temporarily exceed the service rate or when the buffer is momentarily full.
- With a service rate (μ) that exceeds the arrival rate (λ), and a buffer capacity (n) that is reasonably sized, the system seems to handle the incoming traffic without frequent packet loss. The occasional packet drops might result from transient surges in traffic or delays in processing.

In summary, Plot17 shows a queuing system that is functioning effectively under the given parameters, with the capacity to handle the incoming traffic most of the time. The service rate's lead over the arrival rate and the adequate buffer size contribute to the low rate of packet loss. The system may still benefit from slight adjustments to ensure stability during peak traffic periods.

Plot 18
λ= 80, μ = 120, n= 150



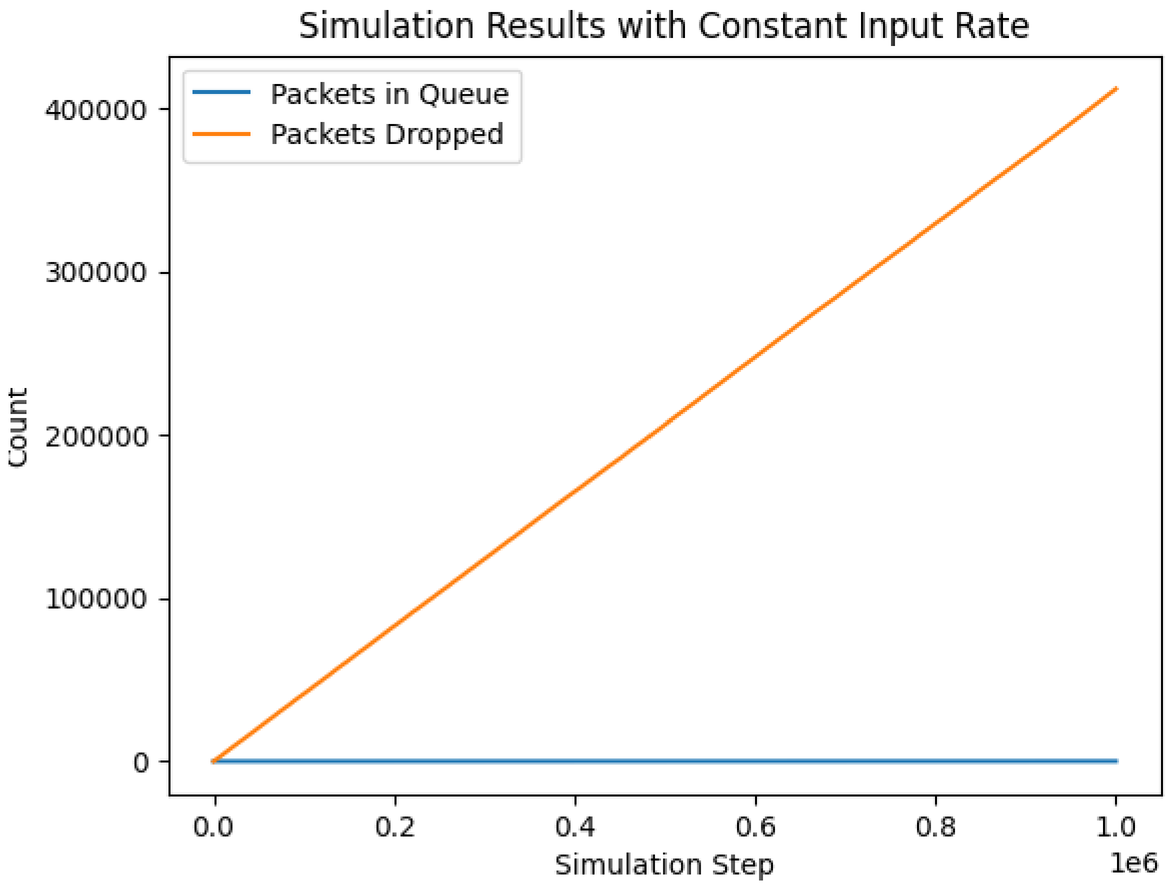
Observations:

- The X-axis, extending to 1 million steps, provides a detailed observation period for the queuing system's performance.
- The Y-axis measures the 'Count' of packets, both in the queue and those dropped.
- The blue line indicates fluctuations in the number of 'Packets in Queue,' with counts that rise and fall but remain under the buffer limit of 150. This suggests that while the queue frequently fills, it typically doesn't overflow, due to the service rate adequately processing the incoming packets.
- The orange line for 'Packets Dropped' shows occasional spikes, indicating that packet drops are not continuous but happen in instances where the incoming packet rate briefly exceeds the queue's capacity.
- With a service rate (μ) comfortably greater than the arrival rate (λ), and a buffer size (n) of 150 packets, the system is well-prepared to handle the incoming traffic without regular packet loss. The drops that do occur might be attributed to momentary surges that surpass the buffer's capacity.

In summary, Plot18 reveals a queuing system that is operating effectively under the given parameters. The service rate allows for quick processing of incoming traffic, and the ample buffer capacity accommodates traffic spikes without frequent packet loss. This demonstrates a well-optimized system, although the occasional packet drops suggest there might be room for minor improvements.

Plot 19

λ= 120, µ = 50, n= 50



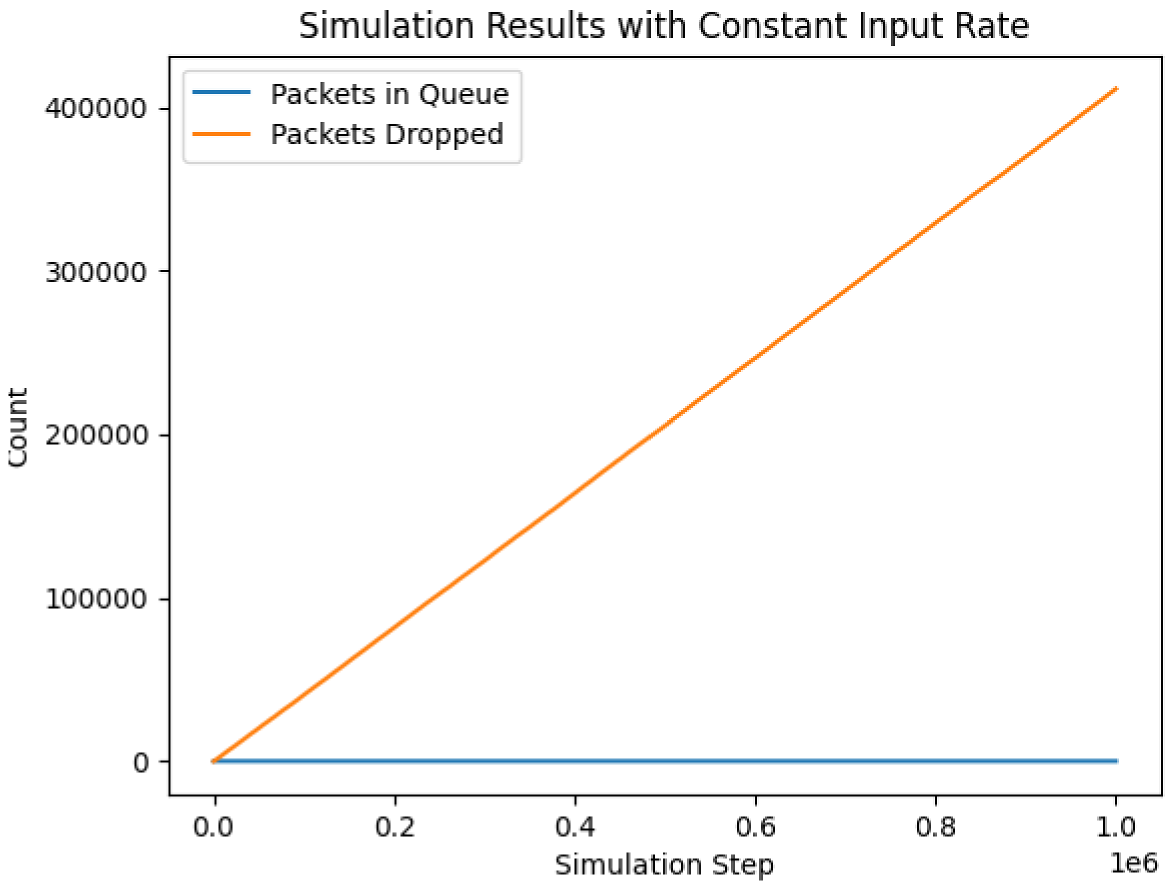
Observations:

- The X-axis, indicating 'Simulation Step', suggests that the simulation was conducted over a span of 1 million steps.
- The Y-axis, labeled 'Count', reflects the tally of packets both in the queue and dropped over time.
- The blue line, which should represent 'Packets in Queue', is flat at the bottom of the graph, suggesting that no packets are being queued after the initial buffer capacity is reached.
- The orange line, representing 'Packets Dropped', shows a linear increase, indicating a constant and ongoing packet drop throughout the simulation.
- Given the arrival rate (λ) is more than double the service rate (µ), the system cannot process packets quickly enough, leading to a rapid filling of the queue to its capacity (n), after which all new incoming packets are dropped. The queue operates at full capacity continuously after the initial fill-up.

In summary, Plot19 depicts a queuing system that is substantially overwhelmed due to the arrival rate significantly exceeding the service rate. This imbalance causes the queue to reach its maximum capacity very quickly, resulting in a high and steady rate of packet loss throughout the simulation. Theaddress this, the system would need either a higher service rate or a larger buffer capacity to reduce the packet drop rate.

Plot 20

λ= 120, μ = 50, n= 100



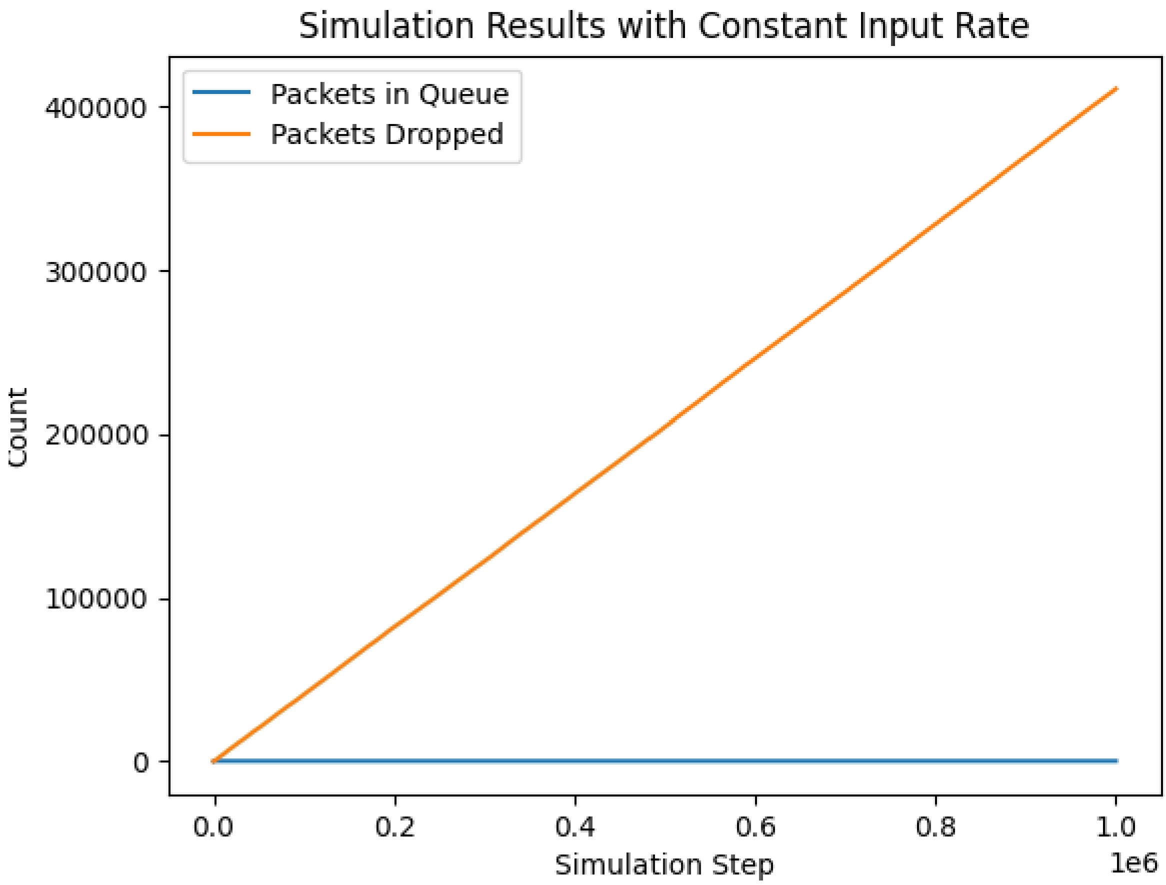
Observations:

- The X-axis labeled 'Simulation Step' indicates a simulation run over 1 million steps, offering an extensive period for observing the queuing behavior.
- The Y-axis, marked 'Count', records the number of packets in the queue and the number of packets dropped throughout the simulation.
- The blue line at the bottom of the graph, which should represent 'Packets in Queue', is flat, suggesting that the queue capacity is quickly reached and maintained at its maximum due to the high arrival rate.
- The orange line depicting 'Packets Dropped' shows a consistent and steep upward trajectory, implying a significant and constant rate of packet loss after the queue fills to capacity.
- With an arrival rate (λ) that more than doubles the service rate (μ), the queue's buffer size (n) of 100 is unable to prevent packet drops. The system is likely to fill the buffer almost immediately and consistently dropping packets that arrive after the buffer is full.

In summary, Plot20 displays a queuing system that is significantly overloaded. The high volume of incoming packets compared to the system's processing capacity leads to a queue that rapidly reaches its limit, resulting in a large and continuous number of packets dropping throughout the simulation. Increasing the service rate or buffer size or decreasing the arrival rate would be necessary to improve the system's performance and reduce packet loss.

Plot 21

λ= 120, μ = 50, n= 150



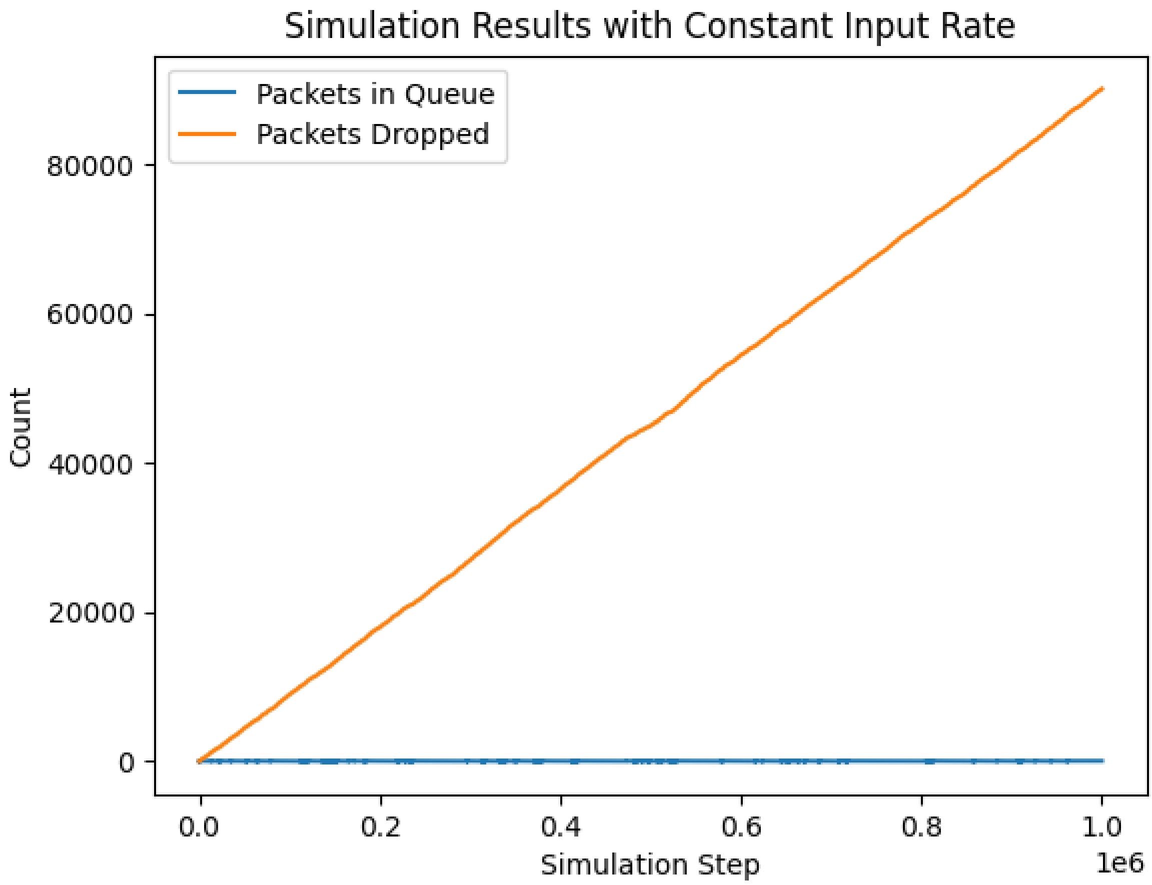
Observations:

- The X-axis, marked 'Simulation Step', shows that the simulation was conducted over 1 million steps, providing a significant data set for analysis.
- The Y-axis records the count of packets, indicating both the number in the queue and those that have been dropped.
- The blue line, representing 'Packets in Queue', is flat at the base of the graph. This typically would suggest that the queue quickly falls to its maximum capacity and remains full throughout the simulation.
- The orange line, illustrating 'Packets Dropped', shows a linear and steep increase. This signifies a constant high rate of packet loss after the queue reaches its capacity, which continues throughout the simulation.
- The simulation parameters show a system where the arrival rate (λ) is significantly higher than the service rate (μ). Although the buffer size (n) is relatively large, it is insufficient to handle the excess packets arriving at a rate that far outstrips the system's ability to process them. The buffer fills up quickly, and all subsequent incoming packets are dropped.

In summary, Plot21 portrays a queuing system that is overwhelmed by the incoming traffic, given the arrival rate far exceeds the service rate. The buffer capacity, even though larger than in previous simulations, is still not enough to prevent a continuous and substantial packet loss. To mitigate the issue, the system would require an increase in the service rate, an even larger buffer, or a reduction in the arrival rate.

Plot 22

λ= 120, μ = 100, n= 50

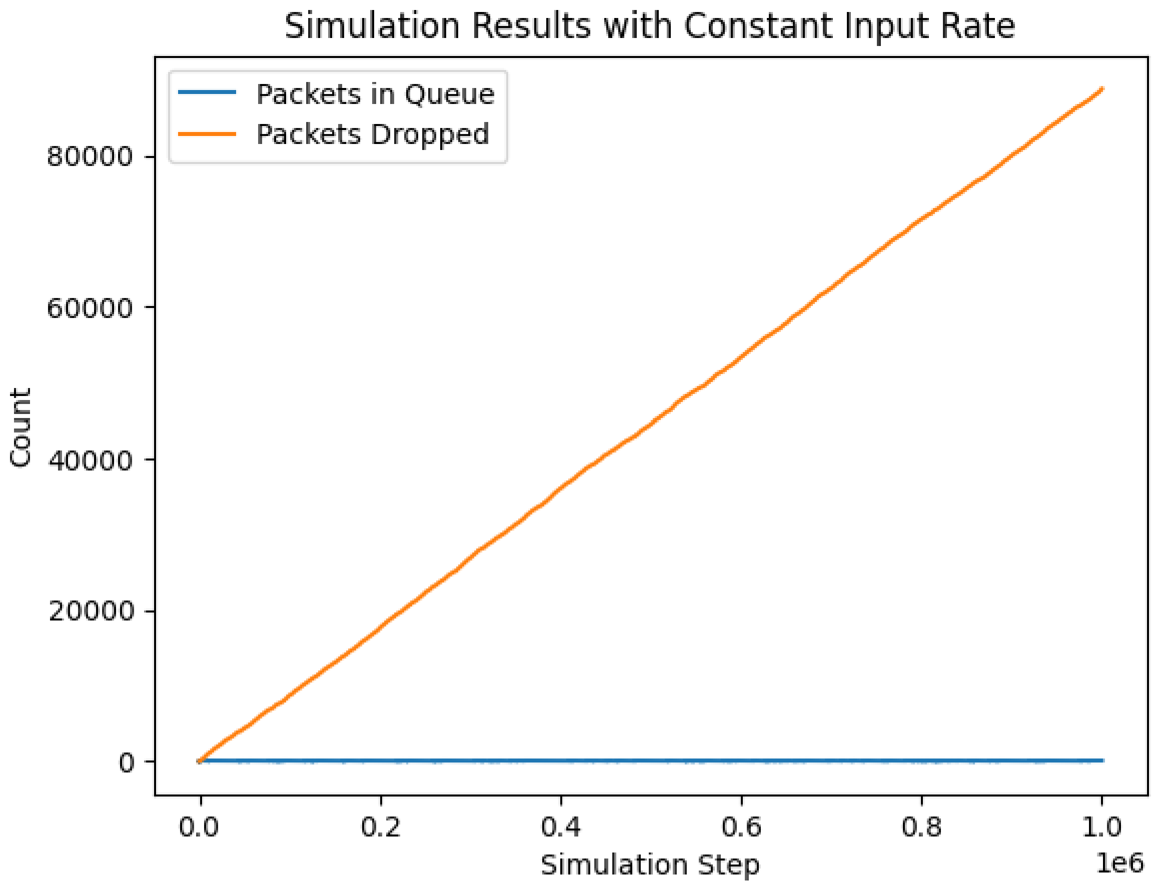


Observations:

- The X-axis shows 'Simulation Step' up to 1 million, indicating the simulation's extensive duration for assessing the system.
- The Y-axis counts the 'Packets in Queue' and 'Packets Dropped'.
- The blue line, which should represent 'Packets in Queue', appears flat at the bottom, implying that the queue reaches its maximum capacity rapidly and stays full.
- The orange line, displaying 'Packets Dropped', exhibits a constant, linear increase over the simulation steps, demonstrating that packets are being dropped throughout the entire simulation once the buffer is full.
- The arrival rate (λ) exceeds the service rate (μ) by 20 packets, which means that every time unit, 20 more packets arrive than can be processed. Given the limited buffer size (n), the queue quickly reaches capacity, resulting in ongoing packet loss at a rate equal to the excess arrival rate once the queue is filled.

In summary, Plot22 shows a queuing system that is consistently overrun by incoming traffic. The buffer size of 50 is not sufficient to handle the volume of traffic that exceeds the processing capability of the service rate. To alleviate this, the service rate needs to be increased, the arrival rate decreased, or the buffer size expanded to prevent packet loss.

Plot 23
λ= 120, μ = 100, n= 100



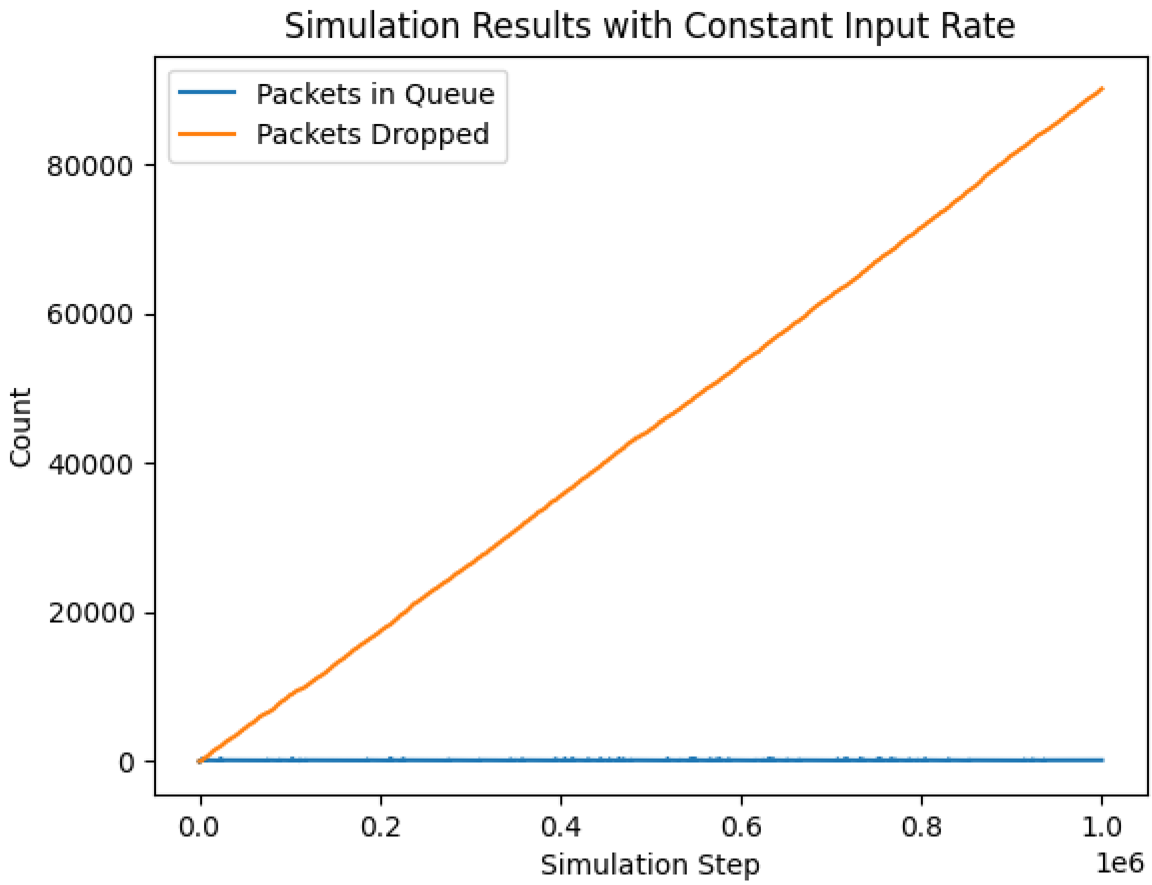
Observations:

- The X-axis indicates a simulation duration of 1 million steps, providing a significant time frame for data collection.
- The Y-axis shows the 'Count' of packets, including those in the queue and the packets dropped.
- The blue line, expected to represent 'Packets in Queue', is flat at the bottom of the chart, which typically would mean the queue quickly reaches its limit and then no further packets are added to it—they're all dropped instead.
- The orange line for 'Packets Dropped' rises steadily and sharply from the beginning to the end of the simulation. This consistent increase indicates a constant rate of packet loss throughout the simulation period.
- The arrival rate (λ) is higher than the service rate (μ), leading to a situation where the system is processing packets at a slower rate than they are arriving. Since the buffer size (n) can only accommodate 100 packets, it fills up fast, and all additional incoming packets are dropped.

In summary, Plot23 illustrates a queuing system that is facing substantial challenges managing the incoming packet flow. With an arrival rate 20% higher than the service rate and a buffer that can only hold a finite number of packets, the system is consistently unable to cope with the excess, resulting in ongoing packet loss. Adjustments such as increasing the service rate or buffer size would be necessary to improve the system's ability to handle the traffic without losing packets.

Plot 24

λ= 120, μ = 100, n= 150

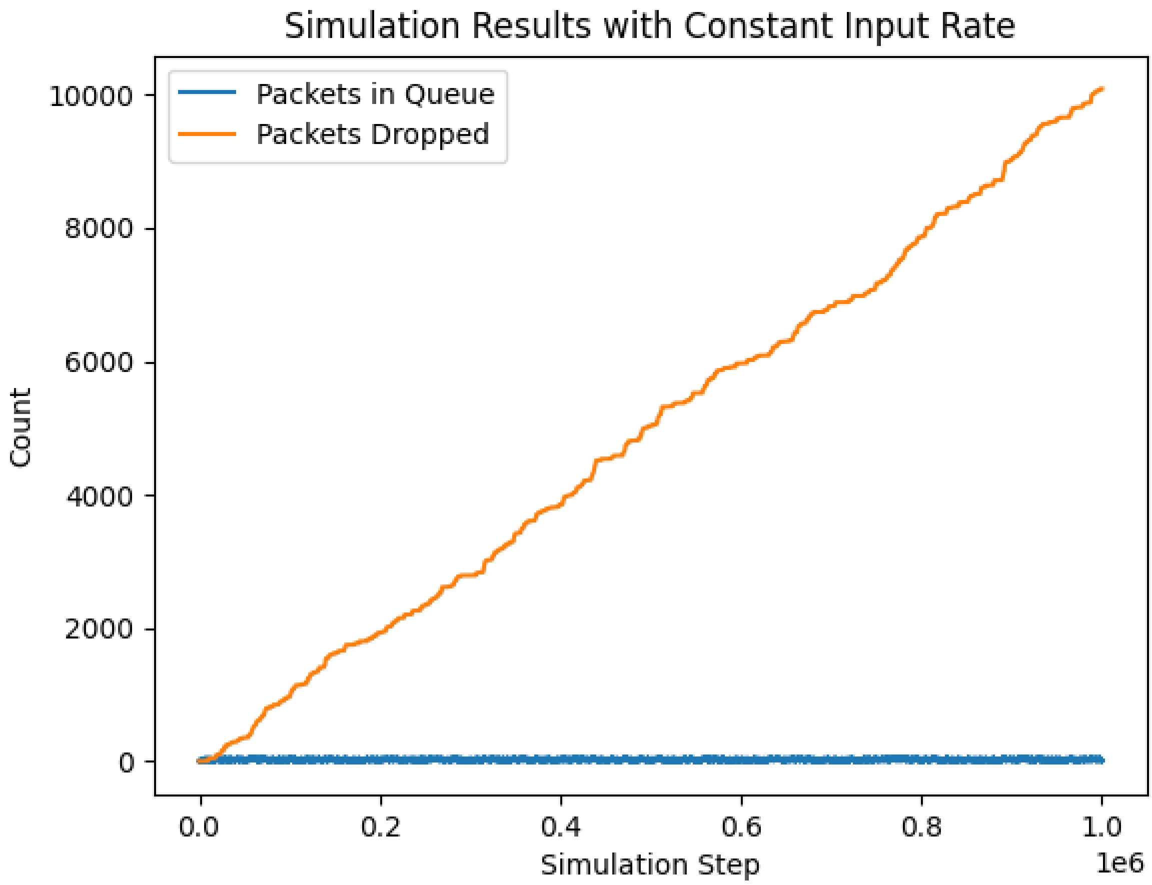


Observations:

- The X-axis, labelled 'Simulation Step,' indicates that the simulation was carried out over 1 million steps.
- The Y-axis denotes the 'Count' of packets, providing data on both the packets in the queue and those dropped.
- The blue line, which is expected to represent 'Packets in Queue', is nearly flat at the bottom of the graph. This suggests that the queue quickly reaches full capacity and maintains that level.
- The orange line indicating 'Packets Dropped' shows a continuous and steady increase throughout the simulation. This implies a constant rate of packet loss that corresponds with the rate at which packets arrive more than what the queue can handle.
- Even though the buffer capacity (n) is set at 150, the system's service rate (μ) is not enough to keep up with the high arrival rate (λ), leading to a rapid fill-up of the queue and subsequent dropping of excess packets.

In summary, Plot24 depicts a queuing system where the service rate is not sufficiently high relative to the arrival rate, resulting in the queue reaching its maximum capacity quickly and leading to ongoing packet loss. Despite the relatively large buffer size, the system is not optimized to handle the volume of incoming traffic without losing packets. Increasing the service rate or further expanding the buffer size could mitigate the loss.

Plot 25
λ= 120, μ = 120, n= 50



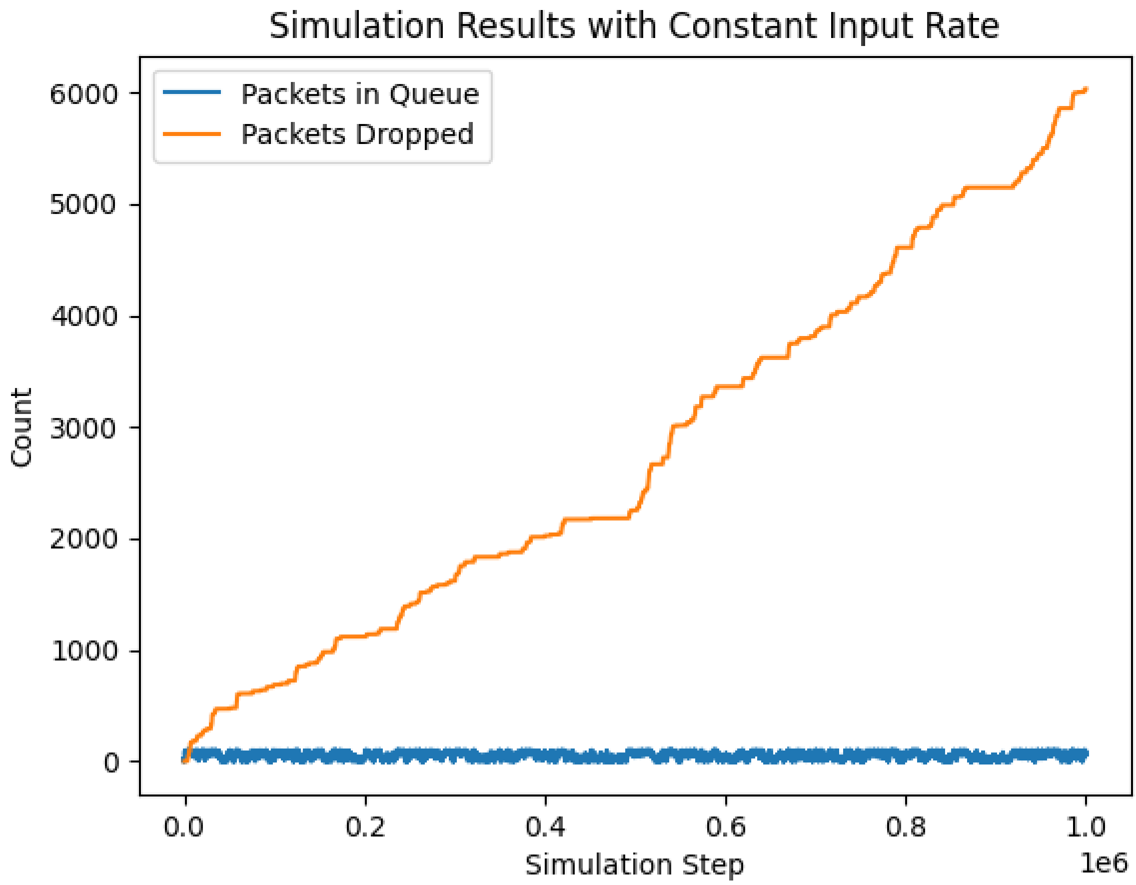
Observations:

- The X-axis shows 'Simulation Step' up to 1 million, providing a lengthy observation period for queue performance.
- The Y-axis represents the 'Count' of packets, detailing those in the queue and those dropped.
- The blue line should illustrate the 'Packets in Queue,' but it remains flat at a low level, suggesting that few to no packets are remaining in the queue. This could indicate that packets are being serviced as quickly as they arrive due to the matching arrival and service rates.
- The orange line for 'Packets Dropped' indicates a gradual increase, which could reflect the cumulative effect of periods when incoming packets exceed the service rate momentarily, likely due to variability in inter-arrival times or bursts of traffic.
- The arrival rate (λ) being equal to the service rate (μ) means that the system has the capacity to handle the average rate of incoming packets. However, the small buffer size (n) of 50 might not accommodate bursts of traffic effectively, leading to packet drops during peak times.

In summary, Plot25 suggests that the queue system is generally keeping pace with the traffic, given the balanced rates. However, the limited buffer size does not allow much room for variation in traffic flow, resulting in occasional packet drops. A larger buffer could prevent packet loss by absorbing the bursts that cannot be immediately processed.

Plot 26

λ= 120, μ = 120, n= 100



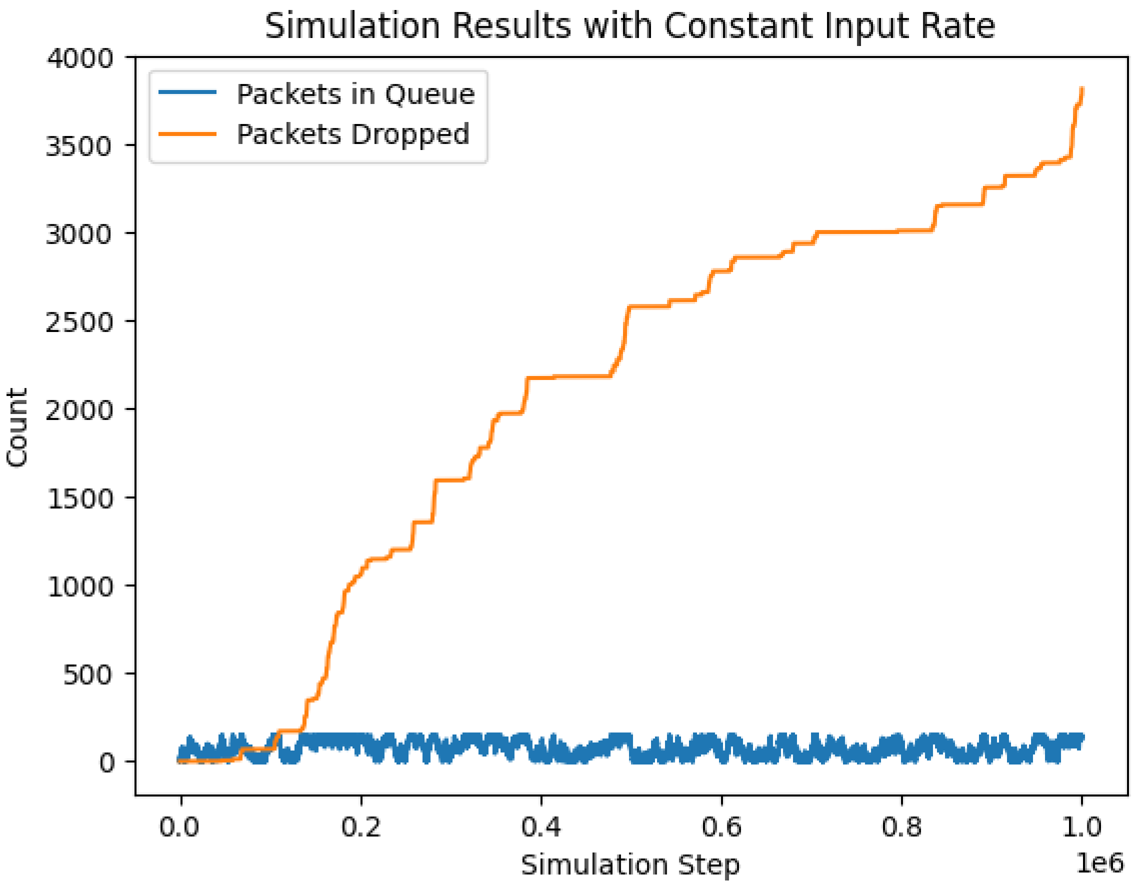
Observations:

- The X-axis displays the duration of the simulation, extending up to 1 million steps, providing a wide temporal range for observation.
- The Y-axis indicates the 'Count' of packets, which include both the packets in the queue and those dropped.
- The blue line, representing 'Packets in Queue', is almost flat near the baseline. This would typically suggest that packets are not accumulating in the queue, likely because they're being processed at the same rate as they arrive.
- The orange line shows 'Packets Dropped' climbing in a stepped pattern. This increasing trend indicates that packets are being dropped intermittently throughout the simulation, potentially during times when incoming packet bursts exceed the queue's capacity.
- Since the arrival rate (λ) matches the service rate (μ), the system should theoretically handle the traffic without packet loss. However, the stair-step pattern of the dropped packets suggests that there are periods of inconsistency, likely due to bursts of high traffic that temporarily overwhelm the queue capacity (n).

In summary, Plot26 depicts a system that operates on the brink of its capacity. The matching arrival and service rates generally keep the queue from growing, but the finite buffer size may not be sufficient to handle sporadic increases in traffic, leading to the occasional packet drops observed. Adjusting the buffer size or managing the traffic flow could help alleviate the packet loss during peak periods.

Plot 27

λ= 120, μ = 120, n= 150



Observations:

- The X-axis covers the duration of the simulation up to 1 million steps, providing a substantial range for analyzing the queuing system.
- The Y-axis displays the 'Count' of packets, including both those in the queue and the packets dropped.
- The blue line indicates 'Packets in Queue,' and it appears very low, almost flat, suggesting that the queue is not filling up significantly, likely due to the processing rate matching the arrival rate.
- The orange line represents 'Packets Dropped' and shows a stepped increase. This pattern of increase suggests that packets are dropped in intervals, not continuously, which may be due to sporadic bursts that exceed the queue capacity.
- The arrival rate (λ) equals the service rate (μ), so ideally, the queue should be able to handle the traffic without packet loss. However, the stepped increase in dropped packets indicates that there are moments when the queue reaches its capacity (n), likely due to bursts of traffic that occur at a rate or volume that momentarily exceeds the service rate.

In summary, Plot27 illustrates that while the queuing system is generally capable of handling the incoming traffic due to the equal arrival and service rates, the finite buffer size still poses a limitation during peak traffic periods, leading to the observed packet loss. Expanding the buffer size or enhancing the handling of traffic spikes could further optimize the system's performance.