# Numerical results

In this chapter, we present simulation and analytical results to demonstrate the performance of the system in two different scenarios. The first scenario involves a single node. The second scenario is a network composed of three interconnected nodes. The above two scenarios have both batch arrivals, and each batch may consist of one or two packets arriving at a time. Additionally, we analyze various parameters to understand their impact on the system's performance.

To evaluate the effectiveness of our proposed system models, we have devised ten performance measures. These measures allow us to assess the efficacy of the system models, not only for all packets and HP/LP packets, but also for each individual node within the three-node network.

## Scenario 1

If not explicitly mentioned, the default values for the different system parameters are as provided below: ,, , , , , the packet queue size is 9, and energy queue size is 100. The energy requirement for both HP and LP packets is one unit, i.e., . To facilitate the discussion, we make the assumption that the HP and LP packets have the same probability of regular battery usage, denoted as . Furthermore, in order to examine the influence of various energy arrival rates on the regular battery utilization, we also consider a scenario with a value of .

It is worth mentioning that the energy request rate is , and the effective service rate is defined as . We set to be twice of , and the HP packet arrival rate is .

In this scenario, we initially utilize the default parameters to determine suitable probabilities for regular battery usage, denoted as . As illustrated in Fig. 5 - 1 and Fig. 5 - 2, with , it becomes evident that as increases gradually, the value of decreases, and correspondingly, the RECR increases. This is because a larger allows more packets to immediately enter the server by utilizing the regular battery before facing blockage or exhausting their patience. However, this also leads to a shorter lifespan for the regular battery, as it drains more energy. Due to these considerations, we set as the upper limit and select the minimum value on the curve that does not exceed this upper bound. As a result, we choose as the suboptimal parameter value. Subsequently, we proceed to investigate the impacts of the HP batch arrival rate on various performance measures. The outcomes of this study are presented in Fig. 5 - 3 to Fig. 5 - 12.

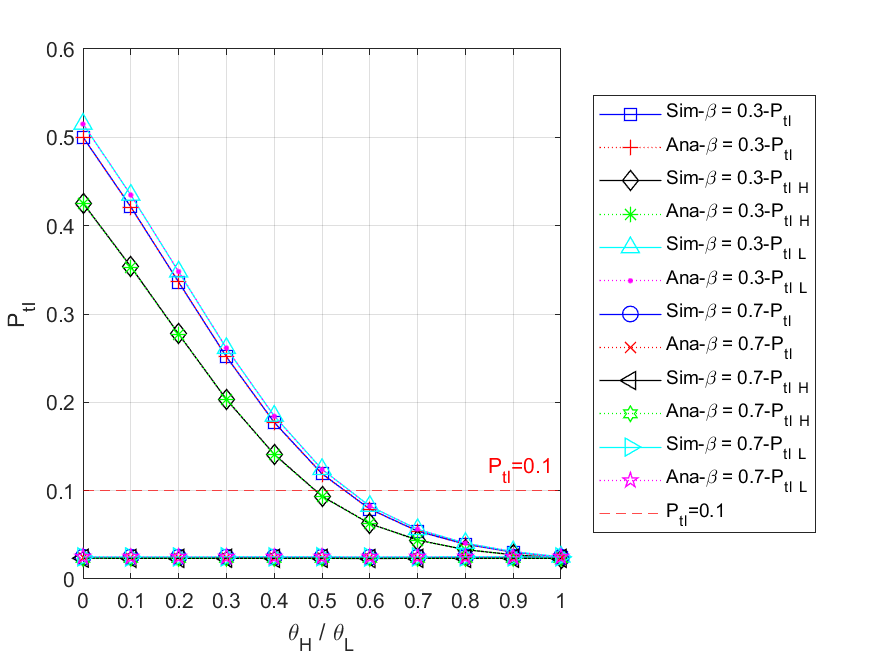


Fig. 5 - 1: The total loss probability of all () packets vs. the regular battery usage probabilities

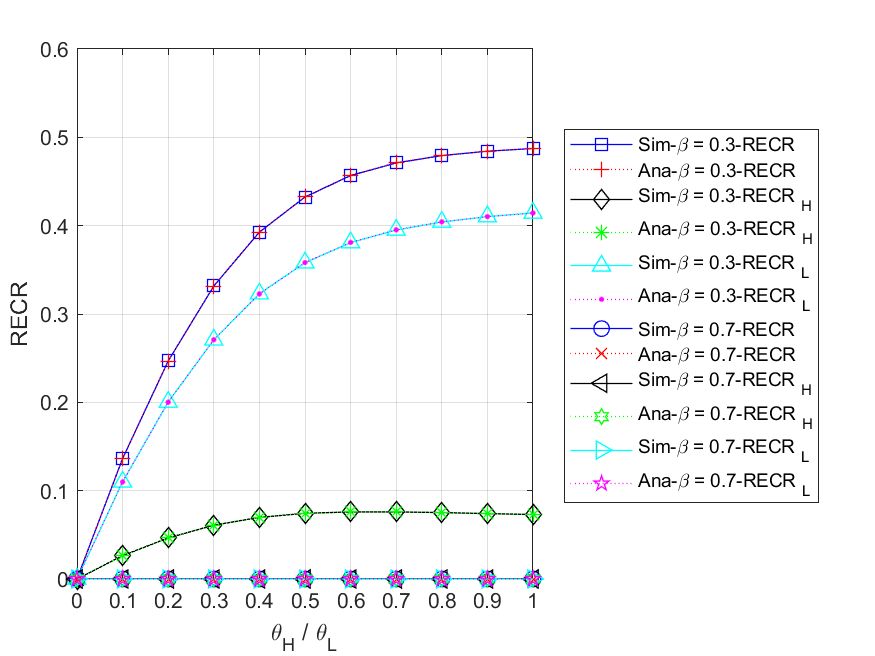


Fig. 5 - 2: The regular energy consumption ratio for serving all () packets vs. the regular battery usage probabilities

* + 1. **Energy arrival rate**

In Fig. 5 - 3, the relationship between the expected number of all packets in the system is depicted in relation to the HP packet arrival rate This is analyzed for various energy arrival rates . When considering or , it is observed that , , and all increase as increases. This relationship is due to the fact that a higher HP packet arrival rate allows for a greater number of packets to enter the system. Additionally, due to the non-preemptive priority of HP packets over LP packets, a significant number of LP packets tend to be backlogged in the queue. As a result, is consistently higher than for both and . In addition, when comparing the curves of and for , , and , it is evident that the curve for is positioned higher than that of for both and . This discrepancy arises because a higher energy arrival rate results in a more abundant energy queue, leading to fewer packets needing to wait in the system. Furthermore, it is worth noting that in the case of , the curve for initially surpasses the curve for and then falls below it. This phenomenon can be explained in two parts. In the former part, the effective service rate for is greater than the energy request rate, while for , it is lower than the energy request rate. Consequently, has an adequate energy supply to meet the service demand, resulting in a lower value of . In the latter part, both and experience an insufficient energy supply in relation to the energy request rate, i.e. . Consequently, due to the lower energy arrival rate, packets have to wait for a longer duration in the system, leading to an increased probability of impatience. As a result, for is expected to be lower compared to .

In Fig. 5 - 4, the relationship between the expected number of all packets in the packet queue is depicted in relation to the HP packet arrival rate This is analyzed for various energy arrival rates . When considering or , it is observed that , , and all increase as increases. This relationship is due to the fact that a higher HP packet arrival rate allows for a greater number of packets to enter the packet queue. Additionally, due to the non-preemptive priority of HP packets over LP packets, a significant number of LP packets tend to be backlogged in the queue. As a result, is consistently higher than for both and . In addition, when comparing the curves of and for , , and , it is evident that the curve for is positioned higher than that of for both and . This discrepancy arises because a higher energy arrival rate results in a more abundant energy queue, leading to fewer packets needing to wait in the packet queue. Furthermore, it is worth noting that in the case of , the curve for initially surpasses the curve for and then falls below it. This phenomenon can be explained in two parts. In the former part, the effective service rate for is greater than the energy request rate, while for , it is lower than the energy request rate. Consequently, has an adequate energy supply to meet the service demand, resulting in a lower value of . In the latter part, both and experience an insufficient energy supply in relation to the energy request rate, i.e. . Consequently, due to the lower energy arrival rate, packets have to wait for a longer duration in the queue, leading to an increased probability of impatience. As a result, for is expected to be lower compared to .

In Fig. 5 - 5, the relationship between the throughput of all packets is depicted in relation to the HP packet arrival rate . This is analyzed for various energy arrival rates . When comparing the curves of and for, , and , it is evident that all the curves with are lower than those with . This can be attributed to the fact that a higher energy arrival rate results in a more abundant energy queue, allowing for a greater number of packets to be served. Additionally, when considering or , it can be observed that increases as the HP packet arrival rate increases, while gradually decreases. This behavior is attributed to the non-preemptive priority of HP packets over LP packets. Consequently, with a higher HP packet arrival rate, more HP packets are able to enter the server and complete their service, resulting in fewer available resources to serve LP packets. Furthermore, the presence of the regular battery as an auxiliary energy source enables an increase in throughput without being constrained by the energy arrival rate. However, as the increases, the energy supply gradually becomes insufficient, rendering the packets in the queue more susceptible to impatience and more challenging to serve. Consequently, this leads to a pattern where with initially rises, then declines, while with exhibits a gradual upward trend towards the end.

In Fig. 5 - 6, the relationship between the mean waiting time of all packets is depicted in relation to the HP packet arrival rate . This is analyzed for various energy arrival rates . When considering or , it is observed that , , and all increase as increases. This relationship is due to the fact that a higher HP packet arrival rate allows for a greater number of packets to enter the system. Additionally, due to the non-preemptive priority of HP packets over LP packets, a significant number of LP packets tend to be backlogged in the queue. As a result, is consistently higher than for both and . Furthermore, it is important to highlight that the difference between the curves for β=0.3 and β=0.7 will be relatively smaller compared to the difference between the curves. This is primarily attributed to the priority policy, where regardless of the energy arrival rate, a significant portion of the available energy will be allocated to serving the HP packets before attending to the LP packets.

In Fig. 5 - 7, the relationship between the energy loss probability is depicted in relation to the HP packet arrival rate . This is analyzed for various energy arrival rates . When considering , it is observed that remains consistently at zero. This is due to the persistent insufficiency of energy to provide the required service, as indicated by . Consequently, whenever an energy unit arrives, it is immediately consumed by a packet in the queue. On the other hand, in the case of , the curve of displays a noticeable decline as increases, eventually settling at zero. This is primarily attributed to the increased demand for service resulting from a higher HP packet arrival rate. As a result, a significant portion of the incoming energy is promptly utilized to serve the packets, thereby reducing the likelihood of the energy queue reaching its capacity.

In Fig. 5 - 8, the relationship between the blocking probability of all arrived packets is depicted in relation to the total HP batch arrival rate . This is analyzed for various energy arrival rates . When considering or , it is observed that their respective , , and values are identical. This relationship is due to the fact that once the packet queue reaches its capacity, any incoming packet, regardless of its priority, will be blocked. Additionally, as the HP packet arrival rate increases, more packets enter the system, thereby increasing the likelihood of the packet queue reaching its capacity. Consequently, for both or , the blocking probability experiences a significant rise with increasing . Furthermore, when comparing the curves of for and simultaneously, it is evident that the curve corresponding to is positioned higher than the curve for . This can be attributed to the fact that a smaller energy arrival rate results in a longer waiting time for packets in the queue, which, in turn, increases the probability of the packet queue reaching its capacity.

In Fig. 5 - 9, the relationship between the impatient loss probability of all arrived packets is depicted in relation to the total HP batch arrival rate . This is analyzed for various energy arrival rates . When comparing the curves of and 0.7 for and curves initially rise first and then decline as increases, while the curves of continue to rise. This can be attributed to the fact that the presence of sufficient energy, allowing a large number of packets to enter the system, leading to an increase in the number of impatient packets in the queue. However, as the HP packet arrival rate continues to increase, eventually surpassing the available energy supply, the packet queue becomes congested, resulting in a significant number of packets being blocked from entering the system. Consequently, the probability of impatience for arrival packets gradually decreases. In contrast, LP packets, which have lower priority compared to HP packets, experience longer waiting times in the queue, making them more prone to impatience. Additionally, when comparing the curves of and 0.7 for ,, and , it can be observed that, in most cases, the curves for are positioned higher than those for . Additionally, as increases, the pairs of curves become progressively closer or even staggered. This can be attributed to the relatively insufficient energy supply in the case of . As a result, arrived packets experience higher probabilities of blocking and impatience. Even if they successfully enter the queue, they are more likely to lose patience while waiting. Moreover, as increases, the aforementioned conditions become more severe, leading to an accelerated increase in blocked packets. Consequently, the number of impatient packets for arrived packets decreases rapidly, bringing the curves of ,, and closer together.

In Fig. 5 - 10, the relationship between the impatient loss probability of all admitted packets is depicted in relation to the HP packet arrival rate . This is analyzed for various energy arrival rates . When comparing the curves of or for , , and , it is evident that all exhibit an increasing trend as increases. This behavior is attributed to the higher HP packet arrival rate leading to a greater likelihood of system congestion, resulting in longer queue waiting times for packets and an increased probability of impatience. Additionally, due to the non-preemptive priority of HP packets over LP packets, the majority of LP packets remain backlogged in the queue, making them more susceptible to impatience. Consequently, consistently surpasses for both and . Furthermore, it is evident that the curve corresponding to is positioned higher than the curve for across , , and . This can be attributed to the higher energy arrival rate, which results in shorter waiting times for packets in the queue, subsequently reducing their likelihood of becoming impatient.

In Fig. 5 - 11, the relationship between the total loss probability of all arrived packets is depicted in relation to the HP packet arrival rate . This is analyzed for various energy arrival rates . When comparing the curves of and for , , and , it is evident that all exhibit an increasing trend as increases. This can be attributed to the fact that the higher HP packet arrival rate causing the system to become more congested, resulting in a greater number of blocked packets. Additionally, due to the non-preemptive priority of HP packets over LP packets, most LP packets remain backlogged in the queue, making them more likely to experience impatience. Consequently, is consistently higher than for both and . Furthermore, it is evident that the curve corresponding to is positioned higher than the curve for across , , and . This is because a lower energy arrival rate leads to a higher likelihood of congestion in the packet queue, resulting in a greater probability of packets being lost due to blocking or impatience. Lastly, it is worth noting that is equal to the sum of and .

In Fig. 5 - 12, the relationship between regular energy consumption ratio for serving all packets is depicted in relation to the HP packet arrival rate . This is analyzed for various energy arrival rates . When comparing the curves of, it is evident that as increases, initially increases and then decreases. In addition, gradually increases while gradually decreases. This can be attributed to two factors. On one hand, as increases, the energy supply becomes insufficient, leading to a higher probability of impatience for packets in the queue and a reduction in the number of served packets. On the other hand, due to the non-preemptive priority of HP packets over LP packets, as more HP packets enter the server for service, the available capacity for serving LP packets decreases, resulting in a decrease in . Additionally, for , it is found that as increases, both and gradually increase, while increases initially and then decreases. This behavior can be explained as follows: initially, when , the arrival rate of LP packets is higher than that of HP packets. Consequently, increases at a faster rate compared to in the early stage. However, as continues to increase and the priority policy takes effect, a significant portion of the available energy is consumed in serving HP packets, resulting in a lower capacity for serving LP packets. Hence, in the latter half, starts to decrease. It is worth mentioning that both and remain at zero until reaches 0.2 since the harvested energy is sufficient to meet the service requirements without relying on the regular battery. Lastly, due to the lower energy arrival rate (), the harvested energy often falls short of meeting the service demands, and the regular battery is frequently utilized as an additional energy source. Therefore, the curves for are positioned higher than those for across , , and as illustrated in the figure.

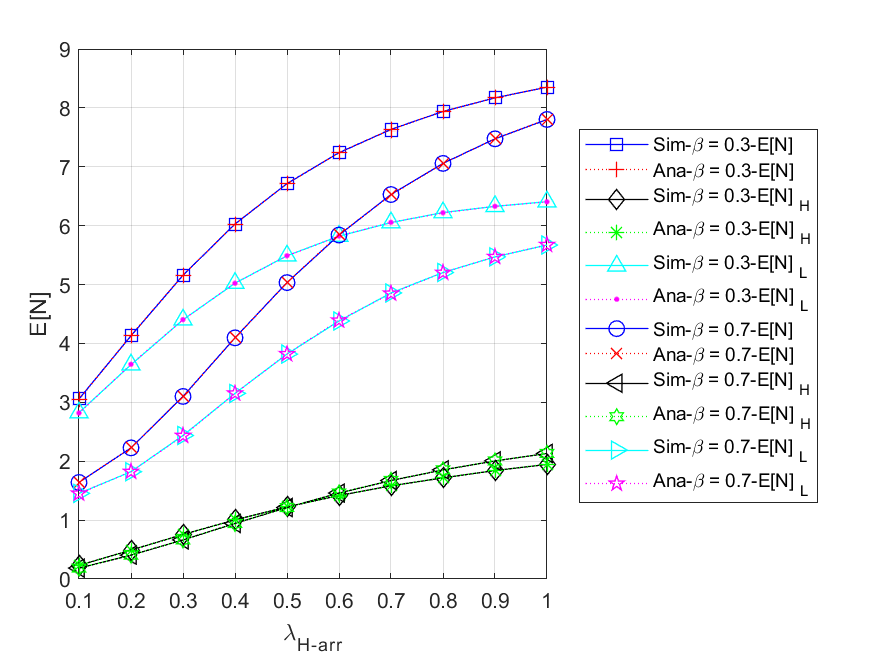


Fig. 5 - 3: The expected number of all () packets in the system vs. the HP packet arrival rate

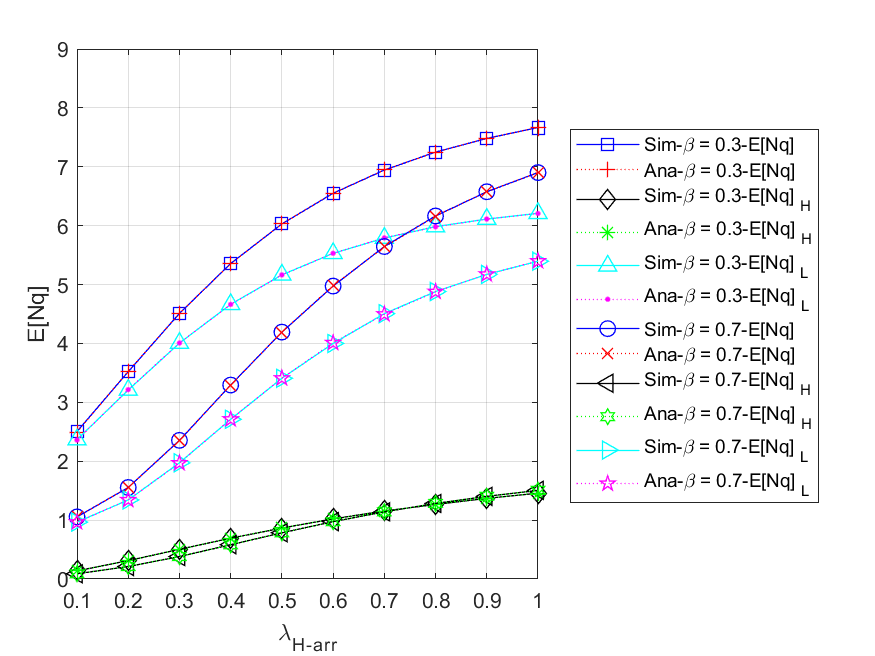


Fig. 5 - 4: The expected number of all () packets in the packet queue vs. the HP packet arrival rate

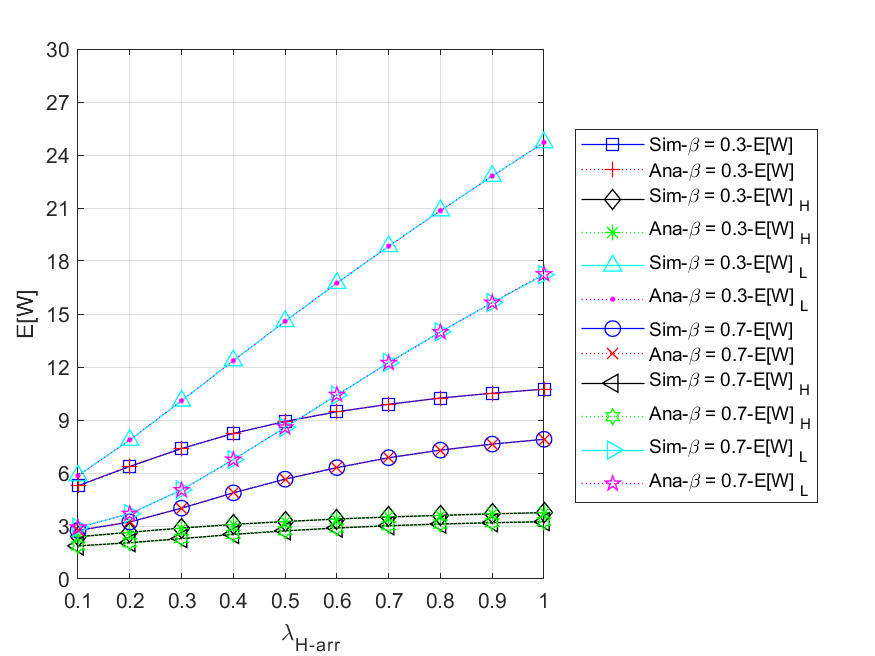


Fig. 5 - 5: The mean waiting time of all () packets in the system vs. the HP packet arrival rate

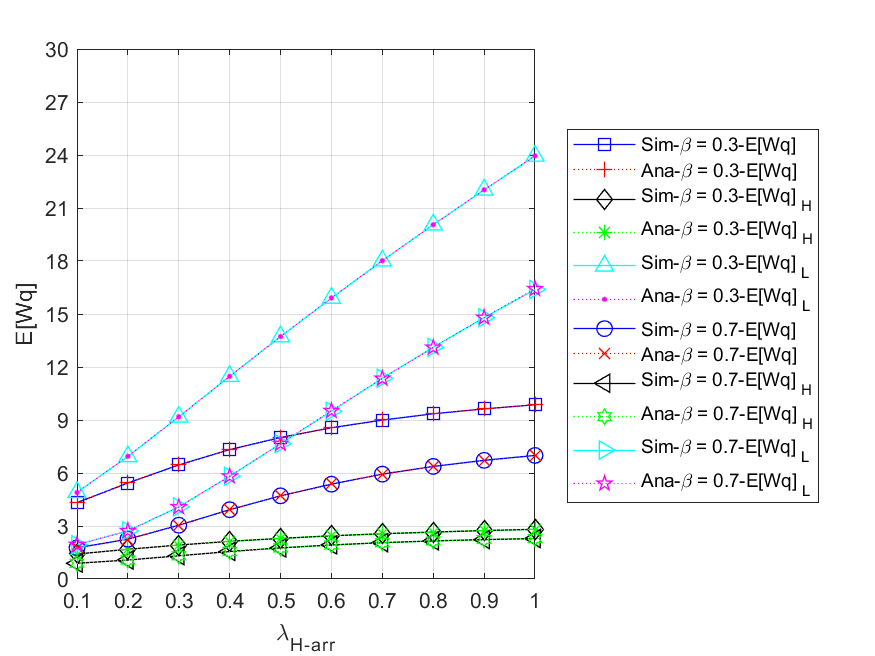


Fig. 5 - 6: The mean waiting time of all () packets in the queue vs. the HP packet arrival rate

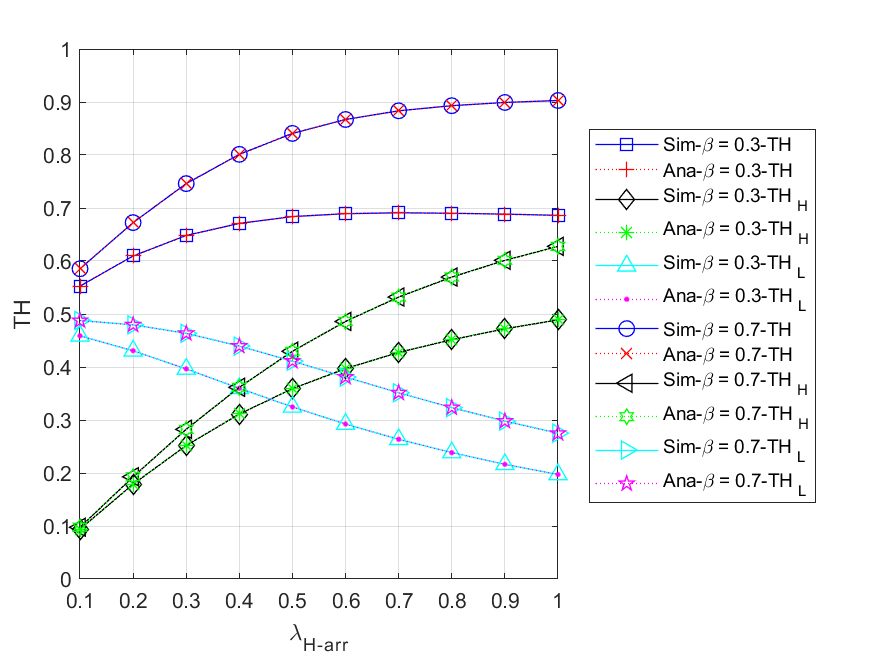


Fig. 5 - 5: The throughput of all (HP,LP) packets vs. the HP packet arrival rate

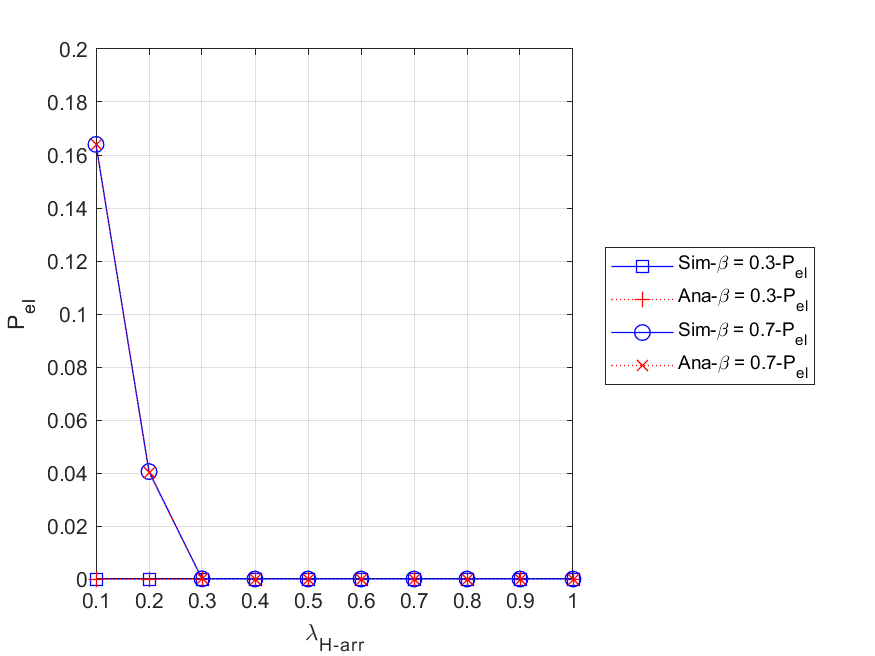


Fig. 5 - 7: The energy loss probability vs. the HP packet arrival rate

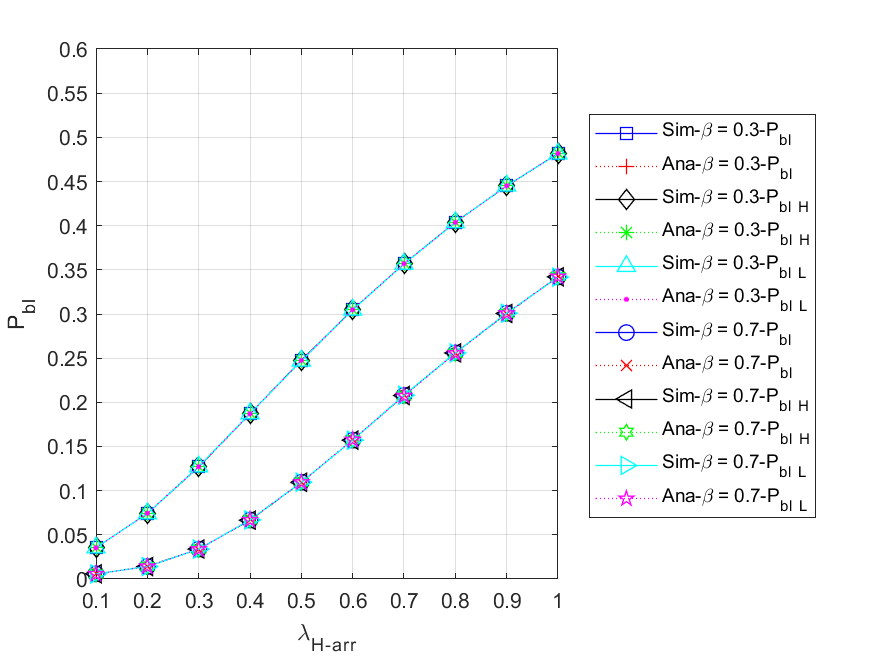


Fig. 5 - 8: The blocking probability of all () arrived packets vs. the HP packet arrival rate

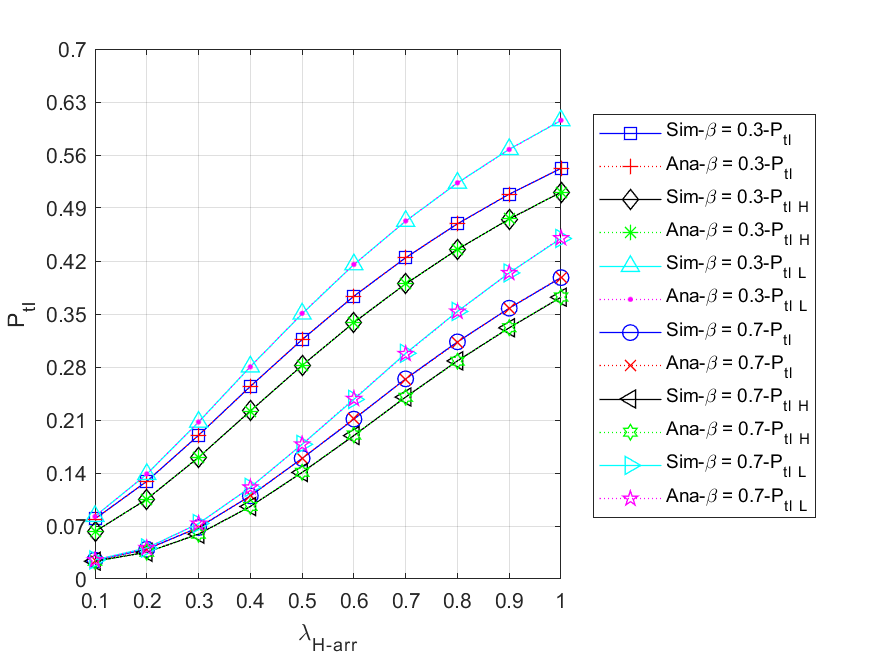


Fig. 5 - 11: The total loss probability of all () arrived packets vs. the HP packet arrival rate

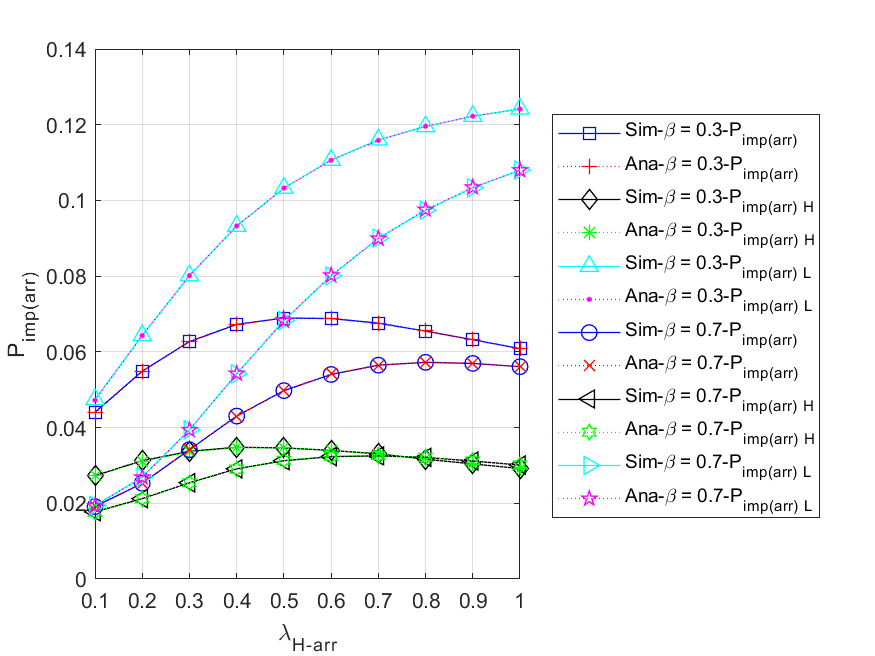


Fig. 5 - 9: The impatient loss probability of all () arrived packets vs. the HP packet arrival rate

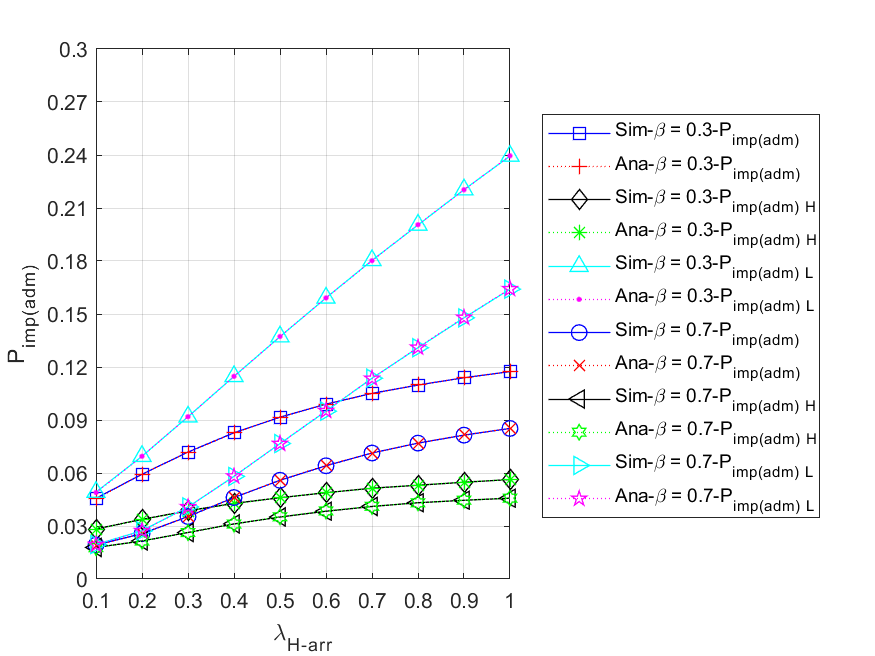


Fig. 5 - 10: The impatient loss probability of all () admitted packets vs. the HP packet arrival rate

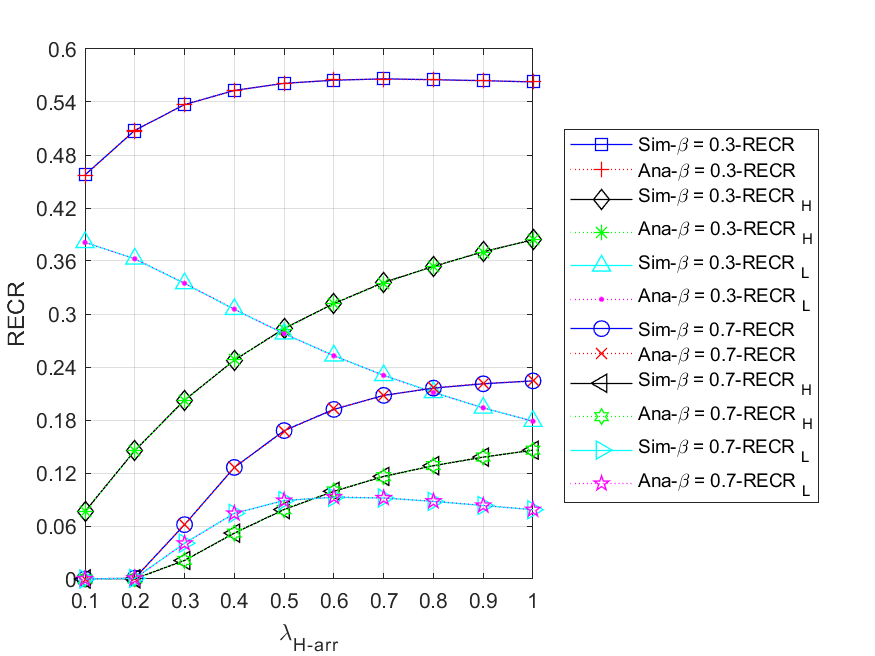


Fig. 5 - 12: The regular energy consumption ratio for serving all () packets vs. the HP packet arrival rate