* + 1. **Regular battery usage probabilities**

In this subsection, we analyze the effects of the external HP packet arrival rate on performance metrics in two scenarios: one without a regular battery () and the other with default values (). We focus on the impact on average network performance and present the results in Fig. 5-80 to Fig. 5-90.

In Fig. 5-80, the relationship between the expected number of all packets in the network and the HP packet arrival rate is depicted. This is analyzed for different regular battery usage probabilities . For and , we observe that the curve with starts lower than the curve with , but gradually surpasses it as increases. This is due to the higher regular battery usage probabilities, which allow more packets to be immediately served and routed to other nodes instead of being backlogged at the entry node. Regarding , the same reasoning applies, along with the non-preemptive priority policy. HP packets are more easily routed to other nodes, resulting in higher values for compared to . Furthermore, for , we observe a gradual decrease in as increases. This is because as the increases, LP packets experience longer waiting times in the queues, making them more susceptible to impatience and the priority discipline. Lastly, the analytical results are in good agreement with the simulation results.

In Fig. 5-81, the relationship between the expected number of all packets in the queue and the HP packet arrival rate is depicted. This is analyzed for different regular battery usage probabilities . This is analyzed for different regular battery usage probabilities . For and , we observe that the curve with starts lower than the curve with , but gradually surpasses it as increases. This is due to the higher regular battery usage probabilities, which allow more packets to be immediately served and routed to other nodes instead of being backlogged in the queue at the entry node. Regarding , the same reasoning applies, along with the non-preemptive priority policy. HP packets are more easily routed to other nodes, resulting in higher values for compared to . Furthermore, for , we observe a gradual decrease in as increases. This is because as the increases, LP packets experience longer waiting times in the queues, making them more susceptible to impatience and the priority discipline. Lastly, the analytical results are in good agreement with the simulation results.

In Fig. 5-82, the relationship between the mean waiting time of all packets and the HP packet arrival rate is depicted. This is analyzed for different regular battery usage probabilities . It is evident that the curve with is consistently lower than the curve with for , , and . This relationship is due to the fact that the higher probabilities of regular battery usage increase the likelihood of immediate packet service at each node, resulting in shorter network delay times. Additionally, due to the non-preemptive priority of HP packets over LP packets, the majority of LP packets experience backlogging and prolonged waiting times in the queues. Consequently, the curve for consistently surpasses that of for both and . Moreover, the difference between the curves for and appears smaller compared to the difference between the curves. Overall, the inclusion of a regular battery as an auxiliary energy resource yields significant improvements in both HP and LP packet performance, as demonstrated by the overall results. Lastly, the analytical results are in good agreement with the simulation results.

In Fig. 5-83, the relationship between the mean waiting time of all packets in the queue , , and and the HP packet arrival rate is depicted. This is analyzed for different regular battery usage probabilities . It is evident that the curve with is consistently lower than the curve with for , , and . This relationship is due to the fact that the higher probabilities of regular battery usage increase the likelihood of immediate packet service at each node, resulting in shorter network delay times. Additionally, due to the non-preemptive priority of HP packets over LP packets, the majority of LP packets experience backlogging and prolonged waiting times in the queues. Consequently, the curve for consistently surpasses that of for both and . Moreover, the difference between the curves for and appears smaller compared to the difference between the curves. Overall, the inclusion of a regular battery as an auxiliary energy resource yields significant improvements in both HP and LP packet performance, as demonstrated by the overall results. Lastly, the analytical results are in good agreement with the simulation results.

In Fig. 5-84, the relationship between the throughput of all packets and the HP packet arrival rate is depicted. This is analyzed for different regular battery usage probabilities . It is observed that the curves for , , and with are higher than those with . This relationship is due to the fact that the higher probabilities of regular battery usage can increase the likelihood of successful packet servicing in each node. Furthermore, when considering , we notice that the throughput remains relatively constant below 0.3 as increases. This behavior can be explained by the absence of a regular battery as an auxiliary energy resource, which limits the effective service rate to the arrival rate of harvested energy. Lastly, the analytical results are in good agreement with the simulation results.

In Fig. 5-85, the relationship between the energy loss probability and the HP packet arrival rate is depicted. This is analyzed for different regular battery usage probabilities . It is observed that the curves for with is higher than that with . This relationship is due to the fact that the higher regular battery usage probability leads the more packets being completed service at node 1, cause more packets to use the harvesting energy in node 2 or 3. This makes the less energy be block. Lastly, the analytical results are in good agreement with the simulation results.

In Fig. 5-86, the relationship between the blocking probability of all arrived packets and the HP packet arrival rate is depicted. This is analyzed for different regular battery usage probabilities . When the packet queue becomes full, packets are blocked regardless of their priority. Therefore, the probabilities of blocking a packet, , , and , are the same for both and . Furthermore, when comparing the curves of for different regular battery usage probabilities, it is evident that the curve corresponding to is higher than the curve for . This discrepancy can be attributed to the fact that lower probabilities of regular battery usage result in a decreased likelihood of serving the packets waiting in the queue. Consequently, this makes it easier for the entry node's queue to reach its capacity and leads to a higher probability of packet blocking. Lastly, the analytical results are in good agreement with the simulation results.

In Fig. 5-87, the relationship between the total loss probability of all arrived packets and the HP packet arrival rate is depicted. This is analyzed for different regular battery usage probabilities . It is observed that for ,, and , the values corresponding to are consistently higher than those for as increases. This difference can be attributed to the fact that lower probabilities of regular battery usage make the network more susceptible to congestion, resulting in a higher probability of packet loss due to blocking or impatience. Overall, the inclusion of a regular battery as an auxiliary energy resource yields significant improvements in both HP and LP packet performance, as demonstrated by the overall results. Lastly, the analytical results are in good agreement with the simulation results.

In Fig. 5-88, the relationship between the impatient loss probability of all arrived packets and the HP batch arrival rate is depicted. This is analyzed for different regular battery usage probabilities . It is observed that for , , and , the curve corresponding to is initially lower than the curve for and then they cross over. This relationship is due to the fact that the higher probabilities of regular battery usage enable more packets to be immediately served and routed to other nodes instead of being backlogged in the entry node. Consequently, the impatient loss probability of arrived packets with is initially lower than that with . However, as the number of arrived packets continues to increase, the congestion in the other nodes of the network gradually intensifies. This leads to a larger impatient loss probability for arrived packets with compared to as increases. Lastly, the analytical results are in good agreement with the simulation results.

In Fig. 5-89, the relationship between the impatient loss probability of all admitted packets and the HP packet arrival rate is depicted. This is analyzed for different regular battery usage probabilities . It is observed that the curve with is consistently lower than the curve with for and . This is due to the higher probabilities of regular battery usage, which result in a greater likelihood of immediate packet service and fewer packets losing patience in the network. Additionally, considering the non-preemptive priority of HP packets over LP packets, a larger proportion of LP packets become backlogged and wait in the queues of nodes. As a result, consistently exceeds for both and . In addition, the difference between the curves of for and appears smaller compared to the difference between the curves of . Overall, the inclusion of a regular battery as an auxiliary energy resource yields significant improvements in both HP and LP packet performance, as demonstrated by the overall results. Lastly, the analytical results are in good agreement with the simulation results.

In Fig. 5-90, the relationship between regular energy consumption ratio for serving all packets and the HP packet arrival rate is depicted. This is analyzed for different regular battery usage probabilities . For , we observe that as increases, the initially increases and then decreases. The gradually increases, while the gradually decreases. The reason is when increases, the energy supply in the system becomes insufficient. Consequently, the served packets are more likely to utilize regular battery, causing the to increase initially. On the other hand, when the congestion is more severe, the packets in the queue are more likely to be impatient, the number of served packets decreases, and thus decreases. In addition, due to the non-preemptive priority of HP packets over LP packets, as more HP packets enter the server and complete their service, fewer resources are available for serving LP packets. This results in a gradual decrease in the . However, when , which means that the regular battery is never used, the corresponding curves remain zero throughout the observation. This is because without the regular battery as an energy source, no energy is consumed or utilized, leading to a constant value of zero. Lastly, the analytical results are in good agreement with the simulation results.

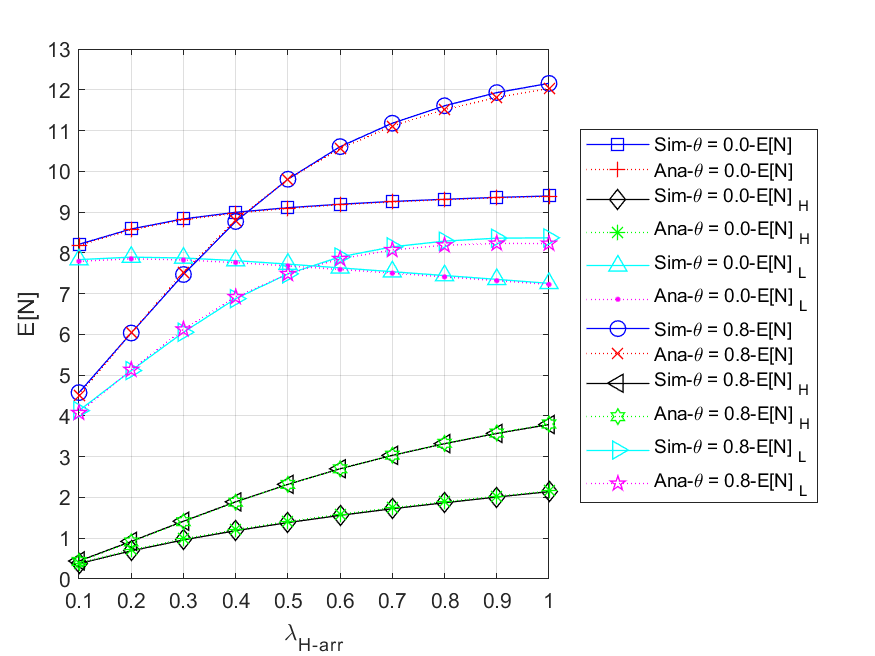


Fig. 5 - 80: The expected number of all () packets in the network vs. the external HP packet arrival rate for different regular battery usage probabilities

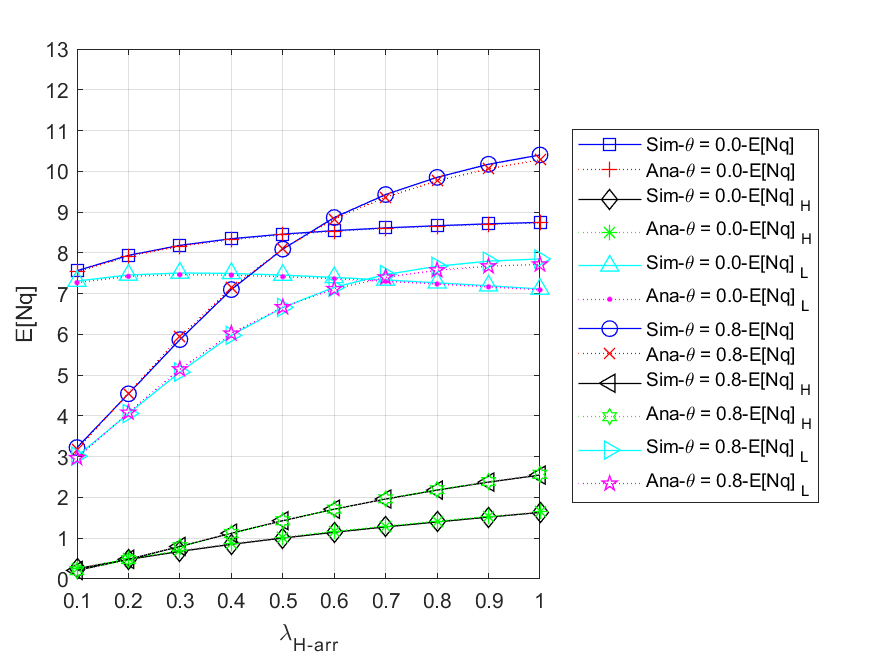


Fig. 5 - 81: The expected number of all () packets in the queue vs. the external HP packet arrival rate for different regular battery usage probabilities

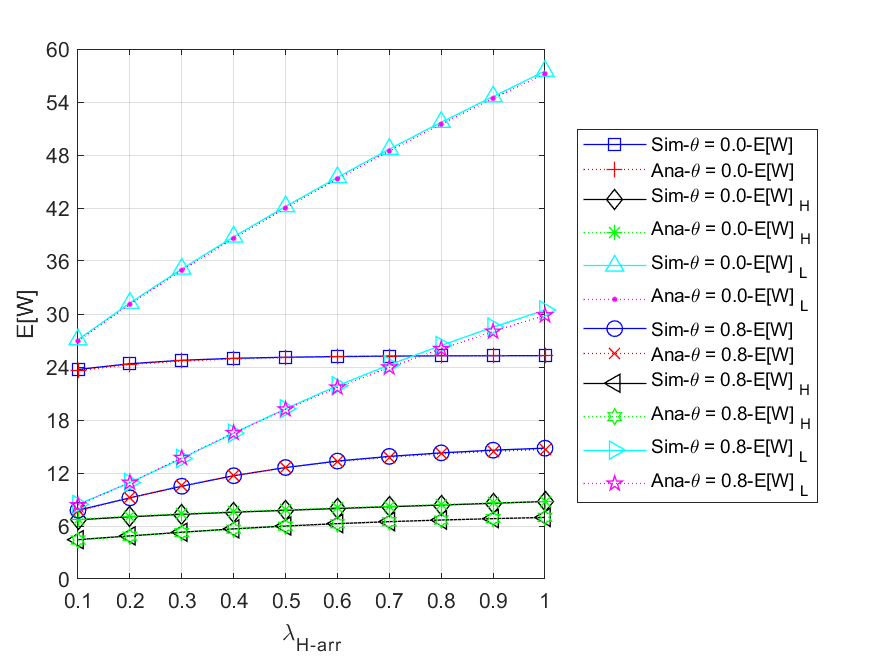


Fig. 5 - 82: The mean waiting time of all () packets in the network vs. the external HP packet arrival rate for different regular battery usage probabilities

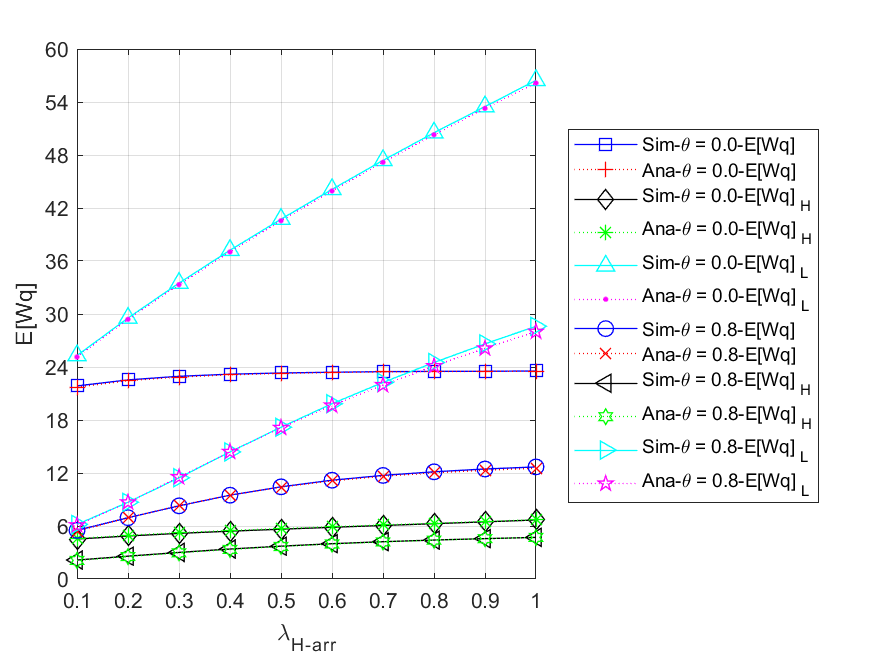


Fig. 5 - 83: The mean waiting time of all () packets in the queue vs. the external HP packet arrival rate for different regular battery usage probabilities

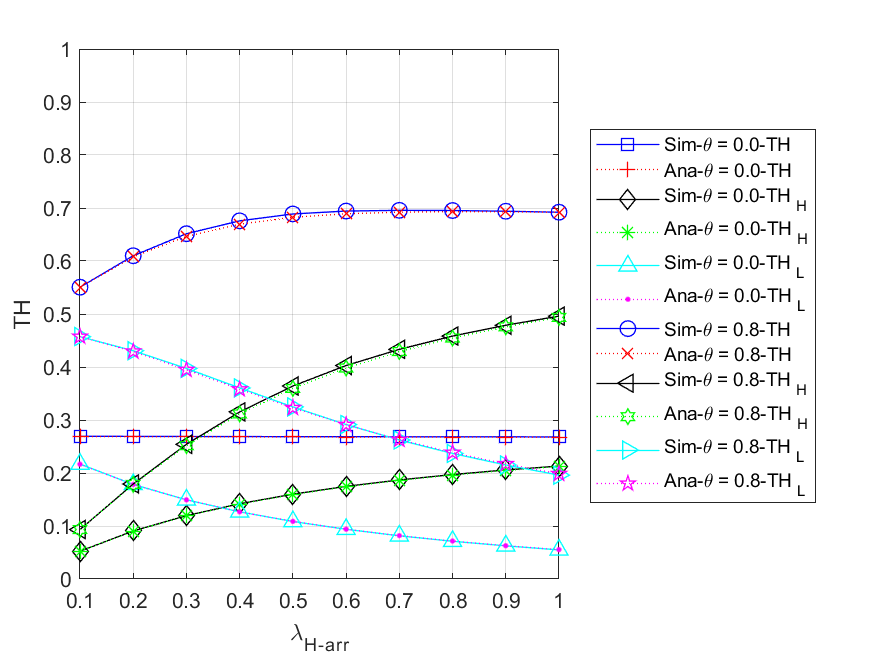


Fig. 5 - 84: The throughput of the network vs. the external HP packet arrival rate for different regular battery usage probabilities

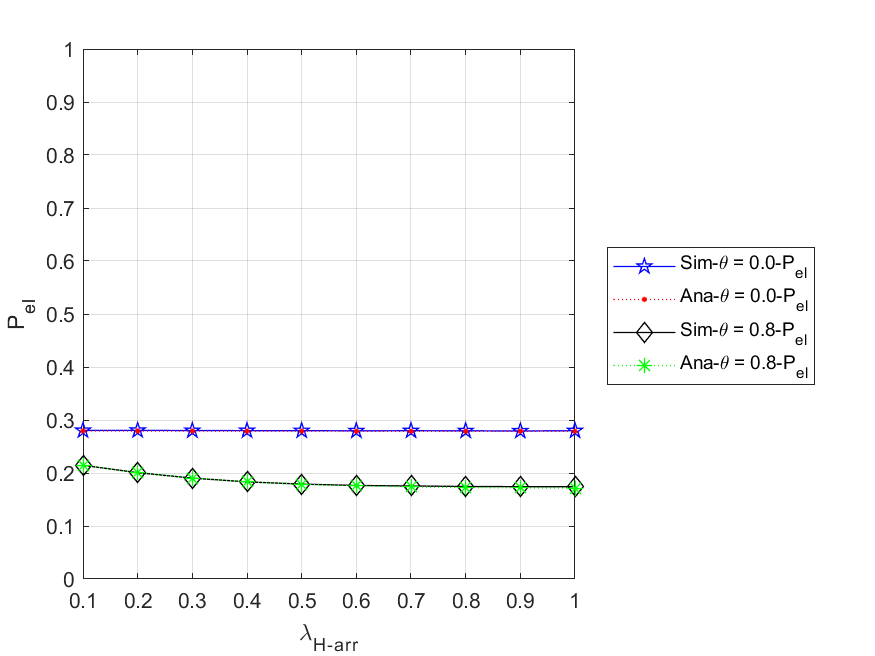


Fig. 5 - 85: The energy loss probability vs. the HP packet arrival rate for different regular battery usage probabilities

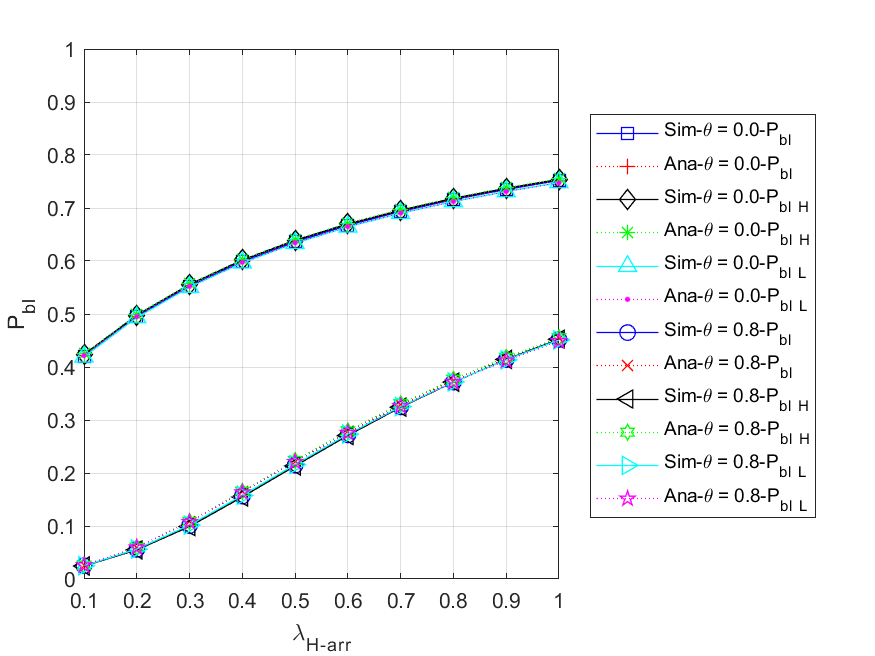


Fig. 5 - 86: The blocking probability of all () arrived packets vs. the HP packet arrival rate for different regular battery usage probabilities

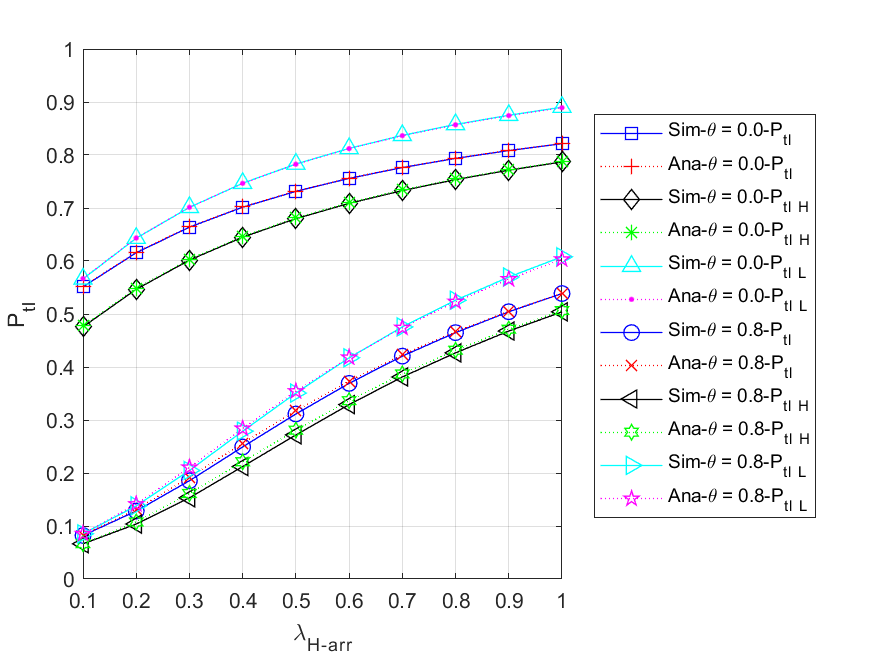


Fig. 5 - 87: The total loss probability of all () arrived packets vs. the HP packet arrival rate for different regular battery usage probabilities

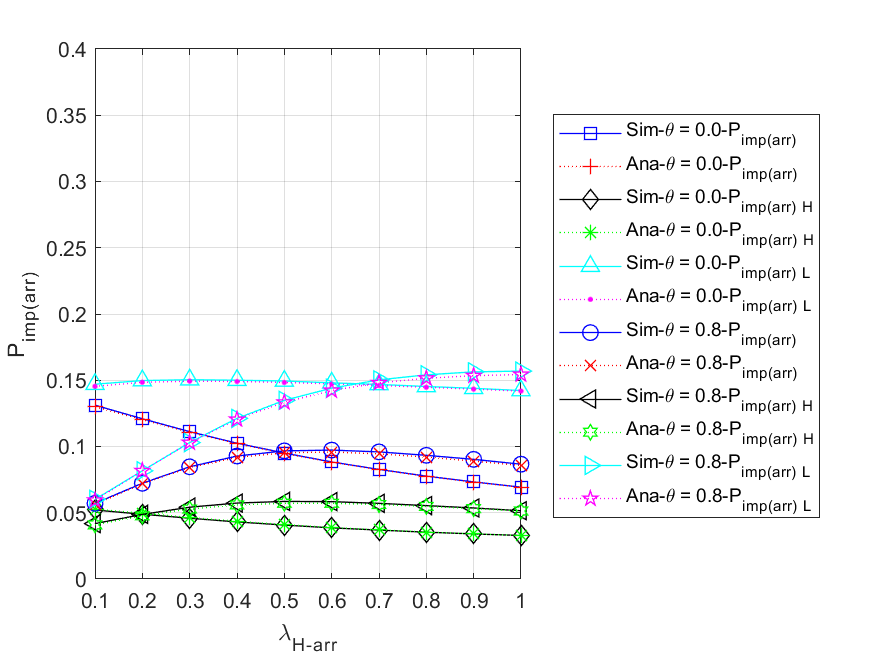


Fig. 5 - 88: The impatient loss probability of all () arrived packets vs. the HP packet arrival rate for different regular battery usage probabilities

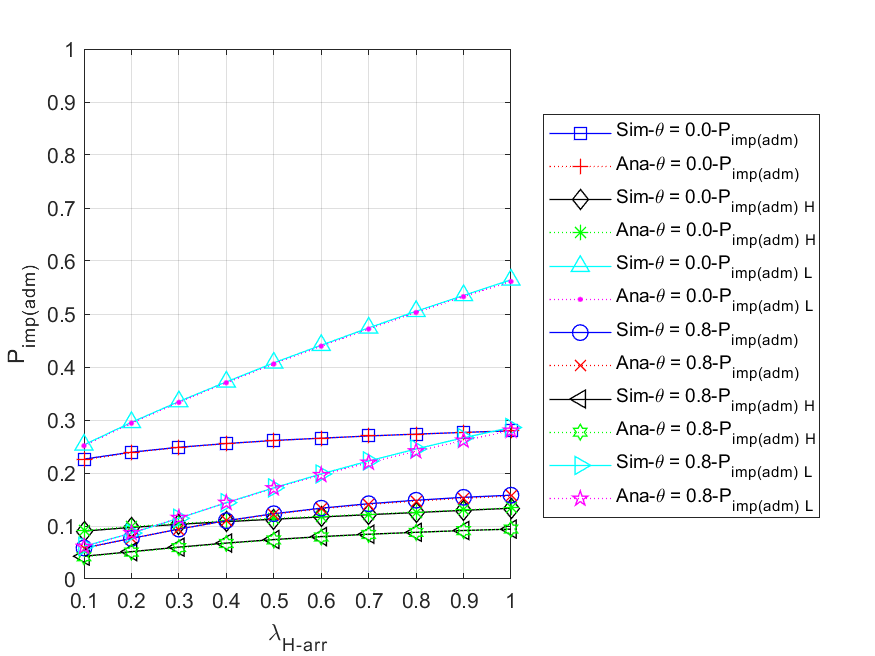


Fig. 5 - 89: The impatient loss probability of all () admitted packets vs. the HP packet arrival rate for different regular battery usage probabilities

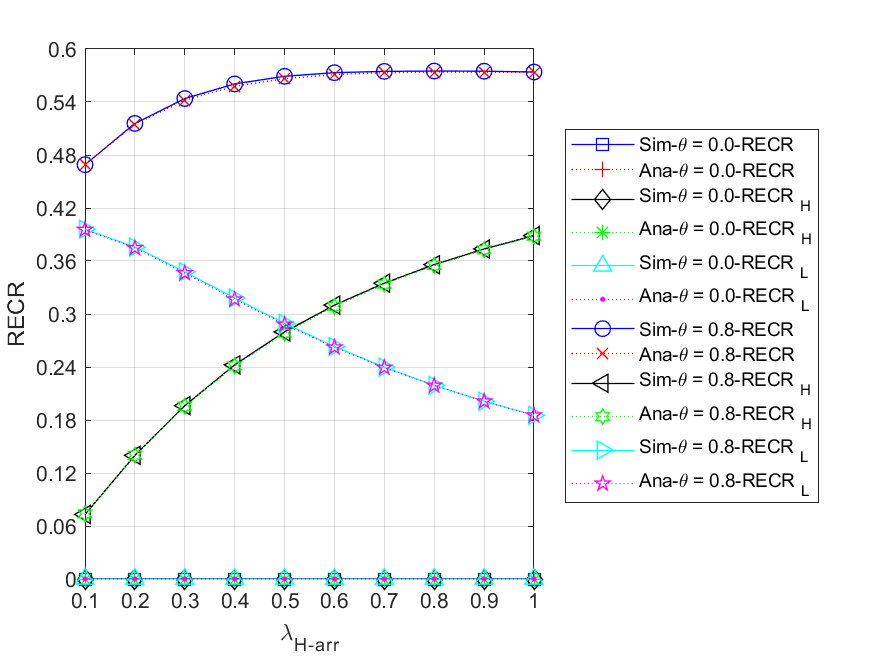


Fig. 5 - 90: The regular energy consumption ratio for serving all () packets vs. the HP packet arrival rate for different regular battery usage probabilities