## Scenario 2

The assumptions regarding the three nodes in this network differ between the simulation model and the analytical model. In the simulation model, the nodes are considered dependent, meaning their behaviors are influenced by factors such as blocking, impatience, and routing policy. As a result, the internal arrival process in the simulation model exhibits non-Poisson characteristics. On the other hand, the analytical model assumes independence among the nodes, resulting in a Poisson arrival process. Thus, the key distinction lies in the consideration of dependencies and the resulting arrival process in the simulation model, while the analytical model assumes independence and a Poisson arrival process.

If not explicitly mentioned, the default values for the different system parameters are as provided below:,,, and for each node , , , , the routing probability from node 1 and node 2 to the control node , 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 . Referring to Fig. 5-37, the following observations can be made: as the ratio of increases gradually, the decreases for the network and node 1. However, for node 2, initially increases and then decreases. Node 3 consistently maintains a of zero. These trends can be explained as follows:

Node 1: With a larger , more packets can be served immediately using the regular battery before experiencing blocking or impatience.

Node 2: The arrival traffic at node 2 depends on the rate of packets leaving from node 1. Therefore, when the throughput of node 1 is high, the energy request rate at node 2 is more likely to exceed the effective service rate. This results in an initial increase in and a subsequent decrease as increases.

Node 3: Due to the routing probability, the arrival traffic at node 3 is significantly smaller than that at the other nodes. Consequently, the harvested energy is sufficient to provide service without relying on the regular battery as an auxiliary energy source.

Considering the distinct characteristics of each node and the energy consumption of the regular battery (as shown in Fig. 5-38), the average curve of the network, represented by -Ave and RECR-Ave, is chosen as the reference. To ensure that the upper limit of does not exceed 0.1, the minimum value on the curve is selected as the suboptimal parameter value, specifically . Subsequently, the effects of external HP (high-priority) packet arrival rate on various performance measures are investigated, and the findings are presented in Fig. 5-39 to Fig. 5-59.

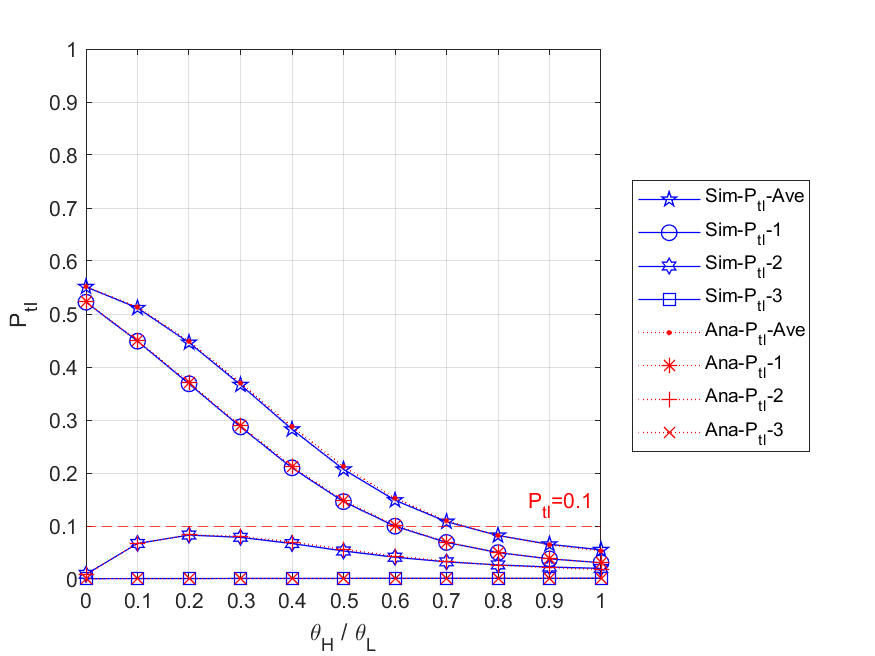


Fig. 5 - 37: The total loss probability of all packets in the network and each node vs. the regular battery usage probabilities

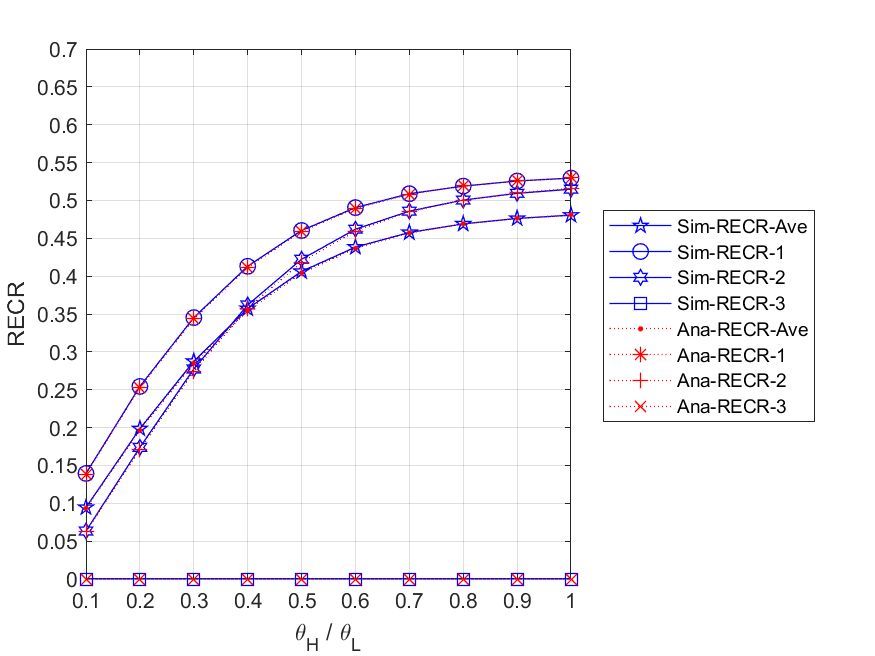


Fig. 5 - 38: The regular energy consumption ratio for serving all packets in the network and each node vs. the regular battery usage probabilities

* + 1. **Energy arrival rate**

In Fig. 5-39, the relationship between the expected number of all packets in the network and each node (-, -, -, -) and the HP packet arrival rate is depicted. It is observed that both - and - gradually 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 network and node 1. Additionally, it is evident that the curve of - initially increases and then flattens out. This behavior can be attributed to the interdependence between the rate at which packets depart from node 1 and the arrival rate of packets at node 2. Specifically, as the increases, the queue at node 1 is more prone to congestion. This congestion, in turn, leads to an increased likelihood of blocking or impatience for externally arriving packets, resulting in a balance in the number of packets entering node 2. In addition, the traffic at node 3 is considerably lower compared to the other nodes due to the routing probability. As a result, a majority of the arrived packets at node 3 can be promptly served, leading to minimal changes in - as increases. Consequently, for a given , we observe that - is higher than -, while - exhibits the lowest value. This discrepancy can be attributed to the characteristics of each node within the network. Node 1, being the entry node, experiences the highest number of arrived packets. Node 2, on the other hand, encounters a slightly lower packet arrival rate due to the occurrence of blocking and impatience at node 1. Furthermore, node 3 has the lowest packet arrival rate owing to its smaller routing probabilities, specifically and . Lastly, it is important to note that since the total expected number of packets in the network is the sum of -, -, and -, the curve of- is expected to be the highest among them.

In Fig. 5-40, the relationship between the expected number of HP and LP packets in the network and each node and the HP packet arrival rate is depicted. It is observed that for node 1, both - and - increase with the increase of the . This can be attributed to the fact that a higher results in more packets being able to enter node 1. As a result, the number of HP and LP packets in the node 1 increases. Additionally, it is evident that - steadily increases with the increase in . Conversely, - initially increases and then decreases. This pattern arises due to the priority given to HP packets over LP packets. Consequently, as the HP packet arrival rate rises, it is more probable for LP packets to become backlogged in the queue and eventually lose patience. In addition, the traffic in node 3 is significantly lower compared to the other nodes due to routing probabilities. Most arrived packets can be served immediately, resulting in minimal changes in -, as increases. Additionally, we observe that in most cases excluding node 3, -, - is lower than -, -. This discrepancy arises from the fact that HP packets have higher priority and can occupy positions ahead of LP packets in the queue, enabling them to be served more promptly. Furthermore, for a given , we can observe that - (-) is higher than - (-), while - (-) is the lowest. This is because node 1, as the entry node, receives the highest number of arrived packets. Node 2 follows with the second highest number due to blocking and impatience at node 1. Node 3 experiences the lowest packet arrival rate due to lower routing probabilities, i.e., and . Lastly, it is important to note that the total expected number of HP (LP) packets in the network can be determined as the sum of - (-), - (-), and - (-). Consequently, the curve of - (-) must be the highest.

In Fig. 5-41, the relationship between the expected number of all packets in queue for the network and each node (-, -, -, -) and the HP packet arrival rate is depicted. It is observed that both - and - gradually increase as increases. This relationship is due to the fact that the higher allow more packets to enter the queues of all nodes and node 1. Additionally, it is evident that the curve of - initially increases and then flattens out. This behavior can be attributed to the rate at which packets leave node 1, which affects the arrival rate of packets at node 2. As increases, the queue at node 1 becomes more susceptible to congestion, resulting in the blocking or impatience of external packets. Consequently, considering the routing probability, we find that the traffic at node 3 is much smaller compared to the other nodes. Additionally, a significant portion of the arrived packets at node 3 can be served immediately. Therefore, - does not exhibit significant changes as increases. In addition, for the same , we can observe that - is higher than -, while - is the lowest. This can be explained by the following reasons: node 1, as the entry node, receives the highest number of arrived packets; node 2 experiences the second-highest number of packets due to blocking and impatience at node 1; and node 3 has the lowest packet arrival rate due to smaller routing probabilities, i.e., and . Lastly, it is worth noting that the total number of expected packets in the queue for the network can be considered as the sum of -, -, and-. Therefore, the curve of - must be the highest among them.

In Fig. 5-42, the relationship between the expected number of HP and LP packets in queue for the network and each node and the HP packet arrival rate is depicted. It is observed that for node 1, both - and - increase as increases. This relationship is due to the fact that a higher HP packet arrival rate leads to a larger backlog of packets in the queue at node 1. Additionally, it is evident that for node 2, we observe that - gradually increases with the increase of , while - first increases and then decreases. This behavior is due to the non-preemptive priority of HP packets over LP packets. As the arrival rate of HP packets increases, there is a higher likelihood that LP packets get backlogged in the queue and eventually get impatience. Consequently, the traffic at node 3 is significantly smaller compared to the other nodes due to routing probabilities. Additionally, most of the arrived packets at node 3 can be served immediately. Therefore, - does not changes significant as increases. In addition, excluding node 3, we find that (-*n*, *n*=1, 2) is generally smaller than (-*n*, *n*=1, 2). This is due to the non-preemptive priority of HP packets over LP packets, allowing them to be serviced more quickly. Furthermore, for the same , we observe that - is higher than -, while - is the lowest. This can be attributed to the fact that node 1, as the entry node, receives the highest number of arrived packets. Node 2 experiences the second-highest number of packets due to blocking and impatience at node 1. Node 3, with smaller routing probabilities, i.e., and , has the lowest packet arrival rate. Additionally, it is worth noting that the total number of expected HP (LP) packets in the queue for the network can be considered as the sum of - (-), - (-), and - (-). As a result, the curve of - and - must be the highest among them.

In Fig. 5-43, the relationship between the mean waiting time of all packets in the network and each node and the HP packet arrival rate is depicted. It is observed that both - and - gradually increase as increases. This behavior is attributed to the higher , which allows more packets to enter the network and node 1. As a result, the queues experience increased congestion, leading to longer waiting times for packets. Additionally, it is evident that the curve of - exhibits a rising and then falling pattern. This is because the departure rate of packets from node 1 affects the arrival rate of packets at node 2. As increases, the congestion in the queue at node 1 intensifies, causing external packets to be blocked or lose patience. Consequently, the number of packets entering node 2 decreases, resulting in a decrease in the waiting time at node 2. In addition, due to the routing probability, the traffic at node 3 is significantly smaller than that at the other nodes. Additionally, most of the arrived packets at node 3 can be served immediately without waiting in the queue. Therefore, - does not change significantly as increases. Furthermore, it can be observed that for the same , - is higher than -, while - is the lowest. This discrepancy is due to the characteristics of each node. Node 1, being the entry node, receives the highest number of arrived packets, leading to a longer waiting time. Node 2 receives the second highest number packets arrived. Node 3, with smaller routing probabilities ( and ), has the lowest packet arrival rate, leading to the lowest waiting time among the nodes.

In Fig. 5-44, the relationship between the mean waiting time of HP and LP packets in the network and each node and the HP packet arrival rate is depicted. It is observed that regardless of whether it is node 1, node 2, or the entire network, the corresponding and gradually increase as increases. The higher leads to more HP packets entering node 1, node 2, and the network, resulting in longer waiting times for both HP and LP packets. Additionally, it is evident that for node 1, node 2, and the entire network, the curves of are much lower than those of . This difference arises due to the non-preemptive priority policy, which favors the service of HP packets. As a result, HP packets have shorter waiting times, while a significant number of LP packets are backlogged in the queues, leading to longer waiting times for LP packets. In addition, considering node 3, the traffic at this node is smaller compared to the other nodes due to routing probabilities. Moreover, most arrived packets at node 3 can be served immediately without waiting in the queue. Therefore, the curves of - and - do not change significantly as increases and are close to the respective mean service times, i.e., and . Furthermore, for the same , it is observed that - (-) is higher than - (-), while - (-) is the lowest. This discrepancy is due to the characteristics of each node. Node 1, being the entry node, receives the highest number of arrived packets, leading to a longer waiting time. Node 2 receives the second highest number packets arrived. Node 3, with smaller routing probabilities ( and ), has the lowest packet arrival rate, leading to the lowest waiting time among the nodes.

In Fig. 5-45, the relationship between the mean waiting time of all packets in the queue for the network and each node and the HP packet arrival rate is depicted. It is observed that both - and - gradually increase as increases. This behavior is attributed to the higher , which allows more packets to enter the queue for network and node 1. As a result, the queues experience increased congestion, leading to longer waiting times for packets. Additionally, it is evident that the curve of - exhibits a rising and then falling pattern. This is because the departure rate of packets from node 1 affects the arrival rate of packets at node 2. As increases, the congestion in the queue at node 1 intensifies, causing external packets to be blocked or lose patience. Consequently, the number of packets entering node 2 decreases, resulting in a decrease in the waiting time at node 2. In addition, due to the routing probability, the traffic at node 3 is significantly smaller than that at the other nodes. Additionally, most of the arrived packets at node 3 can be served immediately without waiting in the queue. Therefore, - does not change significantly as increases. Furthermore, it can be observed that for the same , - is higher than -, while - is the lowest. This discrepancy is due to the characteristics of each node. Node 1, being the entry node, receives the highest number of arrived packets, leading to a longer waiting time. Node 2 receives the second highest number packets arrived. Node 3, with smaller routing probabilities ( and ), has the lowest packet arrival rate, leading to the lowest waiting time among the nodes.

In Fig. 5-46, the relationship between the mean waiting time of HP and LP packets in the queue for the network and each node and the HP packet arrival rate is depicted. It is observed that regardless of whether it is node 1, node 2, or the entire network, the corresponding and gradually increase as increases. The higher leads to more HP packets entering the queue for node 1, node 2, and the network, resulting in longer waiting times for both HP and LP packets. Additionally, it is evident that for node 1, node 2, and the entire network, the curves of are much lower than those of . This difference arises due to the non-preemptive priority policy, which favors the service of HP packets. As a result, HP packets have shorter waiting times, while a significant number of LP packets are backlogged in the queues, leading to longer waiting times for LP packets. In addition, considering node 3, the traffic at this node is smaller compared to the other nodes due to routing probabilities. Moreover, most arrived packets at node 3 can be served immediately without waiting in the queue. Therefore, the curves of - and - do not change significantly as increases and are close to the respective mean service times, i.e., and . Furthermore, for the same , it is observed that - (-) is higher than - (-), while - (-) is the lowest. This discrepancy is due to the characteristics of each node. Node 1, being the entry node, receives the highest number of arrived packets, leading to a longer waiting time. Node 2 receives the second highest number packets arrived. Node 3, with smaller routing probabilities ( and ), has the lowest packet arrival rate, leading to the lowest waiting time in the queue among the nodes.

In Fig. 5-47, the relationship between the throughputs of the network and each node and the HP packet arrival rate is depicted. It is observed that as increases the curves of -, -, and - first increase and then decrease. This relationship is due to the fact that the energy supply is sufficient, with regular batteries acting as auxiliary energy sources, the throughput can be increased without being limited by the arrival rate of harvested energy. However, as continues to increase, the energy supply gradually becomes insufficient. Consequently, packets in the queue of node 1 become more impatient and more difficult to be served, indicated by the condition . In addition, since node 1 serves as the entry node and has the highest traffic, its departure rate determines the arrival rates of the other nodes. As a result, the - and - curves are lower but exhibit similar characteristics to the - curve. Furthermore, we observe that - is not only much lower than the throughputs at the other nodes but also changes only slightly as increases. This is attributed to the fact that the routing probability to node 3 is lower compared to every other node. Consequently, the traffic to node 3 is significantly smaller, resulting in minimal changes in the trend of the - curve.

In Fig. 5-48, the relationship between the throughputs of HP and LP packets for the network and each node and the HP packet arrival rate is depicted. It is observed that as increases - and -*n*, *n*=1, 2, 3, will increase. Conversely, - and -*n*, *n*=1, 2, 3 will gradually decrease regardless of the node. This behavior is attributed to the non-preemptive priority of HP packets over LP packets. As the increases, more HP packets are allowed to enter the server and complete their service, which results in fewer resources available for serving LP packets. In addition, since node 1 serves as the entry node with the highest traffic, its departure rate determines the arrival rates of the other nodes. Consequently, the - (-) and - (-) curves will be lower, but exhibit similar characteristics to the - (-) curve. Furthermore, it can be observed that - and - are not only much lower than the corresponding values at other nodes but also experience minimal changes as increases. This is due to the lower routing probability to node 3 compared to every other node. Consequently, the traffic destined for node 3 is significantly smaller, resulting in a lesser impact on the trend of the throughput curves at that node.

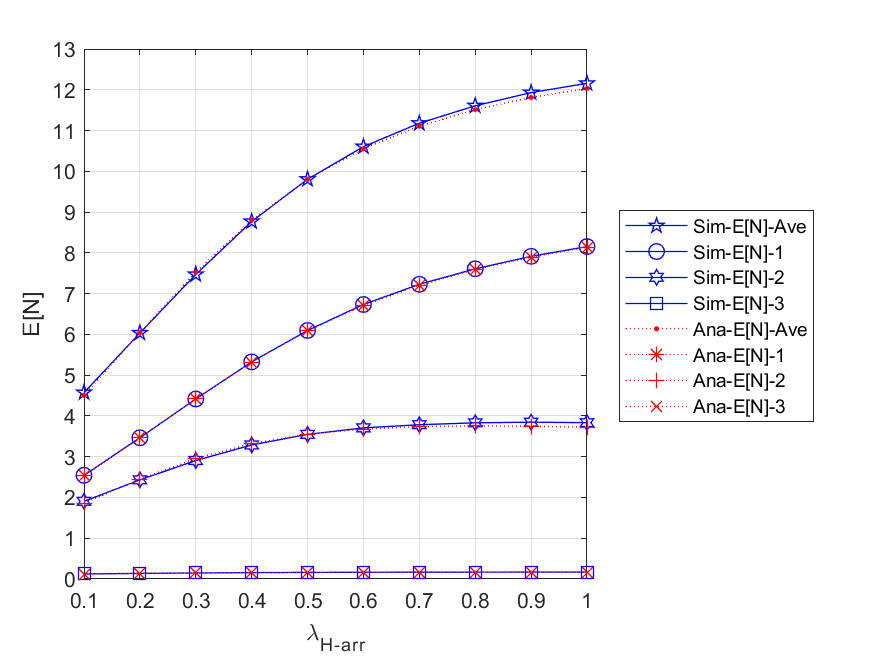


Fig. 5 - 39: The expected number of all packets in the network and each node vs. the external HP packet arrival rate

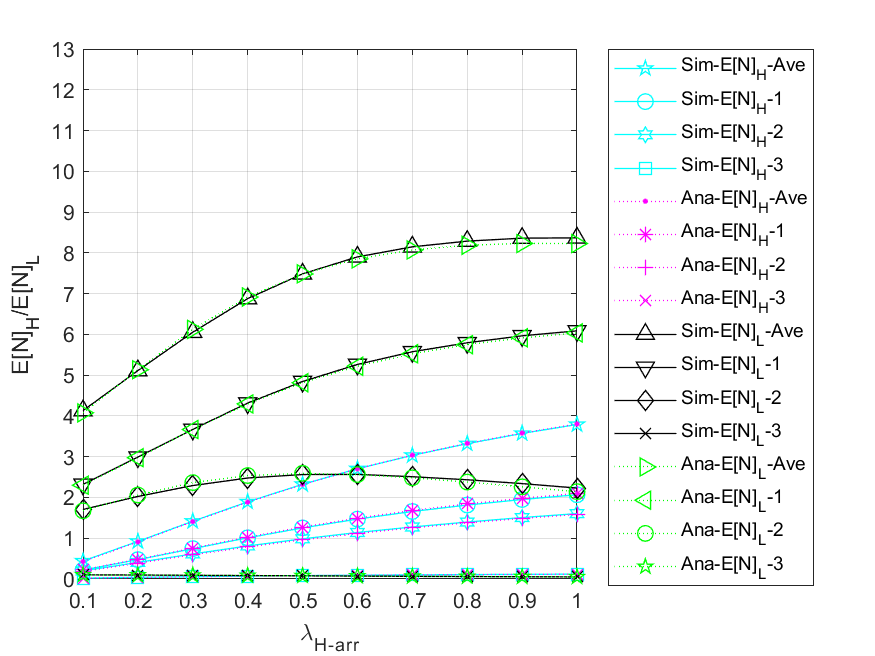


Fig. 5 - 40: The expected number of HP and LP packets in the network and each node vs. the external HP packet arrival rate

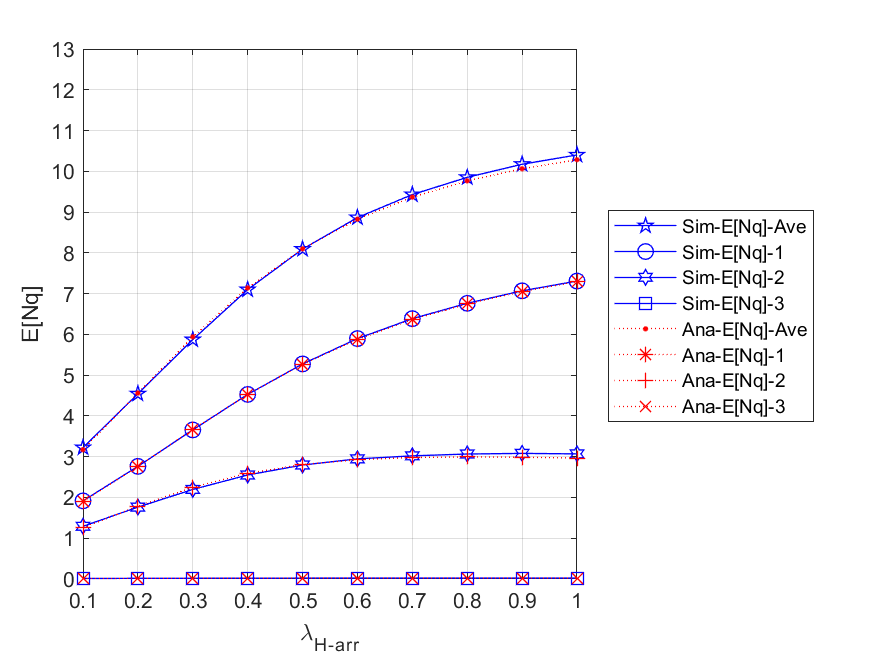


Fig. 5 - 41: The expected number of packets in queue for all nodes and each node vs. the external HP packet arrival rate

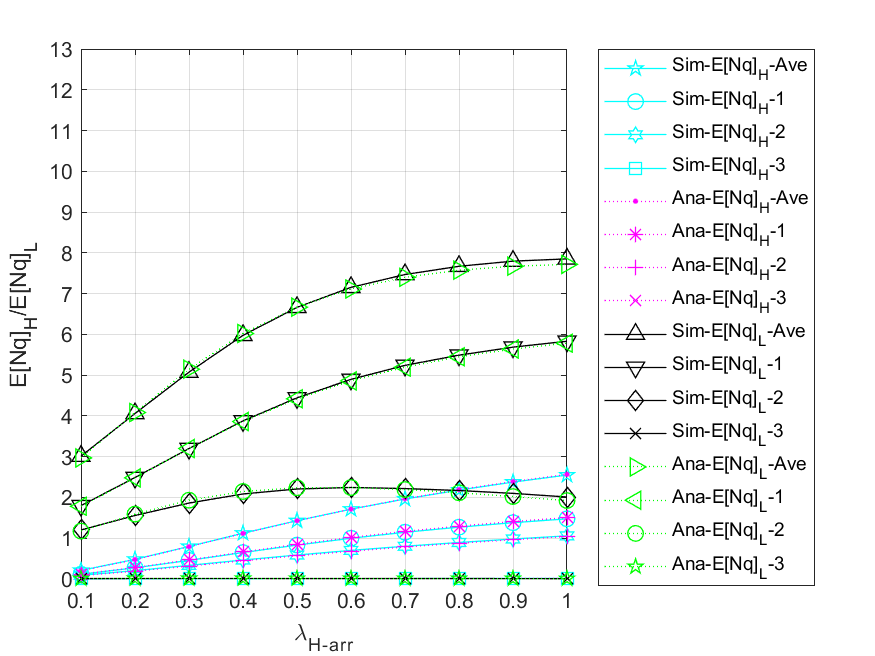


Fig. 5 - 42: The expected number of HP and LP packets in queue for all nodes and each node vs. the external HP packet arrival rate

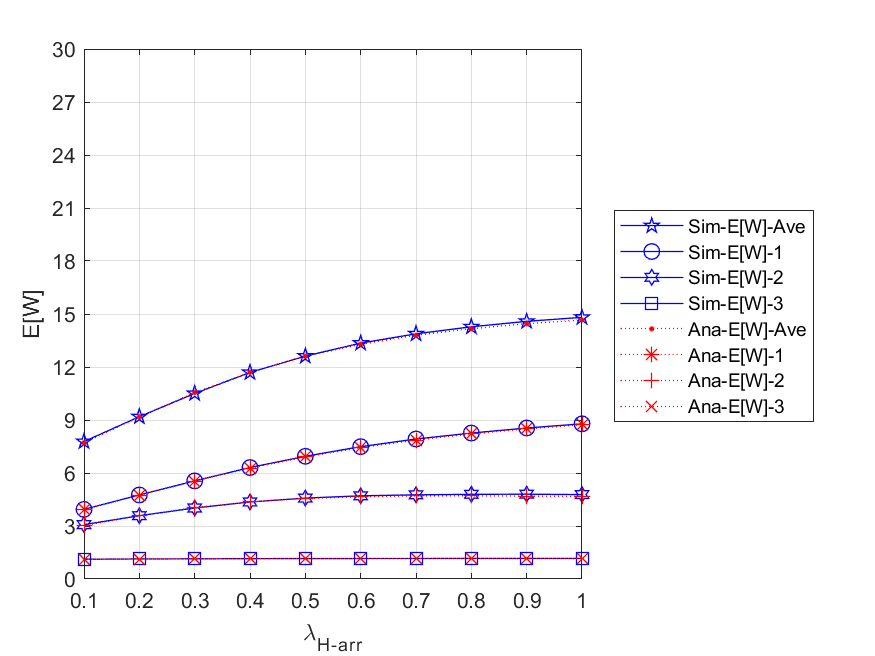


Fig. 5 - 43: The mean waiting time of all packets in the network and each node vs. the external HP packet arrival rate

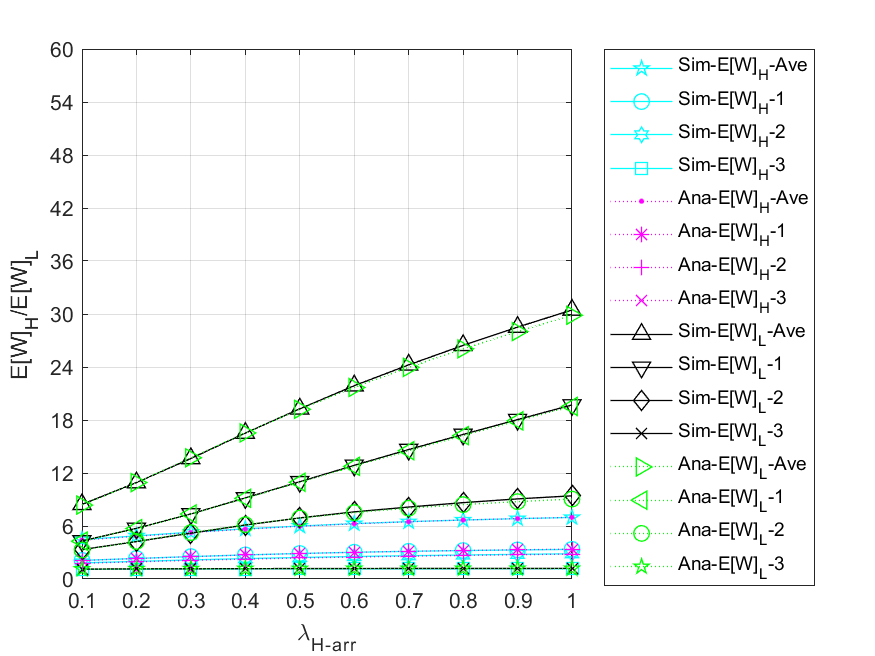


Fig. 5 - 44: The mean waiting time of HP and LP packets in the network and each node vs. the external HP packet arrival rate

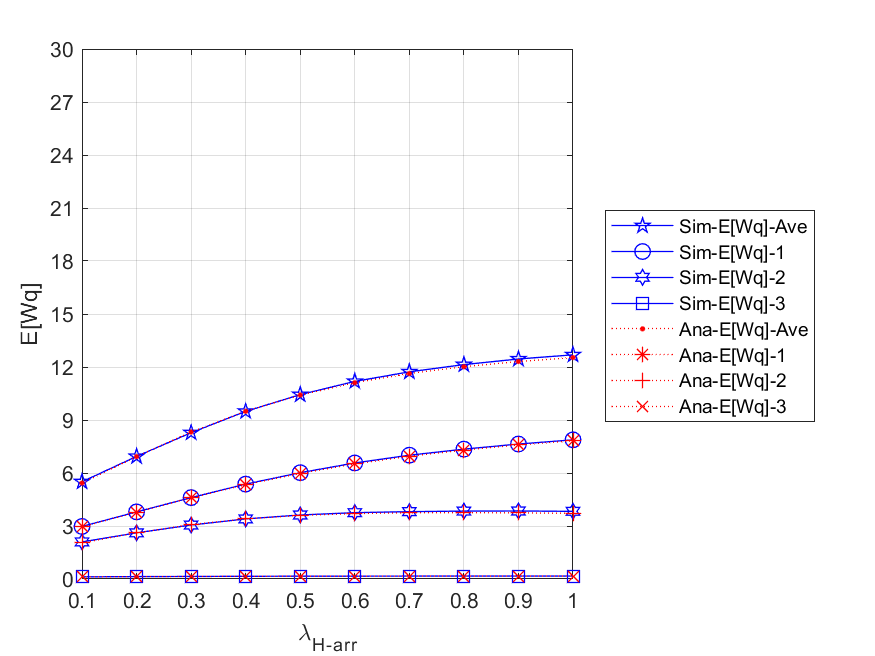


Fig. 5 - 45: The mean waiting time of all packets in the queue for the network and each node vs. the external HP packet arrival rate

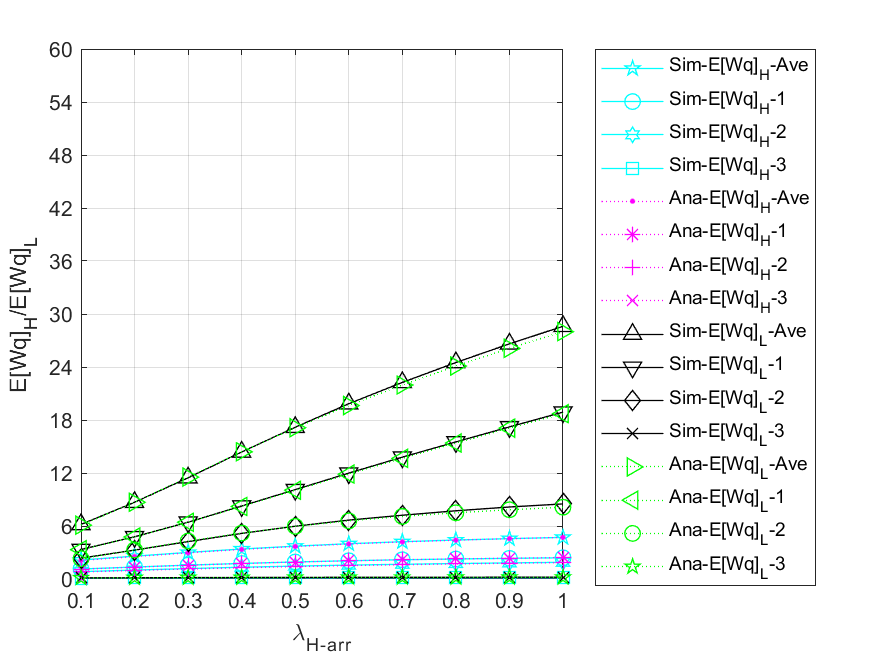


Fig. 5 - 46: The mean waiting time of HP and LP packets in the queue for the network and each node vs. the external HP packet arrival rate

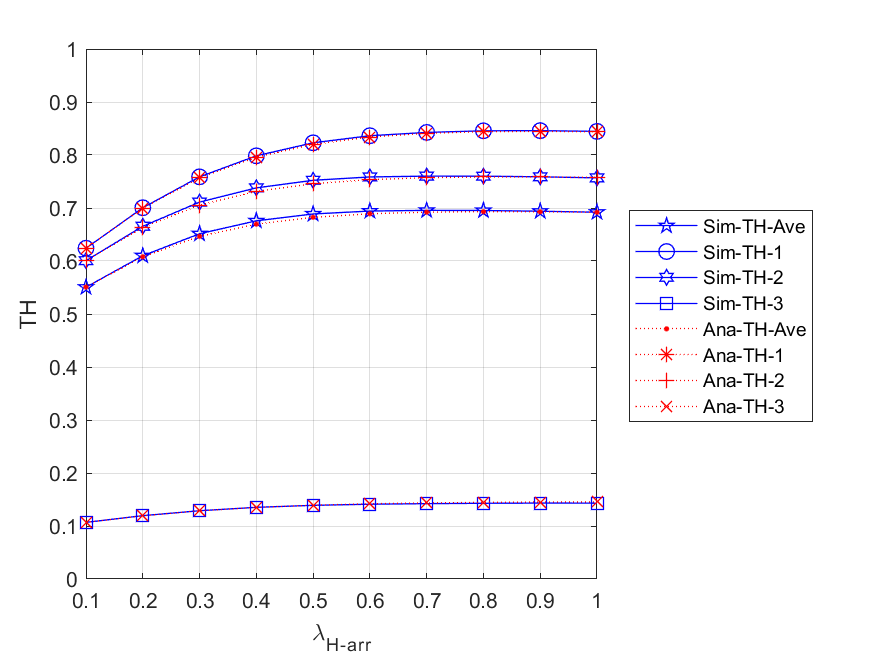


Fig. 5 - 47: The throughputs of the network and each node vs. the external HP packet arrival rate

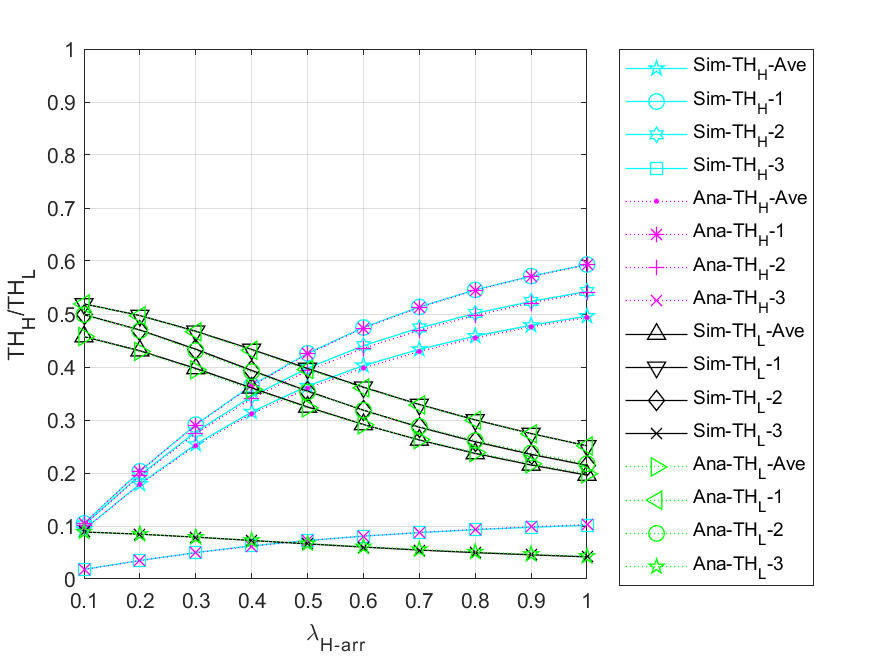


Fig. 5 - 48: The throughputs of HP and LP packets for the network and each node vs. the external HP packet arrival rate