1.1 Packet Loss Ratio

In the simulation, it was observed that there was no packet loss in the Omnet++ network simulation platform. All the packets sent by the client were successfully received by the server and vice versa, indicating no packet loss at the application layer or the physical layer. A flat line reflected this on 0 packet loss in the simulation results.

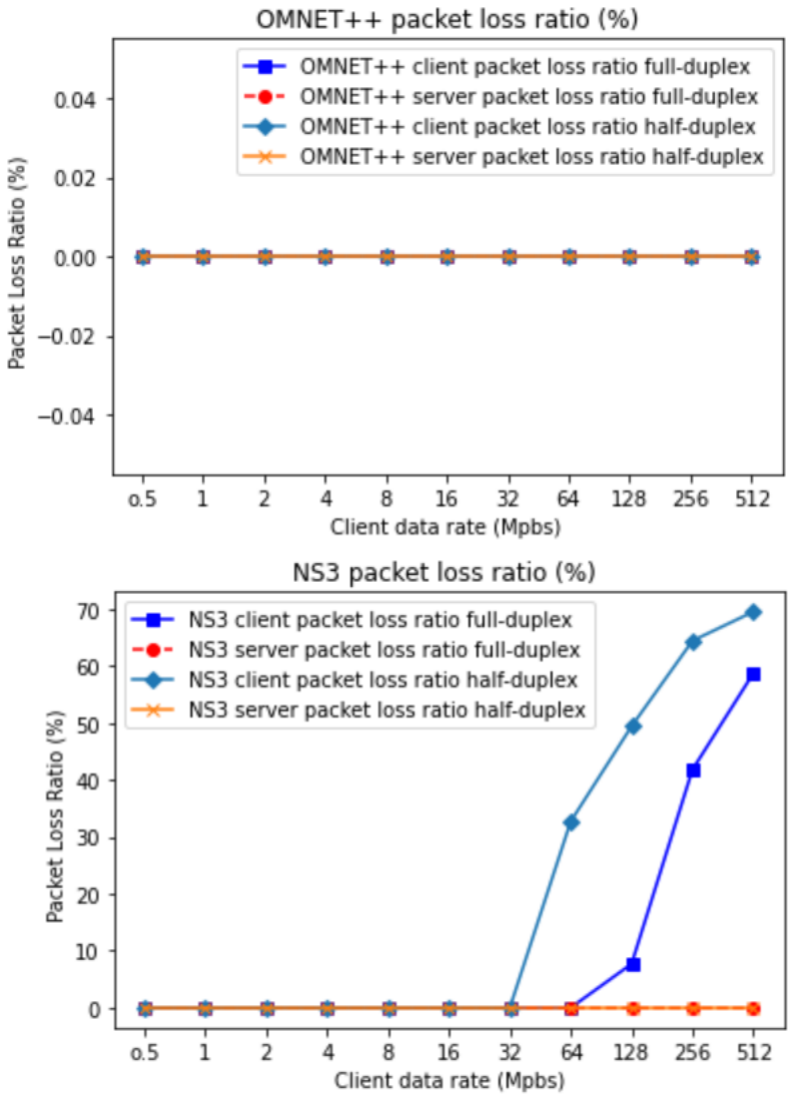


Figure 1.1: Comparison of the packet loss ratio during the execution of the simulation in OMNET++ and NS3

The simulation results for NS3 show that packet loss occurs on the client side for both full-duplex and half-duplex modes. The graph illustrates that the packet loss rate for the simulation in NS3 has an increasing trend for both modes only on the client side. However, it is essential to note that the packet loss ratio for both modes is the same for client data rates from 0.5Mbps to 32Mbps, which is a 0 % loss. In the half-duplex mode using the CSMA/CD protocol, a sharp increase in the packet loss ratio can be observed from a client data rate of 64Mbps. On the other hand, a sharp increase in the packet loss ratio in the full-duplex mode that operates with the PPP protocol can be observed from a client data rate of 128Mbps.

The client machine's internal workings were inspected to understand the cause of the packet loss. The number of bytes sent from the application layer, the number of bytes received by the physical layer, and the number of bytes transmitted into the channel were all monitored.
The next graph in the simulation results shows the results obtained from this inspection.
It is worth noting that the number of bytes was inspected instead of the number of packets, as the number of packets on the application layer can differ from the number of packets on the physical layer due to packet fragmentation and the addition of extra packets caused by the handshake.

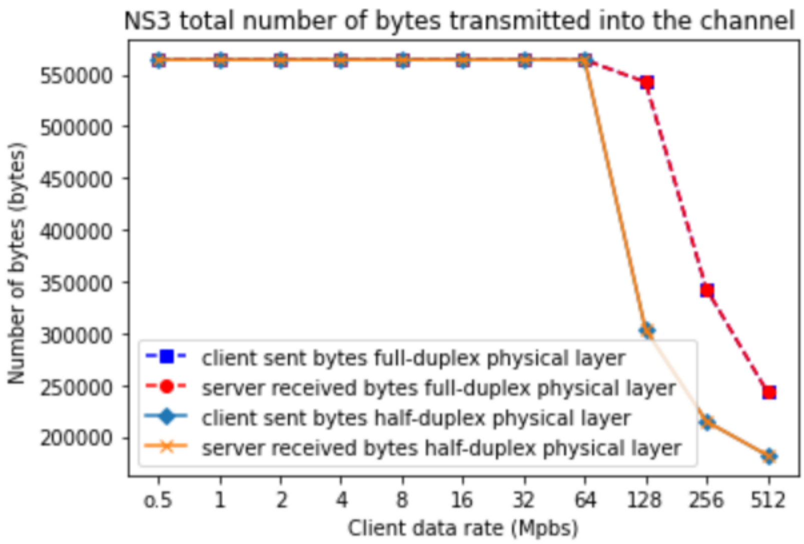


Figure 1.2: Number of bytes transmitted into the channel

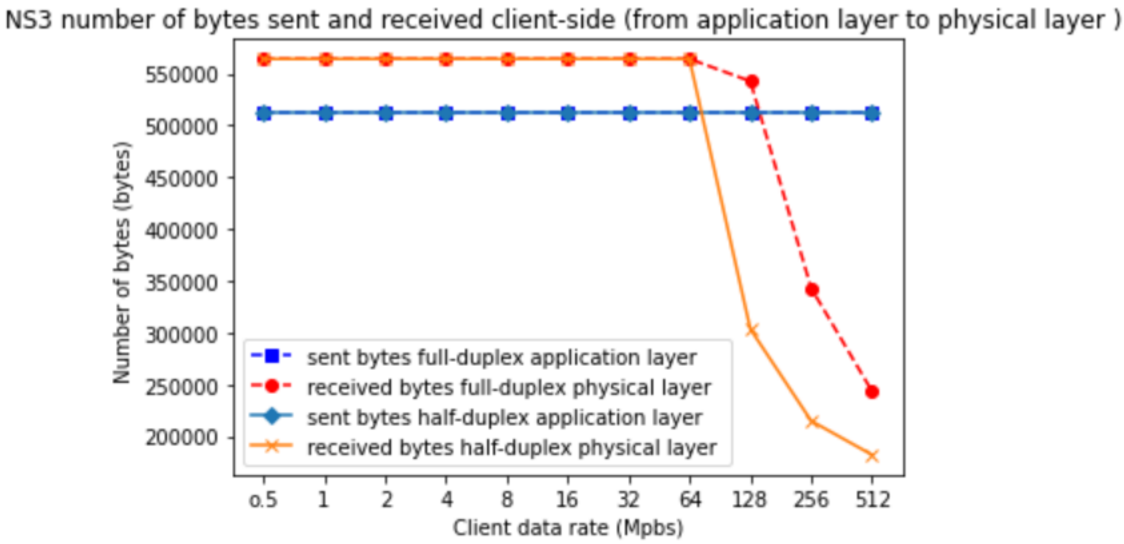


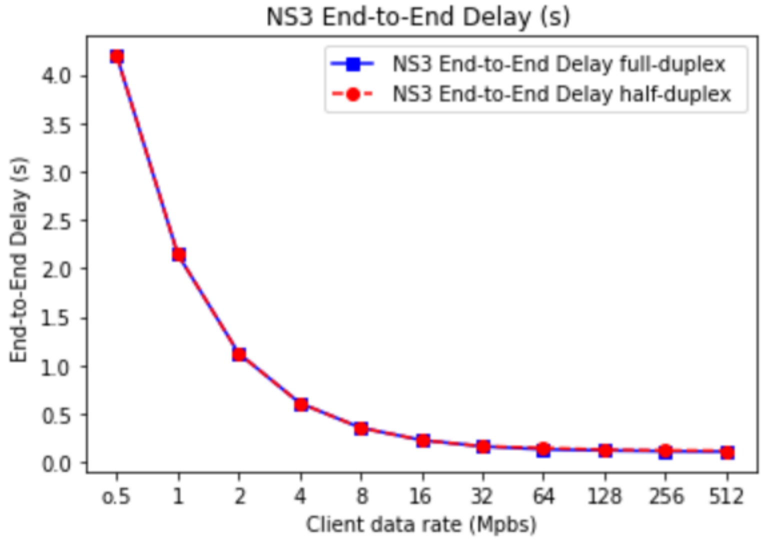
Figure 1.3: Number of bytes sent and received client side from the application layer to the physical layer

The graph shows that for high data rates, not all packets emitted by the application are successfully put into the channel in NS3. The packet loss of the client starts in half duplex mode at lower data rates than in full duplex mode. The duplex mode affects packet loss because it changes the rate at which the channel can handle packets. The full duplex mode can handle a higher data rate because both machines are never occupied simultaneously.

The reason for packet loss in NS3 is that in both duplex modes, packets emitted by the client have to wait for extra time because the server is using the channel. Suppose the waiting time exceeds a certain threshold, and the client's application emits extra packets. In that case, packet loss occurs because the buffer used to make the packets wait in a pending state becomes full (buffer overflow). This is more likely to happen in half-duplex mode as the channel can't handle high data rates when both machines send packets, so some packets have to wait in the machine before being put into the channel. With more packets waiting in the buffer, it can overflow.

It is worth mentioning that this overflow occurs only in NS3, while in Omnet++, both modes' channels can handle many packets. This difference in results is due to the differences in the implementation details of the two protocols on both simulators.

1.2 End-to-end Delay



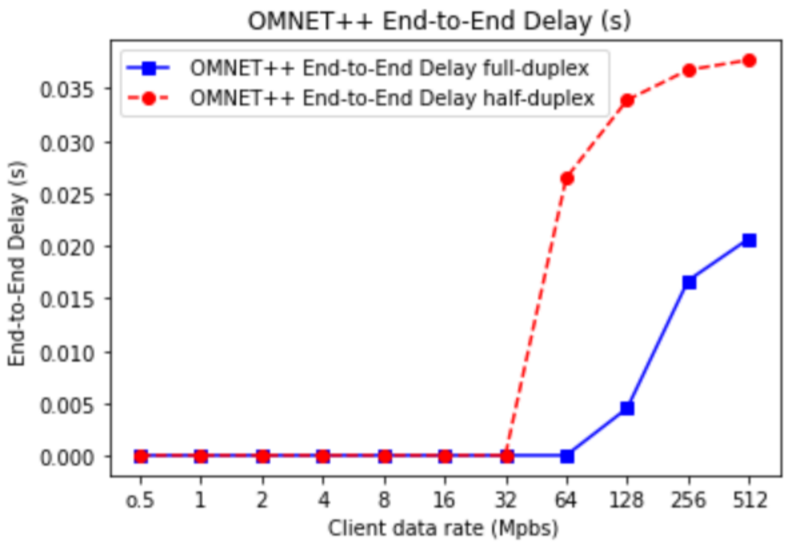


Figure 1.4: Comparison of the end-to-end delay during execution of the simulation in OMNET++ and NS3

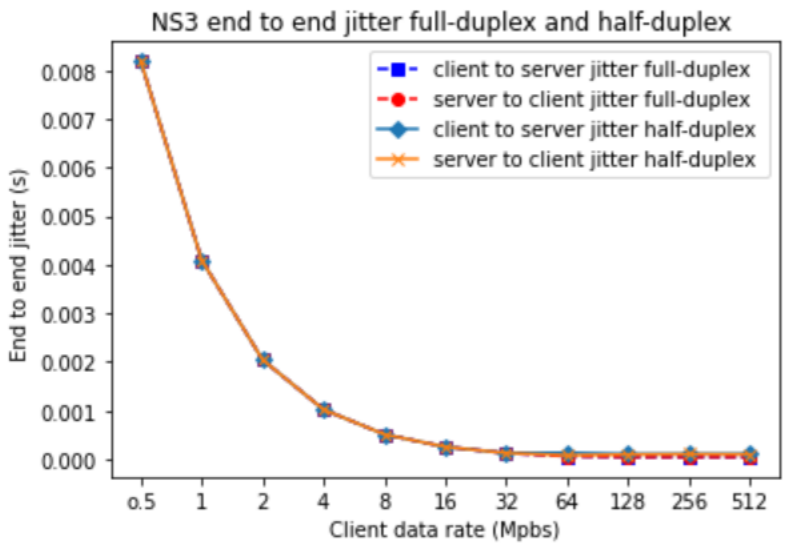
The simulation results show an opposite behavior for both duplex modes in NS3 and Omnet++. In NS3, as the client data rate increases, the end-to-end delay decreases, while in Omnet++ the end-to-end delay remains unchanged until the client data rate reaches 32Mbps for half-duplex mode and 64Mbps for full-duplex mode, at which point the time taken by TCP packets to be transferred increases significantly.

At first glance, it appears that NS3 has a better end-to-end delay for higher client data rates than Omnet++. However, when examining the exact values of the graphs, it can be seen that there is more to consider before concluding. The highest end-to-end delay in Omnet++ was almost 0.035 seconds at a data rate of 512Mbps, while the end-to-end delay of NS3 at a low data rate was 4 seconds.

It is also worth noting that the NS3 end-to-end delay in both modes is the same, while in Omnet++, TCP packets consume more time in half-duplex mode than in full-duplex mode. The end-to-end delay values in NS3 decrease linearly and this is partly due to the increasing data loss with higher data rates. The data loss occurs in the client machine before the packets reach the channel, which means less channel congestion and fewer packets to be echoed. This results in better traffic and less delay.

In Omnet++, as there is no data loss, there are never fewer packets in traffic, and with an increasing data rate, collisions start to happen more frequently. This causes all packets to wait to be sent and with more packets waiting in the client, there is more delay, especially in half-duplex mode. The decreasing delay in NS3 can be attributed to other factors, such as possibly faster packet forwarding through the channel when other packets are coming faster. In Omnet++ full duplex, there is a very small increase in the end-to-end delay for the full-duplex at higher data rates, this can be attributed to the server taking more time to process and send packets as the client using a higher data rate, which increases the delay.

1.3 Jitter



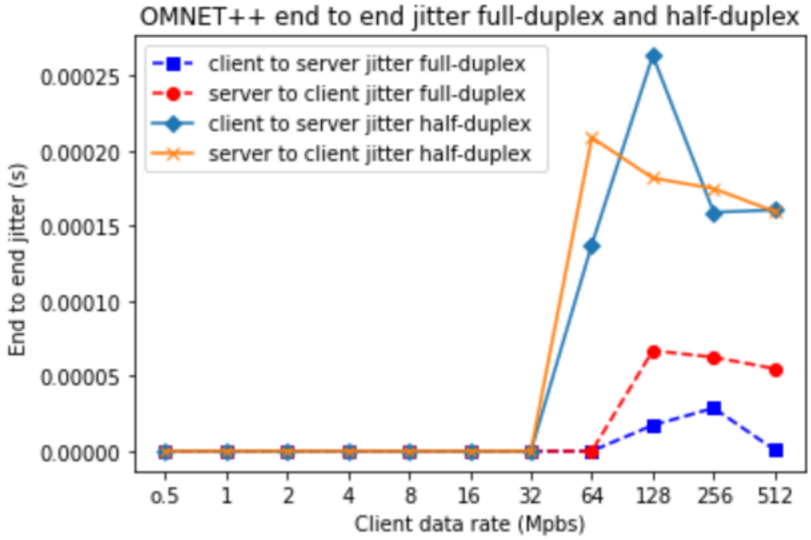


Figure 1.5: Comparison of the end-to-end delay during execution of the simulation in OMNET++ and NS3

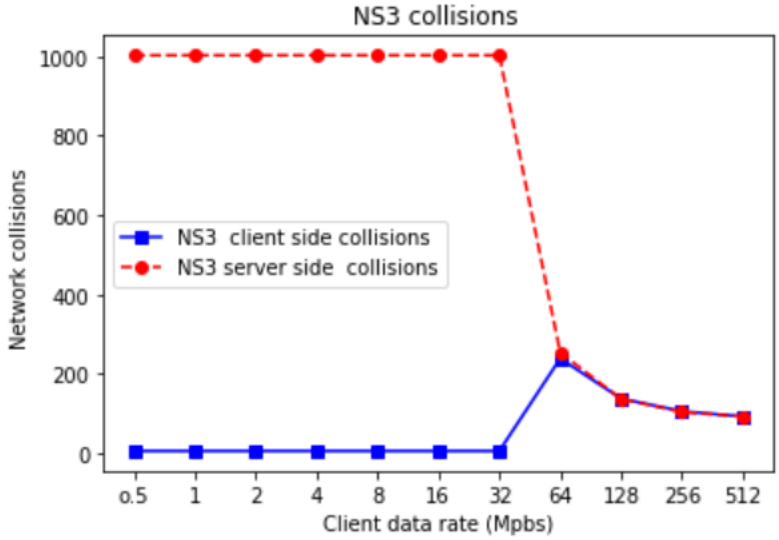
As seen in the graph above, the jitter in NS3 for both modes decreases as the client data rate increases. On the other hand, OMNET++ remains at significantly low values, which is 0 s, until the data rate of the client surpasses the value of 32 Mbps in half-duplex mode and the value of 64 Mbps in full-duplex mode. The jitter in NS3 and Omnet++ differ in their values. The jitter in NS3 starts at 0.008s while in Omnet++ it starts at 0s.

In Omnet++, the jitter is higher for higher data rates, specifically in half-duplex mode due to increasing network unpredictability caused by collisions. In full-duplex mode, the jitter of the client is typically lower than that of the server. This is because the client immediately sends packets without computing, while the server must wait for packets before sending them back, resulting in greater variations in delay.

The relationship between delay and jitter is that the delay measures the amount of time it takes for a packet to be delivered while jitter measures the variability in delay of packets over time. As delay increases, jitter can also increase but as delay decreases jitter will decrease. Because, with low delay values, there is a smaller range for potential fluctuation in the delay, thus reducing the likelihood of high jitter. Jitter values cannot be higher than the delay as jitter is the difference between two successive delays. Jitter is an indicator of network health, and networks with short delays tend to be healthier and have high and stable throughput and a low jitter. So we can explain the Jitter graphs trends from the trends in the delay graphs.

Overall, the jitter in Omnet++ and NS3 are affected by the rate of the client, the mode of communication, and the presence of collisions.

1.4 Network Collisions



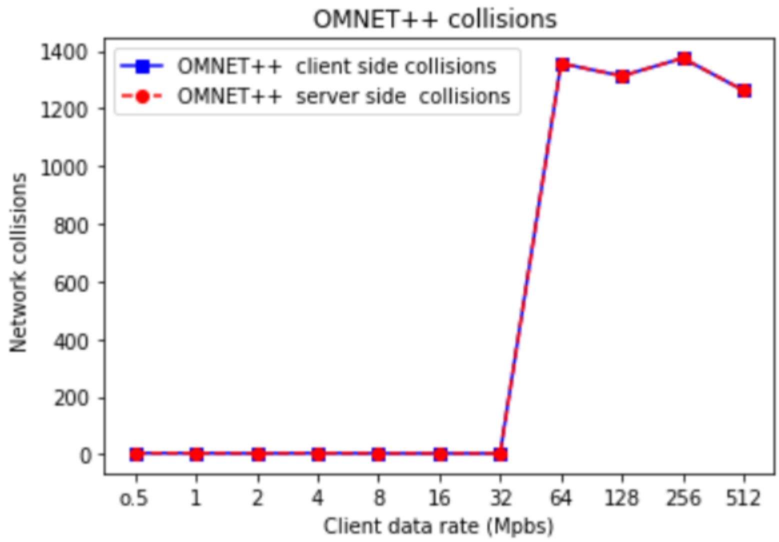
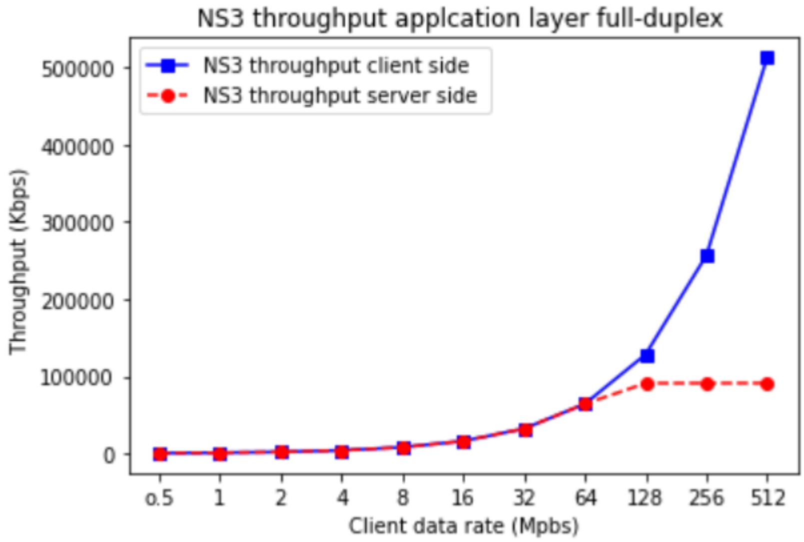


Figure 1.6: Comparison of the network collisions during the execution of the simulation in OMNET++ and NS3

In network simulations, collisions can occur when the client and server simultaneously attempt to send packets in a half-duplex mode. OMNET++ and NS3 are two simulation environments that handle collisions differently. In OMNET++, the number of collisions starts at a specific data rate known as the critical data rate. At this rate, the server and client begin to interrupt each other, leading to collisions. Both machines display the same number of collisions. In contrast, in NS3, the number of collisions differs between the client and server sides. This is because NS3 does not simulate signal jamming, so collisions detected by the client machine are not visible to the server machine, and vice versa. Initially, the client machine has zero collisions as it takes control of the channel. However, at high data rates, both machines start to detect the same collisions simultaneously. This may be because at high data rates, the dynamics of the traffic change such that both machines fail to send and both detect collisions. This can be explained by the backoff algorithm, which changes its behavior at high data rates. It is worth noting that in OMNET++, the CSMA algorithm works better for lower data rates, while in NS3 it's the opposite.

1.5 Network Throughput



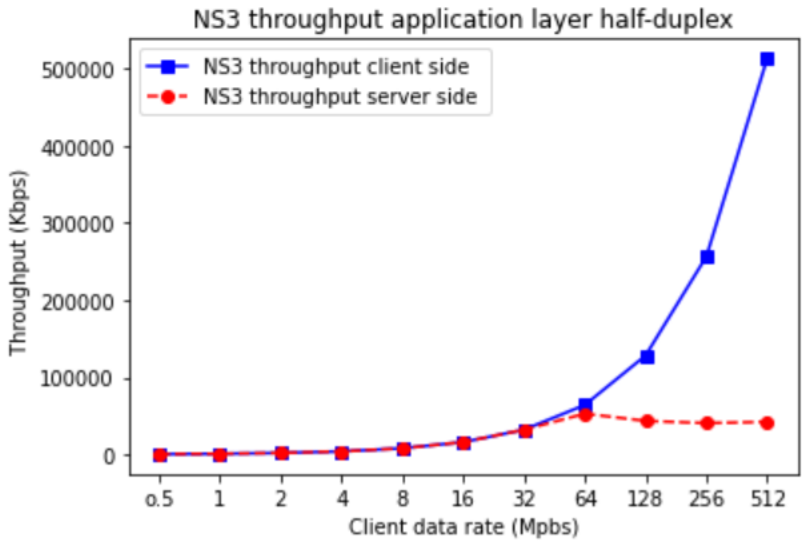


Figure 1.7: The application layer throughput of the client and server in full-duplex mode running PPP protocol and half-duplex mode running CSMA/CD protocol in NS3

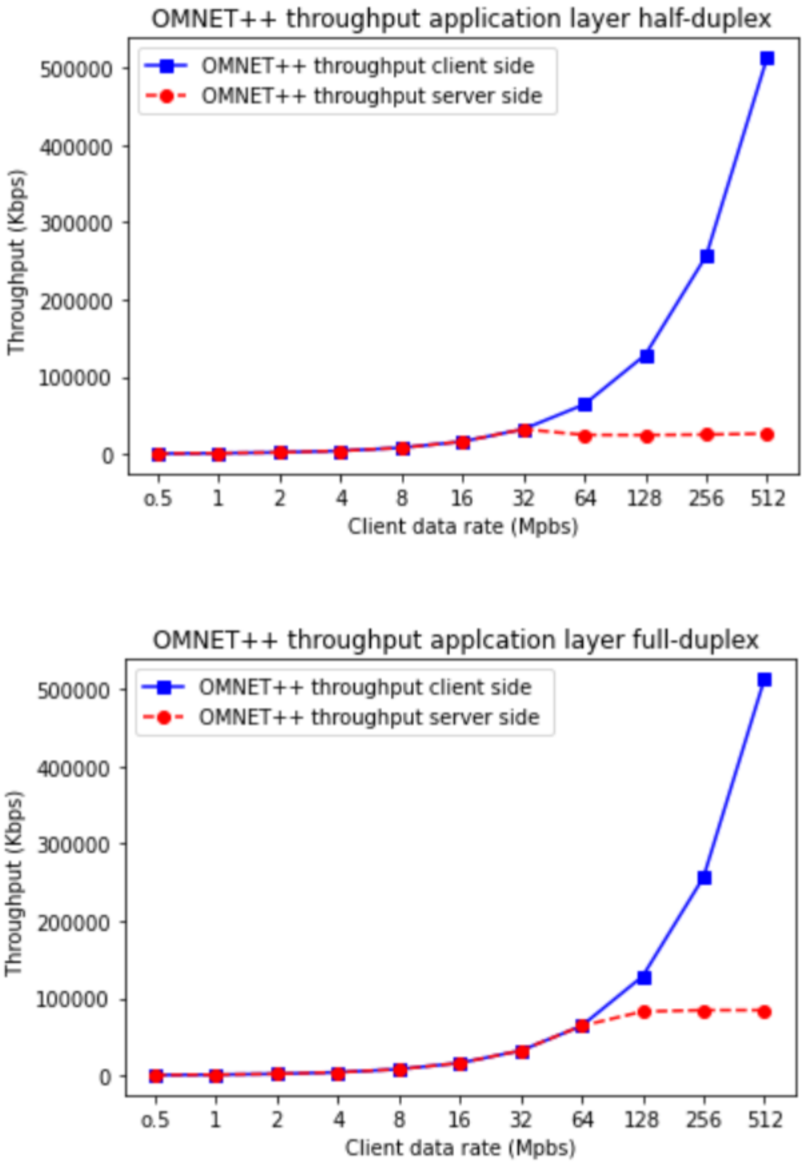


Figure 1.8: The application layer throughput of the client and server in full-duplex mode running PPP protocol and half-duplex mode running CSMA/CD protocol in OMNET++ .

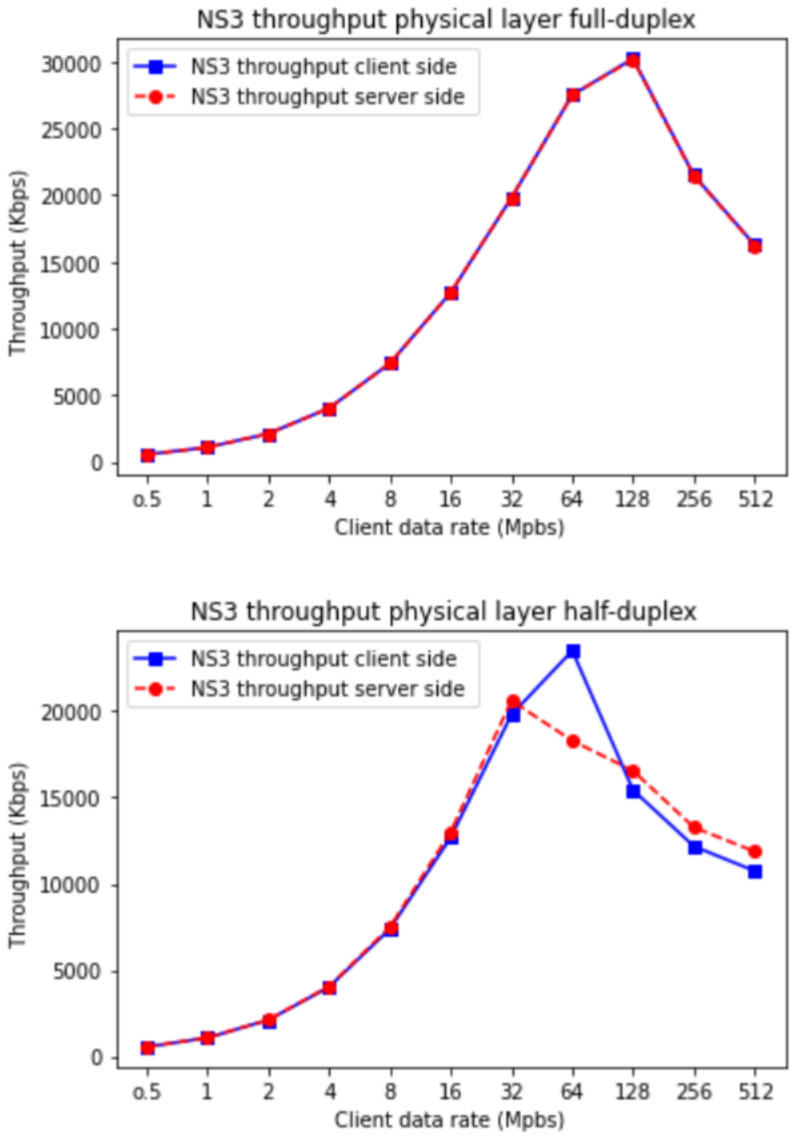
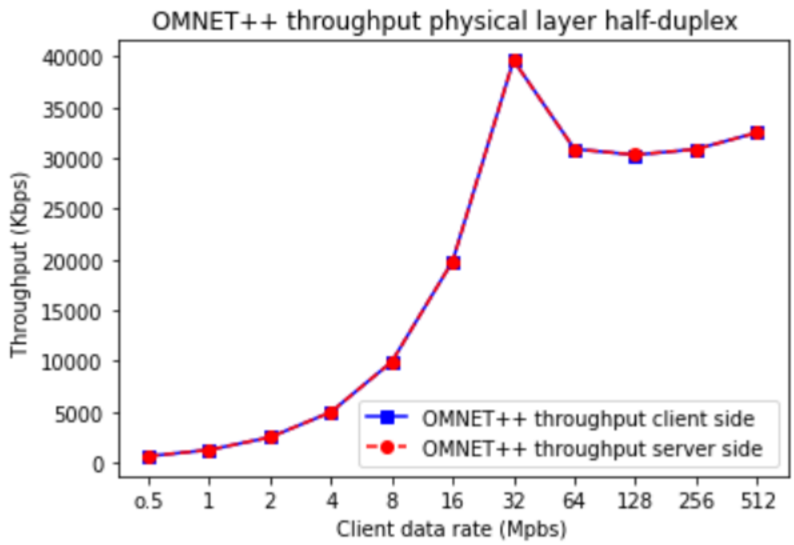


Figure 1.9: The physical layer throughput of the client and server in full-duplex mode running PPP protocol and half-duplex mode running CSMA/CD protocol in NS3



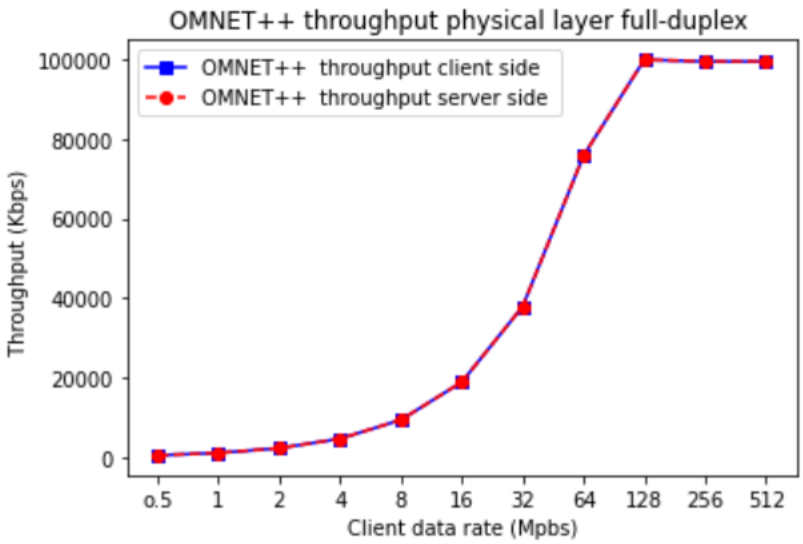


Figure 1.10: The physical layer throughput of the client and server in full-duplex mode running PPP protocol and half-duplex mode running CSMA/CD protocol in OMNET++ .

In the diagrams above, the application layer throughput for the client and server in both duplex modes in OMNET++ and NS3 are proportionally similar. The client's application layer throughput is linearly proportional to the client data rate. On the other hand, the server's application layer throughput increases along with the client's application layer throughput, but not at the same rate due to the delay between the client and the server. The application layer throughput of the server in full-duplex mode is higher than the half-duplex mode in both OMNET++ and NS3. In comparison, the throughput of the physical layer of OMNET++ is higher than NS3 at both the client and server sides in full-duplex and half-duplex modes. This means that OMNET++ provides higher efficiency in data transmission and smooth communication at the physical layer compared to NS3. However, the throughput of the application layer for all software configurations is the same as the client emits more data than the server because the client doesn't have to wait for anything to emit the next packet. On the other hand, the server has to wait for a packet to echo it. So the server is waiting for every packet to send the packet back. But the client doesn't have to do anything to start sending, this is why the client emits more data in the time unit. When it comes to the physical layer, in all configurations on both software, the physical layer of both machines has an increased data rate for when the client data rate is rising. But at a specific critical data rate, it starts decreasing because collisions increase too much and the throughput is falling because the network loses its efficiency, which happens on both machines. OMNET++ throughput on the physical layer reaches a maximum and sometimes starts declining and sometimes starts to be stable. But in NS3, it always declines up to a certain maximum. The difference in behavior is because the two simulators simulate the network in the physical layer differently and handle the collision algorithm differently. The main difference between the two simulators can be seen from the throughput curves.

1.6 Number of Simulation Events

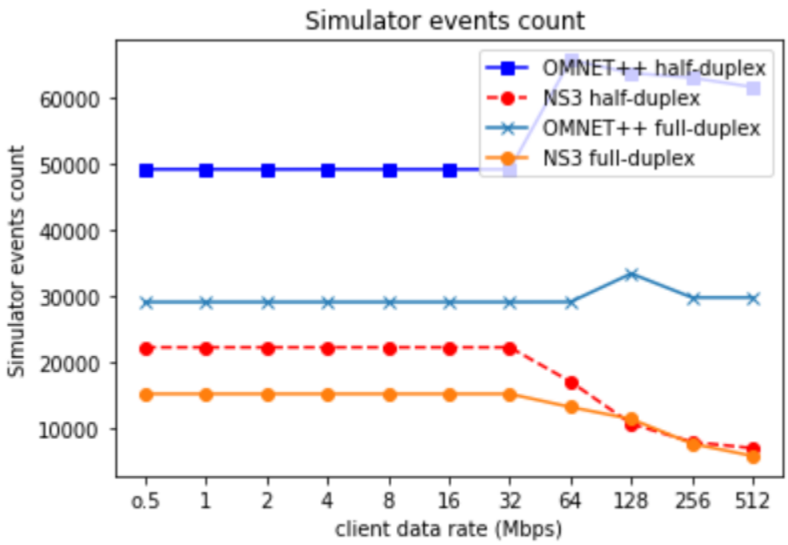


Figure 1.11: Simulator events count

The figure shows interesting compatibility between the two simulators, as the number of simulation events for both OMNET++ and NS3 is in the same order of magnitude and a narrow range. The highest number of simulation events is for OMNET++ simulators in half-duplex mode due to the increasing number of collisions which trigger more events such as signal interference and jamming. Next is OMNET++ full duplex, which indicates that OMNET++ divides the simulations into smaller steps, which can lead to more accurate results because each step is treated separately. In comparison, NS3 performs the same scenario using fewer events. In NS3, the number of events for half and full duplex is almost the same at higher client data rate values. This is mainly related to the decrease in packet delivery, causing lower traffic load and fewer events from the loss of packets. On the other hand, the number of events increases in OMNET++ when the client data rate value surpasses the throughput of the client's physical layer. However, this is not the case in NS3, where the decrease in the number of collisions, the absence of jamming signals, and the decrease in traffic load at a higher client data rate all result in fewer events generated. It is important to note that Omnet++ generates more events to create the simulation, but NS3 generates fewer events. In both simulators, the half-duplex mode has more events because it causes collisions and collisions are events that result in more action in the network by triggering the algorithm, the collision detection and condition CSMA CA CD system or CI CD algorithm, and all that are extra events in both simulators. This is why half-duplex mode has more events in both simulators, but for OMNET++, this is a difference between the two simulators that OMNET++ generates more events than NS3.

1.6.1 Simulation Length

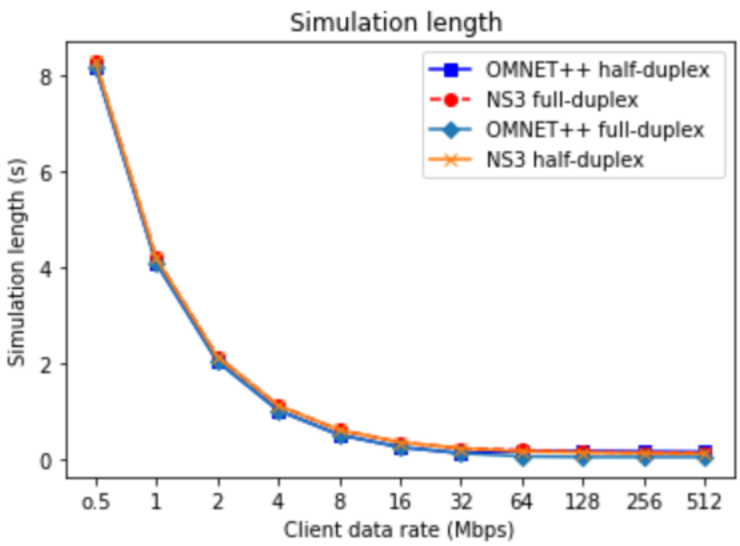


Figure 1.12: Simulator events count

The simulation length of a peer-to-peer network topology in full-duplex mode using PPP protocol and half-duplex mode using CSMA/CD protocol was analyzed in both simulators. The most significant similarity between the two simulators is that the simulation time is cut in half when the client data rate doubles. However, except at high data rates, the simulation time does not decrease as quickly and reaches a minimum value. This minimum value is mainly caused by the packet propagation delay, which cannot be eliminated by a high client data rate. The simulation time decreases linearly as the client rate increases as there is less time needed for the data transfer to occur.