Simulation Setup:

I utilized the provided FIFO queue sample project as the starting point for my simulation.

Network Configuration

My "Tandem Satellite" network consisted of one generator, two FIFO queues/servers, a satellite node, and a sink node. The generator, queue, and sink nodes are all the same as given in the FIFO sample (and the same as Project #1). I defined the satellite node as a simple node which handled any incoming message by forwarding it to the following node immediately. Due to the distance to the satellite, the simulation needed to account for the propagation delay.

$$t_{prop} = \frac{d}{c} \qquad d = 42,000km \qquad c = 299,792,458\frac{m}{s}$$

$$t_{prop} = \frac{4.2 \times 10^7 m}{299792458\frac{m}{s}}$$

$$\boxed{t_{prop} = 0.1401ms}$$

The satellite node accounted for the propagation delay of communication with the satellite by using a channel delay on the links connecting the satellite to the two queues. Figure #1 shows this network setup.

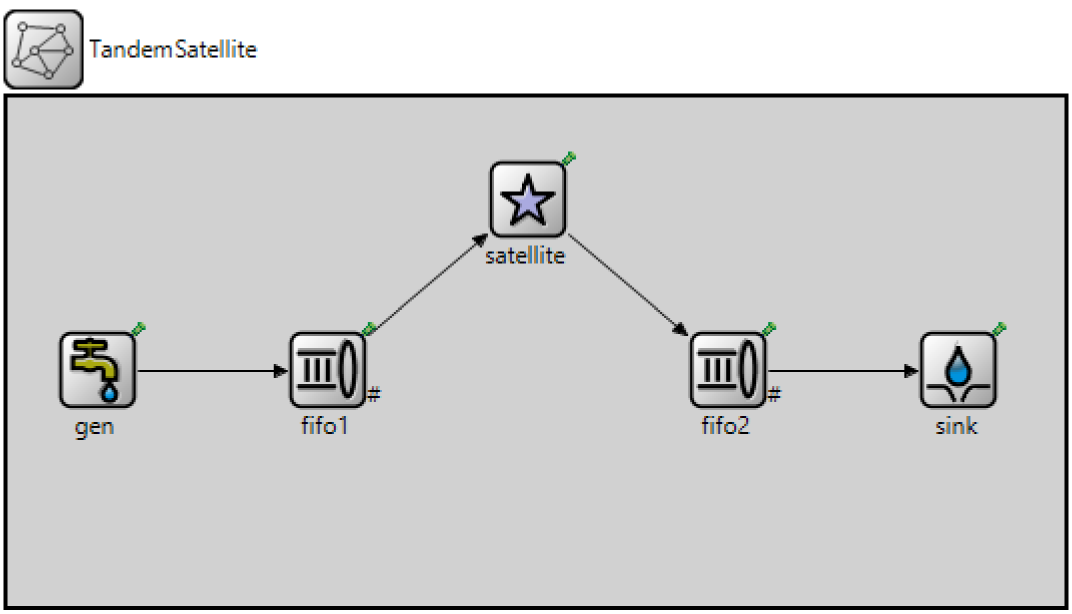

Figure 1: Network diagram

When a packet arrives at the sink, it generates a packet delay data point as defined in Eq. #1

$$Packet\ Delay = time_{arrival} - time_{created} \tag{1}$$

Simulation Time:

Before determining a simulation run-time, I calculated λ, μ, and ρ from the mean service time and interarrival times specified. Table #1 below.

Case #:	Interarrival Time (s)	λ	μ	ρ
1	1.00	1.00	2.00	0.50
2	0.52	1.92	2.00	0.96
3	0.50	2.00	2.00	1.00

Table 1: Queue Parameters

Based on these parameters, Case #3 should become unstable, given a long enough simulation. I started by running the three cases for 1 hour each. However, when I plotted the data, the second case with $t_{IA} = 0.52\, seconds$ actually had a longer average system delay than the final case with $t_{IA} = 0.50\, seconds$, and similar average queue lengths. Based on this result, I decided that a longer simulation was needed. My final simulation run-time was 10 hours, which generated a result aligning with the expectation given the relationship between λ and μ.

Results & Analysis:

System Delay

Figure #2 shows the system delay of each queue.

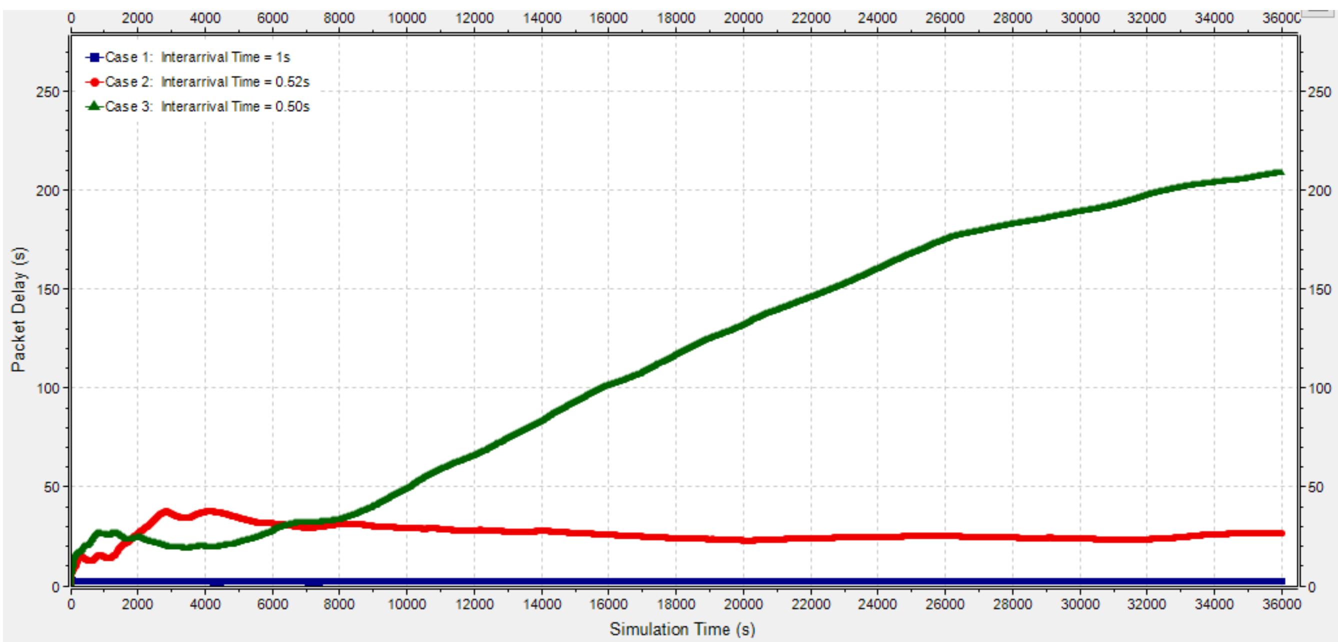

Figure 2: System Delay of varied interarrival times

Case #1 had an average system delay of 2.02 seconds. This occurs because $\mu_1 = 2 \cdot \lambda_1$, meaning packets are serviced at twice the arrival rate. Thus, one would not expect there to be significant delays. Despite only having a difference of $0.02s$ in interarrival times, the average delay of Cases 2 and 3 were significantly different. Case #2 had a mean system delay of 26.28 seconds, while the mean delay for Case #3 was 208.94 seconds. This occurs because when $\rho = 1$, the system is unstable and the queue will grow to an infinite length.

Queue Length & Queue Time

As shown in Tables 2 & 3, the average queue lengths and queue times increased relative to the system delay. Case #1 had a low number of packets in the queue because its arrival rate $\lambda_1 = 0.5 \cdot \mu$.

Module	Case #	Mean (packets)	Std. Dev
fifo1	1	1.550	1.628
fifo1	2	28.641	27.994
fifo1	3	135.166	87.599
fifo2	1	1.509	1.488
fifo2	2	22.831	21.021
fifo2	3	284.557	193.670

Table 2: Queue Length

Module	Case #	Mean (s)	Std. Dev
fifo1	1	0.517	0.912
fifo1	2	14.131	14.333
fifo1	3	67.148	43.887
fifo2	1	0.504	0.862
fifo2	2	11.151	10.748
fifo2	3	141.203	97.621

Table 3: Queue Time

Conclusions

This project demonstrated the effects of using deterministic arrival times and service times, which leads to deterministic arrival and service rates. As long as the service rate is faster than the arrival rate, the system will never queue.

Appendix A: Figures

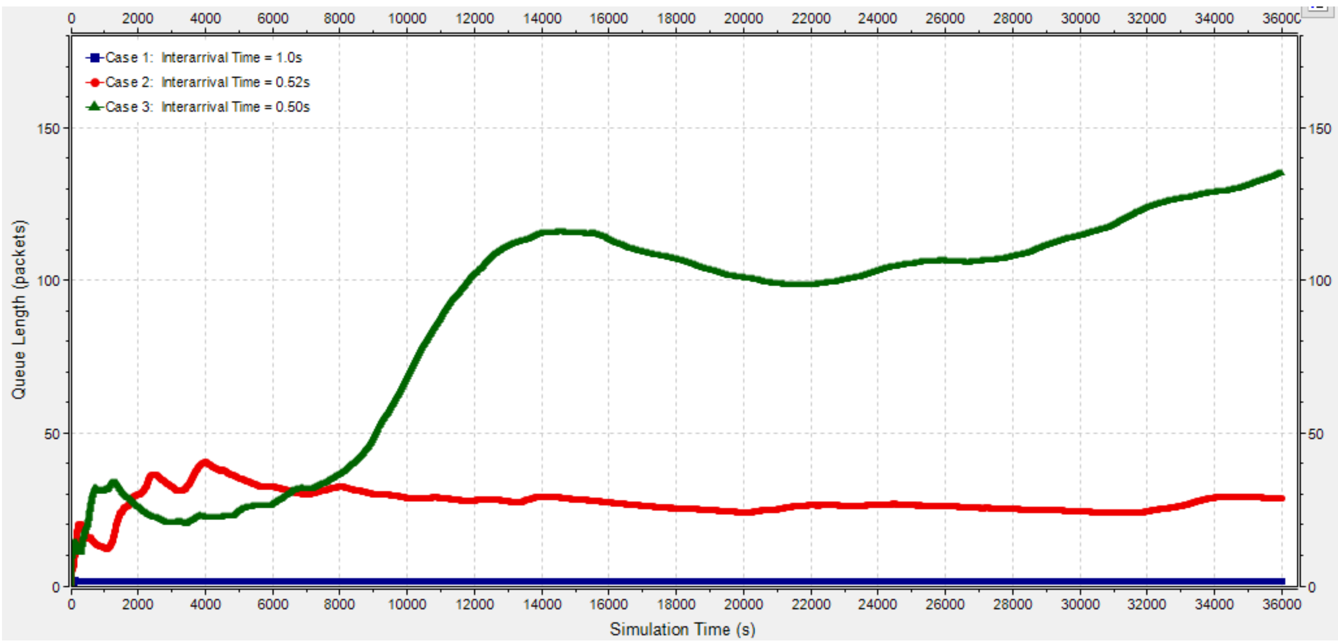

Figure 3: Fifo1 Queue Length

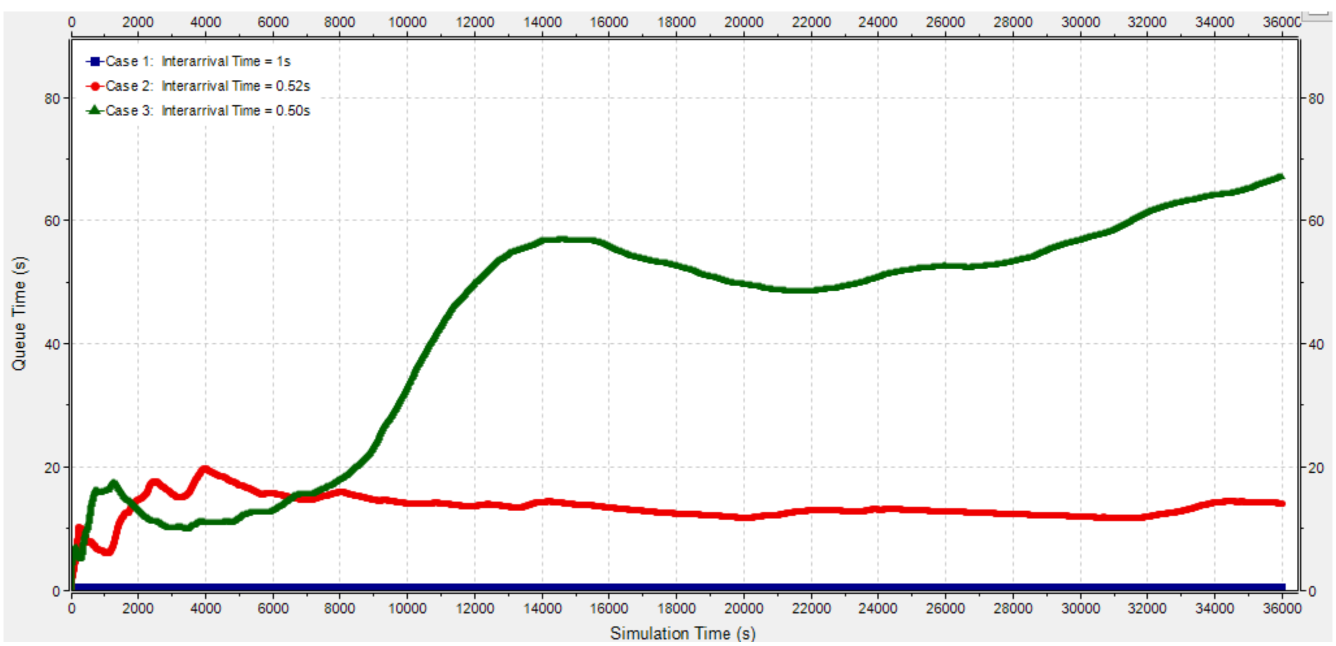

Figure 4: Fifo1 Queue Time

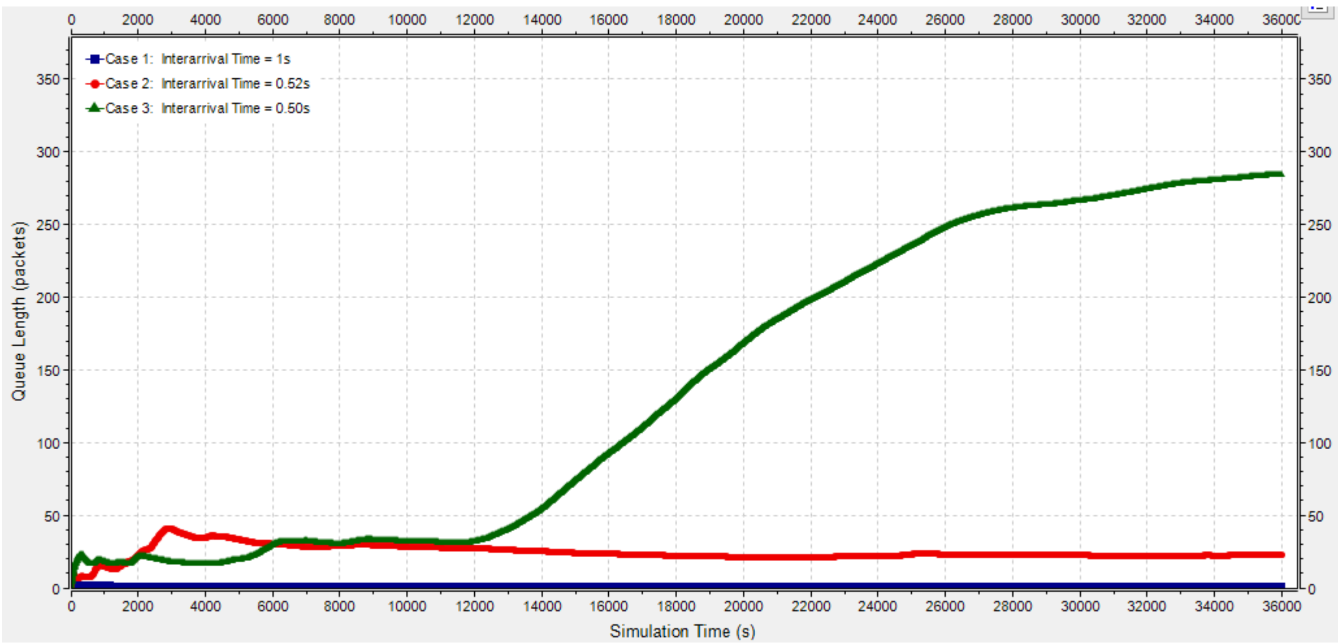

Figure 5: Fifo2 Queue Length

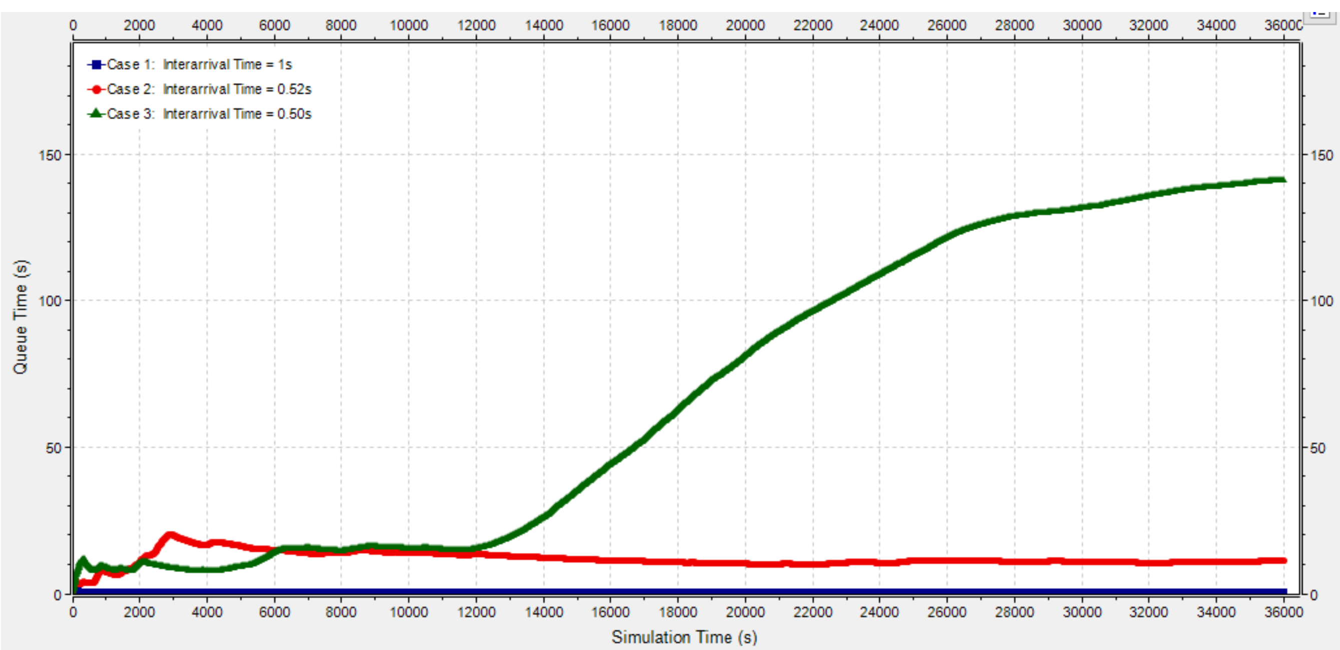

Figure 6: Fifo2 Queue Time