# <u>Delays in Computer Network</u>

**~sankalp nayak**

● Delays in computer networks refer to the time it takes for a packet to travel from the source to the destination. There are several types of delays that occur in a network, each affecting the overall performance.

## 1 . Types of Delays:

**1.1 Transmission Delay ($T_t$):** The time taken to transmit a packet from the host to the transmission medium.
**Formula:**

| |
|---|
| **Transmission Delay($T_t$) = Packet Size (L) / Transmission Rate (B.W)**<br>where L is the size of the data in bits and B.W is the bandwidth in bits per second. |

**Factors Affecting Transmission Delay:**

1. Multiple Active Sessions: More sessions increase congestion, leading to higher delays.
2. Bandwidth: Higher bandwidth reduces delay by allowing more data to be transmitted faster.
3. MAC Protocol: Shared links can cause delays depending on the protocol used (e.g., CSMA/CD).
4. Context Switch: OS context switching adds processing time, increasing delay.

**Example**: If the packet size is 1000 bits and the transmission rate is 10 Mbps, then:

Transmission Delay=1000 bit / 10 x $10^{\wedge 6}$ seconds

**1.2 Propagation Delay ($T_p$):** This is the time it takes for a signal to propagate from the sender to the receiver. It depends on the distance between the two points and the propagation speed. The formula is:
**Formula:**

| |
|---|
| **Propagation Delay($T_p$) = Distance / Propagation Speed** |

● In an optical fibre, signals travel at 70% speed of light.(70% speed of light)
=0.7 x 3 x 10 = 2.1 x $10^{\wedge 8}$ m/sec
So, consider transmission speed(v) = 2.1 x $10^8$ m/sec

**Example Calculation:**

● **Given:**Distance d = 2000 × 10^3 meters (2000 km)
○ Propagation Speed v = 2.1 × 10^8 meters/second
○ **Calculation:** Tp = 2000 × 10^3 meters / (2.1 × 10^8 meters/second) = 0.00952 seconds or 9.52 milliseconds

**1.3 Queuing Delay($T_q$) :** Queuing delay is the time a packet waits in a queue (buffer) before being processed by the destination.

**Formula:**There is no specific formula for queuing delay as it depends on various factors like queue length, traffic load, etc.

**Factors Affecting Queuing Delay:**

- **Queue Size:** Larger queues result in higher queuing delays.
- **Packet Arrival Rate:** Higher arrival rates increase the queuing delay.
- **Number of Servers/Links:** Fewer servers or links increase the queuing delay.

**Example Scenario:**

- **Scenario:** If packets arrive faster than they can be processed, they will queue up, leading to increased queuing delays.

**1.4 Processing Delay($T_{pro}$) :** Processing delay is the time taken by a router or a switch to process the packet header, including tasks such as deciding where to forward the packet, updating the Time-to-Live (TTL), and performing header checksum calculations.

**General Formula:** There is no specific formula for processing delay as it depends on the processor speed and the complexity of operations.

**Factors Affecting Processing Delay:**

- **Processor Speed:** Faster processors reduce processing delay.

**Example Scenario:**

- **Scenario:** A router with a high-speed processor will have a lower processing delay compared to one with a slower processor.

**Delay Formula: Total Delay (Ttotal) = Transmission Delay (Tt) + Propagation Delay (Tp) + Queuing Delay (Tq) + Processing Delay (Tpro)**

Ttotal = Tt+Tp (when taking Tq and Tpro equals to 0)

**Key Points:**

- **Bandwidth:** Always expressed in powers of 10.
- **Data:** Always expressed in powers of 2.

**Examples:**

- **Data Storage:**
    - 1 kilobyte (KB) = 2^10 bytes = 1,024 bytes
    - 1 megabyte (MB) = 2^20 bytes = 1,048,576 bytes
- **Data Transfer Rates:**
    - 1 kilobit per second (Kbps) = 10^3 bits per second = 1,000 bits per second
    - 1 megabyte per second (MBps) = 10^6 bytes per second = 1,000,000 bytes per second

**2. Bandwidth-Delay Product:** This is a measure of the amount of data that can be in transit in the network. It is calculated as:

**Bandwidth-Delay Product=Bandwidth×Round Trip Time (RTT)**

It represents the capacity of the network "pipe."

**3.Total Delay for M Hops and N Packets**

**Total Delay Calculation for M Hops and N Packets:**

In a network with multiple hops and packets, the total delay can be broken down as follows:

- **For M Hops:**
    - Each hop has one transmission delay and one propagation delay.
    - The first hop does not experience the processing and queuing delays that occur when the packet is forwarded to subsequent hops.
- **For N Packets:**
    - The first packet experiences the full transmission delay at each hop.
    - The subsequent packets experience additional transmission delay but can overlap in terms of propagation delay.

**Total Delay (T) = M * (Transmission Delay + Propagation Delay) + (M - 1) * (Processing Delay + Queuing Delay) + (N - 1) * Transmission Delay**

- **M** = Number of hops.
- **N** = Number of packets.
- **Transmission Delay** = Time taken to transmit a packet onto the link.
- **Propagation Delay** = Time taken for the signal to travel from sender to receiver.
- **Processing Delay** = Time taken to process the packet at each hop.

- **Queuing Delay** = Time packets spend waiting in queues at each hop.

**Explanation:**

- The term **M∗(TransmissionDelay+PropagationDelay)M * (Transmission Delay + Propagation Delay)M∗(TransmissionDelay+PropagationDelay)** accounts for the delays at each hop.
- **(M−1)∗(ProcessingDelay+QueuingDelay)(M - 1) * (Processing Delay + Queuing Delay)(M−1)∗(ProcessingDelay+QueuingDelay)** accounts for processing and queuing delays at intermediate hops (since the last hop does not have processing and queuing delay).
- **(N−1)∗TransmissionDelay(N - 1) * Transmission Delay(N−1)∗TransmissionDelay** accounts for the additional transmission delays due to the **N-1** packets after the first packet.

**Solved Examples:**

**Q1.** How much time will it take to send a packet of size L bits from A to B in a given setup if the Bandwidth is R bps, propagation speed is t meter/sec, and distance b/w any two points is d meters (ignore processing and queuing delay)?Assume the setup includes the path A---R1---R2---B. Ignore processing and queuing delays.

**A:**

- Number of links N = Number of hops = Number of routers + 1 = 3
- File size = L bits
- Bandwidth = R bps
- Propagation speed = t meters per second
- Distance = d meters

Transmission Delay:
Transmission delay = (N * L) / R = (3 * L) / R seconds
Propagation Delay:
Propagation delay = N * (d / t) = (3 * d) / t seconds
Total Time:
Total time = 3 * (L / R + d / t) seconds

**Q2.** In a Packet switch network having Hops= 4, transfer 10 packets from A to B given packet size is L bits. Bandwidth to transfer data is R Mbps and speed of propagation is S meter/sec. Assume processing delay= P seconds and the distance between two points is D meters. Find the total time required for 10 packets to reach A from B. A---R1---R2---R3---B

**A:** Number of hops = Number of links = M = 4

- We are sending 10 packets.
- Since there is no acknowledgment required for received packets, parallel processing is performed. For example, when the 1st packet reaches R2, the second packet reaches R1.

Formulas Used:

1. Bandwidth Conversion:
   Bandwidth in bps = $R * 10^6$
2. Transmission Delay:
   Transmission delay = Packet size / Bandwidth = $L / (R * 10^6)$
3. Propagation Delay:
   Propagation delay = Distance / Speed = D / S
4. Processing Delay:
   Processing delay is already in seconds, so no conversion is needed.
5. Total Delay Calculation:
   - Delay for the 1st Packet:
     Delay for the 1st packet = M * (Propagation delay + Transmission delay) + (M - 1) * (Processing delay)
   - Delay for the Remaining N-1 Packets:
     Delay for N-1 remaining packets = (N - 1) * Transmission delay
6. Final Total Delay Formula:
   Total delay = $4 * (L / (R * 10^6) + D / S) + (4 - 1) * (P) + (10 - 1) * (L / (R * 10^6))$

**Question 3:**
A packet of size 1000 bytes is sent over a network link with a transmission rate of 1 Mbps. Calculate the transmission delay.
Solution:
Transmission delay = (Packet size * 8) / Transmission rate
= (1000 * 8) / (10^6)
= 0.008 seconds

**Question 4:**
A network link has a bandwidth of 1 Gbps and a propagation delay of 10 ms. The packet size is 1 MB. Calculate the total delay for transmitting this packet from the sender to the receiver.
Solution:
**Transmission Delay:**

- Packet size = 1 MB = 8 * 10^6 bits
- Bandwidth = 1 Gbps = 10^9 bits/sec
- Transmission delay = Packet size / Bandwidth
- Transmission delay = (8 * 10^6 bits) / (10^9 bits/sec) = 0.008 sec = 8 ms

**Propagation Delay:**

- Given as 10 ms

**Total Delay:**

- Total delay = Transmission delay + Propagation delay
- Total delay = 8 ms + 10 ms = 18 ms

**Question 5:**
Calculate the total time to transmit a 500-byte packet over a 100 Mbps link.
Solution:
Transmission delay = (Packet size * 8) / Transmission rate
= (500 * 8) / (100 * 10^6)
= 0.00004 seconds
= 0.04 ms

**Question 6:**
A network link has a capacity of 10 Mbps. Calculate the throughput if the link utilization is 60%.
Solution:
Throughput = Capacity * Utilization
= 10 Mbps * 0.60
= 6 Mbps

**Question 7:**
A server sends data at a rate of 5 Mbps. What is the throughput if only 80% of the data is successfully received?
Solution:
Throughput = Data rate * Success rate
= 5 Mbps * 0.80
= 4 Mbps

**Question 8:**
A packet switch has a queue of packets to send. If the transmission rate is 2 Gbps and the queue contains 100 packets, each 1000 bytes, calculate the total time to transmit all packets.
Solution:
Total time = (Number of packets * Packet size * 8) / Transmission rate
= (100 * 1000 * 8) / (2 * 10^9)
= 0.0004 seconds
= 0.4 ms

**Question 9:**
In a network with a data rate of 2 Mbps and a propagation delay of 15 ms, what is the delay experienced when transmitting a file of size 5 MB?

**Solution:**

1. **Transmission Delay:**
   - File size = 5 MB = 5 * 8 * 10^6 bits
   - Data rate = 2 Mbps = 2 * 10^6 bits/sec
   - Transmission delay = File size / Data rate
   - Transmission delay = (5 * 8 * 10^6 bits) / (2 * 10^6 bits/sec) = 20 sec
2. **Propagation Delay:**
   - Given as 15 ms = 0.015 sec
3. **Total Delay:**
   - Total delay = Transmission delay + Propagation delay

- Total delay = 20 sec + 0.015 sec = 20.015 sec

**Question 10:**
Determine the bandwidth-delay product for a link with a bandwidth of 1 Gbps and a propagation delay of 10 ms.
Solution:
Bandwidth-delay product = Bandwidth * Propagation delay
= $1 * 10^9 * 10 * 10^{-3}$
= $10^7$ bits

**Question 11:**
A network with a bandwidth of 50 Mbps has an average packet size of 1250 bytes. What is the network's throughput in packets per second?
Solution:
Throughput = (Bandwidth) / (Packet size * 8)
= (50 * 10^6) / (1250 * 8)
= 5000 packets/second

**Question 12:**
Calculate the total time to transmit a 500-byte packet over a 100 Mbps link.
**Solution:**
Transmission delay = (Packet size * 8) / Transmission rate
= (500 * 8) / (100 * 10^6)
= 0.00004 seconds
= 0.04 ms

**Question 13:**
Calculate the total delay (transmission, propagation, and queuing) for a 1000-byte packet sent over a network with a transmission rate of 100 Mbps, a propagation delay of 5 ms, and a queuing delay of 2 ms.
**Solution:**
Total delay = Transmission delay + Propagation delay + Queuing delay
Transmission delay = (Packet size * 8) / Transmission rate
= (1000 * 8) / (100 * 10^6)
= 0.00008 seconds
Total delay = 0.00008 + 0.005 + 0.002
= 0.00708 seconds

**Question 14:**
A file of size 10 MB is sent over a network with two links. The first link has a transmission rate of 100 Mbps and the second link has a transmission rate of 50 Mbps. Calculate the time to send the file, assuming negligible propagation and processing delays.
**Solution:**
Time to send the file = File size / Bottleneck link rate
= (10 * 10^6 * 8) / (50 * 10^6)
= 1.6 seconds

**Question 15:**
A 1 MB file is sent through a network with a transmission delay of 10 ms per packet, where each packet is 1000 bytes. Calculate the total time to send the file.
**Solution:**
Number of packets = File size / Packet size
= (1 * 10^6) / 1000
= 1000 packets
Total time = Number of packets * Transmission delay per packet
= 1000 * 0.01 seconds
= 10 seconds

**Question 16:**
A network link has a bandwidth of 100 Mbps, a propagation delay of 1 ms, and a queuing delay of 0.5 ms. A packet of 1500 bytes needs to be sent. Calculate the total delay.
**Solution:**
Transmission delay = (Packet size * 8) / Transmission rate
= (1500 * 8) / (100 * 10^6)
= 0.12 ms
Total delay = Transmission delay + Propagation delay + Queuing delay
= 0.12 ms + 1 ms + 0.5 ms
= 1.62 ms

**Question 17:**
A packet-switched network has a total link capacity of 2 Gbps. If the network has 4 equal-sized links, each link carrying 10,000 packets per second, and each packet is 1500 bytes, calculate the overall throughput.
**Solution:**
Throughput per link = (Packets per second * Packet size * 8)
= (10,000 * 1500 * 8) bits per second
= 120 Mbps
Total throughput = Number of links * Throughput per link
= 4 * 120 Mbps
= 480 Mbps

**Question 18:**
A network operates at 1 Gbps with a utilization factor of 0.75. If the average packet size is 1000 bytes, calculate the throughput in packets per second.
**Solution:**
Throughput in bps = Link capacity * Utilization factor
= 1 * 10^9 * 0.75
= 750 Mbps
Throughput in packets per second = Throughput in bps / (Packet size * 8)
= (750 * 10^6) / (1000 * 8)
= 93,750 packets per second

Question 19:

Calculate the throughput of a network with a total link capacity of 500 Mbps and a packet size of 2000 bytes if the network has an average delay of 100 ms.
Solution:
Throughput = Link capacity / (Packet size * 8)
= (500 * 10^6) / (2000 * 8)
= 31,250 packets per second

Question 20:
A network link has a capacity of 10 Mbps. Calculate the throughput if the link utilization is 60%.
Solution:
Throughput = Link capacity * Utilization
= 10 Mbps * 0.60
= 6 Mbps

**Question 21:**
A server sends data at a rate of 5 Mbps. What is the throughput if only 80% of the data is successfully received?
**Solution:**
Throughput = Data rate * Success rate
= 5 Mbps * 0.80
= 4 Mbps

**Question 22:**
Consider a packet-switched network with a link bandwidth of 100 Mbps and an average packet size of 1250 bytes. Calculate the throughput when the network is 70% utilized.
**Solution:**
Throughput = Link bandwidth * Utilization
= 100 Mbps * 0.70
= 70 Mbps

**Question 23:**
A network has a maximum transmission rate of 50 Mbps. If the average number of packets transmitted per second is 1000, each with a size of 10 KB, calculate the throughput.
**Solution:**
Throughput = (Number of packets per second * Packet size * 8) / Total capacity
= (1000 packets/s * 10 KB/packet * 8) / 50 Mbps
= 80 Mbps / 50 Mbps
Throughput = 1.6 Mbps

**Question 24:**
A network with a 1 Gbps link capacity is shared by 100 users. If each user utilizes the link for 20% of the time and the network has a 5% packet loss, calculate the effective throughput.
**Solution:**
Utilization per user = 20%
Total utilization = 100 users * 20% = 2000%
Since utilization cannot exceed 100%, maximum possible utilization = 100%
Effective throughput = Link capacity * Utilization * (1 - Packet loss)
= 1 Gbps * 1 * (1 - 0.05)

**Question 25:**A router has a queuing delay of 25 ms, and the network link has a bandwidth of 10 Mbps and a propagation delay of 5 ms. If the packet size is 512 KB, what is the end-to-end delay for the packet?
**Solution:**Transmission Delay:

- Packet size = 512 KB = 512 * 1024 * 8 bits = 4,194,304 bits
- Bandwidth = 10 Mbps = 10 * 10^6 bits/sec
- Transmission delay = Packet size / Bandwidth
- Transmission delay = 4,194,304 bits / (10 * 10^6 bits/sec) = 0.4194 sec = 419.4 ms

Propagation Delay:

- Given as 5 ms

Queuing Delay:

- Given as 25 ms

Total Delay:

- Total delay = Transmission delay + Propagation delay + Queuing delay
- Total delay = 419.4 ms + 5 ms + 25 ms = 449.4 ms

**Question26:** Calculate the delay experienced for a 10 MB file over a network with a bandwidth of 100 Mbps and a propagation delay of 50 ms. Assume that the file is transmitted continuously and there are no additional delays (like queuing or processing delays).

**Solution:**

1. Transmission Delay:
   - File size = 10 MB = 10 * 8 * 10^6 bits
   - Bandwidth = 100 Mbps = 100 * 10^6 bits/sec
   - Transmission delay = File size / Bandwidth
   - Transmission delay = (10 * 8 * 10^6 bits) / (100 * 10^6 bits/sec) = 0.8 sec = 800 ms
2. Propagation Delay:
   - Given as 50 ms
3. Total Delay:
   - Total delay = Transmission delay + Propagation delay
   - Total delay = 800 ms + 50 ms = 850 ms

**Question27:** A network link has a bandwidth of 5 Mbps and a propagation delay of 20 ms. Calculate the bandwidth-delay product and the maximum throughput of the link.

**Solution:**

1. **Bandwidth-Delay Product:**
○ Bandwidth = 5 Mbps = 5 * 10^6 bits/sec
○ Propagation delay = 20 ms = 20 * 10^-3 sec
○ Bandwidth-Delay Product = Bandwidth * Propagation Delay
○ Bandwidth-Delay Product = (5 * 10^6 bits/sec) * (20 * 10^-3 sec) = 100,000 bits = 100 kb
2. **Maximum Throughput:**
○ Maximum throughput is equal to the bandwidth of the link.
○ Maximum throughput = 5 Mbps

**Question28:** A network has a bandwidth of 10 Mbps and a propagation delay of 50 ms. If the packet size is 2 MB, calculate the throughput of the network and the bandwidth-delay product.

**Solution:**

1. **Bandwidth-Delay Product:**
○ Bandwidth = 10 Mbps = 10 * 10^6 bits/sec
○ Propagation delay = 50 ms = 50 * 10^-3 sec
○ Bandwidth-Delay Product = Bandwidth * Propagation Delay
○ Bandwidth-Delay Product = (10 * 10^6 bits/sec) * (50 * 10^-3 sec) = 500,000 bits = 500 kb
2. **Throughput Calculation:**
○ Packet size = 2 MB = 2 * 8 * 10^6 bits = 16 * 10^6 bits
○ Transmission time = Packet size / Bandwidth
○ Transmission time = (16 * 10^6 bits) / (10 * 10^6 bits/sec) = 1.6 sec
○ Throughput = Packet size / (Transmission time + Propagation delay)
○ Throughput = (16 * 10^6 bits) / (1.6 sec + 50 * 10^-3 sec) ≈ 9.9 Mbps

**Question29:** For a network link with a bandwidth of 100 Mbps and a propagation delay of 30 ms, calculate the bandwidth-delay product. If a file of size 15 MB is transmitted, determine the time taken for the file to be transmitted (assuming no other delays).

**Solution:**

1. **Bandwidth-Delay Product:**
○ Bandwidth = 100 Mbps = 100 * 10^6 bits/sec
○ Propagation delay = 30 ms = 30 * 10^-3 sec
○ Bandwidth-Delay Product = Bandwidth * Propagation Delay
○ Bandwidth-Delay Product = (100 * 10^6 bits/sec) * (30 * 10^-3 sec) = 3,000,000 bits = 3 Mb
2. **Transmission Time for File:**
○ File size = 15 MB = 15 * 8 * 10^6 bits = 120 * 10^6 bits
○ Transmission time = File size / Bandwidth
○ Transmission time = (120 * 10^6 bits) / (100 * 10^6 bits/sec) = 1.2 sec
3. **Total Time:**
○ Total time = Transmission time + Propagation delay

- Total time = 1.2 sec + 30 ms = 1.23 sec

**Question 30:** A network has a bandwidth of 2 Gbps and a propagation delay of 10 ms. What is the bandwidth-delay product in bits and bytes? Also, if the network can handle a maximum throughput of 1.8 Gbps, calculate the effective throughput considering the bandwidth-delay product.

**Solution:**

1. **Bandwidth-Delay Product:**
   - Bandwidth = 2 Gbps = 2 * 10^9 bits/sec
   - Propagation delay = 10 ms = 10 * 10^-3 sec
   - Bandwidth-Delay Product = Bandwidth * Propagation Delay
   - Bandwidth-Delay Product = (2 * 10^9 bits/sec) * (10 * 10^-3 sec) = 20,000,000 bits = 20 Mb
2. **In Bytes:**
   - Bandwidth-Delay Product = 20,000,000 bits / 8 = 2,500,000 bytes = 2.5 MB
3. **Effective Throughput:**
   - Maximum throughput = 1.8 Gbps
   - Effective throughput is limited by the network's bandwidth.
   - Effective throughput = Minimum of bandwidth or maximum throughput
   - Effective throughput = 1.8 Gbps

**Question 31:** Two hosts are connected via a packet switch with a transmission rate of $10^7$ bits per second (bps). Each link between the hosts has a propagation delay of 20 microseconds. The packet switch begins forwarding a packet 35 microseconds after receiving it. If 10,000 bits of data are to be transmitted between the two hosts using a packet size of 5,000 bits, calculate the total time elapsed (in microseconds) between the transmission of the first bit of data and the reception of the last bit of data.

**Steps:**

1. **Transmission Delay:** For the given packet size of 5000 bits:
   Transmission Delay= 5000 bits / $10^7$ bps=0.5 milliseconds=500 microseconds
2. **Propagation Delay:** Propagation delay is the time it takes for a bit to travel from the sender to the receiver across a link. Given that each link has a propagation delay of 20 microseconds and the data travels across two links:
   Total Propagation Delay=2×20 microseconds=40 microseconds
3. **Switch Forwarding Delay:** The packet switch introduces a delay of 35 microseconds before it starts forwarding the packet.
4. **Total Delay Calculation:** To find the total time elapsed from the transmission of the first bit of data to the reception of the last bit of data, we calculate the following:
   - **First Packet:** Transmission Delay (for the first 5000 bits) + Propagation Delay + Switch Forwarding Delay.
   - **Second Packet:** Only Transmission Delay (as propagation and switch delays have already been accounted for).

5. Therefore, the total delay TTT is calculated as:
   Total Delay (T)=Transmission Delay for 1st Packet+Propagation Delay+Switch Forwarding Delay+Transmission Delay for 2nd Packet

Plugging in the values:
   Total Delay (T)=500 microseconds+40 microseconds+35 microseconds+500

Total Delay (T)=1575 microseconds

**Question 32:** A link has a transmission speed of 10610^6106 bits per second. It uses data packets of size 1000 bytes each. Assume that the acknowledgment has negligible transmission delay and that its propagation delay is the same as the data propagation delay. Also assume that the processing delays at nodes are negligible. The efficiency of the stop-and-wait protocol in this setup is exactly 25%. Calculate the value of the one-way propagation delay (in milliseconds).

**Solution**: **Given:**

- Transmission Speed: 10610^6106 bits per second (bps)
- Data Packet Size: 1000 bytes
- Efficiency of Stop-and-Wait Protocol: 25% (or 0.25)

**Steps:**

1. **Convert Packet Size to Bits:** Since 1 byte = 8 bits, the packet size in bits is:
   Packet Size=1000×8=8000 bits
2. **Calculate Transmission Delay:**

   Transmission Delay=Packet Size in bits / Transmission Speed in bps
   Substituting the given values:
   Transmission Delay=8000 bits / $10^6$ bps=0.008 seconds

3. **Efficiency of Stop-and-Wait Protocol:** The efficiency (E) of the stop-and-wait protocol is given by the formula:
   E=Transmission Delay / (Transmission Delay+2×Propagation )

   Given that the efficiency is 25%, or 0.25, we can write the equation as:
   0.25=8 milliseconds / 8 milliseconds+2×Propagation Delay

   **Solve for Propagation Delay:** Rearranging the equation to solve for Propagation Delay:
   Propagation Delay=12 milliseconds

**Question 33:** Consider a 100 Mbps link between an earth station (sender) and a satellite (receiver) at an altitude of 2100 km. The signal propagates at a speed of $3\times10^8$. Calculate the time taken (in milliseconds, rounded off to two decimal places) for the receiver to completely receive a packet of 1000 bytes transmitted by the sender.

**Solution:** Given:

- Link speed: 100 Mbps (Megabits per second)
- Distance (altitude): 2100 km = 2100 × 10^3 meters
- Propagation speed: $3 \times 10^8$ meters/second
- Packet size: 1000 byt**es**
- Convert Packet Size to Bits: Since 1 byte = 8 bits, the packet size in bits is:
  Packet Size=1000×8=8000 bits
- Calculate Transmission Delay: Transmission Delay=Packet Size in bits / Link Speed in bps

Substituting the given values:
Transmission Delay=8000 bits / $100 \times 10^6$ bps=0.00008 seconds=0.08 milliseconds

- Calculate Propagation Delay:
  Propagation Delay=DistancePropagation/ Speed

Substituting the given values:
Propagation Delay=$2100 \times 10^3$ meters / $3 \times 10^8$ meters/second=0.007 seconds=7 milliseconds

Total Time=Transmission Delay+Propagation Delay= Total Time=0.08 milliseconds+7 milliseconds=7.08 milliseconds