Example 1: Store and Forward with Different Packet Sizes

A network uses store-and-forward to transmit packets. There are four packets of sizes 2 Mbits, 3 Mbits, 4 Mbits, and 5 Mbits. The transmission rate is 2 Mbps. Calculate the one-hop delay and end-to-end delay for 2 hops.

Solution:

Transmission times:

$$\text{Packet 1: } \frac{2\times10^6 \text{ bits}}{2\times10^6 \text{ bps}} = 1 \text{ second}$$

$$\text{Packet 2: } \frac{3\times10^6}{2\times10^6} = 1.5 \text{ seconds}$$

$$\text{Packet 3: } \frac{4\times10^6}{2\times10^6} = 2 \text{ seconds}$$

$$\text{Packet 4: } \frac{5\times10^6}{2\times10^6} = 2.5 \text{ seconds}$$

One-hop delay:

Total time = 1+1.5+2+2.5=7 seconds1+1.5+2+2.5=7seconds

End-to-end delay (2 hops):

2×7=14 seconds2×7=14seconds

Example 2: Queuing Delay, Transmission delay and Propagation Delay

A router processes 3,000 packets per second and has an average queue length of 12 packets. A 1,500-byte packet arrives. The outgoing link bandwidth is 100 Mbps, and the distance to the next router is 500 km (assume propagation speed is 2×10^8 m/s). Calculate the queueing delay, transmission delay, and propagation delay.

Solution:

1. Queueing Delay

$$\text{Queueing Delay} = \frac{\text{Average Queue Length}}{\text{Processing Rate}} = \frac{12}{3000} = 0.004\,\text{s} = 4\,\text{ms}$$

2. Transmission Delay

$$\text{Transmission Delay} = \frac{\text{Packet Size (bits)}}{\text{Bandwidth}} = \frac{1500 \times 8}{100 \times 10^6} = \frac{12000}{100 \times 10^6} = 0.00012\,\text{s} = 0.12$$

3. Propagation Delay

$$\text{Propagation Delay} = \frac{\text{Distance}}{\text{Propagation Speed}} = \frac{500 \times 10^3}{2 \times 10^8} = \frac{5 \times 10^5}{2 \times 10^8} = 0.0025\,\text{s} = 2.5\,\text{ms}$$

Example 3: Propagation Delay with Different Distance

A 1,500-byte packet is sent over a link with 1 Gbps bandwidth. The distance between routers is 1,000 km, and the propagation speed is 2.5×108 m/s2.5×108m/s. Calculate the transmission and propagation delays.

Solution:

Transmission delay:

$$\frac{1{,}500\times8 \text{ bits}}{10^9 \text{ bps}} = 12\,\mu\text{s}$$

Propagation delay:

$$\frac{1{,}000\times10^3 \text{ m}}{2.5\times10^8 \text{ m/s}} = 0.004 \text{ seconds} = 4\,\text{ms}$$

Example 4: Mixed Delays in a Multi-Hop Network

A 3,000-byte packet traverses 4 hops. Each router has a processing rate of 8,000 packets per second, an average queue length of 10 packets, and a link bandwidth of 200 Mbps. The distance per hop is 200 km (propagation speed = 2×10^8 m/s. Calculate the total nodal delay.

Solution:

Processing delay per hop:

$\frac{1}{8{,}000} = 0.125\,\mathrm{ms}$

Queueing delay per hop:

$10 \times 0.125 = 1.25\,\mathrm{ms}$

Transmission delay per hop:

$\frac{3{,}000\times8}{200\times10^6} = 0.12\,\mathrm{ms}$

Propagation delay per hop:

$\frac{200\times10^3}{2\times10^8} = 1\,\mathrm{ms}$

Total nodal delay per hop:

$0.125 + 1.25 + 0.12 + 1 = 2.495\,\mathrm{ms}$

End-to-end delay:

$4 \times 2.495 = 9.98\,\mathrm{ms}$

$$d_{nodal} = d_{proc} + d_{queue} + d_{trans} + d_{prop}$$

Example 5: Small Packets with High Transmission Rate (Missing values should be assumed)

A 4,000-byte packet traverses 3 hops. Transmission rate is 2.5 Mbps. Each router has a processing rate of 7 packets per second. The distance per hop is 200 km (propagation speed = 2×108 m/s. Calculate the total nodal delay.
Assume any additional required values based on the last digit of your mobile number other than Zero (Previous No. if last No is Zero)

Solution:
The total nodal delay is calculated based on the given parameters and the assumed queuing delay from the last digit of the mobile number (Suppose it is 9). Thus, the queuing delay is assumed to be 9 ms per router.

Packet size = 4,000 bytes = 32,000 bits
Transmission rate = 2.5 Mbps = 2,500,000 bps
Processing rate per router = 7 packets per second
Distance per hop = 200 km = 200,000 meters
Propagation speed = 2 × 10^8 m/s
Number of hops = 3 (implying 3 links and 2 routers)

1. **Transmission Delay (per link):**
   Transmission delay per link = Packet size / Transmission rate = 32,000 bits / 2,500,000 bps = 0.0128 seconds
   Total transmission delay for 3 links = 3 × 0.0128 = 0.0384 seconds

2. **Propagation Delay (per link):**
   Propagation delay per link = Distance / Propagation speed = 200,000 m / 2 × 10^8 m/s = 0.001 seconds
   Total propagation delay for 3 links = 3 × 0.001 = 0.003 seconds

3. **Processing Delay (per router):**
   Processing delay per router = 1 / Processing rate = 1 / 7 seconds ≈ 0.142857 seconds
   Total processing delay for 3 routers = 3 × 0.142857 ≈ 0.428571 seconds

4. **Queuing Delay (per router):**
   Queuing delay per router = 9 ms = 0.009 seconds
   Total queuing delay for 3 routers = 3 × 0.009 = 0.027 seconds

   Total nodal delay= Transmission delay + Propagation delay + Processing delay + Queuing delay
   = 0.0384 seconds + 0.003 seconds + 0.428571 seconds + 0.027 seconds
   = 0.496971 seconds ≈ 0.497 seconds

Example 6: Small Packets with High Transmission Rate

Ten packets of 500 bits each are transmitted over a 10 Mbps link in a single-hop network. Calculate the one hop delay.

Solution:

Transmission time per packet:

$$\frac{500 \text{ bits}}{10 \times 10^6 \text{ bps}} = 50\ \mu\text{s}$$

One-hop delay for 10 packets:

$$10 \times 50\ \mu\text{s} = 500\ \mu\text{s}$$

Example: 7. In a student hostel there is a shared internet connection with a capacity of 2 Mb/s. Each student requires 200 kb/s when active and is active only **10%** of the time. Under **c**ircuit switching and packet switching, how many users can be supported simultaneously on the same link? Explain why packet switching allows more users to share the link than circuit switching. Calculate the probability that more than 10 users are active at the same time in the packet-switched system.

Solution:

Step 1: Circuit Switching

In circuit switching, each user is allocated a fixed bandwidth of 200 kb/s, regardless of activity.
The total link capacity is **2 Mb/s** = 2000 kb/s**.**
Number of students = (2000 kb/s / 200 kb/s per student) =10
Circuit switching supports 10 users.

Step 2: Packet Switching

In packet switching, users share the bandwidth statistically. Each user is active only **10%** of the time, so the average bandwidth required per user is: 200 kb/s × 0.1 = 20 kb/s

The total link capacity = **2000 kb/s**, so:
Number of students = (2000 kb/s / 20 kb/s per student) = 100
Packet switching supports 100 users.

Step 3: Why Packet Switching Allows More Users

Packet switching uses statistical multiplexing**,** where bandwidth is shared among users only when they are active. Since each user is active only 10% of the time, it is unlikely that all users are active simultaneously.

This allows the link to support more users without always exceeding capacity. In contrast, circuit switching reserves bandwidth for each user continuously, even when inactive, leading to inefficient resource utilization.

Step 4: Probability Calculation

In such packet-switched systems with many users and low activity rate, the probability of exceeding the capacity (more than 10 active users) is typically around 0.4 **or** 40%

Example 8: (Related to the Topic Frequency Division Multiplexing – Lecture 09 & 10)

A satellite frequency provider needs to allocate part of their Giga Hertz bandwidth to five radio stations. Each radio station requires 200 kHz of bandwidth. To prevent interference between adjacent channels, the engineer assigns 25 kHz guard bands between channels. Calculate the total bandwidth required on the satellite link for these five radio stations (show the formula and working).

Solution:

Number of radio stations (N) = 5
Bandwidth per station (B) = 200 kHz
Guard band width (G) = 25 kHz
Total bandwidth required (T)

Formula:

$$T=(N\times B)+((N-1)\times G)$$
$$=(5\times 200)+((5-1)\times 25)$$
$$=1000+100$$
$$=1100\text{ kHz}$$

Therefore, the total bandwidth required on the satellite link for five radio stations is 1100 kHz (or 1.1 MHz).

Numericals related to the IP addressing & IP Class Identification:

Finding Available Hosts:

Example-9:

Suppose given IP Address = 192.168.10.0/24

Host Bits:	8 (last one octet)
Usable Hosts	$= 2^{\text{Host Bits}} - 2$
Total Possible Addresses:	$2^8 = 256$
Usable Hosts:	$256 - 2 = 254$

Finding IP Class:

We can directly find IP Class from a given IP address using the information in the 2nd and 3rd column (from left) of the following table:

Class	Leading Bits	First Octet (Decimal)	Example
A	0	1–126	10.0.0.1
B	10	128–191	172.16.0.1
C	110	192–223	192.168.1.1
D	1110	224–239	224.0.0.1 (Multicast)
E	1111	240–255	Reserved for Research

Each IP class has a specific binary ID that consists of first few bits of the first octet (from the left), therefore we can find an unknown class of a given IP address (in binary format) based on these values. For example if we have a binary address: 11000000 01100111 10111111 11100110, the first octet in this case is 11000000. Looking at the leading bits (from left), we found 110 which is class ID for Class C.

If an IP address is given in decimal, we simple check that in which range (the information available in the second column of the above table) the first number (from the left) exists. For example if the given IP address is: 152.19.1.2, the address class is B because the first number of the IP address written in the dotted decimal notation from left is 152 which exists in the range of 128 – 191.

A third method is given in the next example. It is called "Place Value Method".

Example-10: A number 11000101 is the first octet of some IP address. Find its class using place value method.

Solution: $(2^7 \text{ x } 1) + (2^6 \text{ x } 1) + (2^5 \text{ x } 0) + (2^4 \text{ x } 0) + (2^3 \text{ x } 0) + (2^2 \text{ x } 1) + (2^1 \text{ x } 0) + (2^0 \text{ x } 1)$

= 128 + 64 + 0 + 0 + 0 + 4 + 0 + 1

= 197

The in the answer exists in the range 192 – 223, which is the allowed range of class C addresses, therefore the first octet represent a class C address.