Section 1: Calculation of Distance AB

To calculate the total distance from point A to point B (AB), we divide the journey into three phases: acceleration, constant speed, and deceleration. The calculations are based on the following formulas:

- **Distance Formula:**
$$\text{Distance} = \text{Speed} \times \text{Time}$$

- **Average Speed Formula:**
$$\text{Average Speed} = \frac{\text{Initial Speed} + \text{Final Speed}}{2}$$

All speeds are converted to meters per second (m/s) for consistency:

$$1\,\text{km/h} = \frac{1000}{3600} = \frac{5}{18}\,\text{m/s}$$

Step 1: Acceleration Phase (10 minutes to stabilize at 80 km/h)

The car starts from rest ($0\,\text{m/s}$) and accelerates for 10 minutes ($\frac{10}{60}$ hours $= 600\,\text{seconds}$) to a final speed of 80 km/h:

$$80\,\text{km/h} = 80 \times \frac{5}{18} = 22.22\,\text{m/s}$$

The average speed during this phase is:

$$\text{Average Speed} = \frac{0 + 22.22}{2} = 11.11\,\text{m/s}$$

The distance covered is:

$$\text{Distance} = \text{Speed} \times \text{Time} = 11.11\,\text{m/s} \times 600\,\text{s} = 6666\,\text{m} = 6.67\,\text{km}$$

Step 2: Constant Speed Phase (2 hours at 80 km/h)

The car maintains a constant speed of 80 km/h ($22.22\,\text{m/s}$) for 2 hours ($7200\,\text{seconds}$). The distance covered is:

$$\text{Distance} = \text{Speed} \times \text{Time} = 22.22\,\text{m/s} \times 7200\,\text{s} = 160,000\,\text{m} = 160\,\text{km}$$

Step 3: Deceleration Phase (10 minutes to slow down to 5 km/h)

The car slows down over 10 minutes ($600\,\text{seconds}$) to a final speed of 5 km/h ($1.39\,\text{m/s}$). The average speed during this phase is:

$$\text{Average Speed} = \frac{22.22 + 1.39}{2} = 11.81\,\text{m/s}$$

$$\text{Distance} = \text{Speed} \times \text{Time} = 11.81\,\text{m/s} \times 600\,\text{s} = 7086\,\text{m} = 7.08\,\text{km}$$

Adding up the distances from all three phases:

$$AB = 6.67\,\text{km} + 160\,\text{km} + 7.08\,\text{km} = 173.75\,\text{km}$$

Section 2: Calculation of Distances BC, AC, & AD

To calculate the distances BC, AC, and AD, we use the given information and trigonometric relationships. The following are the key properties:

- $\triangle ABC$ is a right triangle, where BC is the hypotenuse, AB is the opposite side, and AC is the adjacent side.
- $\angle ABC = 50°$, $\angle BCA = 40°$, and $\angle CAB = 90°$.
- $AB = 173.75\,\text{km}$, & $AE = 2 \cdot AB = 347.5\,\text{km}$.
- $AE \parallel CD$, so $CD = AE = 347.5\,\text{km}$, & $AC \parallel DE$, so $AC = DE$.

We will use the following trigonometric equations: $\sin(\theta) = \frac{\text{Opposite}}{\text{Hypotenuse}}, \quad \cos(\theta) = \frac{\text{Adjacent}}{\text{Hypotenuse}}$.

Step 1: Calculate BC (Hypotenuse of $\triangle ABC$)

Using $\sin(50°) = \frac{AB}{BC}$, we solve for BC:

$$BC = \frac{AB}{\sin(50°)} = \frac{173.75}{\sin(50°)} \approx 226.815\,\text{km}$$

Step 2: Calculate AC (Adjacent side of $\triangle ABC$)

Using $\cos(50°) = \frac{AC}{BC}$, we solve for AC:

$$AC = BC \cdot \cos(50°) = 226.815 \cdot \cos(50°) \approx 145.794\,\text{km}$$

Step 3: Calculate AD (Diagonal of rectangle $ACDE$)

The diagonal AD is given by: $AD = \sqrt{AE^2 + DE^2} = \sqrt{(347.5)^2 + (145.794)^2} \approx 376.845\,\text{km}$

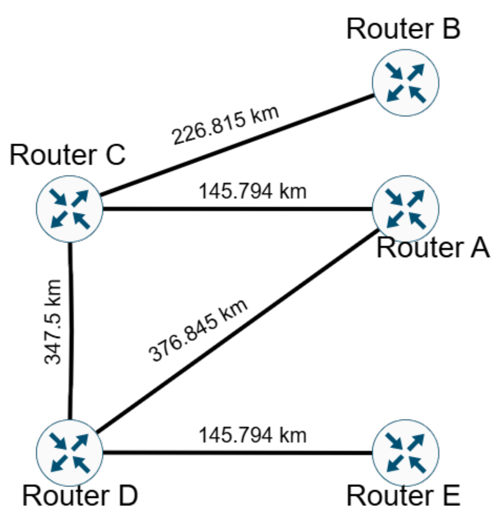

Figure 1: Network Graph with Distances

The network graph is shown in Figure 1, illustrating the nodes and the distances between them.

Section 3: Calculation of Cost

The total cost for each link is calculated as the sum of the processing delay at the transmitting router, the transmission delay, and the propagation delay. The formula is given by:

$$\text{Cost (Router X} \rightarrow \text{Router Y)} = \text{Processing Delay at Router X} + \text{Transmission Delay} + \text{Propagation Delay}$$

Network Characteristics and Assumptions

The network is composed of the following routers and links:

- Router A: IP: 227.0.0.1/40, Processing delay: 10 ms
- Router B: IP: 227.0.0.2/41, Processing delay: 50 ms
- Router C: IP: 227.0.0.3/42, Processing delay: 300 ms
- Router D: IP: 227.0.0.4/43, Processing delay: 200 ms
- Router E: IP: 227.0.0.5/44, Processing delay: 10 ms
- Links:
  - Link BC: Transmission rate: 5 Mbps, Distance: 226.815 km
  - Link CA: Transmission rate: 10 Mbps, Distance: 145.794 km
  - Link CD: Transmission rate: 1 Mbps, Distance: 347.5 km
  - Link AD: Transmission rate: 10 Mbps, Distance: 376.845 km
  - Link DE: Transmission rate: 4 Mbps, Distance: 145.794 km

  Additional assumptions and parameters:

- Packet size: $80,088\,\text{bytes} = 80,088 \times 8 = 640,704\,\text{bits}$
- Propagation speed: $2 \times 10^8\,\text{m/s}$
- The processing delay at Router Y is neglected as the router only parses the header without recalculating the route.

Delay Formulas

- **Propagation Delay:**

$$\text{Propagation Delay} = \frac{\text{Distance (meters)}}{\text{Propagation Speed (meters/second)}}$$

- **Transmission Delay:**

$$\text{Transmission Delay} = \frac{\text{Packet Size (bits)}}{\text{Transmission Rate (bits/second)}}$$

Costs for Each Link

- **Link BC:** Distance $= 226,815\,\text{m}$, Transmission Rate $= 5\,\text{Mbps} = 5 \times 10^6\,\text{bps}$

$$\text{Propagation Delay} = \frac{226,815}{2 \times 10^8} = 1.134\,\text{ms}, \quad \text{Transmission Delay} = \frac{640,704}{5 \times 10^6} = 128\,\text{ms}$$

$$\text{Cost } (\text{B} \to \text{C}) = 50 + 128 + 1.134 = 179.134\,\text{ms}, \quad \text{Cost } (\text{C} \to \text{B}) = 300 + 128 + 1.134 = 429.134\,\text{ms}$$

- **Link CA:** Distance $= 145,794\,\text{m}$, Transmission Rate $= 10\,\text{Mbps} = 10 \times 10^6\,\text{bps}$

$$\text{Propagation Delay} = \frac{145,794}{2 \times 10^8} = 0.729\,\text{ms}, \quad \text{Transmission Delay} = \frac{640,704}{10 \times 10^6} = 64\,\text{ms}$$

$$\text{Cost } (\text{C} \to \text{A}) = 300 + 64 + 0.729 = 364.729\,\text{ms}, \quad \text{Cost } (\text{A} \to \text{C}) = 10 + 64 + 0.729 = 74.729\,\text{ms}$$

- **Link CD:** Distance $= 347,500\,\text{m}$, Transmission Rate $= 1\,\text{Mbps} = 1 \times 10^6\,\text{bps}$

$$\text{Propagation Delay} = \frac{347,500}{2 \times 10^8} = 1.738\,\text{ms}, \quad \text{Transmission Delay} = \frac{640,704}{1 \times 10^6} = 640\,\text{ms}$$

$$\text{Cost } (\text{C} \to \text{D}) = 300 + 640 + 1.738 = 941.738\,\text{ms}, \quad \text{Cost } (\text{D} \to \text{C}) = 200 + 640 + 1.738 = 841.738\,\text{ms}$$

- **Link AD:** Distance $= 376,845\,\text{m}$, Transmission Rate $= 10\,\text{Mbps} = 10 \times 10^6\,\text{bps}$

$$\text{Propagation Delay} = \frac{376,845}{2 \times 10^8} = 1.884\,\text{ms}, \quad \text{Transmission Delay} = \frac{640,704}{10 \times 10^6} = 64\,\text{ms}$$

$$\text{Cost } (\text{A} \to \text{D}) = 10 + 64 + 1.884 = 75.884\,\text{ms}, \quad \text{Cost } (\text{D} \to \text{A}) = 200 + 64 + 1.884 = 265.884\,\text{ms}$$

- **Link DE:** Distance $= 145,794\,\text{m}$, Transmission Rate $= 4\,\text{Mbps} = 4 \times 10^6\,\text{bps}$

$$\text{Propagation Delay} = \frac{145,794}{2 \times 10^8} = 0.729\,\text{ms}, \quad \text{Transmission Delay} = \frac{640,704}{4 \times 10^6} = 160\,\text{ms}$$

$$\text{Cost } (\text{D} \to \text{E}) = 200 + 160 + 0.729 = 360.729\,\text{ms}, \quad \text{Cost } (\text{E} \to \text{D}) = 10 + 160 + 0.729 = 170.729\,\text{ms}$$

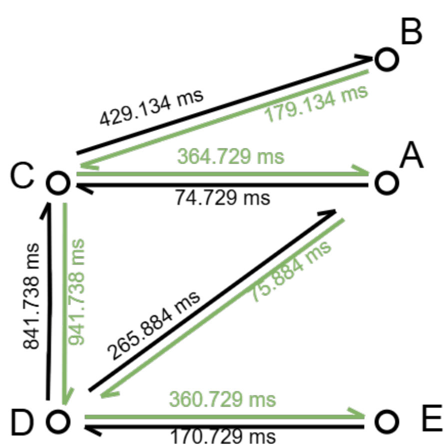

Figure 2: Network Graph with Costs

This figure illustrates the network graph with associated costs for each link. The graph displays routers and the bidirectional links between them, with the costs calculated based on processing delay, transmission delay, and propagation delay as described in the calculation section.
In the figure, the green arrows indicate that the packets of the message will exclusively follow these routes, as the black arrows are not used for sending the packets of the message back. However, this does not mean the black paths are entirely unused—they are utilized during the sharing of forwarding tables between the routers.

Section 4: Calculation of Time of Packet 4 Arrival

Problem Statement

Assume the network is set up and operational. At time $t = 0$, Routers B, C, and D are active and begin sharing their forwarding tables, while Router A will activate at $t = 14$. At $t = 12$, a message containing the text `"Hi crimson crown"` $\times 20020$ is transmitted from Router B (source) to Router E (destination). The goal is to determine, by $t = 20$, which is the last packet that has reached Router E.

Step 1: Calculate Message Size and Number of Packets

The message consists of 16 bytes per repetition of "Hi crimson crown" (including spaces and characters), repeated 20020 times. The total message size is calculated as:

$$\text{Total Size} = 16\,\text{bytes} \times 20020 = 320,320\,\text{bytes}$$

Each packet has a maximum size of 80,088 bytes, including an 8-byte header for metadata like source and destination addresses. Thus, the payload size of each packet is:

$$\text{Payload} = \text{Packet Size} - \text{Header Size} = 80,088\,\text{bytes} - 8\,\text{bytes} = 80,080\,\text{bytes}$$

The number of packets required to transmit the message is determined by dividing the total message size by the payload size:

$$\text{Packets} = \frac{320,320}{80,080} = 4\,\text{packets}$$

Thus, we conclude that the message requires 4 packets to be fully transmitted across the network.

Step 2: Impact of Router Activation and Forwarding Table Sharing

At $t = 14\,\text{s}$, Router A is activated. However, at $t = 15\,\text{s}$, the network pauses to allow routers to share and update their forwarding tables. During this time, no network operations occur until sharing and updating of forwarding tables are done.
The total time required for forwarding table sharing consists of:

- The cost of the link with the highest delay (to ensure all routers can share their tables effectively).
- The processing delay at the receiving routers while updating their tables.

For example, the link with the highest delay in this network is between Router C and D, with a delay of:

$$\text{Cost of Link CD} = 941.738\,\text{ms}$$

Additionally, Router D requires time to process the updated table:

$$\text{Processing Delay at Router D} = 200\,\text{ms}$$

The processing delay is added because routers require computational time to interpret the received forwarding tables and integrate the updated routes into their own tables. This ensures they have the most accurate information about the network's topology.

Thus, the total time for forwarding table sharing is:

$$\text{Total Time for Sharing} = 941.738 + 200 = 1142.738\,\text{ms}$$

After $15,000\,\text{ms} + 1142.738\,\text{ms}$, the routers complete the update, and the best route becomes:

$$B \to C \to A \to D \to E$$

Why Pausing During Table Sharing Prevents Data Loss

Pausing data transmission during forwarding table sharing is critical because:

- It ensures that routers do not receive packets that rely on outdated routing information.
- It prevents potential routing loops or dropped packets caused by inconsistent forwarding tables.

By pausing and resuming with updated routing information, the network guarantees that no packets are lost, as routers store the state of the paused packets in memory and resume processing once the updates are complete.

Step 3: Queueing Delay and Processing for Each Packet

Each packet experiences a queuing delay if the router is already busy processing or forwarding a previous packet. The queuing delay is calculated as:

$$\text{Queuing Delay} = \text{Time of Previous Packet Completion} - \text{Arrival Time of Current Packet at Router}$$

This delay accounts for the time a packet must wait in the router's buffer before it is processed. If there is no congestion or previous packet, the queuing delay is 0.

Step 4: Determine the Last Packet to Reach Router E by $t = 20$

From the table, Packet 4 reaches Router E at $t = 16.9\,\text{s}$. Hence, Packet 4 is the last packet received by Router E by $t = 20$.

Links		BC			CD			DE	
Operations	Proc	Tran	Prop	Proc	Tran	Prop	Proc	Tran	Prop
Packet 1 **Starts at 12000**	12050	12178	12179.134	12479.1	13119	13120.8	13320.8	13480.8	13481.6

Links		BC			CD			DE	
Operations	Proc	Tran	Prop	Proc	Tran	Prop	Proc	Tran	Prop
Packet 2 **Starts at 12178**	12228	12356	12357.1	13419.1	14059.1	14060.8	14260.8	14420.8	14421.6

Links		BC			CD			DE	
Operations	Proc	Tran	Prop	Proc	Tran	Prop	Proc	Tran	Prop
Packet 3 **Starts at 12356**	12406	12534	12535.1	14359.134	14999.134	16142.6	16342.6	16502.6	16503.3

Links		BC			CA			AD		DE		
Operations	Proc	Tran	Prop	Proc	Tran	Prop	Proc	Tran	Prop	Proc	Tran	Prop
Packet 4 **Starts at 12534**	12584	12712	12713.134	16440.8	16504.8	16505.6	16515.6	16579.6	16581.484	16781.484	16941.484	16942.214

Table 1: Timelines for Each Packet (ms)

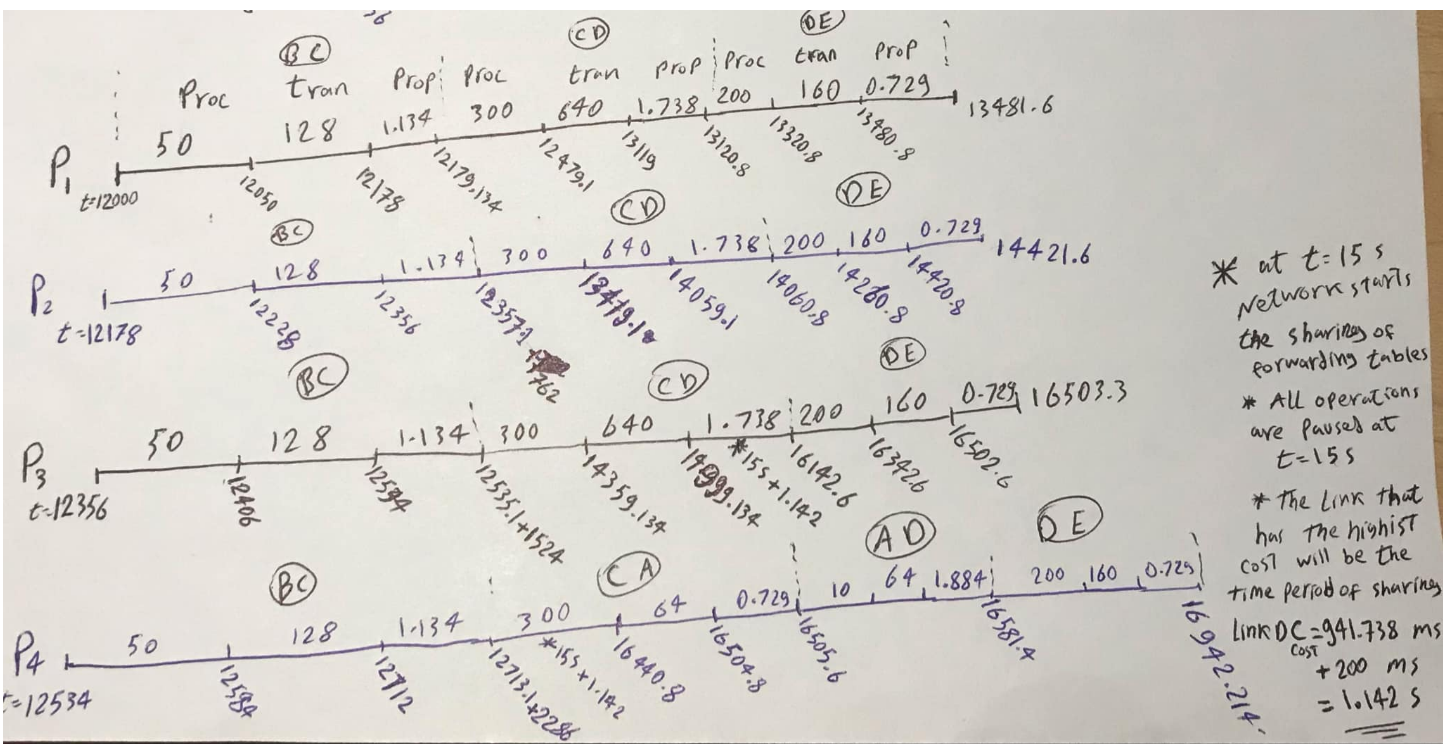

Figure 3: Hand-written Diagram of the Timelines for Each packet