**1) Consider sending a packet from a source host to a destination host over a fixed route. List the delay components in the end-to-end delay. Which of these delays are constant and which are variable**

**Ans:** When a packet travels from a source host to a destination host over a fixed route the end-to-end delay consists of four main components:

**1. Delay Components**

1. **Processing Delay** 
   * Time taken by each router (and the source/destination hosts) to:
     + Examine the packet’s header
     + Determine the packet’s outgoing link
     + Perform error checking, etc.
   * Typically, microseconds or less.
2. **Queuing Delay** 
   * Time the packet spends waiting in the router’s queue before it is transmitted.
   * Depends on the **traffic load** at each router.
   * Can vary widely (from negligible to milliseconds or more).
3. **Transmission Delay**
   * Time needed to push all the packet’s bits onto the link.
   * Formula:

dtrans = L/R

where

L = packet length (bits)

R = transmission rate of the link (bits/sec).

1. **Propagation Delay**
   * Time for a bit to propagate from one end of a link to the other.
   * Formula:

dprop= d/s

where

d = length of the physical link

s = propagation speed of the signal in the medium (≈ 2 \times 10^8 m/s in fiber).

**2. End-to-End Delay**

For a route with N links (and N-1 routers)

**3. Constant vs. Variable Delays**

|  |  |  |
| --- | --- | --- |
| **Delay Component** | **Constant or Variable?** | **Constant or Variable?** |
| **Processing delay** (dproc) | **Constant** (for a fixed route and stable hardware) | Depends mainly on router’s hardware/software and is usually fixed for each hop. |
| **Propagation delay** (dprop) | **Constant** | Determined by the physical distance and medium; does not change unless the path or medium changes. |
| **Transmission delay** (dtrans) | **Constant** (if packet size L and link rate R are fixed) | Depends on link capacity and packet size; stable on a fixed route. |
| **Queuing delay** (dqueue) | **Variable** | Depends on current network congestion and fluctuates with traffic load. |

**Constant delays:** Processing, Transmission, and Propagation (given fixed route, packet size, and link rates).

**Variable delay:** Queuing delay the main unpredictable factor in end-to-end delay.