1. Circuit switched network.

2. Application, transport, network, link, physical.

3. Time for the signal to propagate = 100k/(2.5*10^8meters/sec),
   Ans = 1Mb/sec * Time for the signal to propagate.

4. The delay components are processing delays, transmission delays, propagation delays, and queuing delays. All of these delays are fixed, except for the queuing delays, which are variable.

5. On Linux you can use the command

   traceroute www.targethost.com

   and in the Windows command prompt you can use

   tracert www.targethost.com

   In either case, you will get three delay measurements. For those three measurements, you can calculate the mean and standard deviation. Repeat the experiment at different times of the day and comment on any changes.

Here is an example solution:

   traceroute to www.poly.edu (128.238.24.40), 30 hops max, 40 byte packets
   1  thunder.sdsc.edu (133.249.20.5)  2.802 ms  0.645 ms  0.694 ms
   2  dolphin.sdsc.edu (133.249.31.17)  6.227 ms  0.268 ms  0.239 ms
   3  dc-edg-appl--sdsc-1.cenic.net (137.164.25.129)  0.360 ms  0.260 ms  0.240 ms
   4  dc-riv-corel--edg-appl-10ge-1.cenic.net (137.164.47.14)  8.487 ms  8.497 ms  8.230 ms
   5  dc-lax-corel--lax-corel-10ge-2.cenic.net (137.164.46.64)  9.569 ms  9.320 ms  9.846 ms
   6  dc-lax-gil--lax-corel-10ge-2.cenic.net (137.164.46.102)  9.645 ms  9.729 ms  9.724 ms
   7  hurricane--lax-xl--ge.cenic.net (198.32.251.86)  9.971 ms  14.981 ms  9.850 ms
   8  10gigabivethernet4-4.core1.nyc4.he.net (72.52.91.225)  72.794 ms  85.278 ms  72.346 ms
   9  10gigabivethernet6-4.core1.nyc5.he.net (194.103.213.218)  71.126 ms  71.442 ms  73.625 ms
   10  lightower-fiber-networks.10gigabivethernet3-2.core1.nyc5.he.net (216.66.55.106)  70.926 ms  70.950 ms  71.072 ms
   11  aei.nycnyjsrjk72.lightower.net (72.12.160.156)  70.970 ms  71.089 ms  70.977 ms
   12  72.22.188.102 (72.22.188.102)  71.192 ms  71.226 ms  71.102 ms
### Traceroutes between San Diego Super Computer Center and www.poly.edu

<table>
<thead>
<tr>
<th>Source</th>
<th>Route Details</th>
<th>Delay 1</th>
<th>Delay 2</th>
<th>Delay 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>thunder.sdscc</td>
<td>thunder.sdscc (132.249.20.5) - 0.400 ms - 0.347 ms - 0.358 ms</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>dolphin.sdscc</td>
<td>dolphin.sdscc (132.249.31.17) - 0.215 ms - 0.244 ms - 0.237 ms</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>dc-sdg-agpl</td>
<td>dc-sdg-agpl (137.164.23.129) - 0.342 ms - 0.286 ms - 0.239 ms</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>dc-riv-corel</td>
<td>dc-riv-corel (137.164.47.14) - 8.850 ms - 8.358 ms - 8.127 ms</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>dc-lax-corel</td>
<td>dc-lax-corel (137.164.46.64) - 10.096 ms - 9.849 ms - 10.351 ms</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>dc-lax-pal</td>
<td>dc-lax-pal (137.164.46.151) - 9.721 ms - 9.621 ms - 9.725 ms</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>hurricane</td>
<td>hurricane (198.12.251.66) - 11.345 ms - 10.046 ms - 11.944 ms</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10gigabitethernet3</td>
<td>10gigabitethernet3 (156.105.213.218) - 71.273 ms - 71.147 ms - 71.291 ms</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>lightover-fiber-networks</td>
<td>lightover-fiber-networks (126.66.10.106) - 71.114 ms - 82.516 ms - 71.156 ms</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ael</td>
<td>ael (72.22.188.102) - 71.588 ms - 71.608 ms - 71.491 ms</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Analysis

**a)** The average (mean) of the round-trip delays at each of the three hours is 71.18 ms, 71.38 ms and 71.55 ms, respectively. The standard deviations are 0.075 ms, 0.21 ms, 0.05 ms, respectively.

**b)** In this example, the traceroutes have 12 routers in the path at each of the three hours. No, the paths didn’t change during any of the hours.

**c)** Traceroute packets passed through four ISP networks from source to destination. Yes, in this experiment the largest delays occurred at peering interfaces between adjacent ISPs.
Traceroutes from www.stella-net.net (France) to www.poly.edu (USA).

The average round-trip delays at each of the three hours are 87.09 ms, 86.35 ms and 86.48 ms, respectively. The standard deviations are 0.53 ms, 0.18 ms, 0.23 ms, respectively. In this example, there are 11 routers in the path at each of the three hours. No, the paths didn’t change during any of the hours. Traceroute packets
passed three ISP networks from source to destination. Yes, in this experiment the largest delays occurred at peering interfaces between adjacent ISPs.

6. Throughput = \( \min\{R_s, R_c, R/M\} \).

7.

a) Time to send message from source host to first packet switch = \( \frac{8 \times 10^6}{2 \times 10^6} \) sec = 4 sec

With store-and-forward switching, the total time to move message from source host to destination host = 4 sec \( \times \) 3 hops = 12 sec

b) Time to send 1st packet from source host to first packet switch = \( \frac{1 \times 10^4}{2 \times 10^6} \) sec = 5 m sec. Time at which 2nd packet is received at the first switch = time at which 1st packet is received at the second switch = 2 \( \times \) 5 m sec = 10 m sec

c) Time at which 1st packet is received at the destination host = 5 m sec \( \times \) 3 hops = 15 m sec. After this, every 5 m sec one packet will be received; thus, time at which last (800th) packet is received = 15 m sec + 799 \( \times \) 5 m sec = 4.01 sec. It can be seen that delay in using message segmentation is significantly less (almost 1/3rd).

d)

i. Without message segmentation, if bit errors are not tolerated, if there is a single bit error, the whole message has to be retransmitted (rather than a single packet).

ii. Without message segmentation, huge packets (containing HD videos, for example) are sent into the network. Routers have to accommodate these huge packets. Smaller packets have to queue behind enormous packets and suffer unfair delays.

e)

i. Packets have to be put in sequence at the destination.

ii. Message segmentation results in many smaller packets. Since header size is usually the same for all packets regardless of their size, with message segmentation the total amount of header bytes is more.

8. The circuit-switched telephone networks and the Internet are connected together at "gateways". When a Skype user (connected to the Internet) calls an ordinary telephone, a circuit is established between a gateway and the telephone user over the circuit switched network. The skype user's voice is sent in packets over the Internet to the gateway. At the gateway, the voice signal is reconstructed and then sent over
the circuit. In the other direction, the voice signal is sent over the circuit switched network to the gateway. The gateway packetizes the voice signal and sends the voice packets to the Skype user.