Plan

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Delay and loss in packet-switched networks

Let us come back to the packets that travel a packet-switched network like the Internet.

When a packet crosses a link and a router, it suffers different kinds of delays:

- **nodal processing delay**,
- **queuing delay**,
- **transmission delay**,
- **propagation delay**.

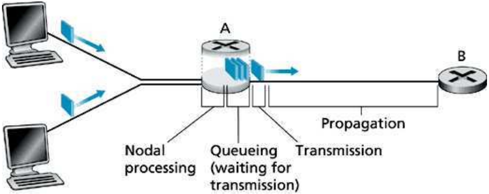
All together, they give the **total nodal delay**.

Let us now look with more attention to each of these delays, because it is necessary if we want to acquire a deep understanding of packet switching.

Delay and loss in packet-switched networks/Types of delay

- **Processing delay** is the time needed to examine the packet's header and find where to direct the packet. Also it can include the time for checking for bit-level errors in the packet.
- **Queuing delay** happens when some earlier-arriving packet is already waiting in the queue, else it is 0.
- **Transmission delay** is the time needed to "push" the packet out on the link (size of the packet/rate of the link).
- **Propagation delay** is the time needed to propagate a signal on the link (distance A-B/signal speed).

Delay and loss in packet-switched networks/Types of delay



What is the difference between transmission delay and propagation delay?

Transmission delay depends on the packet's length (measured in bits) and the bit rate of the link (measured in bits per seconds), but has nothing to do with the distance between two routers.

Propagation delay is the time it takes a bit to propagate from one router to the next; it is a function of the distance between to adjacent routers, but has nothing to do with the packet's length or the transmission rate of the link.

Queuing delay and packet loss

The delay which can be the highest and is the most difficult to assess is the queuing delay.

The main reason is because it depends from packet to packet, contrary to the other kinds of delays. For instance, if ten packets arrive at very short intervals to an empty queue, the first one will suffer no queuing delay but the tenth will have to wait in the queue the other have been retransmitted.

That is why the usual tool to evaluate the queuing delay are **statistical models**, including average queuing delay and the probability that the queuing delay exceeds some specified value.

Queuing delay and packet loss (cont)

The queuing delay depends on

- the rate at which traffic arrives at the queue,
- the transmission rate of the (out-going) link,
- the nature of the incoming traffic:
    - is it periodical?
    - does it arrives in bursts?

Queuing delay and packet loss (cont)

Let us assume that the average rate at which packets reach the queue is a. It is measured in packets/sec.

Let R be the transmission rate, measured in bits/sec, which is the rate at which bits are pushed in the out-going link.

Suppose that all packets are L bits long.

Then the average rate at which bits arrive at the queue is La.

Assume the queue is unbounded.

The ratio La/R, called the **traffic intensity**, plays an important role in estimating the growth of the queue.

Queuing delay and packet loss (cont)

If $La/R > 1$ then the flow of incoming bits exceeds the capacity of the out-going link: the queue will grow forever. So the most important rule here is: *design your network so that the traffic intensity is no greater than 1*.

If $La/R \leqslant 1$ then the nature of the arriving traffic impacts the queuing delay. For example, if packets arrive periodically, one each L/R second, then every packet will arrive at an empty queue and there will be no queuing delay (this is the best case).

If packets arrive in bursts, i.e., if the number of packets per second varies, the delay can be significant (especially if the variation is not linear).

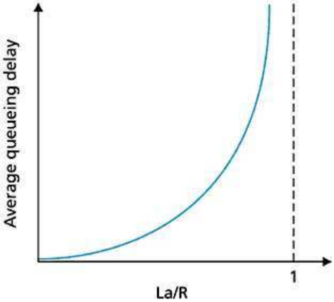
Queuing delay and packet loss (cont)

In practice, periodic arrival or linear bursts are improbable: the arrival is *random*.

Thus the quantity La/R is not enough to fully characterise the queuing delay, but it helps you to grasp the concept.

The curve in the facing column gives you more intuition on the average queuing delay. The important thing to note is that a little variation on La/R, when this quantity is close to 1, may lead to a huge augmentation of the average delay.

Queuing delay and packet loss (cont)



Queuing delay and packet loss (cont)

In our previous presentation, we assumed an unbounded queue, i.e., allowing an infinite number of packets to remain in the queue. That is why the traffic intensity could approach 1 at any distance.

But, in practice, routers have a finite memory, so a packet can arrive and find a full queue. In this case the packet is dropped, i.e., it is lost.

The packet losses increase as the traffic intensity increases.

Therefore, performance at a router is not only measured in terms of traffic intensity but also of packet loss.

Queuing delay and packet loss (cont)

Until now we considered the delay at one node (a router). What about the **end-to-end delay**, that is the cumulated delay of each node from the source to the destination? Assume there are N routers along the path. Let us suppose that there is no congestion (queuing delay is negligible).

- Let d_{proc} be the processing delay at each node (including the source),
- d_{prop} the propagation delay of each link,
- the transmission rate of each node is R bits/sec.

The nodal delays accumulate and give an end-to-end delay

$$d_{\text{end-end}} = N(d_{\text{proc}} + d_{\text{trans}} + d_{\text{prop}})$$

where $d_{\text{trans}} = L/R$, where L is the packet size.

Delays and routes in the Internet

Traceroute is a simple program that can run on any Internet host. It is given a destination host and this program sends special packets to this destination. Along their way, the packets pass through several routers, which send back to the source a message containing their name (if any) and their address, called **IP address** and whose structure we will discuss later.

This allows Traceroute to reconstruct the path and to show it to the end-user.

Imagine there are N routers along the path. Then the source will send N special packets, all addressed to the destination. They are numbered from 1 to N and sent by increasing numbers. The n-th router receives the n-th packet, destroys it and sends an identification message back to the source.

Delays and routes in the Internet (cont)

The source records the elapsed time between the moment it sent a packet and the moment the corresponding return message is received, coming from a router. This delay is called **round-trip delay**.

Traceroute repeats the experiment three times, because the round-trip delay can vary due to queuing delays, so the user gets an idea of the delay variation.

The web site `http://www.traceroute.org` provides a list of links to web sites, classified by countries, which provide an interface to Traceroute.

This way you can experiment by giving the address or name of a destination and the interface will report the path from the host running the web site to the destination host, as given by Traceroute.

Delays and routes in the Internet (cont)

Here is an example of output of Traceroute from a host in the Faroe Islands (Denmark) to a host in France (at INRIA):

```
traceroute to pauillac.inria.fr (128.93.11.35), 30 hops max, 38 byte packets
 1  L4-0-0.bone.olivant.fo (212.55.32.1)  0.977 ms  0.612 ms  0.766 ms
 2  feth1-0-0.utland1.bone2.olivant.fo (212.55.32.98)  1.108 ms  1.234 ms  1.601 ms
 3  ser4-0.45M.ldn2nxi2.ip.tele.dk (195.215.170.85)  30.455 ms  30.676 ms  29.567 ms
 4  ge1-2-2.1000M.ldn2nxg1.ip.tele.dk (195.249.13.121)  30.745 ms  30.134 ms  31.431 ms
 5  pos6-0.2488M.asd9nxg1.ip.tele.dk (195.249.2.134)  37.281 ms  37.332 ms  36.983 ms
 6  Ge7-1.AMSBB1.Amsterdam.opentransit.net (193.251.254.9)  37.103 ms  37.334 ms  37.726 ms
 7  * * *
 8  * * *
 9  * * *
```

Delays and routes in the Internet (cont)

```
10  P14-0.PASCR2.Pastourelle.opentransit.net (193.251.128.105) 58.415 ms  57.089 ms  57.764 ms
11  193.51.185.2 (193.51.185.2)  57.802 ms  61.880 ms  58.485 ms
12  inria-g3-1.cssi.renater.fr (193.51.180.174)  60.999 ms  58.497 ms  57.900 ms
13  royal-inria.cssi.renater.fr (193.51.182.73)  58.860 ms  63.028 ms  58.961 ms
14  193.48.202.2 (193.48.202.2)  63.017 ms  58.502 ms  57.889 ms
15  rocq-gw-bb.inria.fr (192.93.1.100)  60.721 ms  61.437 ms  61.078 ms
16  pauillac.inria.fr (128.93.11.35)  60.759 ms  62.540 ms  61.703 ms
```

The domain extensions (`.fo`, `.dk`, `.fr`) help you to follow the packets along the corresponding countries. Note that some routers have no name (only address). Routers 7, 8 and 9 do not send back their identification messages, that is why Traceroute prints an asterisk for each try.