SC250: Architecture and Performance
Exercises

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1 Naming and Addressing

The goal of this exercise is to explore the different types of "identifiers" used in the Internet at the different protocol layers we have studied. At the application layer, we have names (such as "www.epfl.ch"); at the network layer, we have IP addresses (such as 193.33.210.10), and at the link layer, we have hardware addresses (such as 00:07:E9:42:6A:62).

1. **How many distinct names are there?**
   The number of possible names is theoretically infinite, given that the length of names is unconstrained. Note that names (such as "www.epfl.ch") usually have some meaning and are human-readable.

2. **How many IP (version 4) addresses are there?**
   IPv4 addresses are 32 bits long, and are usually written as four bytes separated by dots (e.g., 193.33.210.10). Sometimes hexadecimal notation is used (FF.FF.FF.FF = 255.255.255.255).

   Given this, the number of possible IP addresses is simply

   $$2^{32} = 4.3 \cdot 10^9, \tag{1}$$

   i.e., about 4 billion.

   Note that as a rule of thumb for such calculations, $2^{10} \approx 1000$.

3. **How many Ethernet addresses are there?**
   Ethernet hardware addresses (also called MAC addresses) are 48 bits in length, and are usually written in hexadecimal notation (e.g., 00:07:E9:42:6A:62). Using the above rule of thumb, there are approx.

   $$2^{48} \approx 0.25 \cdot 1000^5 = 2.5 \cdot 10^{14} \tag{2}$$

   MAC addresses.

4. **How large would an address field have to be to be able to address every atom in the universe?**
   The number of atoms in the universe is roughly estimated to be 10^{80}. The minimum number of address bits is given by

   $$\log_2(10^{80}) = \frac{80}{\log_{10}(2)} = 265.8. \tag{3}$$

   Therefore, only 266 address bits would be required, a surprisingly small number.

2 Statistical Multiplexing

The goal of this exercise is to understand the difference between circuit switching and packet switching, and to illustrate through a small example that packet switching allows to "pack" more users on a link than with circuit switching. This is because with circuit switching, we need to give each user the maximum bandwidth he needs. Therefore, a user holds this link bandwidth even when it is inactive. With packet switching, an inactive user consumes no bandwidth, which is then available to other active users.

Consider a link of capacity $R = 1$ Mbps (Megabits per second), which is shared between N traffic flows (connections) generated by N users. Assume that each user switches back and forth between active and inactive periods. This might occur, for example, because the user downloads information from a web site, studies the downloaded information, then requests more, etc.

We assume that with probability $p = 0.1$, a user is active and generates $r = 100$kbps=0.1Mbps, and with probability $1 - p$, he is inactive and generates no traffic.

1. **How many users can be supported by circuit switching?**
   Only $R/r = 10$ users can be supported. This is because in circuit switching, the maximum traffic rate of $r = 100$ kbps (kilobits per second) has to be allocated on the link *for every individual user.*

2. **With packet switching, what is the probability that the link is overloaded?**
   First note that the link is overloaded if more than $R/r = 10$ users are active at the same time. The probability that exactly k users are active at a given time (and therefore, $N - k$ are inactive), follows a binomial law,

$$\mathsf{P}\{k \text{ active}\} = \binom{N}{k} p^k (1-p)^{(N-k)}. \tag{4}$$

   Therefore, the probability that *more than* R/r users are active at a given time is

$$p_e = \mathsf{P}\{\text{more than } R/r \text{ active}\} = \sum_{k=R/r+1}^{N} \binom{N}{k} p^k (1-p)^{(N-k)}. \tag{5}$$

   First note that with $N \leq 10$, $p_e = 0$, as the link is never overloaded.

   Second, note that if we can tolerate some small probability of generating more traffic than the link can carry, which leads to packet delay and loss, then we can allow more users to share the link. For example, with $N = 35$ users, we find $p_e \approx 0.0004$.

   More generally, for any $N > 10$, p_e is nonzero. In other words, if the number of users is higher than the maximum with circuit switching, we necessarily have some possibility of exceeding the link capacity. This is the reason why this type of multiplexing is called "statistical multiplexing": we have to have some statistical tolerance for packet loss, but we can support more users. In the Internet, packet loss can be tolerated, because the transport layer can detect which packets have been lost and retransmit these packets.