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Computer Networking and IT Security (INHN0012)

Tutorial 4

Problem 1 Transmission Channels

A new undersea cable has connected Japan and the USA since 2010. The cable runs from Chikura near Tokyo to Los Angeles in California (approx. 10 000 km) and consists of 8 fiber pairs (in each fiber pair, one fiber is used for one direction and the other fiber for the other direction). The transmission rate amounts to a total of 7.68 Tbit/s per direction.

As a simplifying assumption, we assume that the light only travels the path of the cable and that no signal impairments or delays occur due to signal amplifiers, connectors and the like. The relative propagation speed of light within an optical fiber (as well as in copper cables) is approximately $\nu = 2/3$ in relation to the speed of light in a vacuum $c_0 = 3 \cdot 10^8\,\mathrm{m/s}$.

a)* Determine the propagation delay from Chikura to Los Angeles within the cable.

$$t_p = \frac{d}{\nu c_0} = \frac{10^7\,\mathrm{m}}{2/3 \cdot 3 \cdot 10^8\,\mathrm{m/s}} = 50\,\mathrm{ms}$$

b)* What does the *bandwidth delay product* mean?

The bandwidth delay product specifies the „amount of data stored“on the line, i.e. how many bits are serialized by the sender before the first bit reaches the receiver.

c) Determine the bandwidth delay product.

$$B = r \cdot t_p = 7{,}68 \cdot 10^{12}\,\mathrm{bit/s} \cdot 50 \cdot 10^{-3}\,\mathrm{s} = 384 \cdot 10^9\,\mathrm{bit} = 384\,\mathrm{Gbit} = 48\,\mathrm{GB}$$

Laying and maintaining a submarine cable is very complex. The connection between the two cities could also be made via satellite. Take a brief look at the two connection paths in relation to the round trip time (RTT[1]).

Assume that the submarine cable is in direct airline connection between Chikura and Los Angeles. In doing so, neglect the curvature of the earth. A geostationary satellite (36 000 km altitude) is located exactly above the center of the route.

[1] RTT is the time it takes for a message to travel from the sender to the recipient and back again

d) Determine the minimum RTT for the submarine cable.
Note: Think about which component of the RTT makes the most significant contribution in this case.

$\mathrm{RTT} = 2 \cdot (t_s + t_p)$.With $t_s \to 0$ (very high transmission rate), the RTT is reduced to $\mathrm{RTT} = 2t_p$.

$$\mathrm{RTT} = 2t_p = 100\,\mathrm{ms}$$

e) Determine the minimum RTT for a corresponding satellite connection.
Note: Consider which sections of the route can be neglected if necessary. The curvature of the earth may be neglected.

$$\mathrm{RTT}_{\mathrm{Satellite}} = 2 \cdot t_{p,sat} = 2 \cdot \frac{d_{sat}}{c_0} = 2 \cdot \frac{2 \cdot \sqrt{5000^2 + 36000^2}\,\mathrm{km}}{3 \cdot 10^8\,\frac{\mathrm{m}}{\mathrm{s}}} \approx 485\,\mathrm{ms}$$

Problem 2 Media Access Control

a)* Briefly explain the principle of *ALOHA*.

A station transmits as soon as data is received. Transmissions are confirmed out-of-band (other frequency).

b) How are collisions detected in *ALOHA*?

Not directly, but via the lack of out-of-band confirmation.

c) Briefly explain the principle of ***Slotted*** *ALOHA*.

Stations start transmitting in the next time slot, regardless of whether a transmission is already taking place.

d) What is the advantage of *Slotted ALOHA* over normal *ALOHA*?

The division into time slots reduces the probability of collisions, as stations can no longer start a transmission at any time.
If the time slots correspond to the transmission duration of a complete message and the nodes are sufficiently synchronized with each other (which is possible with such long time slots), a collision either occurs at the beginning of a time slot or it is guaranteed that at most one station transmits. (see lecture)

e)* Briefly explain the principle of *CSMA*.

Medium is monitored before sending. If the medium is free in the current time slot, a node can start sending in the next one.

f) Briefly explain which additions *CSMA/**CD*** has compared to pure *CSMA*.

Collisions are detected and affected frames are transferred again.

g) How are successful transmissions recognized for *CSMA/CD* with Ethernet?

A transmission is assumed to be successful if no collision was detected during the transmission or no JAM signal was received.

h) Briefly explain which additions *CSMA/**CA*** has compared to pure *CSMA*.

Collisions can generally not be detected. Instead, their probability of occurrence is reduced by randomizing the start of transmission.
(Contention window with a minimum size of several slot times)

i)* What is the *Binary Exponential Backoff*?

CSMA (both CD and CA) wait a random number of slot times after a collision or unsuccessful transmission. This number is drawn randomly and evenly from the backoff window. With each collision or unsuccessful transfer, this window is doubled (binary exponential) until a certain maximum value is reached. After a successful transfer, the window is reset.

Problem 3 ALOHA and CSMA/CD

Let there be a network (see figure 3.1) consisting of three computers which are connected to each other via a hub. The distances between the computers are approximately $d_{12} = 1\,\text{km}$ and $d_{23} = 500\,\text{m}$. Any indirect cable routing may be neglected. The transmission rate shall be $r = 100\,\text{Mbit/s}$. The relative propagation speed is $\nu = 2/3$ as usual. The speed of light is given as $c_0 = 3 \cdot 10^8\,\text{m/s}$.

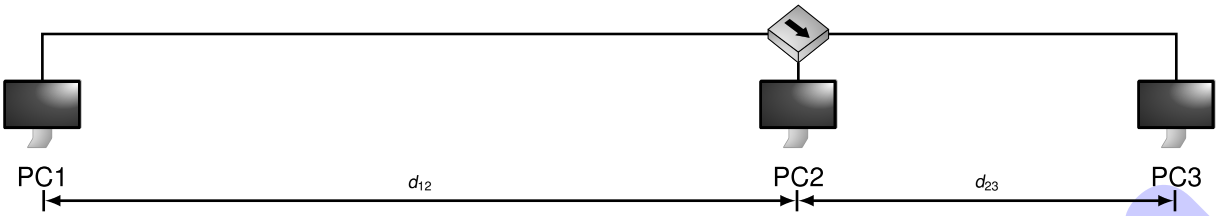


Figure 3.1

At time

- $t_0 = 0\,\text{s}$ no transmission takes place and none of the computers have data to send,
- $t_1 = 5\,\mu\text{s}$ PC1 begins to send,
- $t_2 = 15\,\mu\text{s}$ PC2 begins to send and
- $t_3 = 10\,\mu\text{s}$ PC3 begins to send

to send a frame of length 94 B each.

a)* Calculate the serialisation time t_s for a message.

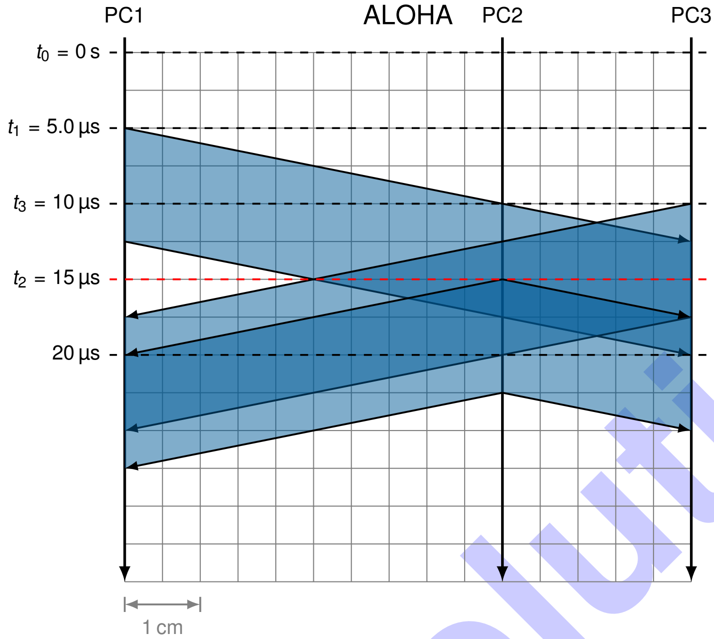
$$t_s = \frac{l}{r} = \frac{94 \cdot 8\,\text{bit}}{100 \cdot 10^6\,\text{bit/s}} = 7.52\,\mu\text{s}$$

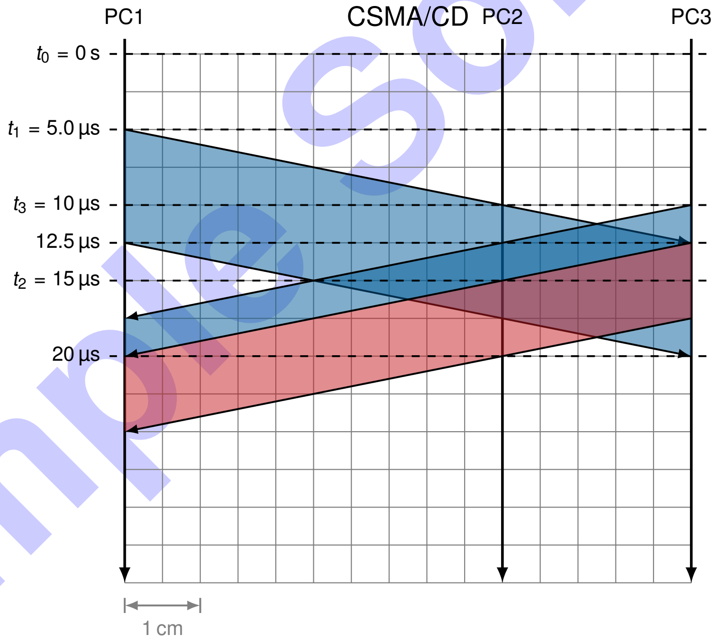
b)* Calculate the propagation delays $t_p(1,2)$ and $t_p(2,3)$ on the two sections.

$$t_p(1,2) = \frac{d_{12}}{\nu c_0} = \frac{1000\,\text{m}}{\frac{2}{3} \cdot 3 \cdot 10^8\,\text{m/s}} = 5.0\,\mu\text{s}$$

$$t_p(2,3) = \frac{d_{23}}{\nu c_0} = \frac{500\,\text{m}}{\frac{2}{3} \cdot 3 \cdot 10^8\,\text{m/s}} = 2.5\,\mu\text{s}$$

c) For ALOHA and 1-persistent CSMA/CD respectively, draw a path-time diagram representing the transmission process in the time interval $t \in [t_0, t_0 + 30\,\mu s)$. Scale: $100\,m \triangleq 5\,mm$ and $2.5\,\mu s \triangleq 5\,mm$, slot time: $\approx 5\,\mu s$





Explanation: With ALOHA, the medium is not monitored. This means that at time t_2 PC2 starts transmitting, although it could already detect the transmission of PC1 and PC3. In contrast, with CSMA/CD the medium is monitored. For this reason, PC2 does not start transmitting. PC3, however, cannot yet know that PC1 is already transmitting due to the finite signal propagation speed. Therefore, a collision occurs.
At $t = 12.5\,\mu s$ PC3 detects the collision and aborts its own transmission. To ensure that all stations connected to the shared medium are informed of the collision, PC3 sends a *JAM signal*. This would be a 4 B long alternating bit pattern for Ethernet (the task so far is not specifically about Ethernet, but only about the underlying media access method CSMA/CD – a hint of the JAM signal is sufficient).

d) From the previous subtask it can be seen that collisions occur with both methods. In contrast to ALOHA, however, CSMA/CD does not work under the given circumstances. Why?

With ALOHA, the loss of a frame is recognised by the fact that the sender does not receive an acknowledgement. Such an acknowledgement procedure does not exist with CSMA/CD. Instead, with CSMA/CD, a sender assumes that a frame was successfully transmitted if no collision occurred during transmission.
In this case, however, PC1 has completed the transmission before the transmission or JAM signal from PC3 reaches it.PC1 therefore does not recognise the collision and wrongly assumes a successful transmission.

e) What is the condition for CSMA/CD that a node can detect a collision in time?

The serialisation time must be at least twice as long as the maximum possible propagation delay between the two nodes furthest apart.This is the only way to ensure that a node is still transmitting when it receives the „interference signal " from the node furthest away from it, which itself started transmitting immediately before the „arrival of the first bit ".

f) For CSMA/CD, calculate the maximum distance between two computers within a collision domain as a function of the minimum frame length. Insert the values for FastEthernet ($r = 100\,\text{Mbit/s}$, $l_{\text{min}} = 64\,\text{B}$).

In the event of a collision, none of the sending nodes may end its transmission process before it has noticed the collision. Otherwise, it would assume that the transmission was successful. This means the minimum serialisation time $t_{s,\text{min}}$ of a frame must be twice the propagation delay between the two farthest stations:

$$
\begin{aligned}
t_{s,\text{min}} &= 2 \cdot t_{p,\text{max}} \\
\frac{l_{\text{min}}}{r} &= 2 \cdot \frac{d_{\text{max}}}{\nu c} \\
d_{\text{max}} &= \frac{1}{2} \cdot \nu c \cdot \frac{l_{\text{min}}}{r} \\
d_{\text{max}} &= \frac{1}{2} \cdot \frac{2}{3} \cdot 3 \cdot 10^8 \,\frac{\text{m}}{\text{s}} \cdot \frac{64 \cdot 8\,\text{bit}}{100 \cdot 10^6\,\frac{\text{bit}}{\text{s}}} \\
d_{\text{max}} &= 10^8\,\frac{\text{m}}{\text{s}} \cdot \frac{64 \cdot 8\,\text{bit}}{100 \cdot 10^6\,\frac{\text{bit}}{\text{s}}} = 512\,\text{m}
\end{aligned}
$$

Problem 4 ALOHA (Homework)

ALOHA (Hawaiian: „Hello“) is one of the oldest media access methods and was developed in 1971 at the University of Hawaii to connect the Hawaiian Islands to a central switching station via a radio link. The two communication directions from the islands to the switching station and back were separated by frequency division duplex (FDD). Controlling media access was extremely simple: as soon as a transmitter received data, it was allowed to start transmitting. However, as no directional antennas were used and all transmitters on the islands used the same frequency, collisions could occur if two transmissions overlapped in time.

Two years later, slotted ALOHA was introduced, in which the transmitters were only allowed to start transmitting at the beginning of fixed time slots. The switching station transmitted a clock signal on the return channel for synchronization.

We now want to define our own strategy, which we call p-persistent Slotted ALOHA. If data is available, a station transmits with probability p in the next slot or delays the transmission by one slot with probability $1-p$. The following initial situation is given:

- Initially, only some of the main islands are connected to the network, i. h. $n \leq 8$[2].
- All n users are saturated, i. e. there is always data to send.
- Each user starts sending with probability p in the next possible time slot.
- The duration of a send process corresponds to the length of a time slot.

a)* What is the probability that a collision-free transmission takes place in a time slot?

Let X be the ZV, which specifies the number of stations transmitting simultaneously in the time slot in question. The transmission is collision-free if and only if $X = 1$, i. h. exactly one *any* user is transmitting. X is therefore binomially distributed with transmission probability p:

$$\Pr[X = k] = \binom{n}{k} p^k (1-p)^{n-k} \quad \Rightarrow \quad \Pr[X = 1] = \binom{n}{1} p(1-p)^{n-1} = np \cdot (1-p)^{n-1} =: f(n, p)$$

b) Determine p^* such that the probability of a collision-free transmission is maximized.

Derivation:

$$\frac{\partial f}{\partial p} = n \cdot (1-p)^{n-1} - np \cdot (n-1) \cdot (1-p)^{n-2} \stackrel{!}{=} 0$$

$$n \cdot (1-p)^{n-1} = np \cdot (n-1) \cdot (1-p)^{n-2}$$

$$1 - p = p \cdot (n-1)$$

$$p = \frac{1}{n}$$

[2]For large n (approx. $n > 15$) and small send probabilities, the Poisson distribution could also be used here

c) Now determine the maximum channel utilization for n users.

$$f(n, p^*) = \left(1 - \frac{1}{n}\right)^{n-1}$$

d) Now determine the maximum channel utilization for a very large number of users.

Hint: $\lim\limits_{n\to\infty} \left(1 + \frac{x}{n}\right)^n = e^x$

$$\lim_{n\to\infty} f(n, p^*) = \lim_{n\to\infty} \left(1 - \frac{1}{n}\right)^{n-1} = \lim_{n\to\infty} \frac{\left(1 - \frac{1}{n}\right)^n}{\left(1 - \frac{1}{n}\right)} = \frac{1}{e} \approx 0.37$$