Exam in
SSY305 Communication Systems

Department of Electrical Engineering

Exam date: March 17, 2022

Teaching Staff

Paolo Monti (examiner), 031-772 6027
Chouaib Bencheikh Lehocine, 073-742 6431

Material Allowed material:

- Chalmers-approved calculator.
- L. Råde, B. Westergren. Beta, Mathematics Handbook, any edition.
- One A4 page with your own handwritten notes. Both sides of the page can be used. Photo copies, printouts, other students' notes, or any other material is not allowed.
- A paper-based dictionary, without added notes (electronic dictionaries are not allowed).

Students are required to solve the exam problems individually. Cooperation, in any form or with anyone, is strictly forbidden.

Grading A correct, precise and well-motivated solution gives at most 12 points per problem. An incorrect answer, unclear, incomplete, or poorly motivated solutions give point reductions to a minimum of 0 points. No fractional points are awarded. Answers in any other language than Swedish or English are ignored.

Solutions Are made available at the earliest on **March 17 at 20:00** on the course web page.

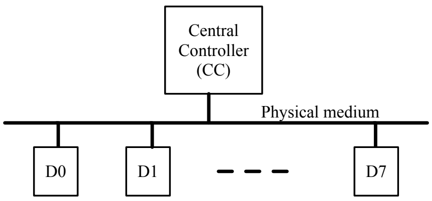
Results Exam results are posted on Canvas no later than **March 29**. The grading reviews will be done remotely according to a process that will be explained in the course webpage.

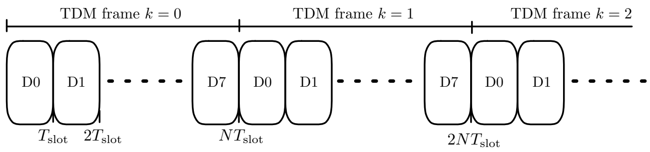
Grades The final grade of the course will be decided by the project (maximum score 46), quizzes (maximum score 6), and final exam (maximum score 48). The project and exam must be passed (see course-PM for rules). The sum of all scores will decide the grade.

Total Score	0–39	40–68	69–79	≥ 80
Grade	Fail	3	4	5

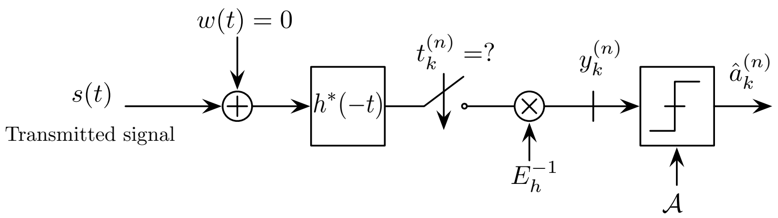
PLEASE NOTE THAT THE PROBLEMS ARE NOT NECESSARILY ORDERED BASED ON THEIR DIFFICULTY
Good luck!

1. Consider a central controller (CC) that is connected to $N = 8$ devices (D0, D1,..., D7) using a shared physical medium. The CC has a physical layer that is based on a 16-PAM with a constellation $\mathcal{A} = \{\pm 1, \pm 3, \ldots, \pm 15\}$, and a rectangular pulse $h(t) = 1$ for $0 \le t \le T_\text{p}$ and $h(t) = 0$ otherwise, where $T_\text{p} = 0.125$ ms. The CC communicates with the N devices using a time division multiplexing (TDM) scheme. That is, time is divided into TDM frames of N time slots, and data of the n^th device is transmitted on time slot n, $n+N$, $n+2N$, etc, where $n = 0, 1, \ldots, 7$. The duration of a time slot is $T_\text{slot} = T_\text{p} = 0.125$ ms (i.e., a device is assigned one symbol every $N = 8$ symbols). We denote by $a_k^{(n)} \in \mathcal{A}$ the transmitted symbol to device n in TDM frame k, $(k = 0, 1, \ldots)$. If the CC has no symbols to transmit to device n in TDM frame k then $a_k^{(n)} = 0$.





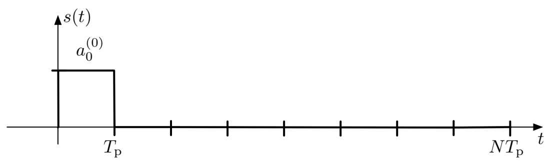
At the receive side each device employs a minimum distance receiver as shown in the figure below. The n^th device needs to receive and detect data transmitted in the n^th time slot only.



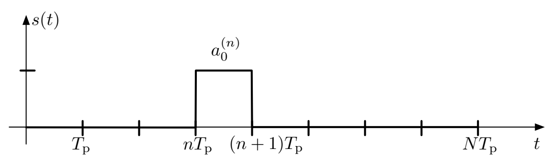
Matched filter Receiver of Dn

(a) What is the maximum data rate of the CC? and what is the data rate experienced by Dn (i.e., device n)? (4p)

(b) Assume that at TDM frame $k = 0$ the CC transmits data to D0 only as shown in the figure below (left), and assuming that the receiver of D0 has a sampling time $t_k^{(0)} = kNT_\text{slot}$, sketch the output of the matched filter and compute $y_k^{(0)}$, at $k = 0$. (3p)



CC transmits data only to D0



CC transmits data only to Dn, $n > 0$

(c) Assume now that at TDM frame $k = 0$ the CC transmits a symbol to Dn only, as shown in the figure above (right). Given that the receiver of D0 has a sampling time of $t_k^{(0)} = kNT_\text{slot}$, sketch the output of its matched filter for $1 \le n \le 7$, and show that $y_k^{(0)} = 0$, at $k = 0$. (3p) *Hint*: recall that $x(t - t_0) = x(t) * \delta(t - t0)$.

(d) What is the correct sampling time $t_k^{(n)}$ at the receiver of Dn ($n = 0, 1, \ldots, 7$) such that only data transmitted in time slot n is detected (i.e., the output of the sampled matched filter $y_k^{(n)} = 0$ for symbols transmitted in time slots $n' \neq n$). (2p)

Solution Problem 1

(a) The maximum symbol rate occurs when the CC has data to transmit to all devices, and it corresponds to

$$R_\mathrm{s} = 1/T_\mathrm{p} = 8 \text{ kbaud/s}$$

The maximum data rate is

$$R_\mathrm{b} = \log_2(M) \times R_\mathrm{s} = 32 \text{ kbit/s}$$

Every device is assigned one symbol each NT_p symbols, therefore, the symbol and data rate experienced by a device n, $n = 0, 1, \ldots, 7$ are

$$R_\mathrm{s}^\mathrm{D} = 1/(NT_\mathrm{p}) = 1 \text{ kbaud/s}$$
$$R_\mathrm{b}^\mathrm{D} = \log_2(M) \times R_\mathrm{s}^\mathrm{D} = 4 \text{ kbit/s}$$

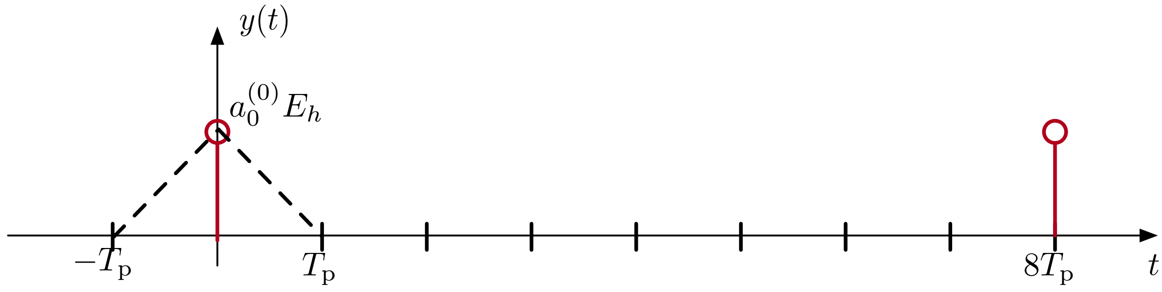
(b) Given that the CC transmits data only to D0 in TDM frame $k = 0$, the transmitted signal can be expressed as

$$s(t) = a_0^{(0)} h(t) = a_0^{(0)} rect\left(\frac{t - T_\mathrm{p}/2}{T_\mathrm{p}}\right)$$

Then the output of the matched filter at the receiver of D0 can be computed as follows

$$\begin{aligned}
y(t) = s(t) * h(-t) &= a_0^{(0)} rect\left(\frac{t - T_\mathrm{p}/2}{T_\mathrm{p}}\right) * rect\left(\frac{-t - T_\mathrm{p}/2}{T_\mathrm{p}}\right) \\
&= a_0^{(0)} rect\left(\frac{t}{T_\mathrm{p}}\right) * \delta(t - T_\mathrm{p}/2) * rect\left(\frac{-t}{T_\mathrm{p}}\right) * \delta(t + T_\mathrm{p}/2) \\
&= a_0^{(0)} rect\left(\frac{t}{T_\mathrm{p}}\right) * rect\left(\frac{-t}{T_\mathrm{p}}\right) * \delta(t - T_\mathrm{p}/2 + T_\mathrm{p}/2) \\
&= a_0^{(0)} \Lambda\left(\frac{t}{T_\mathrm{p}}\right) \\
&= a_0^{(0)} \times \begin{cases} 0 & t \leq -T_\mathrm{p} \\ t + T_\mathrm{p} & -T_\mathrm{p} < t \leq 0 \\ -t + T_\mathrm{p} & 0 < t \leq T_\mathrm{p} \\ 0 & t > T_\mathrm{p} \end{cases}
\end{aligned}$$

The output of the matched filter is shown in the figure below. Note that $E_h = \int_{-\infty}^{+\infty} |h(t)|^2 dt = \int_0^{+T_\mathrm{p}} 1 dt = T_\mathrm{p} = 0.125$ mJ.



P1,b)

Output of matched filter of D0

Sampling time instances $t_k^{(0)}$ are indicated in red circle

The sampling time instances $t_k^{(0)} = kNT_{\text{slot}}$ at the receiver of D0 are shown in the figure. We can compute $y_k^{(0)}$ as follows

$$y_k^{(0)}|_{k=0} = \frac{y(kNT_{\text{slot}})|_{k=0}}{E_h} = \frac{a_0^{(0)}\Lambda(0)}{E_h} = a_0^{(0)}.$$

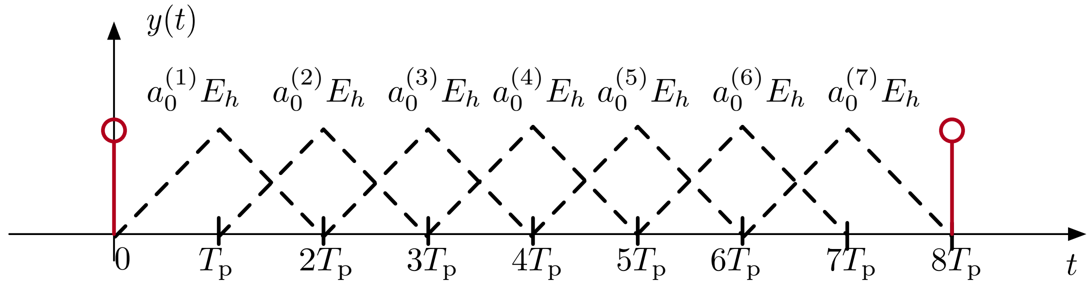
(c) Given that the CC transmits data only to Dn in TDM frame $k = 0$, the transmitted signal can be expressed as

$$s(t) = a_0^{(n)} h(t - nT_{\text{p}})$$

Following that, the output of the matched filter at the receiver of D0 is

$$\begin{aligned} y(t) = s(t) * h(-t) &= a_0^{(n)} h(t - nT_{\text{p}}) * h(-t) \\ &= a_0^{(n)} h(t) * \delta(t - nT_{\text{p}}) * h(-t) \\ &= a_0^{(n)} h(t) * h(-t) * \delta(t - nT_{\text{p}}) \\ &= a_0^{(n)} \Lambda\left(\frac{t}{T_{\text{p}}}\right) * \delta(t - nT_{\text{p}}) \\ &= a_0^{(n)} \Lambda\left(\frac{t - nT_{\text{p}}}{T_{\text{p}}}\right) \end{aligned}$$

The output of the matched filter for $n = 1, 2, \ldots, 7$, is shown in the figure below.



P1, c)

Output of matched filter of D0, when CC transmits data to Dn, $n = 1, 2, \ldots, 7$

From the figure we can see that when D0 uses a sampling time $t_k^{(0)} = kNT_{\text{slot}}$, the output of the sampled matched filter $y_k^{(0)} = 0$ for $n = 1, 2, \ldots, 7$. This can also be be obtained as follows. We have

$$y_k^{(0)}|_{k=0} = \frac{y(kNT_{\text{slot}})|_{k=0}}{E_h} = \frac{1}{E_h} a_0^{(0)} \Lambda\left(\frac{0 - nT_{\text{p}}}{T_{\text{p}}}\right).$$

Moreover, for $1 \leq n \leq 7$, we have that $-7T_{\text{p}} \leq -nT_{\text{p}} \leq -T_{\text{p}}$, then

$$\Lambda\left(\frac{-nT_{\text{p}}}{T_{\text{p}}}\right) = 0,$$

since $\Lambda(\frac{t}{T_{\text{p}}}) = 0$ for $t \leq -T_{\text{p}}$ or $t \geq T_{\text{p}}$.

(d) From questions b) and c) we know that the correct sampling time of $D0$ is $t_k^{(0)} = kNT_{\text{s}}$. Since all devices employ the same matched filter, then the output $y(t) = s(t) * h(-t)$ is the same at the receivers of all devices. From the figure used in question c), we see that if we choose sampling time $t_k^{(n)} = kNT_\mathrm{s} + nT_\mathrm{p}$ then we are able to detect only the symbol transmitted in time slot n.

Additional

This can be formally expressed at TDM frame $k = 0$ as follows. Let $s(t) = \sum_{n'=0}^{N} a_0^{(n')} h(t - n'T_\mathrm{p})$. Given the use of sampling time $t_k^{(n)} = kNT_\mathrm{s} + nT_\mathrm{p}$ ($k = 0$), at the receiver of Dn, we have

$$\begin{aligned}\left(\sum_{n'=0}^{N} a_0^{(n')} h(t - n'T_\mathrm{p}) \;*\; h(-t)\right)\Bigg|_{nT_\mathrm{p}} &= \sum_{n'=0}^{N} a_0^{(n')} \Lambda\left(\frac{t - n'T_\mathrm{p}}{T_\mathrm{p}}\right)\Bigg|_{nT_\mathrm{p}} \\ &= \sum_{n'=0}^{N} a_0^{(n')} \Lambda\left(\frac{(n - n')T_\mathrm{p}}{T_\mathrm{p}}\right) \\ &= a_0^{(n)} \Lambda\left(\frac{(n - n)T_\mathrm{p}}{T_\mathrm{p}}\right) \\ &\qquad + \sum_{n' \neq n} a_0^{(n')} \Lambda\left(\frac{(n - n')T_\mathrm{p}}{T_\mathrm{p}}\right) \\ &= a_0^{(n)} E_h\end{aligned}$$

since, $\Lambda\left(\frac{(n-n')T_\mathrm{p}}{T_\mathrm{p}}\right) = 0$, for $n \neq n'$. We can perform the same analysis for a general TDM frame k. The transmitted signal $s(t)$ in this case is expressed as

$$s(t) = \sum_{k} \sum_{n'=0}^{N} a_0^{(n')} h(t - n'T_\mathrm{p} - kNT_\mathrm{p}).$$

2. Consider two stations, A and B, that are communicating over a 10^4 m long full-duplex optical cable. The propagation speed in the optical cable is $2c_0/3$, where $c_0 = 3 \times 10^8$ m/s. The physical layer has data rate of $R = 10$ Gbit/s. The data link (DL) protocol serves two network protocol entities (i.e., NET1 and NET2) by multiplexing their PDUs. NET1 sends PDUs consisting of B1 bytes while NET2 sends PDUs of B2 bytes. To maintain fairness between NET1 and NET2, the transmitting DL protocol entity accepts data from NET1 and NET2 in a round-robin fashion, i.e., the first DL SDU comes from NET1, the second DL SDU comes from NET2, the third DL SDU from NET1, etc. We assume that both NET1 and NET2 always have data to send. The DL data frame header and trailer amount together to 50 bytes, and the DL ACK frame is 40 byte long. The DL processing delay (for error detection etc.) is $3\,\mu$s. Assume that there are no transmission errors.

   (a) Assume that the DL layer uses a Stop-And-Wait ARQ and that B1 = 1500 bytes.

   - What is the minimum size (in bytes) for B2 such that the data rate experienced by NET2 (i.e., R_2) is at least 100 Mbit/s? (3p)
   - Using the value of B2 just computed, derive the value of R_1, i.e., the data rate experienced by NET1. (1p)

   Hint: the value of R_2 can be expressed as a function of t_1, t_2, t_{f_2}, and R, where t_{f_2} is the time required to transmit a NET2 SDU, while t_1 and t_2 are the times required to transmit a DL PDU for NET1 and NET2, respectively.

   (b) Assume now that the DL layer aggregates one NET1 PDU and one NET2 PDU and transmit them in single DL PDU. The value of B1 is 1500 byte and B2 is as computed in Part (a).

   - What is the data rate experienced by the NET1 and NET2 protocol entities? (2p)
   - Compare these values with the ones computed in Part (a) and comment on the results. (For simplicity you can assume that in Part (a) the date rate experienced by NET 2 is 100 Mbit/s). (2p)

   (c) Assume now that the DL layer uses a Go-Back-N ARQ with a window size that maximizes efficiency. The value of B1 is 1500 byte and B2 is as computed in Part (a).

   - What is the data rate experienced by the NET1 and NET2 protocol entities when NET1 and NET2 PDUs are sent as separate DL PDUs? (2p)
   - What is the data rate experienced by the NET1 and NET2 protocol entities when NET1 and NET2 PDUs are aggregated in a single DL PDU? (2p)

Solution Problem 2

(a) The effective rate experinced by NET2 can expressed as:

$$R_2 = \frac{t_{f2}}{t_1 + t_2} \cdot R$$

where t_{f2} is the time required to transmit a NET2 SDU, while t_1 and t_2 are the times required to transmit a DL PDU for NET1 and NET2, respectively. We know that:

$$t_2 = 2 \cdot (t_{prop} + t_{proc}) + t_{f2} + t_a + t_{oh} \rightarrow$$
$$t_{f2} = \frac{R_2}{R - R_2} \cdot [t_1 + 2 \cdot (t_{prop} + t_{proc}) + t_a + t_{oh}]$$

and that

$$t_{f2} = \frac{B2 \cdot 8}{R}$$

So we can derive B2 as:

$$B2 = \frac{R}{8} \cdot \frac{R_2}{R - R_2} \cdot [t_1 + 2 \cdot (t_{prop} + t_{proc}) + t_a + t_{oh}]$$

The only unkown is the value of t_1 that can be computed as follows:

$$t_1 = 2 \cdot (t_{prop} + t_{proc}) + t_{f1} + t_a + t_{oh}$$

Where

$$t_{prop} = \frac{10000}{2 \cdot 10^8} = 50 \cdot 10^{-6} \text{ [s]}$$
$$t_{f1} = \frac{B1 \cdot 8}{R} = \frac{1500 \cdot 8}{10 \cdot 10^9} = 1.2 \cdot 10^{-6} \text{ [s]}$$
$$t_a = \frac{40 \cdot 8}{R} = 32 \cdot 10^{-9} \text{ [s]}$$
$$t_{oh} = \frac{50 \cdot 8}{R} = 40 \cdot 10^{-9} \text{ [s]}$$

t_{oh} accounts for the time needed to transmit the DL data frame header and trailer. As a result we have:

$$t_1 = 0.107 \cdot 10^{-3} \text{ [s]} \rightarrow B2 = 2694 \text{ [byte]}$$

We can then derive

$$t_{f2} = \frac{B2 \cdot 8}{R} = 2.15 \cdot 10^{-6} \text{ [s]}$$
$$t_2 = 0.108 \cdot 10^{-3} \text{ [s]}$$

The data rate experienced by NET1 can be computed as:

$$R_1 = \frac{t_{f1}}{t_1 + t_2} \cdot R = 55.68 \text{ [Mbit/s]}$$

(b) When the SDUs of both NET1 and NET2 are aggregated in the same PDU transmitted by the DL, the data rate experienced by NET1 and NET2 can be expressed as:

$$R_1 = \frac{t_{f1}}{t} \cdot R, R_2 = \frac{t_{f2}}{t} \cdot R,$$

where t is the turn around time of the DL PDU expressed as:

$$t = 2 \cdot (t_{prop} + t_{proc}) + t_{f1} + t_{f2} + t_a + t_{oh} = 0.109 \cdot 10^{-3} \text{ [s]}$$

As a result we have:

$$R_1 = \frac{t_{f1}}{t} \cdot R = 109.7 \text{ [Mbit/s]}$$
$$R_2 = \frac{t_{f2}}{t} \cdot R = 196.9 \text{ [Mbit/s]}$$

When comparing these results with the values of the data rates experienced by both networking protocols in Part (a) we can see that PDU aggregation at the DL has a positive effect. The idle time between the transmission of consecutive frames is shortened, i.e., during the same reaction time-interval two network layer PDUs are transmitted instead of only one. Additionally, frame aggregation reduces the amount of control overhead transmitted over the physical layer. Without PDU aggregation each network layer PDU requires its own header and trailer when transmitted by the DL. Finally, without aggregation we have to account for a separate ACK and processing time. With PDU aggregation one DL header/trailer is needed to transmit two network layer PDUs, and only one ACK needs to be sent after reception at the receiver.

(c) When a GBN ARQ protocol is used we know from class that the (average) time needed to deliver a frame can be expressed as

$$t_{GBN} = t_f \cdot (\frac{P_f}{1 - P_f} \cdot N \cdot t_f + 1),$$

where t_f is the time to transmit a DL PDU, N is the window size for maximum efficiency, and P_f is the frame error probability. Since we are assuming error free transmissions we have that:

$$t_{GBN} = t_f$$

Based on the above we can compute the following:

- data rate experienced by the NET1 and NET2 protocol entities when NET1 and NET2 PDUs are sent as separate DL PDUs

$$R_1 = \frac{t_{f1}}{t_{f1} + t_{oh} + t_{f2} + t_{oh}} \cdot R = 3.49 \text{ [Gbit/s]}$$
$$R_2 = \frac{t_{f2}}{t_{f1} + t_{oh} + t_{f2} + t_{oh}} \cdot R = 6.27 \text{ [Gbit/s]}$$

- data rate experienced by the NET1 and NET2 protocol entities when NET1 and NET2 PDUs are aggregated in a single DL PDU

$$R_1 = \frac{t_{f1}}{t_{f1} + t_{f2} + t_{oh}} \cdot R = 3.53 \text{ [Gbit/s]}$$
$$R_2 = \frac{t_{f2}}{t_{f1} + t_{f2} + t_{oh}} \cdot R = 6.35 \text{ [Gbit/s]}$$

3. Consider a network of $N = 100$ stations that are attached to a common physical medium. The medium access control method is a simple reservation protocol where communication is done in cycles. A cycle consists of N minislots (reservation slots) followed by M data slots. Here, M is the number of stations that have data to send.

   The data link layer consists of the data link control (DLC) sublayer just above the medium access control (MAC) sublayer, which in turn is just above the physical (PHY) layer.

   Suppose the medium access control (MAC) layer overhead (i.e., header and trailer) requires in total 25 byte. The reservation messages (created by the MAC sublayer) are 25 byte long. The physical layer provides the data rate $R_{PHY} = 100$ Mbit/s to the MAC sublayer. For simplicity, we assume that the physical layer is error-free and that the propagation and processing times are negligible.

   Let ρ be the efficiency (i.e., normalized throughput) of the MAC protocol.

   (a) Let T_D be the slot duration of one data frame. Compute the value of T_D that maximizes the effective data rate. Using the value of T_D just computed derive the value of ρ. Assume that the MAC protocol service data unit (SDU) is 400 byte long and $M = 20$. (3p)

   (b) Suppose the data slot duration is the same one derived in Part (a) and $M = 20$. What is the value of ρ when the MAC SDU is 800 byte? Assume that the MAC protocols splits the DLC PDU into a number of smaller fragments before pushing the data down to the physical layer. (3p)

   (c) Suppose the data slot duration is as in Part (a) and the MAC SDU is 400 bytes. For which value of M the efficiency of the MAC protocol is maximized? Motivate and compute the value of ρ_{MAX}. (3p)

   (d) Suppose the data slot duration is as in Part (a), the MAC SDU is 400 bytes and $M = 5$. Each station can now reserve up to p slots per cycle. Compute the value of p that maximizes the MAC protocol efficiency. (3p)

Solution

(a) Let T_r be the slot duration of one reservation frame, and T_D be the slot duration of one data frame. Assuming that the propagation and processing times are negligible, the effective data rate is maximized if the slot duration is equal to the transmission time of a frame, hence

$$T_r = \frac{n_r}{R_{PHY}},$$
$$T_D = \frac{n_o + n_{MSDU}}{R_{PHY}},$$

where n_o is the overhead due to the MAC header and trailer in bits, and n_r and n_{MSDU} are the length of the reservation message and of the MAC SDU in bits, respectively. Using their numerical values, we get:

$$T_r = \frac{25 \times 8}{10^8} = 2\,\mu\text{s}.$$
$$T_D = \frac{425 \times 8}{10^8} = 34\,\mu\text{s}.$$

To compute ρ we can use the following expression together with the info that $M = 20$ and $N = 100$:

$$\rho = \frac{\text{data portion of cycle}}{\text{cycle duration}} = \frac{MT_D}{NT_r + MT_D} = 0.77.$$

Note that here we assume that each active station has always data to transmit.

(b) Since each data slot is dimensioned to transmit MAC SDUs of 400 byte, each one of the M stations needs to split the MAC SDUs into two parts, each one of 400 byte. Because of this two transmission cycles are required to complete the operation. Overall, the value of the MAC protocol efficiency is not impacted since during each cycle we have the same number of active stations ($M = 20$) transmitting MAC SDUs of 400 byte as in Part (a).

$$\rho = \frac{\text{data portion of cycle}}{\text{cycle duration}} = \frac{MT_D}{NT_r + MT_D} = 0.77.$$

(c) The value of ρ is maximized when all the station have data to transmit, i.e., when $M = N$

$$\rho = \frac{MT_D}{NT_r + MT_D} = \frac{T_D}{T_r + T_D} = 0.94 = \rho_{max}.$$

(d) If each one of the M active stations can reserve up tp p slots per cycle, the value of p that maximizes ρ can be derived as follows:

$$\frac{MpT_D}{NT_r + MpT_D} = \rho_{max} = \frac{T_D}{T_r + T_D} \rightarrow p = N/M = 20.$$

4. (a) Suppose vehicles (cars, buses, trucks, etc.) use 802.11 to enable cooperative traffic safety applications. Explain why communication outside the context of a BSS is preferable compared to using BSS-based communication. (2p)

   (b) Explain what the *hidden terminal* problem is in Wi-Fi and how it can be mitigated using the RTS/CTS handshake. (3p)

   (c) Explain what a *network* and a *link-layer* address are and name which protocol can be used to resolve a network address. (2p)

   (d) Define the security goals integrity and confidentiality. Give an example of an application when integrity is required but not confidentiality. (3p)

   (e) Explain why slotted Aloha has better maximum throughput compared to unslotted Aloha. (2p)

Solution

(a) In 802.11p, operating outside the context of a BSS (OCB) allows for more agile (i.e., lower latency) communication among vehicles. More precisely, the delay due to authentication and association for establishing a BSS is avoided in the OCB operation mode. The setup procedure is simplified, allowing low-latency communication, a fundamental requirement in safety applications.

(b) Let's consider a scenario where two terminals (A and C) would like to communicate wirelessly with a third terminal B. A and C are both in the reach of B, but they are out of reach of each other. As a result, it might happen that A is not able to detect a transmission from C to B while sensing the channel (i.e., during its initial DIFS time). In this case, we say that C is hidden from A. With an RTS/CTS handshake, things happen differently. If A wants to transmit a frame, it must first send a Request to Send (RTS) frame to B. If B senses that the channel is free, it will reply with a Clear to Send (CTS) frame back to A. Only at this point will A start data transmission. Otherwise (i.e., if B senses a busy channel or two concurrent RTS frames collide at B), B will not send out a CTS reply. If A does not receive a CTS frame, it will not start the data transmission.

(c) A network address (also referred to as an internet address) is an IP address used to identify a network interface card (NIC) univocally. Network layer protocols use it. A NIC can have several network addresses, which can vary with time. A link-layer address (also referred to as physical or MAC address) is also used to identify a network card univocally. On the other hand, a NIC has only one link-layer address that does not change with time. Link-layer protocols use it within a LAN to transfer frames to the correct destination. A network address can be resolved to its corresponding link-layer address using the Address Resolution Protocol (ARP).

(d) The goal of confidentiality ensures that two entities (e.g., Alice and Bob) can communicate privately, without any third party (e.g., Eve) to intercept and decode the messages correctly. It can be achieved, for example, using symmetric encryption schemes. The goal integrity ensures that a message received (e.g., by Bob) has not been altered during the transmission. For example, it can be achieved using a private key solution such as Message Authentication Code (MAC). An example in which integrity is required by not confidentiality is a software update. The update's content does not have to be necessarily secret, but you would like to ensure that what you are installing has not been tampered with.

(e) In Slotted Aloha, a station with a frame to transmit is allowed to do so only at the beginning of a time slot. As a result, the probability of collision decreases, and the throughput increases. Downside: guard bands and synch among stations are required.