

## Problem 1

a: From the pmf given, we have

$$\begin{aligned}0.2 + 0.4 + a + 0.1 + 0.1 &= 1 \\ a &= 0.2\end{aligned}$$

b: The expectation of  $X$  is

$$\begin{aligned}E[X] &= \sum xp(x) \\ &= -2 * 0.2 + (-1) * 0.4 + 0 * a + 1 * 0.1 + 2 * 0.1 \\ &= -0.5\end{aligned}$$

, while the variance of  $X$  is

$$\begin{aligned}Var[X] &= E[X^2] - (E[X])^2 \\ &= 4 * (0.2 + 0.1) + 1 * (0.4 + 0.1) + a * 0 - (0.4)^2 \\ &= 1.45\end{aligned}$$

c: The sample space of  $X$  given  $A$  is  $\{-2, -1\}$  (omit the event "otherwise" with probability 0), and the probability of these events are

$$\begin{aligned}p_{X|A}(X = -2) &= \frac{0.2}{0.2 + 0.4} = \frac{1}{3} \\ p_{X|A}(X = -1) &= \frac{0.4}{0.2 + 0.4} = \frac{2}{3}\end{aligned}$$

d

$$\begin{aligned}E[X|A] &= \sum xp_{X|A}(x) \\ &= (-2) * \frac{1}{3} + (-1) * \frac{2}{3} \\ &= -\frac{4}{3} \\ Var[X|A] &= E[X^2] - (E[X])^2 \\ &= \sum x^2 p_{X|A}(x) - (E[X])^2 \\ &= 4 * \frac{1}{3} + 1 * \frac{2}{3} - \left(-\frac{4}{3}\right)^2 = \frac{2}{9}\end{aligned}$$

e The sample space of  $Y$  is  $\{-1, 1, 3, 5, 7\}$  (omit the event "otherwise" with probability being 0), and the probability of these events are 0.2, 0.4, 0.2, 0.1, 0.1 respectively.

## Problem 2

a: The pmfs of Transmitter 1 and 2 are

$$P_1(x) = \frac{1}{3} * \left(\frac{2}{3}\right)^{x-1}$$
$$P_2(x) = \frac{1}{2} * \left(\frac{1}{2}\right)^{x-1},$$

where  $x \in N^+$ .

From the problem, we have  $P(x) = 0.7 * P_1(x) + 0.3 * P_2(x)$ , thus the pmf of  $X$  is

$$P(X) = 0.7 * \frac{1}{3} * \left(\frac{2}{3}\right)^{x-1} + 0.3 * \frac{1}{2} * \left(\frac{1}{2}\right)^{x-1}, \quad X \in N^+$$

b:

$$\begin{aligned} E[X] &= \sum_{x=1}^{+\infty} xP(x) \\ &= \sum_{x=1}^{+\infty} x(0.7 * P_1(x) + 0.3 * P_2(x)) \\ &= 0.7 * \sum_{x=1}^{+\infty} xP_1(x) + 0.3 * \sum_{x=1}^{+\infty} xP_2(x) \\ &= 0.7 * 3 + 0.3 * 2 \\ &= 2.7 \end{aligned}$$

c: *Theorem 1*: The expectation of  $X^2$  is  $\frac{2-p}{p^2}$ , where  $X$  is a geometric random variable ranging from 1 to infinity with mean  $\frac{1}{p}$ .

*Proof*:

$$\begin{aligned} E[X^2] &= Var[X] + (E[X])^2 \\ &= \frac{1-p}{p^2} + \left(\frac{1}{p}\right)^2 \\ &= \frac{2-p}{p^2} \end{aligned}$$

So, the variance of  $X$  is

$$\begin{aligned}
 \text{Var}[X] &= E[X^2] - (E[X])^2 \\
 &= \sum_1^{+\infty} x^2 P(x) - (E[X])^2 \\
 &= \sum_1^{+\infty} x^2 (0.7 * P_1(x) + 0.3 * P_2(x)) - (E[X])^2 \\
 &= 0.7 * \sum_1^{+\infty} x^2 P_1(x) + 0.3 * \sum_1^{+\infty} x^2 P_2(x) - (E[X])^2 \\
 &= 0.7 * 15 + 0.3 * 6 - 2.7^2 \\
 &= 5.01
 \end{aligned}$$

### Problem 3

**a:** The pdf should satisfy the constraint that  $\int_{-\infty}^{+\infty} f(x)dx = 1$ , in this case

$$\begin{aligned}
 \int_0^1 cx(2+x)dx &= 1 \\
 c(1 + \frac{1}{3}) &= 1 \\
 c &= \frac{3}{4}
 \end{aligned}$$

**b:** The cdf of  $X$  is

$$\begin{aligned}
 F(x) &= \int_{-\infty}^x f(t)dt \\
 &= \int_0^x \frac{3}{4}t(2+t)dt \\
 &= \frac{3}{4}x^2 + \frac{1}{4}x^3
 \end{aligned}$$

for  $x \in [0, 1]$ , and for all  $x < 0$ ,  $F(x) = 0$ , and all  $x > 1$ ,  $F(x) = 1$ . In conclusion, the cdf is

$$F(x) = \begin{cases} 0 & x < 0 \\ \frac{3}{4}x^2 + \frac{1}{4}x^3 & x \in [0, 1] \\ 1 & x > 1 \end{cases}$$

c: The expectation of  $X$  is

$$\begin{aligned} E[X] &= \int_{-\infty}^{+\infty} xf(x)dx \\ &= \int_0^1 x * \frac{3}{4}x(2+x)dx \\ &= \frac{3}{4}(\frac{2}{3} + \frac{1}{4}) \\ &= \frac{11}{16}, \end{aligned}$$

and the variance is

$$\begin{aligned} Var[X] &= E[X^2] - (E[X])^2 \\ &= \int_0^1 \frac{3}{4}x^2 * x(2+x)dx - (\frac{11}{16})^2 \\ &= \frac{3}{4} * (\frac{1}{5} + \frac{1}{2}) - \frac{11^2}{16} \\ &= 0.0523. \end{aligned}$$

d: The probability of event  $A$  is given by

$$\begin{aligned} P(A) &= F(0.8) - F(0.4) \\ &= \frac{3}{4}(0.8^2 - 0.4^2) + \frac{1}{4}(0.8^3 - 0.4^3) \\ &= \frac{59}{125} \end{aligned}$$

e: The conditional pdf(denoted by  $f_{X|A}$ ) will be

$$\begin{aligned} f_{X|A}(x|A) &= \frac{d}{dx}F_{X|A}(x) \\ &= \lim_{\epsilon \rightarrow 0} P(X \in [x, x + \epsilon]|A) \\ &= \lim_{\epsilon \rightarrow 0} P(X \in [x, x + \epsilon])/P(A) \\ &= f(x)/P(A) \\ &= \frac{375}{236}x(2+x), \end{aligned}$$

for  $x \in (0.4, 0.8)$ , otherwise  $f_{X|A}(x|A) = 0$ . Thus, the conditional expectation is

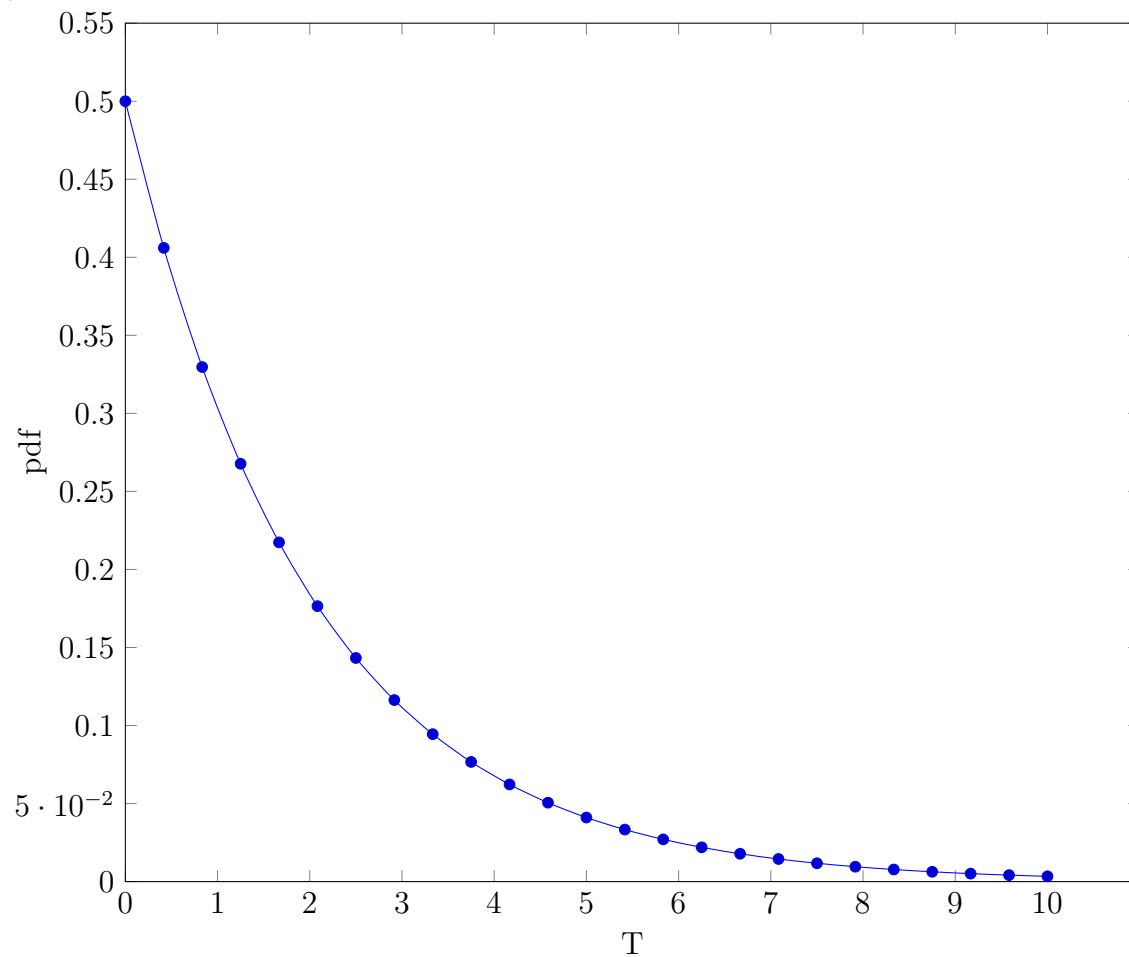
$$\begin{aligned} E[X|A] &= \int_{0.4}^{0.8} xf_{X|A}(x)dx \\ &= \frac{375}{236} \int_{0.4}^{0.8} x * x(2+x)dx \\ &= \frac{375}{236} * \frac{148}{375} \\ &= 0.6271 \end{aligned}$$

## Problem 4

The pdf of  $T$  is

$$f(t) = \begin{cases} 0.5e^{-0.5t} & x \geq 0 \\ 0 & x < 0 \end{cases}$$

a:



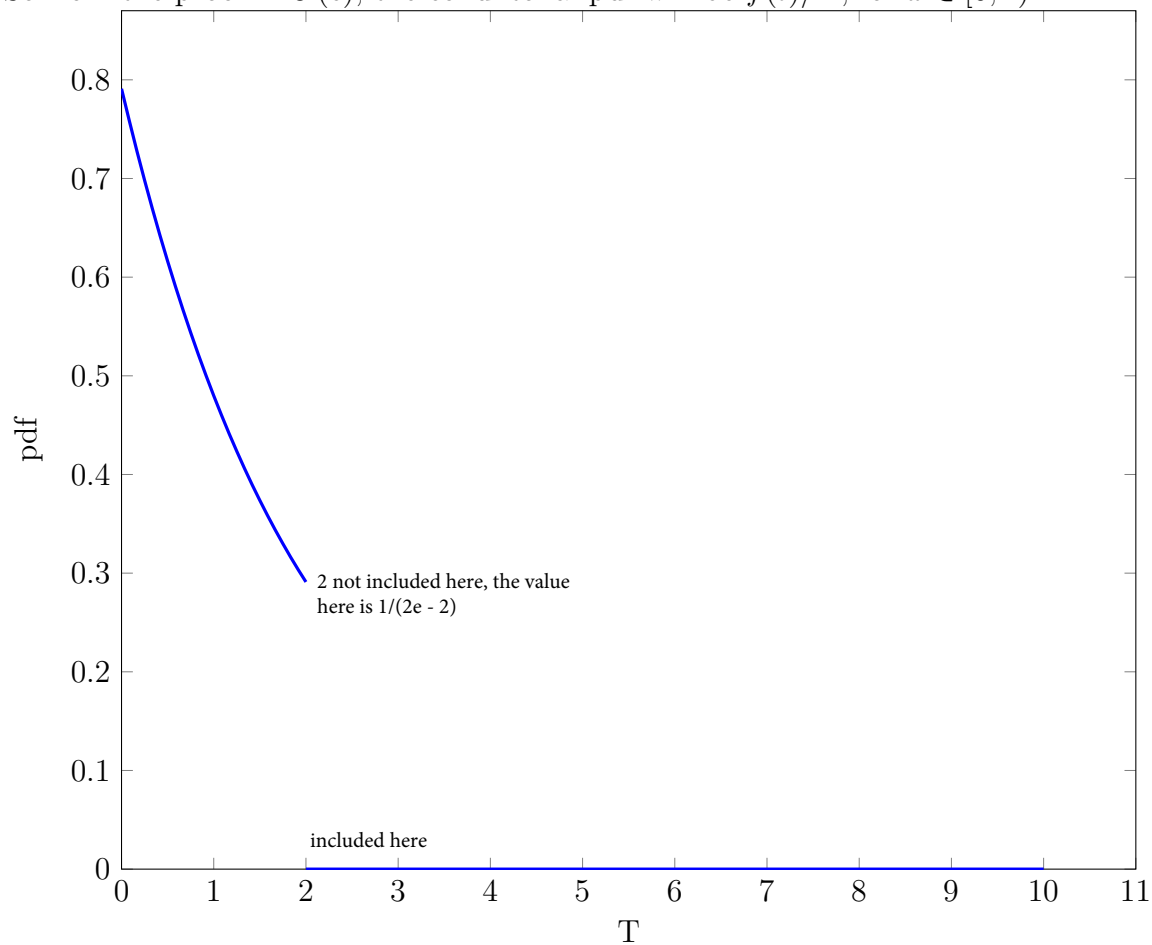
**b:** The expectation of  $T$  is

$$\begin{aligned} E[T] &= \int_0^{+\infty} \frac{1}{2} t e^{-\frac{1}{2}t} dt \\ &= 2 \int_0^{+\infty} u e^{-u} du, \quad (\text{let } u = \frac{1}{2}t) \\ &= 2 \int_0^{+\infty} -u de^{-u} \\ &= 2(-ue^{-u}|_0^{+\infty} + \int_0^{+\infty} e^{-u} du) \\ &= 2 \end{aligned}$$

**c:** The probability of the waiting time being less than 2 mins is given by

$$\begin{aligned} P &= \int_0^2 f(t) dt \\ &= \int_0^2 \frac{1}{2} e^{-\frac{1}{2}t} dt \\ &= \int_0^1 e^{-u} du, \quad (\text{same as 4.(b)}) \\ &= 1 - e^{-1} \end{aligned}$$

So from the proof in 3.(e), the conditional pdf will be  $f(t)/P$ , for  $x \in [0, 2)$



d: The conditional probability is

$$\begin{aligned}
 E[T \mid A] &= \int_0^2 t f(t \mid A) dt \\
 &= \frac{1}{2 - 2e^{-1}} \int_0^2 t e^{-\frac{1}{2}t} dt \\
 &= \frac{2}{1 - e^{-1}} \int_0^1 u e^{-u} du \\
 &= \frac{2}{1 - e^{-1}} (-u - 1) e^{-u} \Big|_0^1 \\
 &= \frac{2e - 4}{e - 1}
 \end{aligned}$$

e: The probability that waiting time exceeds 4 minutes is

$$\begin{aligned} P(T > 4) &= \int_4^{+\infty} f(t)dt \\ &= \int_4^{+\infty} \frac{1}{2}e^{-\frac{1}{2}t}dt \\ &= \int_2^{+\infty} e^{-u}du \\ &= e^{-2} \end{aligned}$$

f: From the memoryless property of the exponential distributuion, we have

$$\begin{aligned} P(T \geq 5 \mid T \geq 4) &= P(T \geq 1) \\ &= \int_1^{+\infty} \frac{1}{2}e^{-\frac{1}{2}t}dt \\ &= \int_{\frac{1}{2}}^{+\infty} e^{-u}du \\ &= e^{-\frac{1}{2}} \end{aligned}$$

## Problem 5

a: The cdf of  $Y$  is

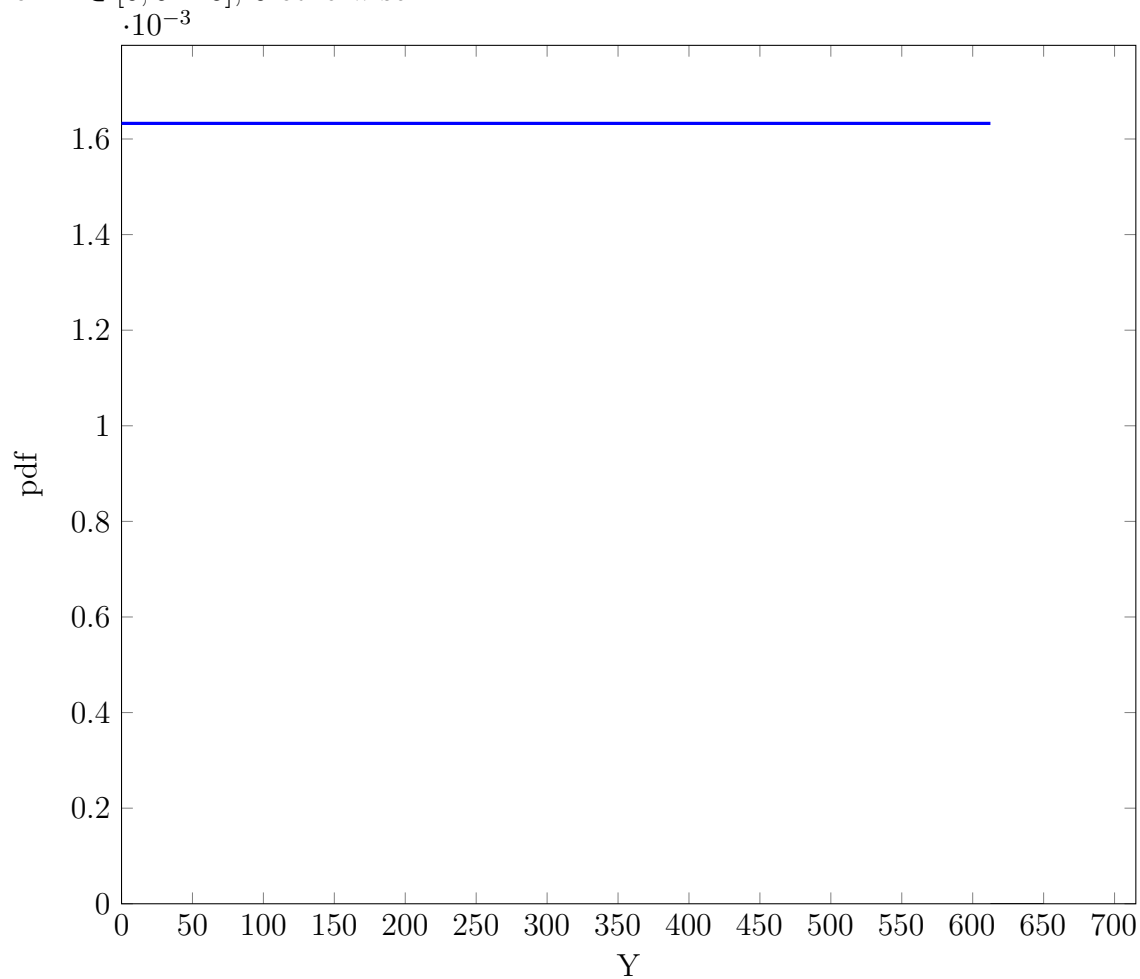
$$\begin{aligned} F[Y] &= P(y \leq Y) \\ &= P(0.25x - 37.5 \leq Y) \\ &= P(x \leq 4(Y + 37.5)) \\ &= \frac{4(Y + 37.5) - 150}{2600 - 150} \\ &= 0.001633 \end{aligned}$$

for  $4(Y + 37.5) \in [150, 2600]$ , so the pdf of  $Y$  is the derivitive of its cdf function

$$f(y) = \frac{4}{2600 - 150}$$



for  $Y \in [0, 612.5]$ , 0 otherwise.



**b:** From  $Y = 0.25X - 37.5$  and  $E[X] = \frac{150+2600}{2}$ ,  $Var[X] = \frac{(2600-150)^2}{12}$ , we have

$$\begin{aligned} E[Y] &= 0.25E[X] - 37.5 \\ &= 306.25 \\ Var[Y] &= 0.25^2 Var[X] \\ &= 31263.0208 \end{aligned}$$

c: Follow the procedure in 5.a, we have

$$\begin{aligned} F[Z] &= P(z \leq Z) \\ &= P(4x^2 \leq Z) \\ &= P(x \leq \sqrt{Z}/2), \quad \text{for } P(X \leq 0) = 0 \\ &= \frac{\sqrt{Z}/2 - 150}{2600 - 150} \\ f(z) &= \frac{d}{dz} F[Z] \\ &= \frac{1}{9800} z^{-1/2} \end{aligned}$$

for  $z \in [90000, 27040000]$ , 0 otherwise.