TD5: IoT Protocols

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1 Battery Life Time in LoRa

Question 1

Given the bandwidth B and the spreading factor SF (number of bits per symbol) we have

$$\begin{cases} N &= 2^{SF} = 4096 \\ T_{\text{symbol}} &= \frac{N}{B} = 3.28 \cdot 10^{-2}\text{s} \end{cases} \tag{1}$$

We compute number of symbols in the transmitted packet n,

$$n = q + \frac{1}{SF}\left(\frac{8p}{r} + o\right) = 81.5 \approx 82 \text{ symbols} \tag{2}$$

now we can compute the packet transmission time

$$T_{tx} = n \cdot T_{\text{symbol}} = 2.68\text{s} \tag{3}$$

Question 2

Both the receive windows needs to be long enough to detect a preamble, we have

$$T^A_{window} = q \cdot T_{\text{symbol}} = 0.393\text{s} \tag{4}$$

now to compute total receive time, we add the two window durations

$$T^A_{rx} = 2T^A_{window} = 0.786\text{s} \tag{5}$$

Question 3

We calculate the average current

$$I_{avg} = \frac{I_{tx} \cdot T_{tx} + I_{rx} \cdot T^A_{rx} + I_{\text{sleep}} \cdot T_{\text{sleep}}}{T_{\text{transmission}}} = 47.8\mu\text{A} \tag{6}$$

and now we compute the battery life

$$L = \frac{C}{I_{avg}} = 52256.3 \text{ hours} = 5.96 \text{ years} \tag{7}$$

Question 4

Beacon duration

Let's compute the duration of a beacon symbol

$$T^{\text{beacon}}_{\text{symbol}} = \frac{2^9}{125\text{kHz}} = 4.1\text{ms} \tag{8}$$

Now let's compute the number of symbols in the beacon. The 17 bytes in the payload with a coding rate of $\frac{4}{5}$ and a spreading factor of 9 bits per symbol are equivalent to $\frac{17\cdot 8}{\frac{4}{5}\cdot 9} = 19$ symbols. We have

$$N^{\text{beacon}} = 29 \text{ symbols} \tag{9}$$

The beacon duration is

$$T^{\text{beacon}} = N^{\text{beacon}} \cdot T^{\text{beacon}}_{\text{symbol}} = 0.12\text{s} \tag{10}$$

Ping slot duration

Let's compute the duration of a symbol in the ping slot

$$T^{\text{ping}}_{\text{symbol}} = \frac{2^{12}}{125\text{kHz}} = 32.8\text{ms} \tag{11}$$

We know the number of symbols in the ping slot is $N^{\text{ping}} = 12$ symbols.
The ping slot duration is

$$T^{\text{ping}} = N^{\text{ping}} \cdot T^{\text{ping}}_{\text{symbol}} = 0.39\text{s} \tag{12}$$

T^B_{rx} calculation

The average packet reception time of B is a weighted average of the reception times of beacons and ping slots. Using $T = 2$ hours $= 7200$ s We have

$$T^B_{rx} = T^A_{rx} + \frac{T \cdot T_{\text{beacon}}}{t_b} + \frac{T \cdot T_{\text{ping}}}{t_p} = 2838.6 \text{ s} \tag{13}$$

Question 5

We calculate the average current

$$I^B_{avg} = \frac{I_{tx} \cdot T_{tx} + I_{rx} \cdot T^B_{rx} + I_{\text{sleep}} \cdot T_{\text{sleep}}}{T_{\text{transmission}}} = 3.99\text{mA} \tag{14}$$

and now we compute the battery life

$$L^B = \frac{C}{I^B_{avg}} = 626.68 \text{ hours} = 0.071 \text{ years} \tag{15}$$

Question 6

In Class C, the device will listen continuously to the downlink channel (no time is spent on standby), which means

$$T^C_{rx} = T = 7200\text{s} \tag{16}$$

Question 7

We calculate the average current

$$I^C_{avg} = \frac{I_{tx} \cdot T_{tx} + I_{rx} \cdot T^C_{rx} + I_{\text{sleep}} \cdot T_{\text{sleep}}}{T_{\text{transmission}}} = 0.01\text{A} \tag{17}$$

and now we compute the battery life

$$L^C = \frac{C}{I^C_{avg}} = 248.8 \text{ hours} = 10.37 \text{ days} \tag{18}$$

2 Sigfox MAC Performance

Question 8

We add the expected arrival rate of each of the $N-1$ other devices. Each device sends λr packets with probability $\frac{\delta_f}{W}$.
So the arrival rate of packets in the vulnerability window is

$$\lambda_v = (N-1)\lambda r \cdot \frac{\delta_f}{W} \tag{19}$$

Question 9

The probability of at least one arrival is

$$P_{\text{arrival}} = 1 - \mathbb{P}[k=0] \tag{20}$$
$$= 1 - e^{\lambda_v T} \tag{21}$$
$$= 1 - e^{(N-1)\lambda r \frac{\delta_f}{W}} \tag{22}$$

Question 10

Since each retransmission is independant, the probability of failure is

$$P_{\text{failure}} = \left(1 - e^{\lambda_v T}\right)^r = \left(1 - e^{(N-1)\lambda r \frac{\delta_f}{W}}\right)^r \tag{23}$$

3 LoRa Coverage

Question 11

Given N_0 and W, we compute the noise power

$$N = N_0 + 10\log_{10}(W) = -174 + 10\log_{10}(125000) = -123\text{dBm} \tag{24}$$

and now we compute the receiver sensitivity

$$P_{\min} = N + SNR = -123\text{dBm} + (-20\text{dB}) = -143\text{dBm} \tag{25}$$

Question 12

The total gain is $G = 6 + 10\log_{10}(2) = 12.93\text{dBi}$.

The total loss is $L = 3\text{dB} + 18\text{dB} = 21\text{dB}$.

The shadowing margin M_s can be calculated with

$$P_{out} = 1 - Q\left(\frac{P_{tx} + G - L - M_s}{\sigma}\right) \tag{26}$$

$$\iff M_s = (P_{tx} + G - L) + \sigma Q^{-1}(1 - P_{out}) \tag{27}$$

which gives

$$M_s = 17.05\text{dB} \tag{28}$$

Question 13

MAPL(Maximum Allowable Path Loss)

Let's compute the MAPL(source)

$$\text{MAPL} = P_{tx} + G - L - P_{\min} = 151.11\text{dB} \tag{29}$$

this means the signal can lose up to 151.11dB before it becomes too weak to detect.

Cell range in urban and rural areas

We use the Hata model with

$$\text{MAPL} = A + B\log_{10}(d) + C \tag{30}$$

For urban areas we have

$$\begin{cases} A_{\text{urban}} & = 69.55 + 26.16\log_{10}(f_c) - 13.82\log_{10}(h_b) = 282.97 \\ B_{\text{urban}} & = 44.9 - 6.55\log_{10}(h_b) = 35.22 \\ C_{\text{urban}} & = 3.2(\log_{10}(11.75 f_c))^2 - 4.97 = 315.58 \end{cases} \tag{31}$$

which gives

$$d_{\text{urban}} = 10^{\frac{\text{MAPL} - A_{\text{urban}} + C_{\text{urban}}}{B_{\text{urban}}}} = 164.3\text{km} \tag{32}$$

For rural areas we have

$$\begin{cases} A_{\text{rural}} & = A_{\text{urban}} \\ B_{\text{rural}} & = B_{\text{urban}} \\ C_{\text{rural}} & = 4.78(\log_{10}(f_c))^2 - 18.33\log_{10}(fc) + 40.94 = 259 \end{cases} \tag{33}$$

which gives

$$d_{\text{rural}} = 10^{\frac{\text{MAPL} - A_{\text{rural}} + C_{\text{rural}}}{B_{\text{rural}}}} = 4.07\text{km} \tag{34}$$