Networked Embedded Systems WS 2016/17

Exercise 2: Communication

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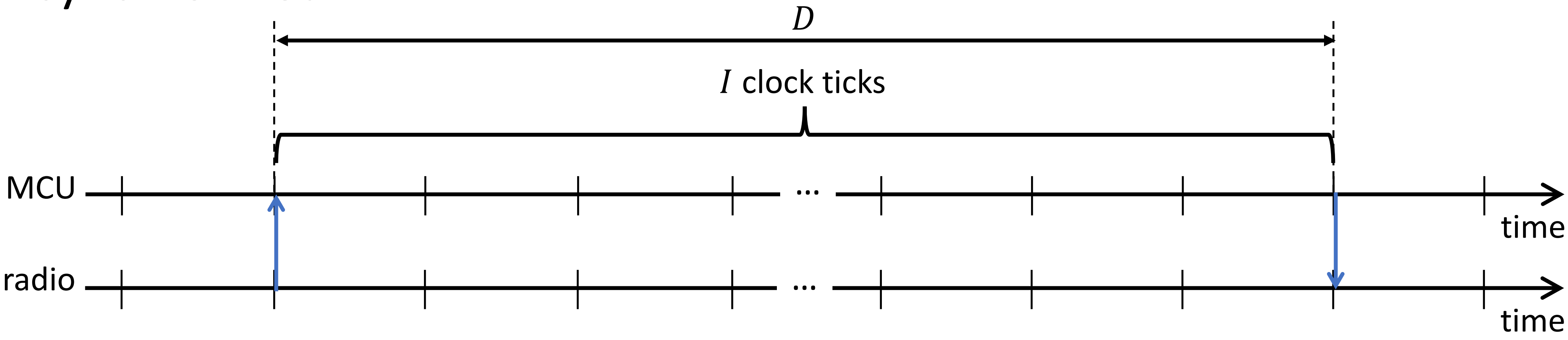
Task 1 (a): Sample Solution

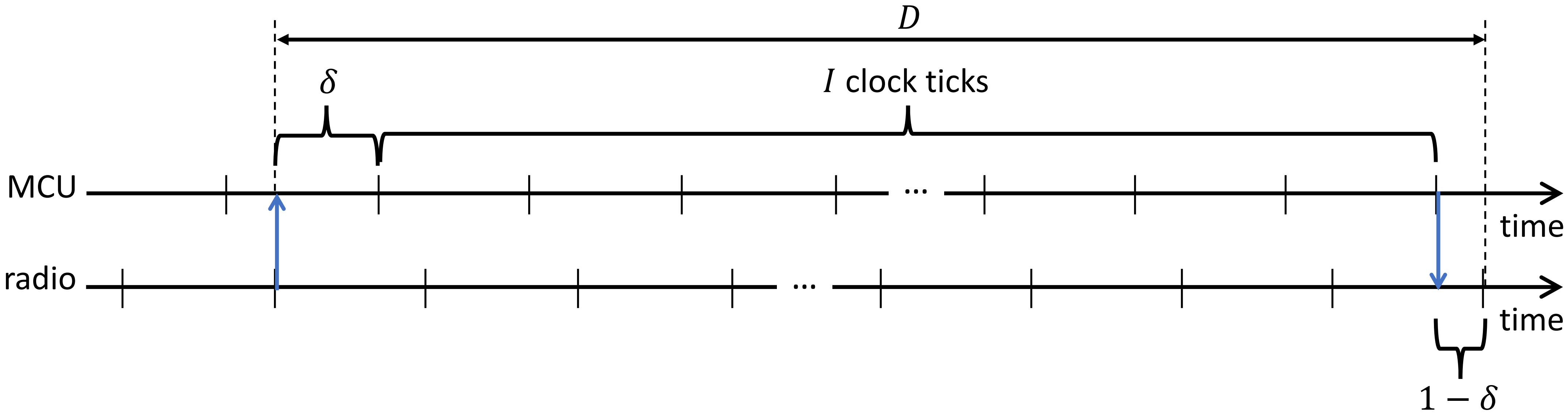
- Like on a system-on-chip (SoC) platform, radio and MCU are perfectly synchronized



- So the delay is simply the time the MCU needs to execute for 100 clock ticks: $D = \frac{I}{f} = \frac{100}{8000000} = 12.5\mu s$

Task 1 (b): Sample Solution

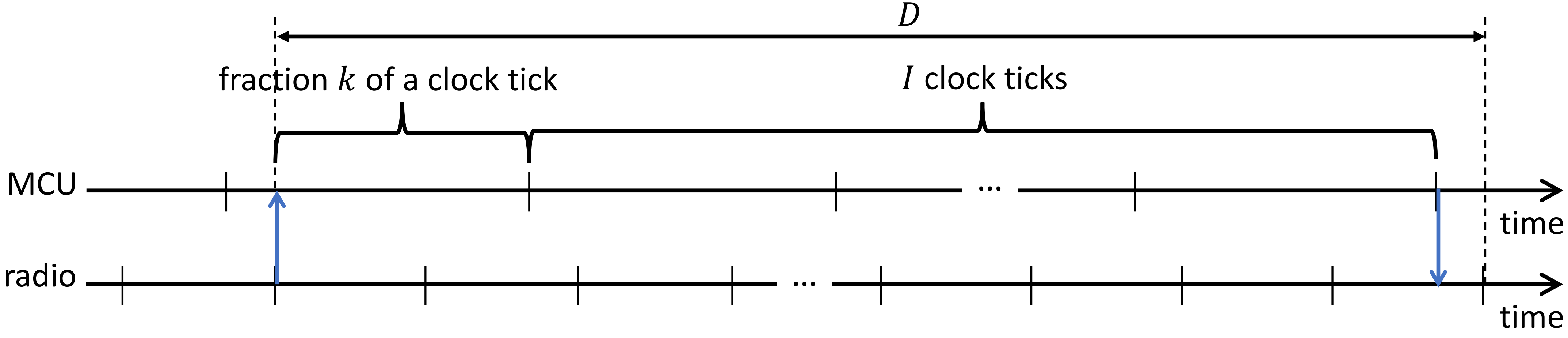
- Like on the Tmote Sky, radio and MCU are not synchronized
- This results in a variable initial delay δ representing the time it takes for the MCU to detect the signal from the radio



- δ is a continuous random variable uniformly distributed in]0,1/f]
- Delay increases by one clock period: $D = \frac{I+1}{f} = \frac{101}{8000000} = 12.625\mu s$

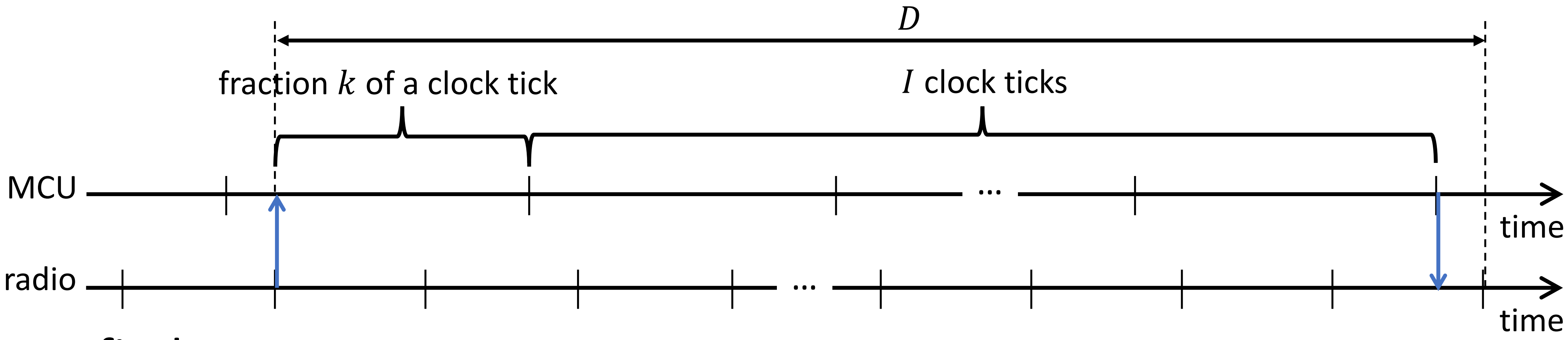
Task 1 (c): Sample Solution (1)

- Represent initial delay δ as fraction k of MCU clock period $1/f$
- k is a continuous random variable uniformly distributed in]0,1]



Task 1 (c): Sample Solution (2)

- Represent initial delay δ as fraction k of MCU clock period $1/f$
- k is a continuous random variable uniformly distributed in]0,1]



- We find

$$D = \frac{1}{f_r}\left\lceil (I + k)\,\frac{f_r}{f_m} \right\rceil$$

Task 1 (c): Sample Solution (3)

For $I = 100$, $f_r = 8\,\text{MHz}$, and $f_m = 4\,\text{MHz}$, we have $D = \frac{1}{8{,}000{,}000}(200 + \lceil 2k \rceil)$. Thus, depending on the initial delay represented by k there are two possible values for the delay D:

- $0 < k \leq 0.5 \Rightarrow \lceil 2k \rceil = 1$: $D = \frac{201}{8{,}000{,}000}\,\text{s} = 25.125\,\mu\text{s}$
- $0.5 < k \leq 1 \Rightarrow \lceil 2k \rceil = 2$: $D = \frac{202}{8{,}000{,}000}\,\text{s} = 25.25\,\mu\text{s}$

Task 1 (d): Sample Solution (1)

Solution: The delay D can take three possible values for $I = 100$. To see this, we note that since $(I + k)f_r/f_m \approx 190.7 + 1.907 \cdot k$, the smallest possible delay measured in radio clock ticks is $\lceil 190.7 \rceil = 191$. We find three ranges for the initial delay represented by k yielding three distinct values for the delay D:

- $0 < k \leq 191 \cdot f_m/f_r - I \approx 0.139 \Rightarrow \lceil (I + k)f_r/f_m \rceil = 191$: $D = \frac{191}{8{,}000{,}000}$ s $= 23.875\,\mu$s
- $0.139 < k \leq 192 \cdot f_m/f_r - I \approx 0.663 \Rightarrow \lceil (I + k)f_r/f_m \rceil = 192$: $D = \frac{192}{8{,}000{,}000}$ s $= 24\,\mu$s
- $0.663 < k \leq 1 \Rightarrow \lceil (I + k)f_r/f_m \rceil = 193$: $D = \frac{193}{8{,}000{,}000}$ s $= 24.125\,\mu$s

Task 1 (d): Sample Solution (2)

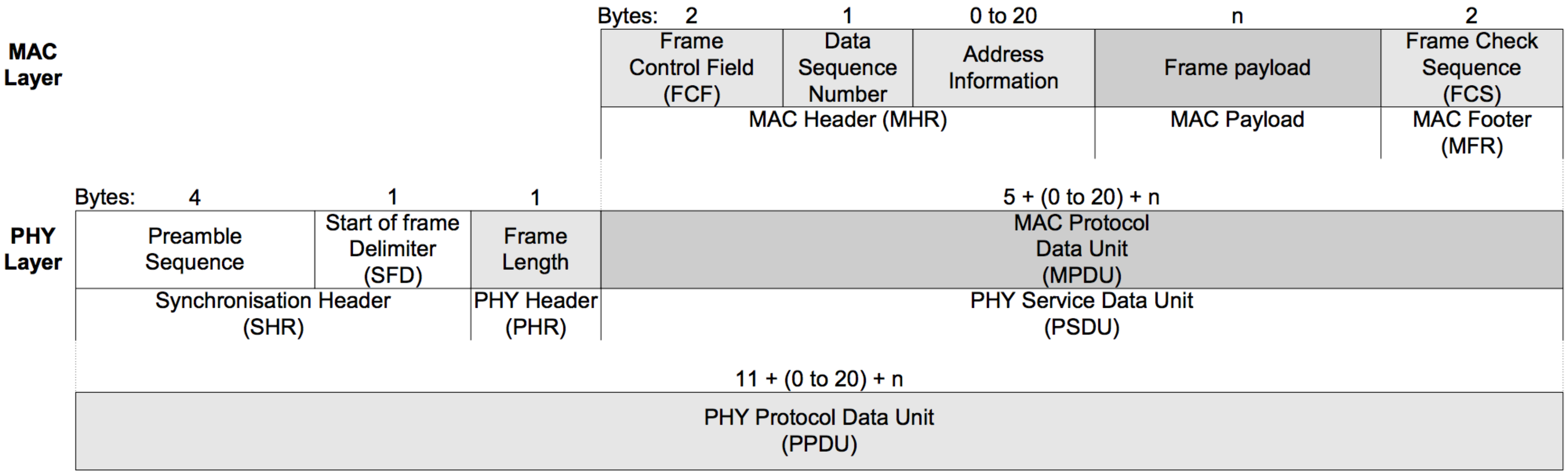
Yes, there are certain numbers of clock ticks I for which the delay D takes only two instead of three possible values. The smallest such number of clock ticks greater than 100 is $I = 107$. In this case, the smallest possible delay measured in radio clock ticks is $\lceil 204.08 \rceil = 205$. We find

- $0 < k \leq 205 \cdot f_m/f_r - I \approx 0.479 \Rightarrow \lceil (I + k) f_r / f_m \rceil = 205$: $D = \frac{205}{8{,}000{,}000}\,\text{s} = 25.625\,\mu\text{s}$
- $0.479 < k \leq 1 \Rightarrow \lceil (I + k) f_r / f_m \rceil = 206$: $D = \frac{206}{8{,}000{,}000}\,\text{s} = 25.75\,\mu\text{s}$

Using (4) we can determine the delay D for a given I and a set of random values for k uniformly chosen from the interval $]0, 1]$. Figure 5 plots the number of possible values for D depending on I. We can see that for any $I \in \{107, 118, 129, 140, 151, 161, \ldots\}$ there are only two possible values of the delay D. These two values are $1/f_r = 0.125\,\mu\text{s}$ apart.

Task 2 (a): Sample Solution

- Frame length field has only 7 bits available (MSB reserved)
- Thus, MPDU can be at most 127 bytes, MAC payload 125 bytes
- This corresponds to a maximum PPDU of 4+1+1+125+2=133 bytes



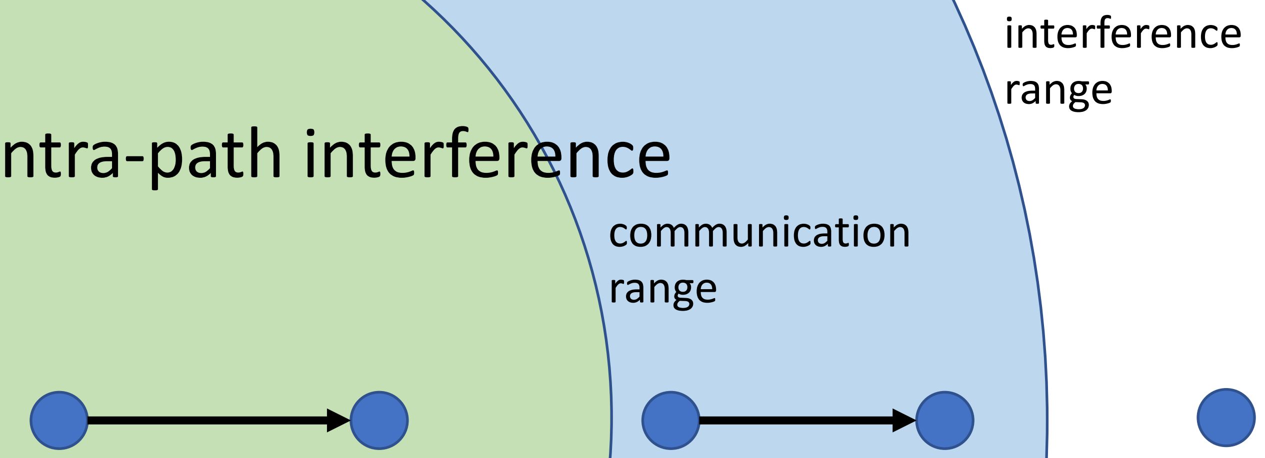
Task 2 (b): Sample Solution

- MAC payload should be chosen as large as possible (*i.e.*, 125 bytes) to minimize the overhead that comes with each packet (*e.g.*, SHR)
- The gap between two packets (Rx-Tx-turnaround) is 192us, which corresponds to an additional overhead of 6 bytes
- Considering any other overhead we get as maximum single-hop throughput

$$T_s = \frac{125}{4+1+1+125+2+6} \times 250 \text{ kbit/s} \approx 224.8 \text{ kbit/s}$$

Task 2 (c): Sample Solution

- Problem: intra-path interference



- Solution: use a different channel for each link/hop
- Because radios are half-duplex, they cannot send and receive at the same time, so we get as maximum multi-hop throughput $T_m = T_s/2$

Task 2 (d): Sample Solution

- The end-to-end reliability is

$$R = p_{hop}^{H}$$

where H is the number of hops and p_{hop} is the probability of success across any given link after at most N retransmissions

- Probability of failure even after N retransmissions is

$$(1-p)^{N+1}$$

- Overall, we get

$$R = [1-(1-p)^{N+1}]^{H}$$

Task 2 (e): Sample Solution

- We can express the node lifetime as

$$T = \frac{Q}{D_{on}I_{on} + D_{off}I_{off}}$$

where D_{on} and D_{off} are the fractions of time the radio is on and off.

- We can write $D_{on} = T_{on}/T_w$ and $D_{off} = 1 - T_{on}/T_w$
- Substituting and solving for T_w, we get for the given values that T_w must be about 2 seconds or longer to achieve a lifetime of 2 years
- The throughput is thus significantly lower than the theoretical maximum, so only applications with low traffic load can be supported.