Exercise 2

Chiara Thien Thao Nguyen Ba 10727985

May 24, 2025

1 802.15.4

Consider the following pseudocode for a ESP32-based IoT monitoring system.

```
// Global Timer Handle
declare timer_handle as

// Initialization
function setup_camera():
    initialize_camera(QVGA)

function setup_timer():
    declare timer_config as esp_timer_create_args_t
    set timer_config.callback to process_frame
    set timer_config.name to "10_sec_timer"
    call esp_timer_create(&timer_config,
    &timer_handle)
    call esp_timer_start_periodic(timer_handle,
    10_000_000) // 10s

function app_main():
    call setup_camera()
    call setup_timer()
    loop forever:
        delay(100 ms)

// Called every 10 seconds
function process_frame(arg):
    image = capture_camera_frame()
    person_count = estimate_number_of_people(image)
    if person_count == 0:
        payload = create_message(size=1KB)
    else if person_count == 1:
        payload = create_message(size=3KB)
    else:
```

```
payload = create_message(size=6KB)
```

Assuming the system is operated with IEEE 802.15.4 in beacon-enabled mode (CFP only) and that the number of people present in the camera frame at any instant follows a Poisson distribution with an average rate of lambda = 0.15 persons/frame.

1. Compute the Probability Mass Function of the output rate of the ESP32 P(r = r_0), P(r = r_1), P(r =r_2), where r_0, r_1 and r_2 are the output rates when there are 0, 1 or more than 1 persons in the captured frame, respectively.

2. Based on the output rate PMF, compute a consistent slot assignment for the CFP in a monitoring system composed of 1 PAN coordinator and 3 camera nodes. Assume nominal bit rate R=250kbps, packets of L=128bytes, 1 packet fits exactly in one slot. Compute Ts (slot time), Number of slots in the CFP, Tactive, Tinactive and the duty cycle of the system.

3. How many additional cameras can be added to keep the duty cycle below 10%?

1.1 Answer 1

From the pseudocode we know that ESP32 processes the frame every 10 seconds, and based on the number of estimated people in the image, it produces payloads of size: 1KB if 0 persons, 3KB if 1 person and 6KB if 2 or more persons.

Thus, we know that $r_0 = 1KB/10s, r_1 = 3KB/10s, r_2 = 6KB/10s$ and that the number of people in image follows a Poisson distribution with a rate $\lambda = 0.15$. We can write the PMF as:

$$P(k) = \frac{e^{-\lambda}\lambda^k}{k!}$$

We compute the probabilities for 0 persons (P_0), 1 person (P_1) and 2 or more persons (P_2):

$$P_0 = (k = 0) = e^{-0.15} \cdot \frac{0.15^0}{0!} = e^{-0.15} = 0.8607 \tag{1}$$

$$P_1 = (k = 1) = e^{-0.15} \cdot \frac{0.15^1}{1!} = e^{-0.15} 1 \cdot 0.15 = 0.1291 \tag{2}$$

$$P_2 = (k \geq 2) = 1 - P(k = 0) - P(k = 1) = 1 - 0.8607 - 0.1291 = 0.0102 \tag{3}$$

In conclusion, the PMF of output rates are: $P(r_0 = 100[byte/s]) = 0.8607, P(r_1 = 300[byte/s]) = 0.1291, P(r_2 = 600[byte/s]) = 0.0102$.

1.2 Answer 2

We can compute the time slot T_s, knowing that the packet size is $L = 128\ bytes = 1024\ bit$ and the nominal bit rate is $R = 250\ kbps = 250,000\ bit/s$:

$$T_s = \frac{L}{R} = \frac{1024\ bit}{250000\ bit/s} = 4.096\ ms$$

The minimum rate required by all the nodes is 100[byte/s]=800[bit/s]. The beacon interval can be dimensioned such that one slot in the CFP per beacon interval corresponds to 800[bit/s]. Thus, we have:

$$BI = \frac{1024\ bit}{800\ bit/s} = 1.28\ s$$

The three nodes in the worst case require a bit rate of $r^{max} = 600\ byte/s = 4800\ bit/s$. Thus, the total number of slots in the CFP is:

$$N_{CFP} = \frac{4800\ bit/s}{800\ bit/s} \cdot 3 = 18\ slots$$

The duration of the CFP is:

$$T_{CFP} = 18 \cdot T_s = 18 \cdot 4.096\ ms = 73.728\ ms$$

The duration of the inactive part is:

$$T_{inactive} = BI - T_{CFP} - T_s = 1.28 - 0.073728 - 0.004096 = 1.202\ s$$

The active time is:

$$T_{active} = (N_{CFP} + 1) \cdot T_s = 19 \cdot 4.096 = 77.824\ ms$$

The duty cycle of the system is:

$$\eta = \frac{T_{active}}{BI} = \frac{0.077824}{1.28} = 6.08\%$$

1.3 Answer 3

Starting from the duty cycle formula, we have:

$$\eta = \frac{(N_{CFP} + 1) \cdot T_s}{BI}$$

The requirements state that this value must be less than 10%, so we obtain:

$$\frac{(N_{CFP} + 1) \cdot T_s}{BI} < 0.1$$

$$N_{CFP} < \frac{0.1 \cdot BI}{T_s} - 1 = \frac{0.1 \cdot 1.28}{0.004096} - 1 \simeq 30$$

Each camera requires $\frac{4800 \ bit/s}{800 \ bit/s} = 6$ slots in the worst scenario , so the maximum number of cameras is:

$$N^* = \frac{N_{CFP}}{6} = \frac{30}{6} = 5$$

Since we have already 3 cameras, we have to add up to $5 - 3 = 2$ cameras in order to have a duty cycle less than 10%.

We can verify the value of the duty cycle as:

$$\eta = \frac{T_{active}}{BI} = \frac{(N_{CFP} + 1) \cdot T_s}{BI} = \frac{(30 + 1) \cdot 0.004096}{1.28} = 9.92\%$$