IoT Project C 2024

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Report related to simulations and their analysis

To study our program, we decided to extract the **hit ratio** value taking into account two cases:

1) All the parameters are fixed except the **sensor data send frequency**.
   Fixed parameters: number of sensors = 4, number of balloons = 3, cache size = 40

2) All the parameters are fixed except the **number of sensors**.
   Fixed parameters: sensor data send rate = 1, number of balloons = 3, cache size = 40

In both cases, for each value chosen for the variable we made 15 simulations, in order to have a large variety of results to analyse.

In particular, for every fixed value we extracted the mean and the standard deviation of the hit ratios got. Knowing that results could be largely influenced by few outliers, to calculate those we adopted the combination of two techniques: jack-knife resampling method and the trimmed mean.
The first one for each of the 15 values, creates a new sample by omitting one value at a time. This will give us 15 subsets, each containing 14 of the original values. Then, for each subset, it calculates the mean (and the standard deviation).
The second one takes the resulting 15 means (or standard deviations) and calculates their mean, discarding the lowest and highest values. This process leads to a single value for the mean (and one for the standard deviation) for each fixed value.

Thanks to these two mechanisms, we reduced the bias from our results and made them robust against outliers. The cons are just related to the high computational cost.

Notes:

- We waited for about 100 requests per simulation before extracting the hit ratio

- We sent up to 3 requests per sensor every 6 seconds

- To make the analysis homogeneous, we adjusted the code ensuring that all the balloons received requests from the base station with the same pseudo-random distribution

Plot of the **hit ratios** related to the **variations of the sensor data send frequency**

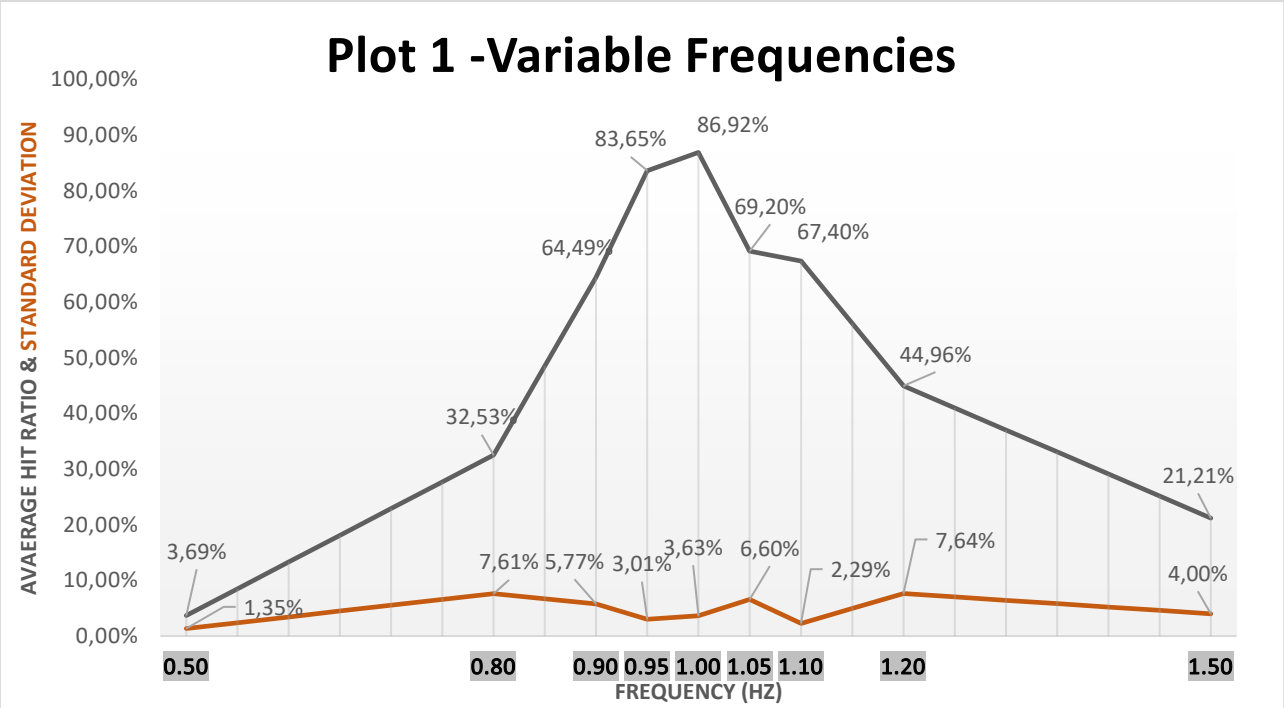

Table showing the **results of each simulation** made

Table 1 – Variable Frequencies

Sensor's data sending interval (sec)	*Hit Ratio (%) over ~ 100 requests*																
	#1	**#2**	**#3**	**#4**	**#5**	**#6**	**#7**	**#8**	**#9**	**#10**	**#11**	**#12**	**#13**	**#14**	**#15**	**Mean**	**Std Dev**
0.50	1.00	4.67	4.76	2.83	4.72	2.94	3.00	1.00	3.81	3.96	4.90	3.92	5.50	3.70	4.72	3.69	1.35
0.80	36.79	23.53	51.52	37.04	30.19	42.48	29.52	27.72	25.93	31.78	26.62	37.96	30.56	30.19	25.23	32.53	7.61
0.90	63.73	53.27	68.93	72.38	61.76	62.73	63.64	55.93	70.09	70.48	62.14	68.93	58.42	64.42	70.75	64.49	5.77
0.95	80.00	89.32	86.11	82.69	81.90	77.78	83.65	81.19	85.58	84.68	84.62	87.74	84.91	83.33	81.31	83.65	3.01
1.00	81.37	88.79	84.11	83.81	84.11	81.90	90.18	92.38	90.91	83.02	87.38	91.01	86.40	89.62	88.79	86.92	3.63
1.05	73.08	71.29	75.00	57.55	68.22	63.96	65.71	80.58	68.22	60.95	72.12	79.41	70.75	61.32	69.81	69.20	6.60
1.10	65.66	69.16	67.96	70.87	72.00	65.05	65.05	65.14	66.35	68.00	64.76	68.27	69.16	67.96	65.38	67.40	2.29
1.20	46.08	33.85	52.48	50.0	31.13	47.47	45.71	56.6	52.88	44.66	45.28	43.19	38.32	52.29	34.61	44.96	7.64
1.50	21.57	30.00	21.30	22.77	17.65	20.00	21.70	17.65	22.00	16.67	22.64	28.70	20.79	17.65	16.67	21.21	4.00

These are the values got while applying the combination of **jack-knife** and the **trimmed mean** to the hit ratios, in order **to extract means and standard deviations:**

Statistical analysis for interval = **0.50 s**:

- **Jackknife Resampled Means:** [3.89, 3.63, 3.62, 3.76, 3.62, 3.75, 3.75, 3.89, 3.69, 3.68, 3.61, 3.68, 3.57, 3.69, 3.62]
  - **Trimmed Resampled Mean: 3.69%**
- **Jackknife Resampled Standard Deviations:** [1.16, 1.37, 1.36, 1.37, 1.37, 1.38, 1.38, 1.16, 1.40, 1.39, 1.35, 1.40, 1.30, 1.40, 1.37]
  - **Trimmed Standard Deviation: 1.35%**

Statistical analysis for interval = **0.80 s**:

- **Jackknife Resampled Means**: [32.16, 33.11, 31.11, 32.14, 32.63, 31.76, 32.68, 32.81, 32.94, 32.52, 32.89, 32.08, 32.61, 32.63, 32.99]
  - **Trimmed Resampled Mean**:
- **Jackknife Resampled Standard Deviations**: [7.69, 7.35, 5.54, 7.67, 7.76, 7.24, 7.74, 7.66, 7.56, 7.78, 7.60, 7.62, 7.77, 7.76, 7.50]
  - **Trimmed Standard Deviation**:

Statistical analysis for interval = **0.90 s**:

- **Jackknife Resampled Means**: [64.56, 65.31, 64.19, 63.94, 64.70, 64.63, 64.57, 65.12, 64.11, 64.08, 64.68, 64.19, 64.94, 64.51, 64.06]
  - **Trimmed Resampled Mean**: **64.49%**
- **Jackknife Resampled Standard Deviations**: [5.95, 5.01, 5.82, 5.51, 5.91, 5.94, 5.95, 5.43, 5.74, 5.71, 5.92, 5.82, 5.70, 5.96, 5.68]
  - **Trimmed Standard Deviation**: **5.77%**

Statistical analysis for interval = **0.95 s**:

- **Jackknife Resampled Means**: [83.91, 83.25, 83.48, 83.72, 83.78, 84.07, 83.65, 83.83, 83.52, 83.58, 83.59, 83.36, 83.56, 83.68, 83.82]
  - **Trimmed Resampled Mean**: **83.65%**
- **Jackknife Resampled Standard Deviations**: [2.93, 2.65, 3.03, 3.10, 3.07, 2.61, 3.11, 3.03, 3.06, 3.09, 3.10, 2.88, 3.09, 3.11, 3.04]
  - **Trimmed Standard Deviation**: **3.01%**

Statistical analysis for interval = **1.00 s**:

- **Jackknife Resampled Means**: [87.31, 86.78, 87.12, 87.14, 87.12, 87.28, 86.69, 86.53, 86.63, 87.20, 86.89, 86.63, 86.96, 86.73, 86.79]
  - **Trimmed Resampled Mean: 86.92%**
- **Jackknife Resampled Standard Deviations**: [3.41, 3.73, 3.68, 3.66, 3.68, 3.48, 3.65, 3.43, 3.59, 3.60, 3.77, 3.58, 3.76, 3.69, 3.73]
  - **Trimmed Standard Deviation: 3.63%**

Statistical analysis for interval = **1.05 s**:

- **Jackknife Resampled Means**: [68.92, 69.05, 68.78, 70.03, 69.27, 69.57, 69.45, 68.39, 69.27, 69.79, 68.99, 68.47, 69.09, 69.76, 69.15]
  - **Trimmed Resampled Mean**: **69.20%**
- **Jackknife Resampled Standard Deviations**: [6.73, 6.80, 6.62, 5.95, 6.82, 6.66, 6.75, 5.99, 6.82, 6.40, 6.77, 6.16, 6.81, 6.44, 6.82]
  - **Trimmed Standard Deviation**: **6.60%**

Statistical analysis for interval = **1.10 s**:

- **Jackknife Resampled Means**: [67.51, 67.26, 67.34, 67.14, 67.05, 67.55, 67.55, 67.54, 67.46, 67.34, 67.57, 67.32, 67.26, 67.34, 67.53]
  - **Trimmed Resampled Mean**: **67.40%**
- **Jackknife Resampled Standard Deviations**: [2.31, 2.31, 2.36, 2.14, 1.95, 2.26, 2.26, 2.27, 2.34, 2.35, 2.24, 2.35, 2.31, 2.36, 2.29]
  - **Trimmed Standard Deviation**: **2.29%**

Statistical analysis for interval = **1.20 s**:

- **Jackknife Resampled Means**: [44.89, 45.76, 44.43, 44.61, 45.96, 44.79, 44.92, 44.14, 44.40, 44.99, 44.95, 45.10, 45.44, 44.45, 45.71]
  - **Trimmed Resampled Mean**: **44.96%**
- **Jackknife Resampled Standard Deviations**: [7.89, 7.23, 7.60, 7.77, 6.83, 7.87, 7.90, 7.16, 7.57, 7.90, 7.90, 7.88, 7.67, 7.61, 7.32]
  - **Trimmed Standard Deviation**: **7.64%**

Statistical analysis for interval = **1.50 s**:

- **Jackknife Resampled Means**: [21.16, 20.55, 21.18, 21.07, 21.44, 21.27, 21.15, 21.44, 21.13, 21.51, 21.08, 20.65, 21.21, 21.44, 21.51]
  - **Trimmed Resampled Mean**: **21.21%**
- **Jackknife Resampled Standard Deviations**: [4.11, 3.24, 4.11, 4.09, 3.98, 4.10, 4.11, 3.98, 4.10, 3.90, 4.09, 3.50, 4.11, 3.98, 3.90]
  - **Trimmed Standard Deviation**: **4.00%**

Plot of the **hit ratios** related to the **variations of the number of sensors**

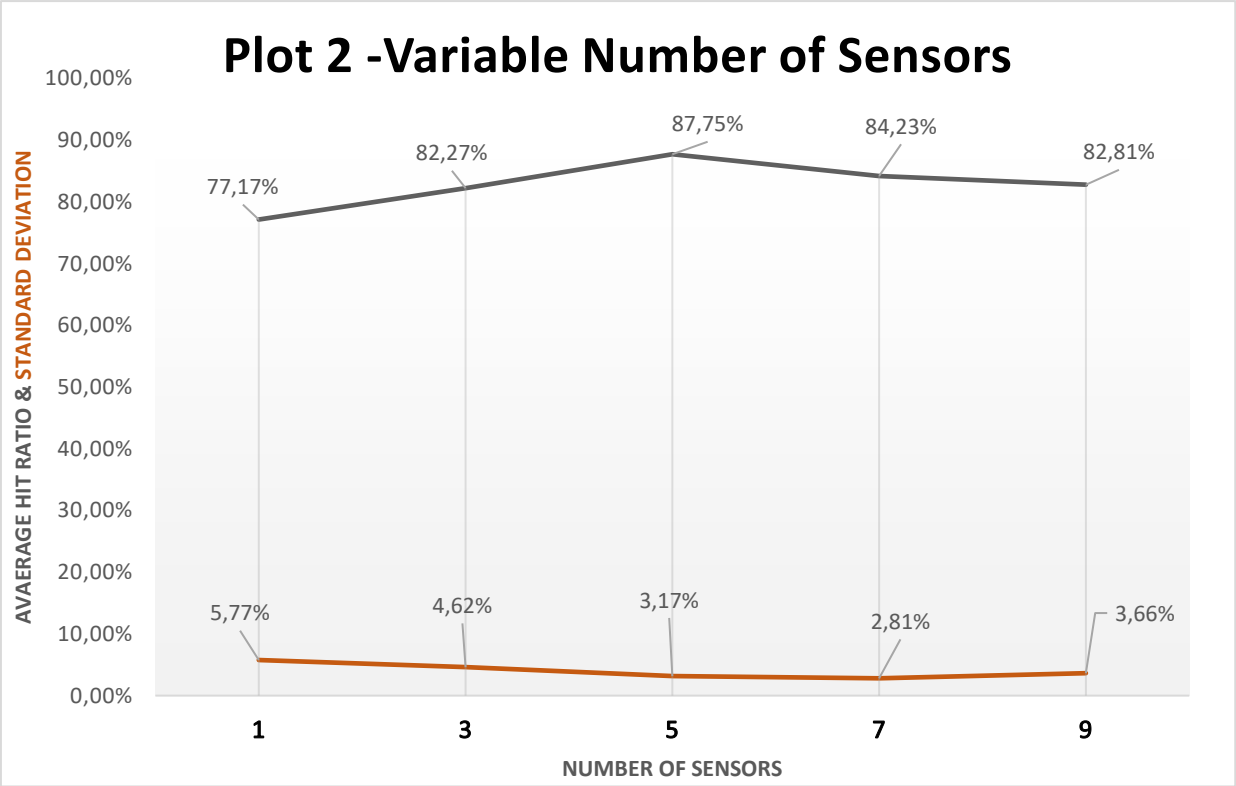

Table showing the **results of each simulation** made

Table 2 – Variable Number of Sensors

Number of Sensors	Hit Ratio (%) over ~ 100 requests																
	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10	#11	#12	#13	#14	#15	Mean	Std Dev
1	75.73	83.50	74.04	71.43	77.14	74.04	82.41	75.93	91.26	74.26	77.06	80.95	67.65	73.08	78.70	77.17	5.77
3	86.92	77.88	81.00	75.49	86.79	84.55	75.96	79.00	82.18	90.0	82.41	79.05	78.70	85.32	88.68	82.27	4.62
5	91.96	83.64	85.44	87.50	85.44	85.00	91.09	87.25	92.97	87.62	84.62	88.79	92.08	89.11	83.64	87.75	3.17
7	83.33	80.55	86.67	82.88	87.16	83.05	84.96	81.90	89.62	87.38	85.05	82.88	78.90	85.32	83.81	84.23	2.81
9	82.41	82.86	84.40	76.85	79.44	81.90	79.82	85.29	82.41	89.38	88.57	77.98	86.13	80.19	84.40	82.81	3.66

These are the values got while applying the combination of **jack-knife** and the **trimmed mean** to the hit ratios, in order **to extract means and standard deviations:**

Statistical analysis **1 sensor**:

- **Jackknife Resampled Means:**
  [77.25, 76.69, 77.37, 77.55, 77.15, 77.37, 76.77, 77.23, 76.14, 77.35, 77.15, 76.87, 77.82, 77.44, 77.03]
    - **Trimmed Resampled Mean: 77.17%**
- **Jackknife Resampled Standard Deviations:**
  [5.90, 5.63, 5.85, 5.68, 5.91, 5.85, 5.72, 5.90, 4.31, 5.86, 5.91, 5.81, 5.25, 5.80, 5.90]
    - **Trimmed Standard Deviation: 5.77%**

Statistical analysis **3 sensors**:

- **Jackknife Resampled Means**:
  [81.93, 82.58, 82.35, 82.75, 81.94, 82.10, 82.71, 82.50, 82.27, 81.71, 82.25, 82.49, 82.52, 82.04, 81.80]
    - **Trimmed Resampled Mean**: **82.27%**
- **Jackknife Resampled Standard Deviations**:
  [4.60, 4.62, 4.77, 4.37, 4.61, 4.74, 4.43, 4.69, 4.79, 4.24, 4.79, 4.70, 4.68, 4.71, 4.42]
    - **Trimmed Standard Deviation**: **4.62%**

Statistical analysis for **5 sensors**:

- **Jackknife Resampled Means**:
  [87.44, 88.04, 87.91, 87.76, 87.91, 87.94, 87.50, 87.78, 87.37, 87.75, 87.97, 87.67, 87.43, 87.65, 88.04]
    - **Trimmed Resampled Mean**: **87.75%**
- **Jackknife Resampled Standard Deviations**:
  [3.05, 3.06, 3.21, 3.28, 3.21, 3.19, 3.14, 3.28, 2.92, 3.28, 3.16, 3.27, 3.04, 3.26, 3.06]
    - **Trimmed Standard Deviation**: **3.17%**

Statistical analysis for **7 sensors**:

- **Jackknife Resampled Means**:
  [84.29, 84.49, 84.06, 84.33, 84.02, 84.31, 84.18, 84.40, 83.85, 84.01, 84.17, 84.33, 84.61, 84.15, 84.26]
    - **Trimmed Resampled Mean**: **84.23%**
- **Jackknife Resampled Standard Deviations**:
  [2.89, 2.70, 2.81, 2.87, 2.78, 2.88, 2.89, 2.82, 2.45, 2.76, 2.89, 2.87, 2.46, 2.88, 2.90]
    - **Trimmed Standard Deviation**: **2.81%**

Statistical analysis for **9 sensors**:

- **Jackknife Resampled Means**:
  [82.83, 82.80, 82.69, 83.23, 83.04, 82.87, 83.02, 82.62, 82.83, 82.33, 82.39, 83.15, 82.56, 82.99, 82.69]
    - **Trimmed Resampled Mean: 82.81%**
- **Jackknife Resampled Standard Deviations**:
  [3.78, 3.78, 3.75, 3.37, 3.65, 3.77, 3.68, 3.71, 3.78, 3.27, 3.40, 3.52, 3.66, 3.70, 3.75]
    - **Trimmed Standard Deviation: 3.66%**

Final considerations

Plot 1:

The hit ratio reaches its peaks with small variations of the sensor data send rate with respect to the standard value (1.00 Hz), while it drops when variations of +/- 30-50% occur, and this makes sense since these are extreme cases that create a strong mismatch between the transmission, reception, and processing of data in the cache.
The standard deviation, instead, is not affected by the same variability. Indeed, it ranges between 1.35% and 7.64%, meaning that values were quite close to the mean and not too much spread.

Plot 2:

The hit ratio is not much influenced by the number of sensors; indeed, it reaches always high values. This was predictable given that we dropped the balloons in best possible way, in order to cover all the field regardless of the number of sensors.
For the same reason, the standard deviation has little variations (2.81%-5.77%).

Final remark

This is the python code used to calculate means and standard deviations through jack-knife resampling method and trimmed mean:

```
import numpy as np


def jackknife_resampling(data):
    n = len(data)

    # Arrays to store resampled means and standard deviations
    jackknife_means = np.zeros(n)
    jackknife_stds = np.zeros(n)

    # Perform Jackknife resampling
    for i in range(n):
        # Exclude the i-th element and calculate the statistics
        resampled_data = np.delete(data, i)
        jackknife_means[i] = np.mean(resampled_data)
        jackknife_stds[i] = np.std(resampled_data, ddof=1)  # ddof=1 for
sample std deviation

    return jackknife_means, jackknife_stds

def remove_max_min_and_calculate_mean(data):
    # Sort data and remove the maximum and minimum values
    sorted_data = np.sort(data)
    trimmed_data = sorted_data[1:-1]  # Remove the smallest and largest values

    # Calculate the mean of the remaining values
    mean_trimmed = np.mean(trimmed_data)

    return mean_trimmed

def main():
    # Input: string of numbers separated by space
```

```
    input_str = input("Enter the set of numbers separated by space: ")

    # Convert input string into a list of floats
    data = np.array([float(num) for num in input_str.split()])

    # Perform Jackknife resampling
    jackknife_means, jackknife_stds = jackknife_resampling(data)

    # Output the results
    print("\nJackknife Resampled Means:")
    print(", ".join(f"{mean:,.2f}" for mean in jackknife_means))
    print("\nJackknife Resampled Standard Deviations:")
    print(", ".join(f"{std:,.2f}" for std in jackknife_stds))

    trimmed_mean = remove_max_min_and_calculate_mean(jackknife_means)
    trimmed_stdv = remove_max_min_and_calculate_mean(jackknife_stds)

    print("\nJackknife Trimmed Mean:")
    print(trimmed_mean)
    print("\nJackknife trimmed Standard Deviation:")
    print(trimmed_stdv)

    real_mean = np.mean(data)
    print(real_mean)


if __name__ == "__main__":
    main()
```