EchoPulse Benchmark Enhancements (Document C6, internally labeled 14.1)

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This document details several advanced enhancements to the existing benchmarking and performance analysis framework for the EchoPulse Key Encapsulation Mechanism (KEM). These additions aim to provide improved visual clarity, presentation-ready metrics, and the inclusion of forward-looking energy consumption profiles.

1. Component Time Distribution Table

This table presents the estimated percentage of the total cycle time attributed to the major computational components of the EchoPulse encapsulation process (SHA3-256, symbolic δ-transitions, and graph mutation) for each target platform. These distributions provide insights into the performance bottlenecks on different architectures.

Platform	SHA3 (%)	Transition (%)	Mutation (%)	Notes
M0+	70%	25%	5%	Based on L=28
M4F	60%	35%	5%	SHA3 is HW-assisted
RV64	50%	45%	5%	Fully optimized case

Note: These percentages are based on the estimated cycle counts provided in Document C2 and assume a single row mutation occurs during the encapsulation cycle (for approximation purposes). The transition percentage is calculated based on 28 symbolic transitions during encapsulation.

2. Heatmap Preparation

Generating a color-coded timing heatmap can provide a compelling visual representation of the performance breakdown across different operations and platforms. This can be achieved using libraries like `matplotlib` in Python. The heatmap would typically have the following structure:

* **Axes:**
  * X-axis: Platforms (M0+, M4F, RV64)
  * Y-axis: Operations (Encapsulation, Decapsulation, SHA3, Transition, Mutation)
* **Cell Values:** The timing (in µs) for each operation on each platform.
* **Color Coding:** A gradient color scheme where intensity represents the execution time (e.g., lighter colors for faster times, darker colors for slower times).

Legend Suggestion: A color bar should be included to clearly map the color intensity to the corresponding time values in microseconds.

Chart Dimensions: A suggested size for presentation purposes is 8 inches (width) by 6 inches (height), ensuring readability of labels and color scale.

Optional: Python Export Template:

```python
import matplotlib.pyplot as plt
import numpy as np
import pandas as pd
import seaborn as sns

# Sample data (replace with actual benchmark data)
data = {'Platform': ['M0+', 'M0+', 'M0+', 'M0+', 'M4F', 'M4F', 'M4F', 'M4F', 'RV64', 'RV64', 'RV64', 'RV64'],
        'Operation': ['Encapsulation', 'Decapsulation', 'SHA3', 'Mutation', 'Encapsulation', 'Decapsulation', 'SHA3', 'Mutation', 'Encapsulation', 'Decapsulation', 'SHA3', 'Mutation'],
```

Note: These energy figures are rough approximations based on typical power consumption characteristics of microcontrollers at their specified clock speeds. Actual energy consumption will depend on the specific device, voltage levels, and other active peripherals. The "Source" column indicates the assumed energy per cycle for the calculation.

This Python script demonstrates how to use seaborn to generate a basic heatmap from benchmark data. The actual data would need to be populated from the benchmark results.

3. Energy Profile Addition (Optional C6)

Estimating the energy consumption per encapsulation operation provides a crucial metric for evaluating the suitability of EchoPulse for energy-constrained devices. This table presents approximated energy figures based on typical energy-per-cycle values for the target platforms.

4. Conclusion

The enhancements outlined in this document provide valuable, presentation-ready metrics for showcasing the performance characteristics of the EchoPulse KEM. The component time distribution offers a clear breakdown of computational cost, the heatmap provides an intuitive visual comparison across platforms and operations, and the energy profile offers a forward-looking metric crucial for IoT and embedded applications. It is recommended to present these enhanced metrics in separate slides or appendices for clarity in academic or technical comparisons, such as those for QCE (IEEE International Conference on Quantum Computing and Engineering), PQCrypto conferences, or NIST PQC standardization evaluations.

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Document C6 (14.1) — Performance Metrics Enhancement Layer — EchoPulse Initiative

```
    'Time (µs)': [9375, 8125, 2500, 4, 375, 325, 100, 0.5, 167, 150, 42, 1]}



df = pd.DataFrame(data)

pivot_table = df.pivot_table(values='Time (µs)', index='Operation', columns='Platform')



plt.figure(figsize=(8, 6))

sns.heatmap(pivot_table, annot=True, fmt=".1f", cmap="viridis", cbar_kws={'label': 'Time (µs)'})

plt.title('EchoPulse Operation Timing Heatmap')

plt.ylabel('Operation')

plt.xlabel('Platform')

plt.tight_layout()

plt.savefig('echopulse_timing_heatmap.png')

plt.show()
```