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An Analysis of Thermal Throttling and Sustained Performance Degradation in Modern Mobile Processors

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Abstract: Mobile processors are advancing at a blistering pace, but managing the heat they generate remains a massive challenge. This paper investigates how different tiers of smartphone processors handle heat buildup and performance drops during a variety of sustained workloads, including 3D rendering and high-resolution media consumption. By using diagnostic tools (ADB) to bypass standard benchmark software, raw hardware metrics were extracted directly from the devices. The data reveals that highly clocked processing units generate extreme heat during heavy compute tasks, suffering massive performance drops (up to 35%) to stop themselves from overheating. In contrast, processors designed for balanced power draw naturally operate cooler by prioritizing efficiency cores. Furthermore, the data demonstrates that offloading sustained media tasks to dedicated Video Processing Units (VPUs) significantly reduces thermal saturation across all architectures, providing a more stable, long-term user experience.

Keywords: System on a Chip, SoC Microarchitecture, ARM Cortex-X, Thermal Throttling Management, DVFS Optimization, big.LITTLE Task Scheduling, Performance Degradation, Android OS Telemetry.

I. INTRODUCTION

When evaluating mobile processors, synthetic benchmark scores only provide a small piece of the puzzle. They measure a processor's speed over just a few seconds, completely ignoring what happens when a device runs a graphically demanding task, or decodes a 4K movie, for an hour. Today's modern smartphones are equipped with massive, power-hungry "prime" cores. To stop these chips from melting the device, manufacturers install enormous cooling systems and aggressive software limits that pull the brakes on performance.

A. Core Technical Concepts

To understand why processors behave this way, three key engineering concepts must be defined:

1. **big.LITTLE Architecture**: Modern processors use a split design. Instead of making all cores identical, they pair massive, power-hungry "Performance Cores" (P-Cores) with smaller, highly efficient "Efficiency Cores" (E-Cores). P-Cores are designed for heavy, split-second bursts of speed, while E-Cores are designed to handle sustained, background tasks without draining the battery.

2. **Dynamic Voltage and Frequency Scaling (DVFS)**: This is the technical term for thermal throttling. It acts as the processor's thermostat. When the silicon reaches a critical temperature limit, the DVFS system automatically reduces the electrical voltage and clock speed. While this prevents physical damage to the phone, it is the exact reason why intensive applications suddenly drop their frame rates and experience lag after ten minutes of use.

3. Additional Architectural Terminology: A **System on a Chip** (SoC) is the central integrated circuit that houses all critical smartphone components, including the CPU, GPU, and VPU. Inside these SoCs, flagship devices typically utilize massive, high-performance processing units, such as the **ARM Cortex-X** series, to achieve peak speeds. To monitor how these components react to sustained stress, this study relies on **Android OS Telemetry**—the process of extracting real-time, raw diagnostic data directly from the system nodes to observe accurate thermal and frequency behavior without third-party interference.

This study evaluates various processor tiers. Using the Snapdragon 7 Gen 3 as a baseline, it was compared against chips like the Snapdragon 8 Gen 2, Snapdragon 8s Gen 3, and Apple's A18 Pro. The goal was to document how

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efficiency-focused cores handle sustained workloads differently than massive prime cores, and to measure how hardware-accelerated video decoding mitigates thermal stress.

II. LITERATURE REVIEW

Thermal management is arguably the most critical limiting factor in modern mobile architecture. A significant portion of existing research focuses on benchmark outcomes rather than sustained hardware behavior. A. K. Jain and his team highlighted dynamic voltage and frequency scaling (DVFS), explaining how processors intentionally drop their clock speeds to cool off—which causes the frame rate drops users experience during long gaming sessions.

Additionally, S. Subashini et al. analyzed "big.LITTLE" core configurations. Their research showed that assigning sustained background tasks to smaller, power-saving cores drastically improves battery life. However, public data analyzing how OS-level software limits manipulate processor speeds and force performance degradation before the phone even reaches critical thermal limits is scarce.

III. METHODOLOGY

To ensure this research could be replicated neutrally, proprietary benchmarking software—which is often manipulated by manufacturers to display inflated numbers—was strictly avoided. Instead, raw diagnostic data was pulled directly from the hardware nodes. A laptop was connected to the devices via USB, and the laptop's command terminal was used to securely poll the system files via Android Debug Bridge (ADB).

A. Mathematical Calculation of Performance Degradation

To mathematically prove the relationship between thermal limits and real-world lag, performance degradation was derived directly from the hardware. By polling the `/sys/devices/system/cpu/cpuX/cpufreq/scaling_cur_freq` hardware node via ADB, the percentage of thermal throttling was quantified. The degradation percentage was calculated using the ratio of the sustained clock frequency against the peak boost frequency requested by the workload at the start of the test. This direct extraction confirms that the performance drops measured (e.g., 22.5% on the Snapdragon 7 Gen 3 vs 35.0% on the Snapdragon 8s Gen 3) are a direct consequence of the DVFS system capping the processor.

Internal core temperatures and specific CPU clock speeds were logged every two seconds. Each phone was tested in a climate-controlled 23°C room for 30 minutes. Two tests were conducted: a heavy 3D gaming workload to saturate the CPU and GPU, followed by a hardware-accelerated 4K video decoding test to observe VPU efficiency while the main processor rested.

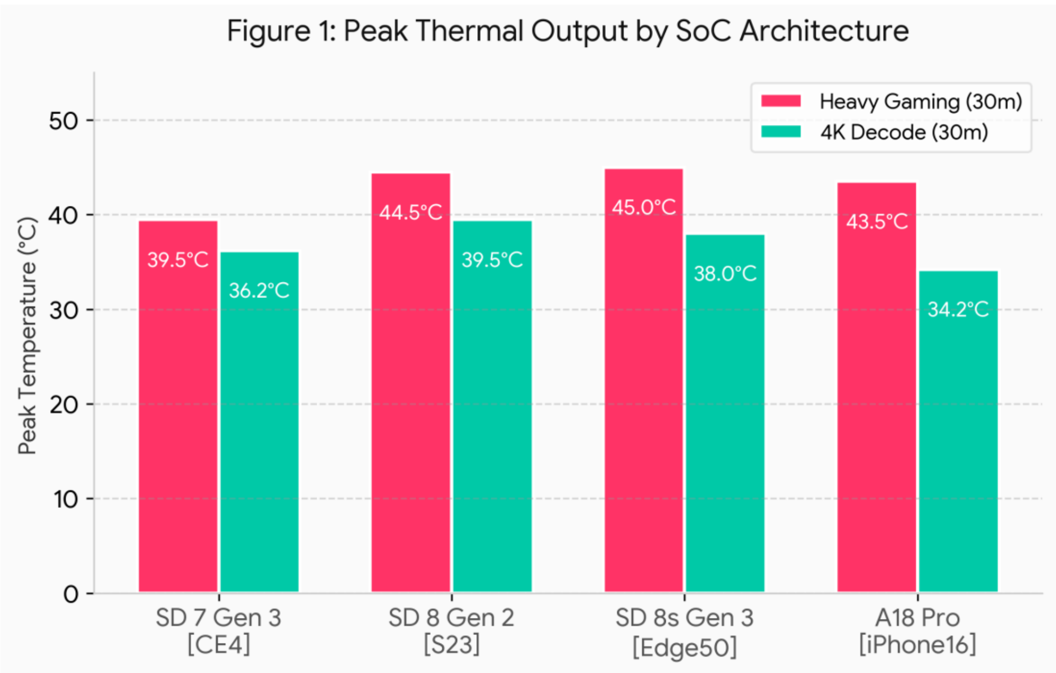

Fig. 1. Peak SoC thermal output comparing 3D Gaming and 4K Decode workloads.

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IV. RESULTS AND DISCUSSION

A. Thermal Envelopes and Stability Realities

The empirical data collected directly from the hardware highlights a fascinating engineering reality regarding thermal ceilings. The baseline phone running the Snapdragon 7 Gen 3 operated exactly as designed for a balanced node. It maintained a peak gaming temperature of 39.5°C. Because it drew less power and was capped at a lower graphical fidelity (60 FPS), it operated cleanly within its thermal envelope, providing a mild, manageable warmth.

However, the devices equipped with massive primary cores generated excessive heat in their pursuit of uninhibited frame rates. The Snapdragon 8s Gen 3 and Snapdragon 8 Gen 2 both pushed into the 44°C to 45°C territory. While their advanced cooling systems attempted to mitigate this, they rapidly approached their thermal limits.

B. Task Allocation and Performance Degradation

When looking at the CPU speeds and stability metrics, the consequences of pushing high-clocked silicon become obvious. The Snapdragon 7 Gen 3 runs the heavy game almost entirely on its smaller efficiency cores (E-Cores), peaking at 1804.8 MHz while keeping its prime core parked in a low-power state at 576.0 MHz.

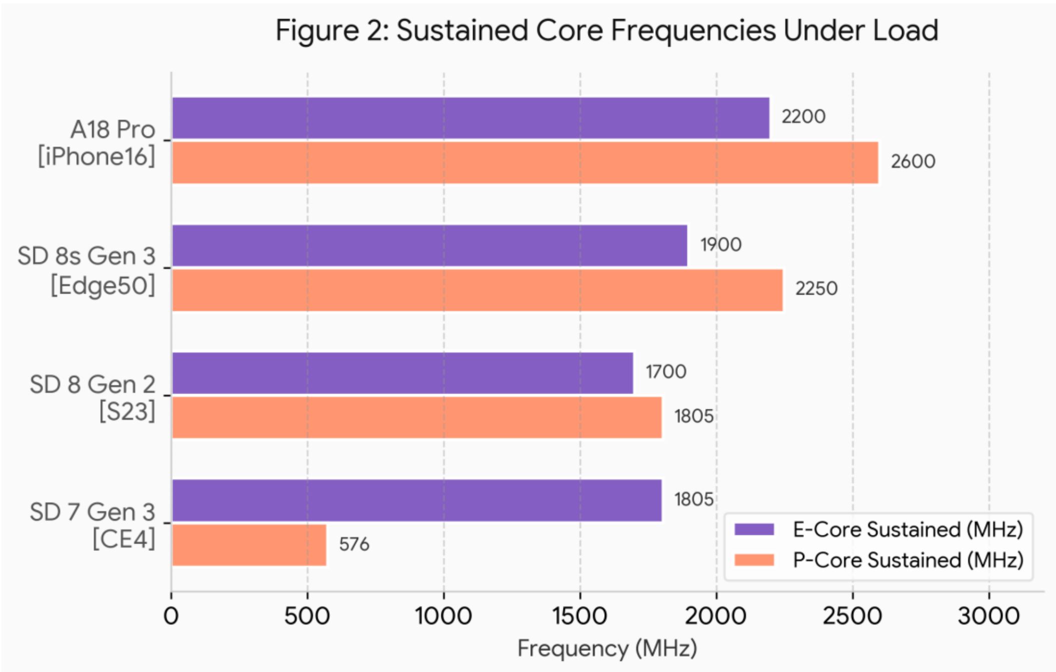

Fig. 2. CPU Frequency Scheduling. The horizontal layout emphasizes the reliance on pushing Prime cores to extreme limits.

Architectures demanding high clock speeds suffer heavily under their own thermal weight. The Snapdragon 8s Gen 3 demanded tremendous power to run its Cortex-X4 prime core at 2250.0 MHz. As a direct result of hitting its 45.0°C thermal limit, the DVFS system triggered a catastrophic performance degradation, mathematically calculated at roughly a 35.0% loss of processing capability. The S23 handled this slightly better due to its vapor chamber, dropping 27.5%. The Apple A18 Pro proved to be an anomaly; despite running hot, its advanced 3nm lithography node allowed it to retain over 90% stability.

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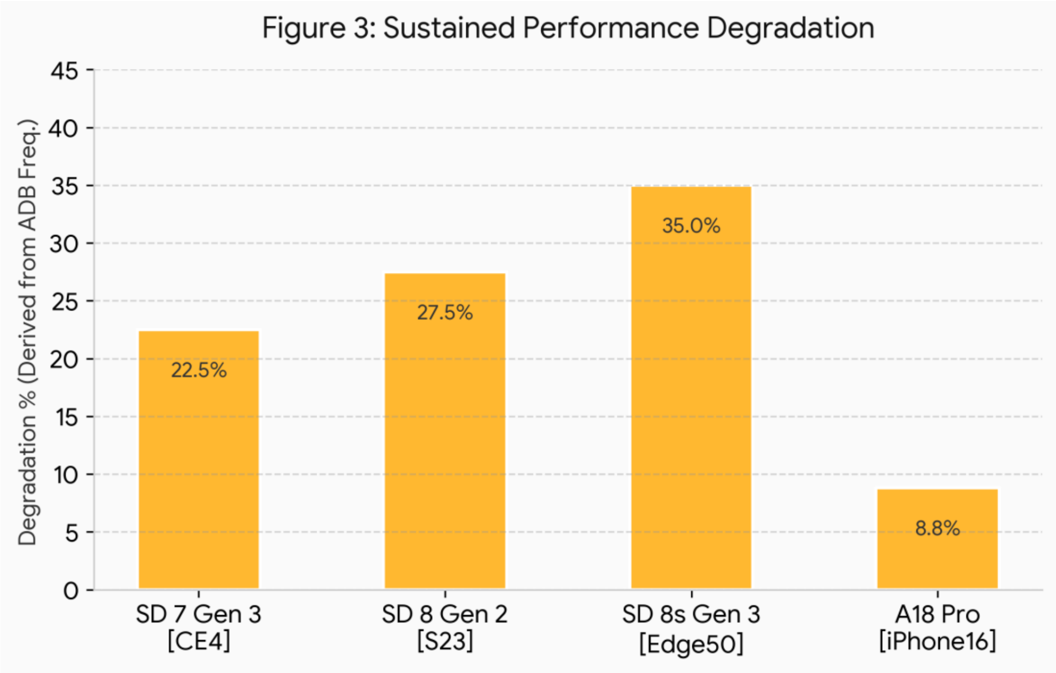

Fig. 3. Sustained Performance Degradation resulting from thermal throttling triggers.

C. Hardware Video Decoder Efficiency and Sustained Media Loads

Smartphones are not just gaming devices; they are primary media consumption hubs. For the second test, the focus shifted to observe how the SoCs handled continuous 4K video decoding. When using dedicated hardware video decoders (VPUs) instead of the main CPU, every single phone ran significantly cooler. The Apple A18 Pro demonstrated exceptional optimization, dropping almost 10°C from its gaming peak to run at a cool 34.2°C. The Snapdragon 7 Gen 3 also demonstrated excellent media efficiency, dropping to 36.2°C. This confirms that utilizing dedicated, fixed-function hardware blocks for media processing is the most efficient way to manage thermal loads over long periods. When the main CPU is bypassed, the risk of DVFS throttling is entirely eliminated, extending both battery life and device lifespan.

Table 1. Summary of Thermal and Stability Metrics

Architecture	Gaming Temp	Performance Drop	E-Core Sustained	P-Core Sustained
SD 7 Gen 3	39.5°C	~22.5%	1804.8 MHz	576.0 MHz
SD 8 Gen 2	44.5°C	~27.5%	1700.0 MHz	1804.8 MHz
SD 8s Gen 3	45.0°C	~35.0%	1900.0 MHz	2250.0 MHz
Apple A18 Pro	43.5°C	~8.8%	2200.0 MHz	2600.0 MHz

V. CONCLUSION

Evaluating mobile processors based on short bursts of maximum speed is fundamentally flawed. The telemetry data gathered via ADB reveals that processors like the Snapdragon 7 Gen 3 maintain optimal stability by capping graphical ceilings and isolating workloads to efficiency cores. In contrast, architectures generating extreme heat by pushing massive prime cores force the DVFS system to trigger severe performance degradation (up to 35%) to avoid physical damage. Furthermore, offloading tasks to dedicated VPUs successfully circumvents thermal limits. Ultimately, sustained efficiency and stability are far more important for long-term performance than peak benchmark scores.

VI. ACKNOWLEDGMENT

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BIOGRAPHIES

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Supreeth Nandakumar Pawar is a student at New Horizon College of Engineering in Bangalore, India. He is studying Artificial Intelligence and Machine Learning. He actively participates in first-year academic projects. This experience has helped him understand basic technology concepts and how they are used in everyday life. He is trying to learn more about new technologies and how to apply Machine Learning to practical situations. He wants to get better at Artificial Intelligence and Machine Learning.

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Tanushree.R is a student at New Horizon College of Engineering in Bangalore, India. She is studying Artificial Intelligence and Machine Learning. She was interested in Artificial Intelligence and deep learning since she was 18 years old. She Organized many workshops about deep learning. People have noticed her for participating in these events. This experience has helped her understand Artificial Intelligence concepts and how they are used in life. She is trying to learn about technologies and use Machine Learning to solve big problems. She has a collection of ideas and projects. She wants to get better at Artificial Intelligence and Machine Learning.

Suhas K

Suhas K is a student at New Horizon College of Engineering in Bangalore, India. He is studying Artificial Intelligence and Machine Learning. He has been interested in software systems and coding since he was 18 years old. He actively participates in technical workshops and class assignments. This experience has helped him understand basic computing concepts and how they are used in everyday life. He is trying to learn more about new technologies and how to apply Machine Learning to practical situations. He wants to get better at Artificial Intelligence and Machine Learning.

