

Energy and Performance of Smartphone Radio Bundling in Outdoor Environments

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Radio Bundling

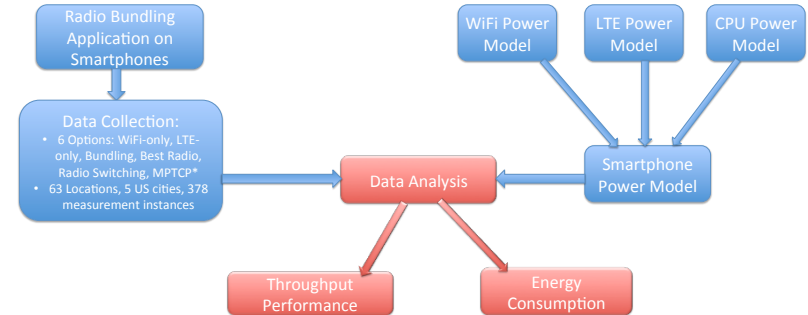


Use **WiFi + LTE** at the same time on smartphones

Questions:

1. What is the maximum benefit that can be provided by bundling?
2. What are the energy costs of achieving that performance gain?
3. What role do CPU and radio interfaces play in the energy profile of radio bundling protocols?

Methodology



*MPTCP (Multipath TCP) is a bundling protocol implementation in the transport layer that aims to be fair to TCP users.

Throughput Performance

Metric: $R_x = \frac{THROUGHPUT_x}{THROUGHPUT_{bundling}}$ against $q = \frac{THROUGHPUT_{WiFi}}{THROUGHPUT_{LTE}}$

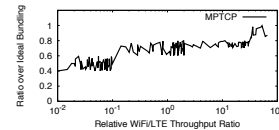
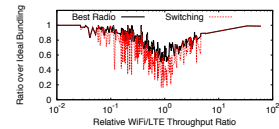
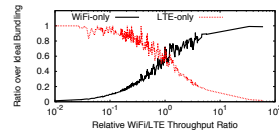
where X can be WiFi-only, LTE-only, Best Radio, Radio Switching, MPTCP

- The throughput of Bundling is the sum of the LTE radio throughput and the WiFi throughput.

$$R_{LTE-only} \approx \frac{1}{1+q} \quad \text{and} \quad R_{WiFi-only} \approx \frac{q}{1+q}$$

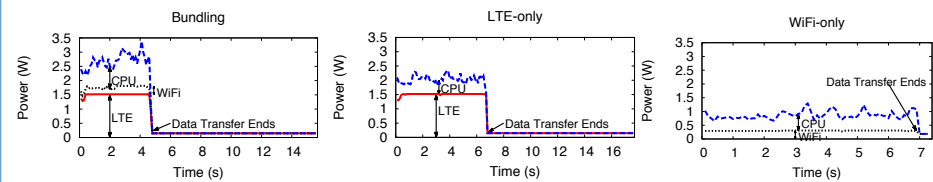
- Bundling can achieve up to 2x throughput gain over Best Radio.
- Bundling can have up to 5x throughput gain over Radio Switching, because of switching overhead.

- MPTCP is able to achieve 40%-85% of the optimal Bundling performance.
- MPTCP is insensitive to the relative RF condition between WiFi and LTE.



Energy Consumption

Instantaneous Componentized Power Draw



- The LTE radio is the heaviest energy consumer. Consumes at least 50% of the total power draw.
- CPU consumes a significant amount of energy. Median value of CPU energy consumption over total energy is 20% for LTE-only and MPTCP, 23% for Bundling, and 60% for WiFi-only.
- Bundling consumes less energy compared to LTE-only, despite turning on the extra WiFi radio. This is because Bundling improves the transfer throughput so that the transfer ends earlier.

$$Cost_x = \frac{Energy_{Bundling}}{Energy_x} \quad \text{against} \quad \frac{1}{R_x}$$

where X can be WiFi-only, LTE-only, MPTCP

