Storage on Your Smartphone Uses More Energy Than You Think

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Limited battery capacity is a major concern!

However, battery density doubles only once every 10 years

What consumes battery?

Usual suspects: screen, network

Is storage a major contributor?

Storage subsystem takes

36%

Of total energy for random IO intensive workload.

Measure energy

Differentially

to segregate storage sub-system energy on a commercial smartphone.

Random writes take

20x

more energy than sequential writes.

Random reads take

8x

more energy than sequential reads.

Outline

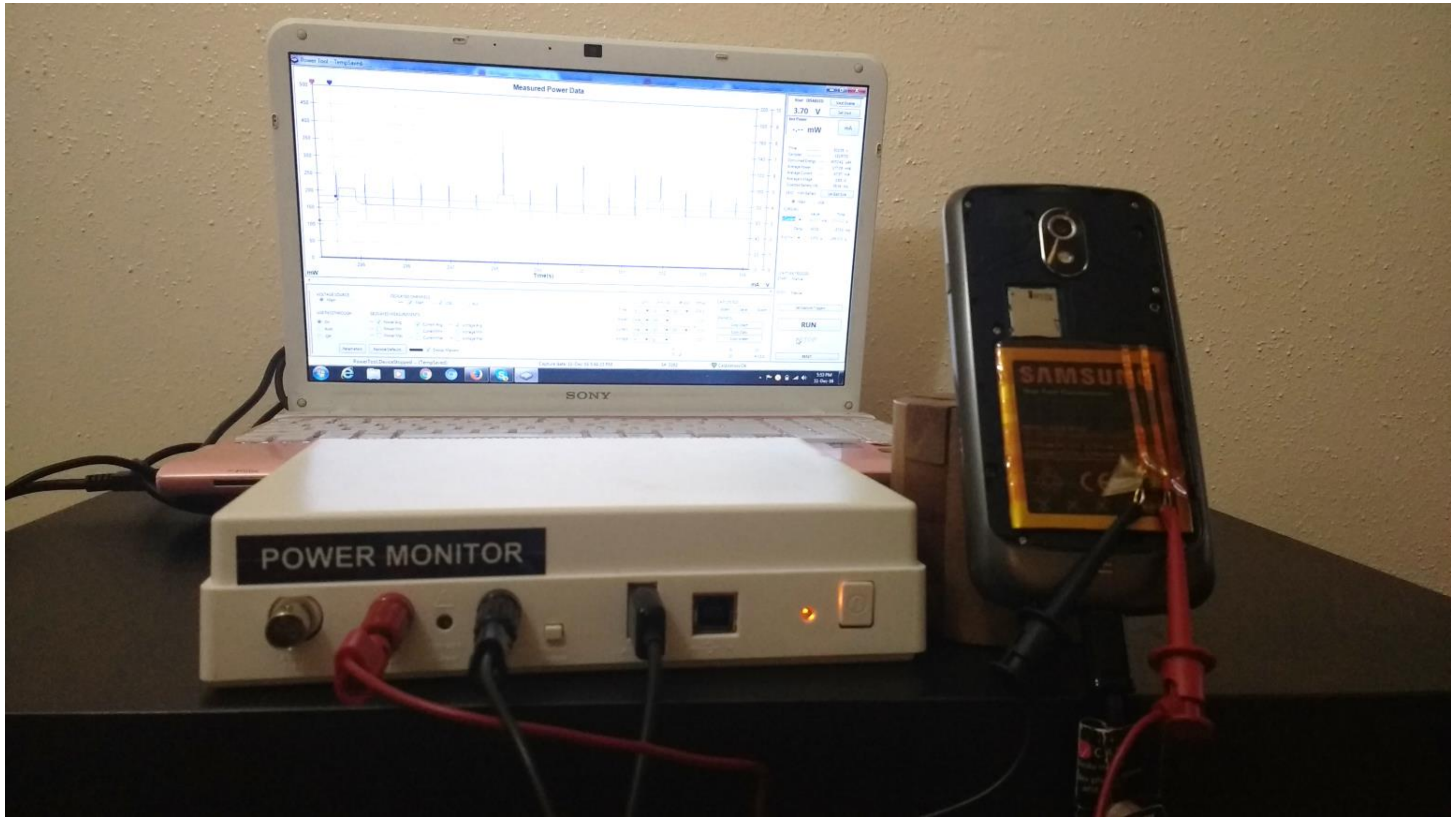
- Overview
- How do we measure storage energy?
- Energy at different layers of storage stack
  - File IO Operations
  - SQLite Operations
  - Android applications
- Implications for File System Design
- Conclusions

Tools to measure energy

- Software Based:
  - Battery sensor: Periodically check current battery level
  - Apps: Requires power models.
  - Very crude measure.
  - Cannot detect small consumptions.

- Hardware Based:
  - More fine-grained measure.
  - Requires specialized hardware to get component-wise energy.

Experimental setup

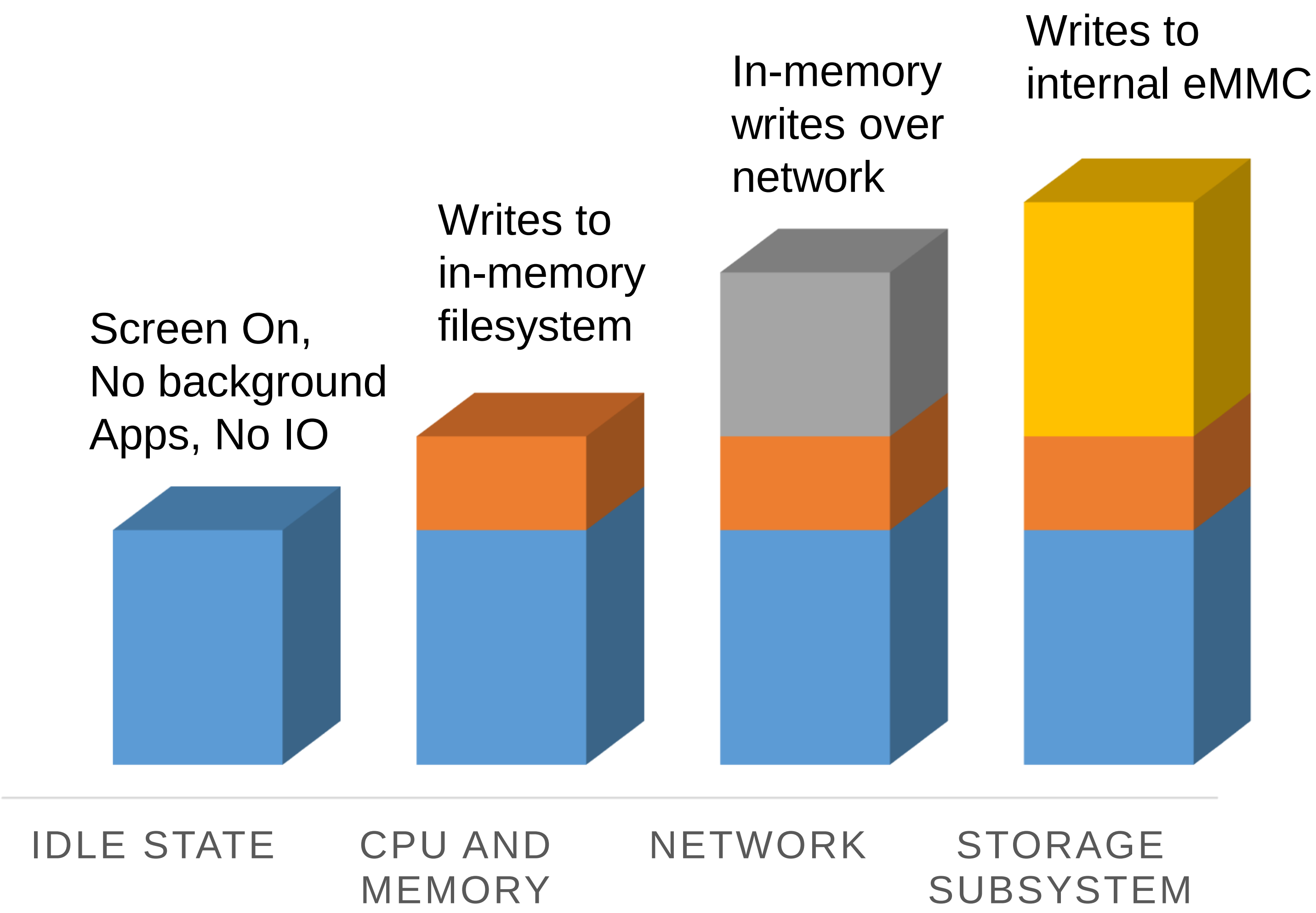


Samsung Galaxy nexus connected to Monsoon Power Monitor

Differential Energy Analysis

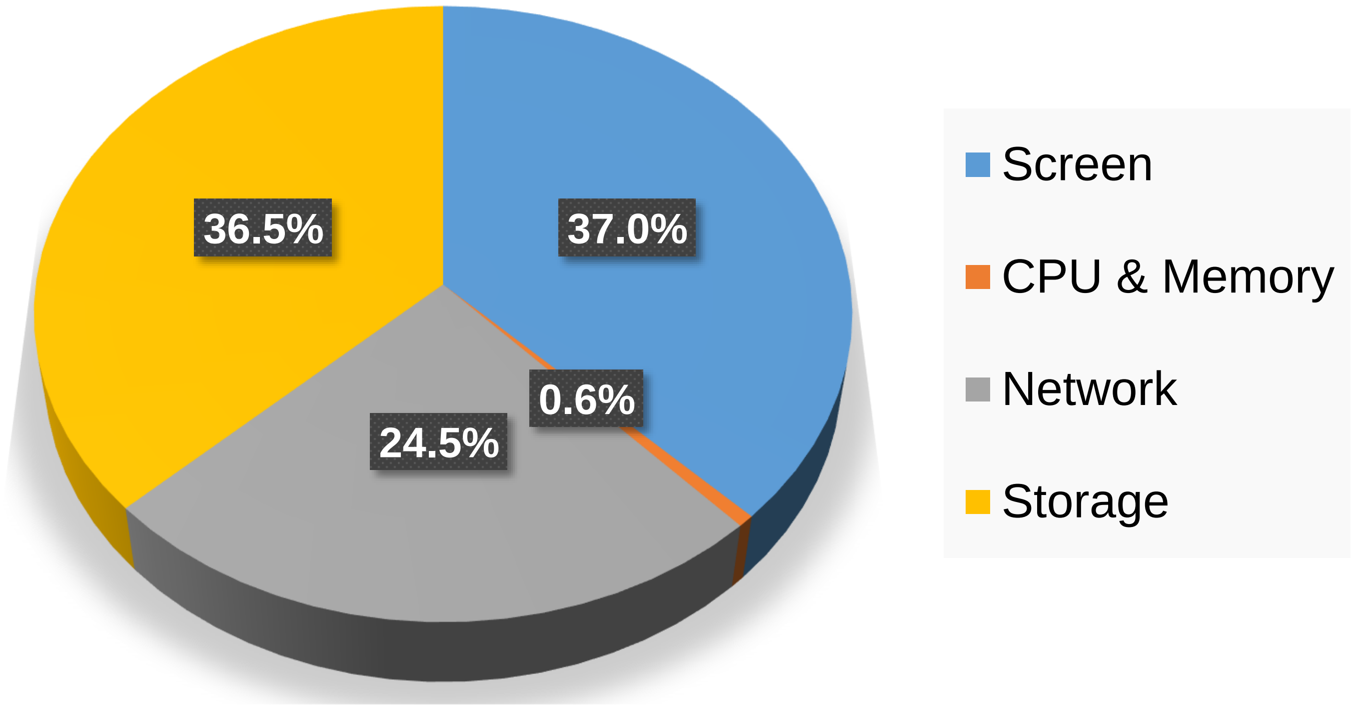
- Hardware tools provide fine-grained energy measurements, but not component-wise.
- Design experiments to measure energy “differentially”.
- IO intensive Workload: 100 MB of random writes of IO size 4KB.

Differential energy measurement



Overall Storage Energy Consumption

- Energy consumed by storage subsystem is almost ***equal*** to the energy consumed by screen for an IO intensive workload.



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File IO operations

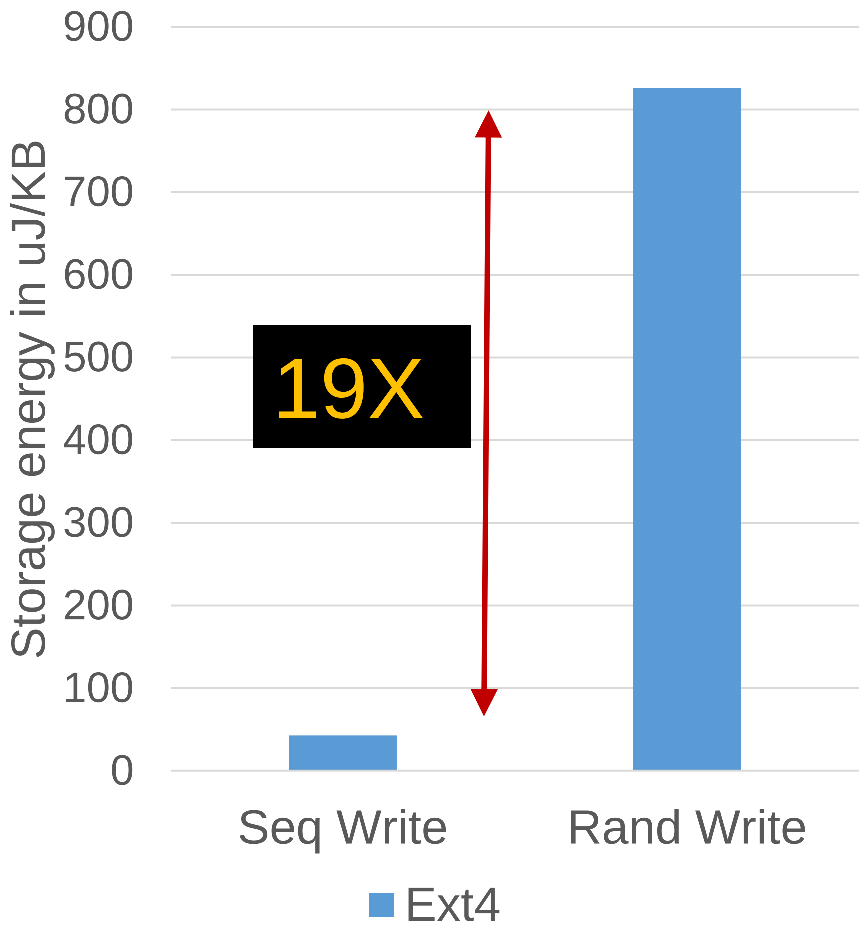
Sequential IO Workload:

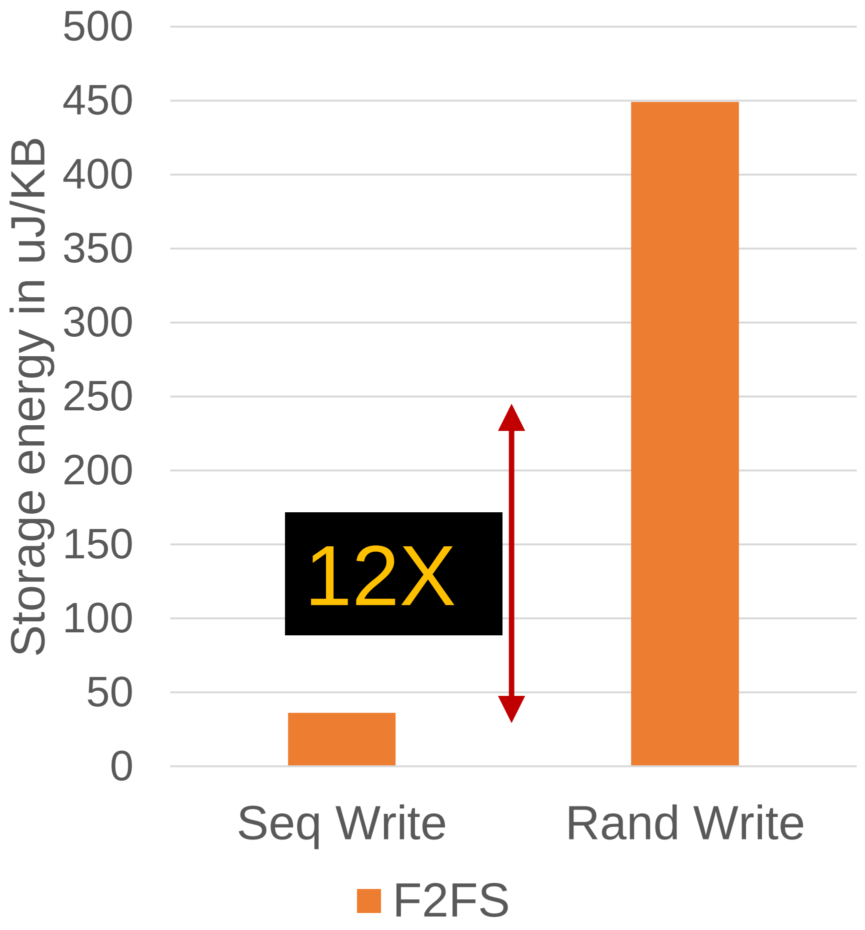
- **IO Size :** 512KB blocks.
- **Total IO :** 1GB of file reads and writes.

Random IO Workload:

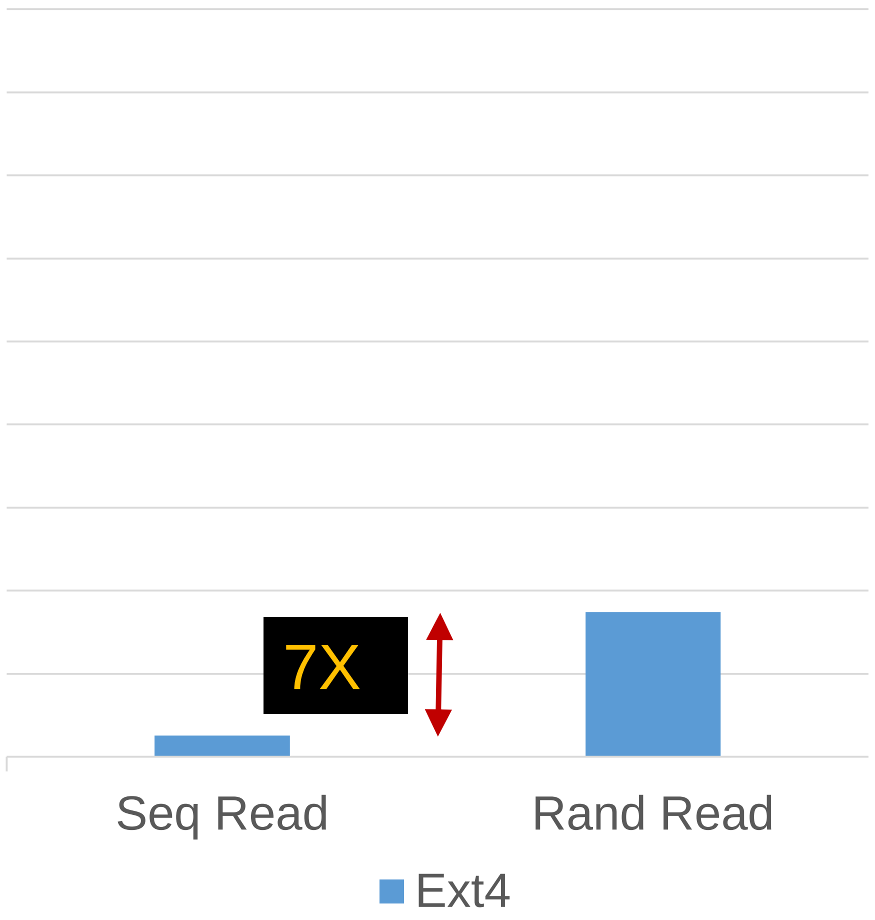
- **IO Size :** 4KB blocks.
- **Total IO :** 100MB of file reads and writes.
- Fsync issued after every IO request.

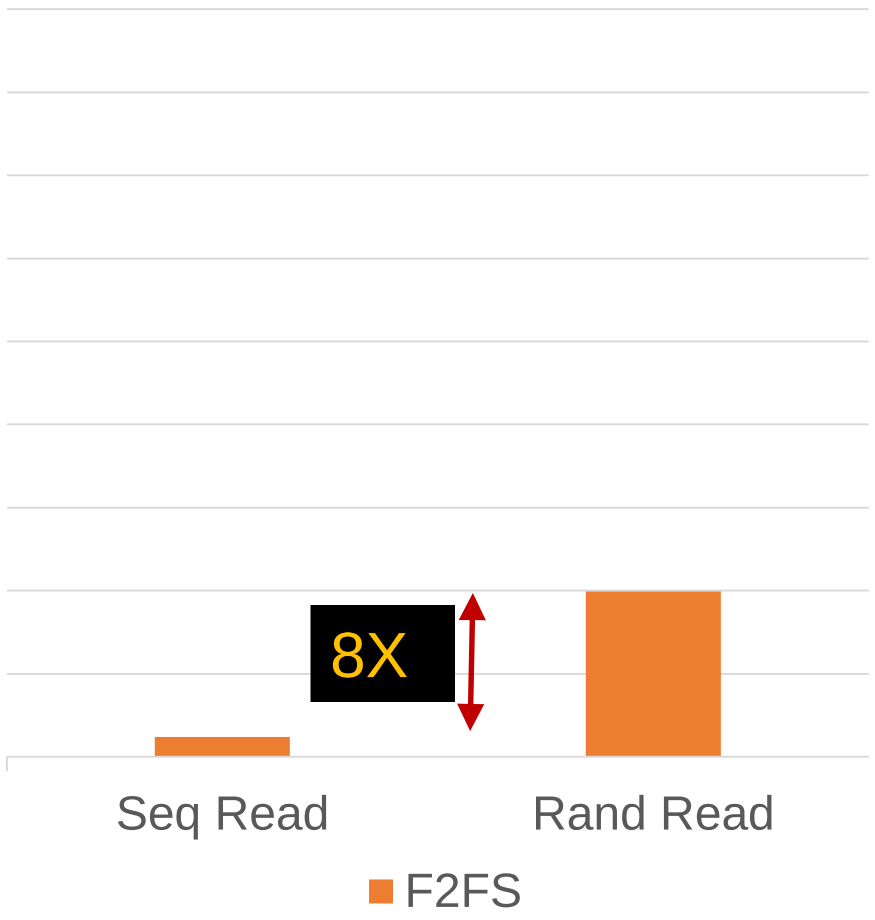
F2FS vs Ext4 : File ops



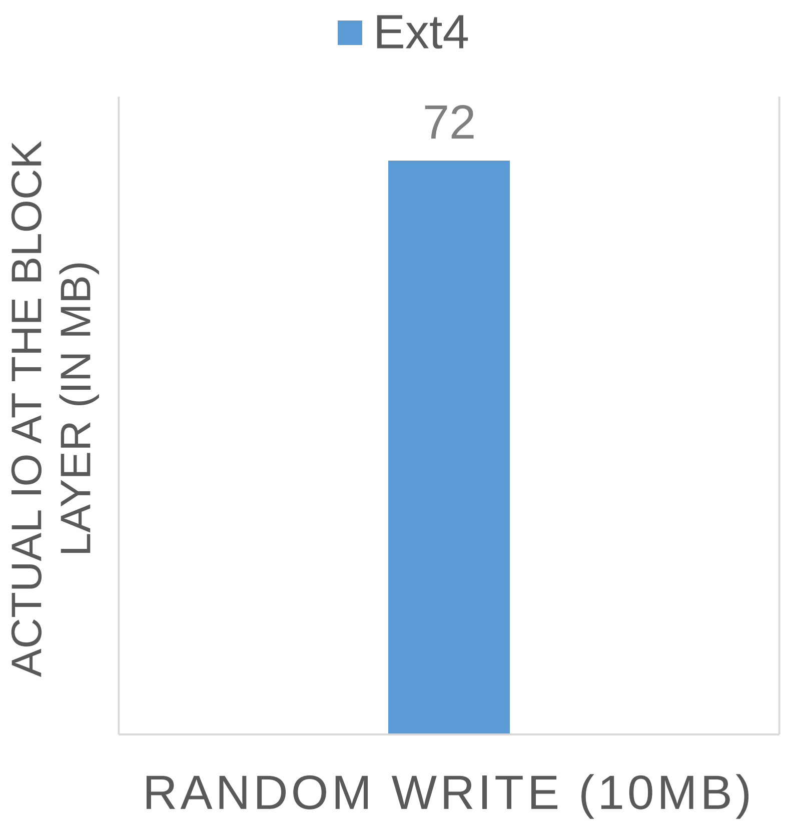


F2FS vs Ext4 : File ops





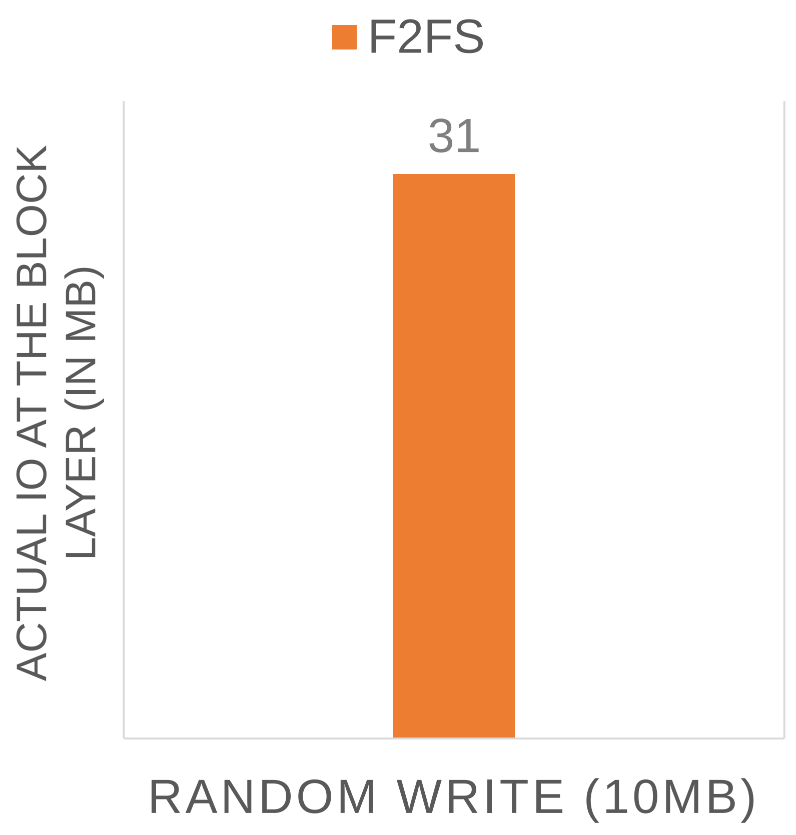
F2FS vs Ext4: Write Amplification



Ext4:

- In-place updates.
- Fsync forces both data and metadata to be written on to the disk.
- Meta data includes:
  - Inode table
  - Journal transaction begin block
  - Journal transaction end block
  - list of blocks in the transaction.

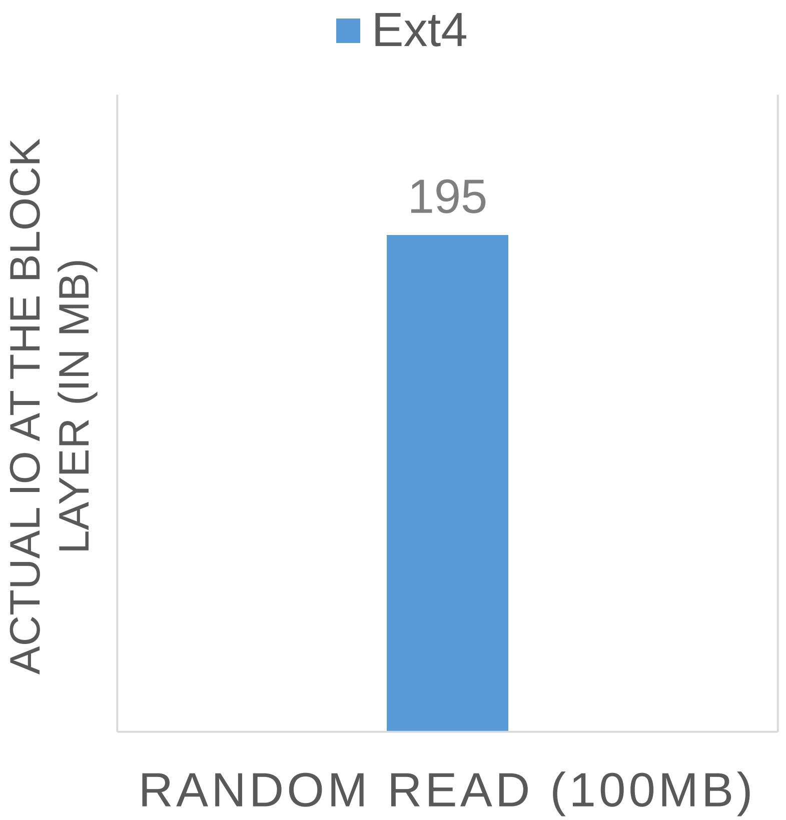
F2FS vs Ext4: Write Amplification



F2FS:

- Log structured.
- Maintains NAT table for address translation.
- Only data blocks and their direct node blocks are written after every fsync.
- Meta data includes – File inodes, NAT and SIT updates.

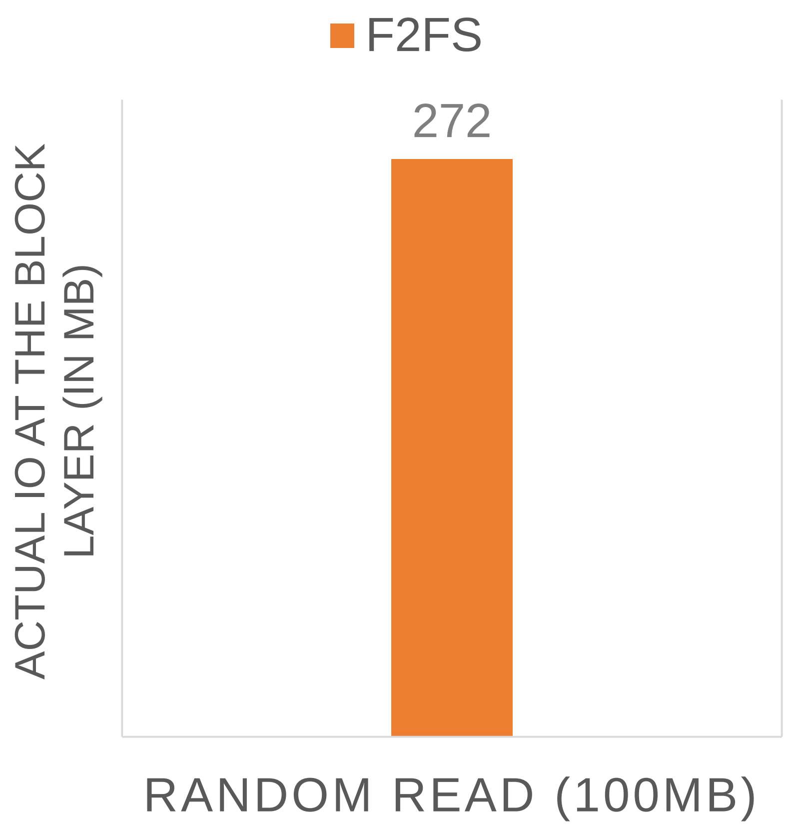
F2FS vs Ext4: Read Amplification



Ext4:

- Android uses aggressive read prefetching.
- Blktrace reveals minimum size of read request is 8KB.

F2FS vs Ext4: Read Amplification



F2FS:

- Every read constitutes of a request to read direct node block and the data.
- Every read request to direct node block results in NAT translation.

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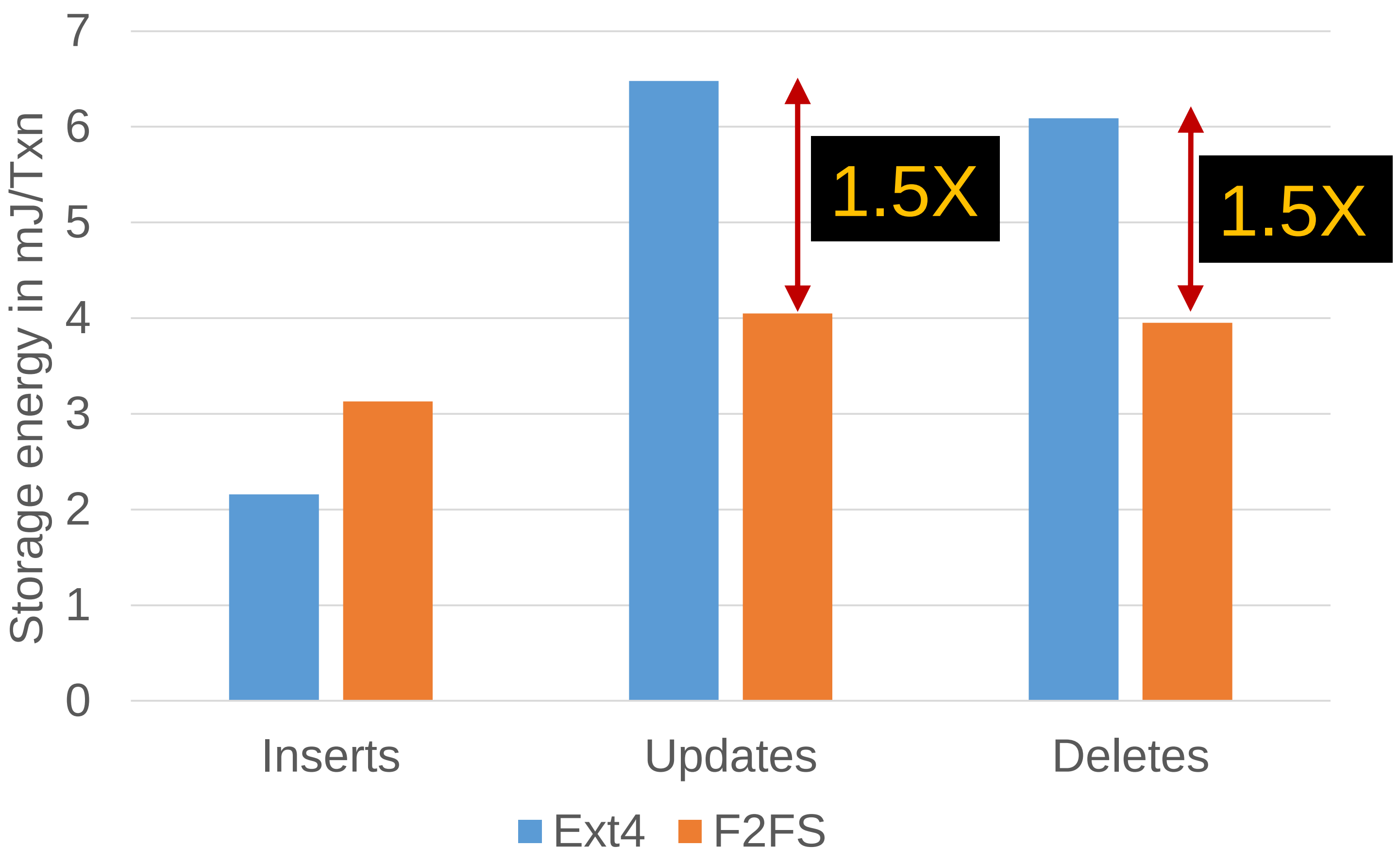
SQLite operations

Workload:

- Prepopulate 1M entries.
- 15K each of SQLite Inserts, Updates and Deletes.
- SQLite record size : 4KB.
- WAL-NORMAL

F2FS vs Ext4 : SQLite Operations



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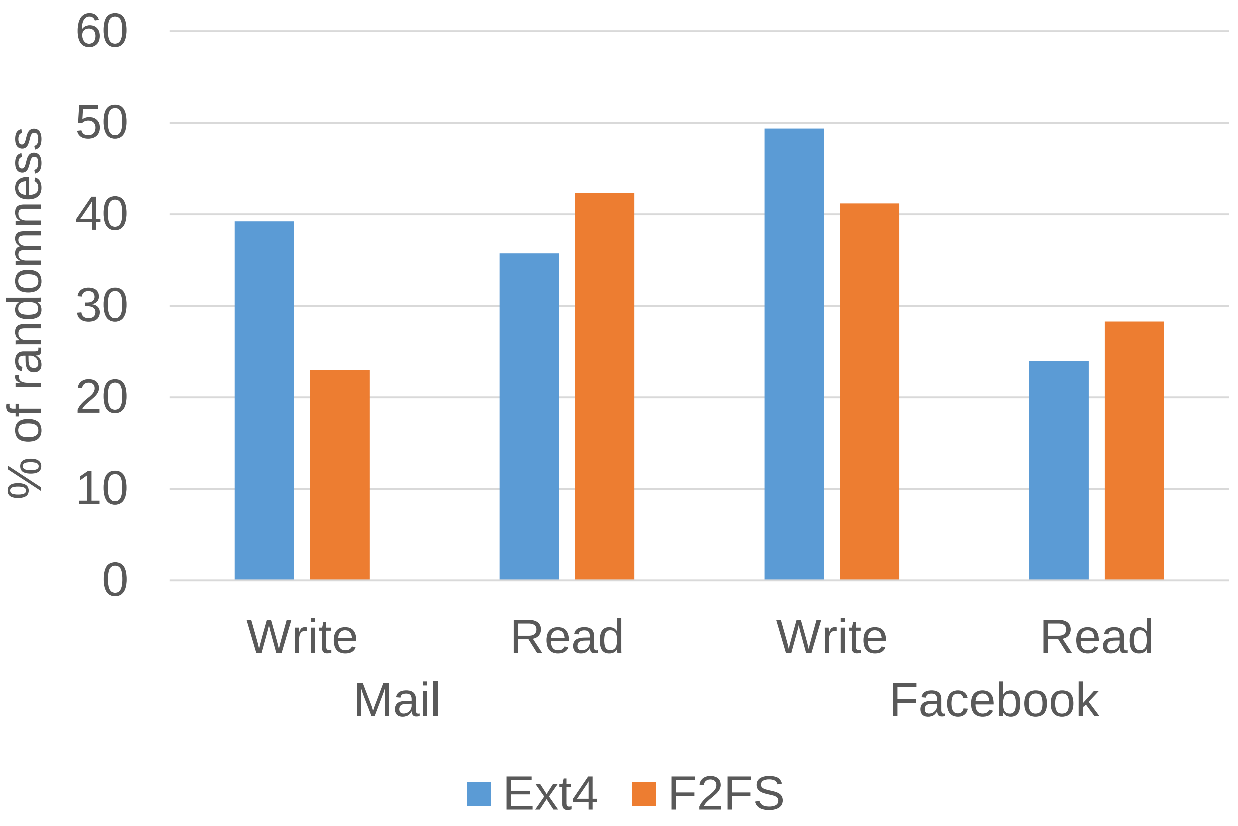
Android applications

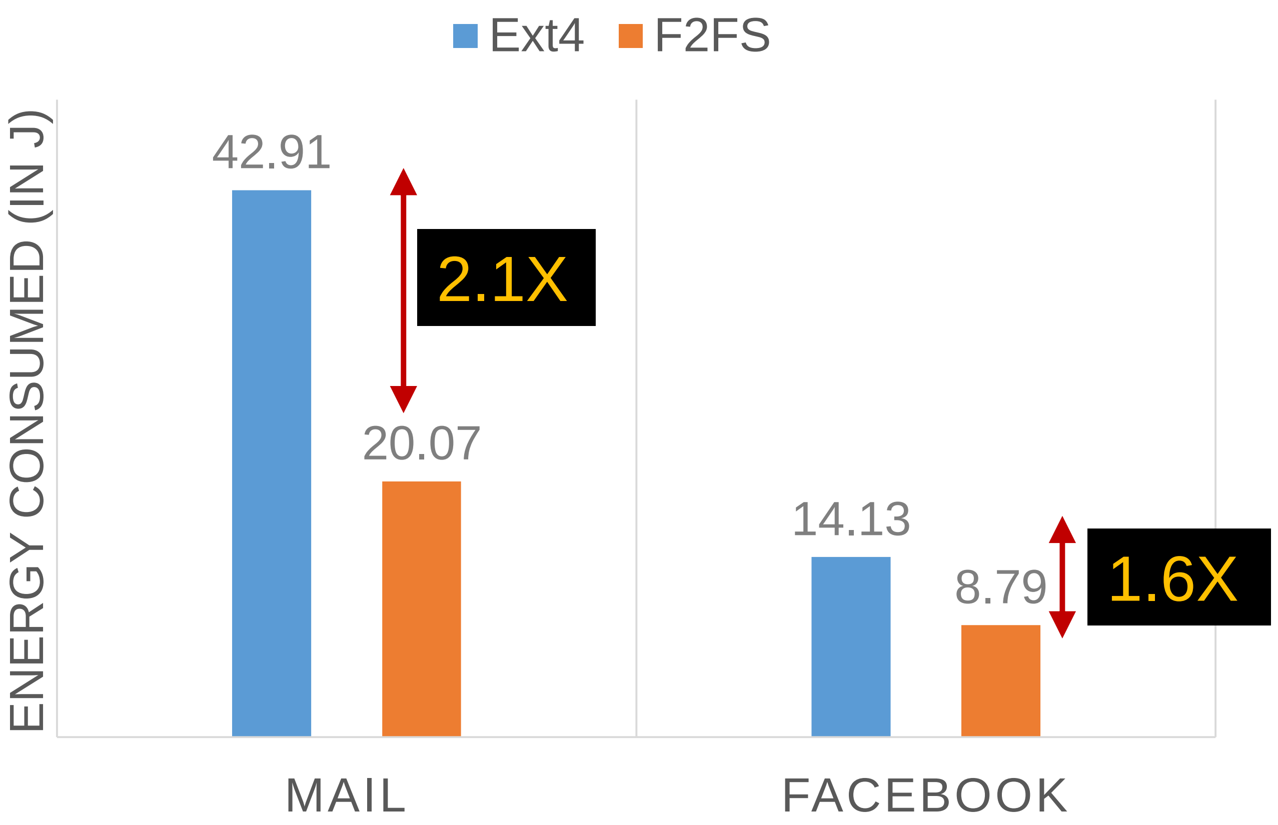
- **Applications Studied:** Mail and Facebook
- **Duration traced:** 180 seconds
- **Energy estimation:**
  - Percentage of random and sequential IO is computed using ***blktrace.***
  - Sequential IO between two flushes are merged.
  - IO size < 32KB after merge is tagged as random.
  - Application energy consumption is estimated using File IO energy stats.

F2FS vs Ext4 : Android applications



Percentage of Random IO at block level

F2FS vs Ext4 : Android applications



Total energy consumed by storage for different Android applications

Implications for File System Design

- Use sequential IO
  - F2FS still performs around 20-28% of random writes and about 12-20% of random reads.
  - Sequentializing the last 20-28% of random writes in F2FS can reduce energy consumption by ***half*.**
- Account for trade-off between sequential writes and random reads.
- Use compression to reduce IO.

Conclusions

- Differential analysis gives component-wise energy measurements on commercial phones.
- Contribution of storage to energy consumption in Android is significant - **36%**!
- Huge energy benefits by sequentializing I/O.
- F2FS can be made significantly more energy-efficient.

Thank you!