Modeling Flash Translation Layers to Enhance System Lifetime

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Background – Flash Memory System

- Modern Flash Memory System (HDD -> SSD)
Background – Flash Challenges

1. Program-Then-Erase
2. Course-Grained Structures (Block & Page)
3. Finite Endurance
FTL Types: Block-Mode and Page-Mode
Background - Segments

- Flash Memory Markets
  - Client – Cost ($/GB)
  - Enterprise – Speed/Endurance (IOPS, DWPD)
  - Embedded – Reliability (BER)
Background - Embedded Systems

- "Fixed function system"
  - Telecom, automotive, industrial control systems, medical equipment ...
  - 2009: 10B embedded processors (EETimes)
  - 2009: 300M PCs (Gartner), 3%

- Commonality: Flash Storage
  - Code & data
Motivation

- ~$30B market (2014, iSupply) dominated by client ($/GB) needs (Apple ~30%, iSupply)
- Smaller process, more bits per cells
  - Endurance & ECC
  - Retention
- Challenge: Maintain acceptable service-life for embedded systems
Write amplification factor (WAF) is a function of Flash Translation Layer (FTL)

- FTLs are trade secrets. WAF measurements are unpublished
Technique

- Software application to perform fine-grained write performance measurements and characterize FTL and provide WAF measurements

[McCormick FMS2014]
Measurements – Sequential, 64 KB
WAF Equation (Block-Mode FTL)

\[
WAF_{\text{Sequential}} = \frac{\text{Superblock Size + Management Data}}{\text{Superblock Size}}
\]

\[
WAF_{\text{Sequential}} = \frac{65536 \text{ KB} + 256 \text{ KB}}{65536 \text{ KB}} = 1.004
\]

\[
WAF_{\text{Random}} = \frac{\text{User Data + Buffer Data + Management Data}}{\text{Buffer Data}}
\]

\[
WAF_{\text{Random}} = \frac{(119 \times 64 \text{ MB}) + (5.7 \times 64 \text{ MB}) + (11.4 \text{ MB})}{5.7 \times 64 \text{ MB}} = 21.91
\]
WAF Equation (Page-Mode FTL)

\[
WAF_{\text{Sequential}} = \frac{\text{Superblock Size} + \text{Management Data}}{\text{Superblock Size}}
\]

\[
WAF_{\text{Sequential}} = \frac{65536 \text{ KB} + 128 \text{ KB}}{65536 \text{ KB}} = 1.002
\]

\[
WAF_{\text{Random}} = \frac{\text{Superblock Size} + \text{Management Data}}{\text{Buffer Data}}
\]

\[
WAF_{\text{Random}} = \frac{(64 \text{ MB}) + (2.0 \text{ MB})}{5.206 \text{ MB}} = 12.66
\]
WAF Modeling (Random)
File System Operations (FAT)

File Creation:
1. Directory (Repeated)
2. FAT #1 (Repeated)
3. FAT #2 (Repeated)
4. Data (Sequential)

File Deletion:
1. Directory (Repeated)
2. FAT #1 (Repeated)
3. FAT #2 (Repeated)
WAF (File System - Simulated)
WAF Equation (Repeated)

\[
WAF_{\text{Repeated}} = \frac{N_{\text{Repeated}} \cdot \text{Allocation Unit}_{\text{Repeated}} + \text{Allocation Unit}_{\text{Transfer}} + \text{Consolidation}}{N_{\text{Repeated}} \cdot \text{Size}_{\text{Repeated}} + \text{Size}_{\text{Transfer}}}
\]

\[
WAF_{\text{Block-Mode, 4KB}} = \frac{(3 \cdot 32 \text{ KB}) + (32 \text{ KB}) + (478.8 \text{ KB})}{3 \cdot 512 \text{ B} + 4 \text{ KB}} = 110.3
\]

\[
WAF_{\text{Page-Mode, 4KB}} = \frac{(3 \cdot 8 \text{ KB}) + (8 \text{ KB})}{3 \cdot 512 \text{ B} + 4 \text{ KB}} = 5.818
\]
WAF Modeling (File Creation)
Summary & Conclusions

1. WAF Measurements (Block-Mode)
   a. Sequential: 1.004
   b. Random 21.91
   c. Repeated (4K): 110.3
2. WAF Measurements (Page-Mode)
   a. Sequential: 1.002
   b. Random 12.66
   c. Repeated (4K): 5.818
3. Page-Mode FTL incurs less WAF than Block-Mode FTL
4. Characterization of file-system operations needs to include repeated writes
5. FTL design should include consideration of repeated writes
Flash Memory System Embedded Events:

- Beer, Pizza, and Chat with the Experts
  - Tues 7:00 – 8:30 PM
- Embedded Applications, Part 1 (203-B)
  - Wed 3:10 – 4:15 PM
- Embedded Applications, Part 2 (204-B)
  - Wed 4:30 – 5:45 PM
- Embedded Applications, Part 3 (301-B)
  - Thurs 8:30 – 9:35 AM
Questions?

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