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  - Jim Espy (EMC)
  - Herb Tanzer (Hp)

- **In the technology area and validation of much of the work presented here**
  - Alan Yoder (Huawei)

- **Members of SNIA GSI and Green Technical Working Group**

- **Emerald™ Director**
  - Dave Thiel
Agenda

SNIA green activities
- Green Storage Initiative
- Green Technical Working Group
- Emerald™ Program
- Why should storage consumers use the emerald program?

Background and green storage
- Revisit a basic storage unit
- What influences green storage
- Storage Power example
- Introduce metrics

Storage taxonomy

the use of the Emerald™ Program
- Basic configuration and requirements
- Specification Requirements
- Conditioning Test Phase
- Active Test IO Profile
- Ready Idle
- Capacity Optimization Method Test
- Valid Flow to generate data

The Best Foot Forward

Other Associations Green Storage Efforts
Green Activities

- SNIA green activities
  - Green Storage Initiative
  - Green Technical Working Group
  - Emerald™ Program
  - Why should storage consumers use the emerald program?
SNIA Green Activities
Green Storage Initiative

SNIA Green Storage Initiative (GSI)

- To conduct research on power and cooling issues confronting storage administrators
- Educate the vendor and user community about the importance of power efficiency in shared storage environments
- Leverage SNW and other SNIA and partner conference to focus attention on energy efficiency for networked storage infrastructures
- Provide input to the SNIA Green Storage TWG on requirements for green storage metrics and standards
- Provide external advocacy and support of SNIA Green TWG technical work
SNIA Green Activities
Green Technical Working Group

- Technical body working on green storage metrics and standards
- Gets direction from GSI
- Wrote the SNIA Emerald™ Power Efficiency Measurement Specification and related documents
- Supports the Emerald™
  - White papers
  - Tutorials
  - Training
- Works with regulatory agencies; i.e. EPA, on green storage specifications
SNIA Emerald™ Program Overview

Purpose
- Provide open access to storage system power efficiency information using a well-defined testing procedure and additional information related to system power characteristics
- The report data can help IT professionals make storage platform selections as part of an overall Green IT and Sustainability objective
- Easily identifiable program logo

Test procedure:
- SNIA Emerald™ Power Efficiency Measurement Specification

Public access and submittal is through the sniaemerald.com web site
- No charge for access to test results, specifications or user guides
- Submission of results is for a modest fee, discounted or waived for SNIA/GSI members
- SNIA membership is not required to submit or to access test results
- Voluntary, non-exclusionary, low cost program for manufacturers - Options to self-measure or third party measurement
Process
- Storage Vendors test their equipment and submit test results to the Emerald Program
- Emerald Program publishes results on the sniaemerald.com web site
- IT users (public) download results from the sniaemerald.com web site
- Vendor gains right to use the SNIA Emerald™ logo in conjunction with tested products

Legal protections
- Terms of Use: conditions on use of test results agreed to by those downloading results
- Terms of Submission: agreed to by vendor submitting test results

Sign up for the mailing list: sniaemerald.com
Why Should Storage Consumers Use the Emerald™ Program? – Overview

SNIA Emerald™ Program seeks to

- Provide a collection of standard metrics and data that allows IT architects to objectively compare a range of possible storage solutions

SNIA Emerald™ Program

- Enables users to select the mode of storage usage that accomplishes their work objectives with the lowest overall energy consumption
- Drives vendor companies to innovate and compete in the development of energy efficient products as measured by the standard yardsticks

The question is:

WHERE IS THE ENERGY USED???
Background and Green Storage

- Revisit a basic storage unit anatomy and its use
- What influences green storage power consumption
- Storage power example
- Opportunities to make storage **greener**
  - (OK lets call it by its name ... Use less Power)
- Introduce metrics
  - And the meaning for the IT managers?
Basic Anatomy of a Disk Storage System and its Use

Switches (sometimes optional)

Disks (Spin or Solid State)
Diverse technologies (SAS, FC, SATA)

Power supplies, Batteries & fans (may or may not be redundant)

Controller's (may or may not be redundant)

Disks (Spin or Solid State)
Diverse technologies (SAS, FC, SATA)

Users and Apps

Other:
Software (firmware & microcode)
Hardware Design
Environment
What Influences Power Consumption

- **Storage capacity / usage efficiency**
  - increasing data → larger capacity → more disks
  - redundant copies → magnify capacity needs
  - variability in usage and utilization → inefficient allocation of space
  - What is valuable data? What is the retention policy?

- **Data transfer rate / access speed**
  - high I/O bandwidth → higher rotational speed; striping across many drives
  - low access times → faster actuators; higher rotational speeds; caches
  - How fast and immediate must data be available? (time-to-data)

- **Data integrity**
  - 25% of “digital universe” is unique, but 75% are replicas / duplicates
  - partly to ensure data integrity and survivability; partly wasteful

- **Data availability / system reliability**
  - RAID uses extra drives, plus redundant power supplies, fans, controllers,
  - How valuable is data? How likely are failures? How fast must data be available?
Ideally, systems consume minimum power in all modes.
- Example system consumes significant power in ready idle (80% of max).
- % of time in Idle versus Active depends on storage type, application and workloads; available optimizations will vary.
  - Power itself is only one part of the story it must be reflected as a metric.
- Power consumed is not linearly proportional to workload.
Opportunities to Make Storage Green(er)

▸ Environment
  ➢ Higher system tolerance to high/lower temperatures and humidity
  ➢ In line with cold and hot aisles designs on new data centers

▸ Improve usage efficiency
  ➢ De-duplication and compression
  ➢ Thin provisioning

▸ Minimize energy consumption
  ➢ Improved component designs – high-efficiency power supplies, advanced & flexible storage devices
  ➢ Variants of MAID – idle and spin-down

▸ New technologies
  ➢ Solid state storage
  ➢ Alternative + hybrid system designs (opportunity to rethink)
SNIA recommended metrics

- **Capacity metric (ready-idle)**
  - Relates the power of the system to its total storage raw capacity. It is reported as GB/watt (or TB/watt)
  - Power required to store and protect the data

- **Workload metric (Active – Also known as transactional)**
  - Relates the power of the system to the maximum possible IOPS generated by a specific random stress load. It is reported as IOPS/watt
  - Power required to randomly supply data to and from a host

- **Bandwidth metric (Active – Also known as streaming)**
  - Relates the power drawn by the system to the maximum possible MBPS generated by a specific sequential stress load. It is reported as MBPS/watt
  - Power required to stream data to and from a host
Depending on the systems and their usage their energy usage may be evaluated according to:

- **Is the system idle time at least 12 hours or more a day?**
  - You should be interested in the power required to store the data
  - **capacity metric (GB/Watt)** may be your best indicator on how energy efficient your system is
  - The larger this number is the less watts are used to energize the total storage of your system
What are the Active Metrics and what it Means to an IT Manager?

- Depending on the systems and their usage their energy usage may be evaluated according to:
  - For systems running more than 12 hours a day
    - You should be interested in the Power to move the data onto and off the storage system
    - Is your load predominantly sequential?
      - Bandwidth metric (MBS/Watt) will help you to determine how effective is your power use. The larger this number is, the more data the system is pushing per watt
    - Is your load predominantly random?
      - Workload metric (IOPS/Watt) will help you determine how effective is your power use. The larger this number is the system is provides more operations per watt.
  - Independently on how long the system is idle it is always good to know what is your capacity per watt ratio
Storage Taxonomy

Taxonomy

1. the science or technique of classification.
2. a classification into ordered categories: a proposed taxonomy of educational objectives.
3. Biology . the science dealing with the description, identification, naming, and classification of organisms.

Source:
Dictionary.com
Why Have a Storage Taxonomy

- Need a taxonomy to enable fair comparisons among similar storage products
  - e.g. for motor vehicles – motorcycles, cars, trucks
- Similar green metrics may apply to all product categories, but different values establish best-in-class
- Unique considerations apply to special categories
  - e.g. amphibious cars, skid steer loaders, tanks
- Clear taxonomy will simplify comparisons and aid regulatory efforts
- SNIA Storage Taxonomy is defined in SNIA Emerald™ Power Efficiency Measurement Specification
### Taxonomy – Categories

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Category</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Online</td>
</tr>
<tr>
<td>Access Pattern</td>
<td>Random/Sequential</td>
</tr>
<tr>
<td>MaxTTFD (t)</td>
<td>t &lt; 80 ms</td>
</tr>
<tr>
<td>User Accessible Data</td>
<td>Required</td>
</tr>
</tbody>
</table>

- **Six categories, covering most storage industry products**
## Taxonomy – Categories

<table>
<thead>
<tr>
<th>Category</th>
<th>Online</th>
<th>Near Online</th>
<th>Removable Media Library</th>
<th>Virtual Media Library</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level</td>
<td>Online 1</td>
<td>Near Online 1</td>
<td>Removable 1</td>
<td>Virtual 1</td>
</tr>
<tr>
<td>Consumer/Component</td>
<td>Online 2</td>
<td>Near Online 2</td>
<td>Removable 2</td>
<td>Virtual 2</td>
</tr>
<tr>
<td>Low-end</td>
<td>Online 3</td>
<td>Near Online 3</td>
<td>Removable 3</td>
<td>Virtual 3</td>
</tr>
<tr>
<td>Mid-range</td>
<td>Online 4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>High-end</td>
<td>Online 5</td>
<td>Near Online 5</td>
<td>Removable 5</td>
<td>Virtual 5</td>
</tr>
<tr>
<td>Mainframe</td>
<td>Online 6</td>
<td>Near Online 6</td>
<td>Removable 6</td>
<td>Virtual 6</td>
</tr>
</tbody>
</table>

- **23 total “buckets” covering the breadth of the industry**
### Most common storage systems

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Online 1</th>
<th>Online 2</th>
<th>Online 3</th>
<th>Online 4</th>
<th>Online 5</th>
<th>Online 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Access Pattern</td>
<td>Random/Sequential</td>
<td>Random/Sequential</td>
<td>Random/Sequential</td>
<td>Random/Sequential</td>
<td>Random/Sequential</td>
<td>Random/Sequential</td>
</tr>
<tr>
<td>MaxTTFD (t)</td>
<td>t &lt; 80 ms</td>
<td>t &lt; 80 ms</td>
<td>t &lt; 80 ms</td>
<td>t &lt; 80 ms</td>
<td>t &lt; 80 ms</td>
<td>t &lt; 80 ms</td>
</tr>
<tr>
<td>User-Accessible Data</td>
<td>Required</td>
<td>Required</td>
<td>Required</td>
<td>Required</td>
<td>Required</td>
<td>Required</td>
</tr>
<tr>
<td>Consumer/Component</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Connectivity</td>
<td>Not specified</td>
<td>Connected to single or multiple hosts</td>
<td>Network-connected</td>
<td>Network-connected</td>
<td>Network-connected</td>
<td>Network-connected</td>
</tr>
<tr>
<td>Maximum Configuration</td>
<td>≥1</td>
<td>≥ 4</td>
<td>≥ 12</td>
<td>&gt; 100</td>
<td>&gt;400</td>
<td>&gt;400</td>
</tr>
<tr>
<td>Integrated Storage Controller</td>
<td>Optional</td>
<td>Optional</td>
<td>Required</td>
<td>Required</td>
<td>Required</td>
<td>Required</td>
</tr>
<tr>
<td>Storage Protection</td>
<td>Optional</td>
<td>Optional</td>
<td>Required</td>
<td>Required</td>
<td>Required</td>
<td>Required</td>
</tr>
<tr>
<td>No SPOF</td>
<td>Optional</td>
<td>Optional</td>
<td>Optional</td>
<td>Required</td>
<td>Required</td>
<td>Required</td>
</tr>
<tr>
<td>Non-Disruptive Serviceability</td>
<td>Optional</td>
<td>Optional</td>
<td>Optional</td>
<td>Optional</td>
<td>Required</td>
<td>Required</td>
</tr>
<tr>
<td>FBA/CKD Support</td>
<td>Optional</td>
<td>Optional</td>
<td>Optional</td>
<td>Optional</td>
<td>Optional</td>
<td>Required</td>
</tr>
</tbody>
</table>

---

Green Storage and Energy Efficiency
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## Taxonomy – Near Online

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Classification</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Near Online 1</td>
</tr>
<tr>
<td>Access Pattern</td>
<td>Random/Sequential</td>
</tr>
<tr>
<td>MaxTTFD (t)</td>
<td>t &gt; 80 ms</td>
</tr>
<tr>
<td>User-Accessible Data</td>
<td>Required</td>
</tr>
<tr>
<td>Consumer/Component</td>
<td>Yes</td>
</tr>
<tr>
<td>Connectivity</td>
<td>Not specified</td>
</tr>
<tr>
<td>Maximum Configuration</td>
<td>≥1</td>
</tr>
<tr>
<td>Integrated Storage Controller</td>
<td>Optional</td>
</tr>
<tr>
<td>Storage Protection</td>
<td>Optional</td>
</tr>
<tr>
<td>No SPOF</td>
<td>Optional</td>
</tr>
<tr>
<td>Non-Disruptive Serviceability</td>
<td>Optional</td>
</tr>
<tr>
<td>FBA/CKD Support</td>
<td>Optional</td>
</tr>
</tbody>
</table>

For more taxonomy definitions please consult the emerald spec.
Basic configuration and requirements
Specification Requirements
Conditioning Test Phase
Active Test IO Profile
Ready Idle
Capacity Optimization Method Test
Valid Flow to generate data
Test Configuration and Requirements

Basic configuration

- Not allowed to change configuration or tune parameters during test phases
Specification Requirements

Test setup requirements
- Input voltage – standard world voltages
- Environmental – standard datacenter conditions
- Benchmark driver – VdBench, IOMeter, required conditions
- Meters
  - Power – accuracy level
  - Temperature – accuracy level

Equations
- Average response time and power
- Periodic power efficiency
- Metric stability – 10 point rolling average
- Time interval of 1 minute or a specified measurement interval

Some important changes to the requirements are expected on version 2 of the Emerald Spec
SUT Conditioning Test Phase

- Intended to provide a uniform initial condition for subsequent measurements
- Demonstrate the SUT’s ability to process IO requests
- Assure that each storage device in the SUT is fully operational and capable of satisfying any supported request
- Achieve typical operational temperature
- Each taxonomy category will have different measurement interval requirement to demonstrate stability
Active Test IO Profiles

<table>
<thead>
<tr>
<th>IO Profile</th>
<th>IO Size (KiB)</th>
<th>Read/Write Percentage</th>
<th>IO Intensity</th>
<th>Transfer Alignment (KiB)</th>
<th>Access Pattern</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mixed Workload 1 (i=MW1)</td>
<td>8</td>
<td>70/30</td>
<td>100</td>
<td>8</td>
<td>Random</td>
</tr>
<tr>
<td>Mixed Workload 2 (i=MW2)</td>
<td>8</td>
<td>70/30</td>
<td>25</td>
<td>8</td>
<td>Random</td>
</tr>
<tr>
<td>Random Write (i=RW)</td>
<td>8</td>
<td>0/100</td>
<td>100</td>
<td>8</td>
<td>Random</td>
</tr>
<tr>
<td>Random Read (i=RR)</td>
<td>8</td>
<td>100/0</td>
<td>100</td>
<td>8</td>
<td>Random</td>
</tr>
<tr>
<td>Sequential Write (i=SW)</td>
<td>256</td>
<td>0/100</td>
<td>100</td>
<td>256</td>
<td>Sequential</td>
</tr>
<tr>
<td>Sequential Read (i=SR)</td>
<td>256</td>
<td>100/0</td>
<td>100</td>
<td>256</td>
<td>Sequential</td>
</tr>
</tbody>
</table>

- All or some of the IO profiles are used by the defined taxonomy categories
  - Drive enough IOs to reach the required response time or through-put specified in the measurement specification
  - The 25 IO intensity is 25% of the IO defined for MW1
SUT Active Test Phase

- **IO profiles used by taxonomy category**
  - Online and Near-Online use all six IO profiles
  - Removable Media and VML use only the sequential IO profiles

- **Run as an uninterrupted sequence of workloads**
  - Specification defines the order to be run for each taxonomy category
SUT Ready Idle Test Phase

- Defined as storage systems and components that are configured, powered up, connected to one or more hosts and capable of satisfying externally-initiated, application-level initiated IO requests within normal response time constraints, but no such IO requests are being submitted.
- Average power measured in the measurement window
- No external IO given by the host
- Can perform any IO within the taxonomy required response time interval
SUT Capacity Optimization Method

Test Phase

- Heuristic tests
  - Delta snapshots
  - Thin provisioning
  - Data de-duplication
  - Parity RAID
  - Compression
- Run after ready idle test phase
- C program generated by SNIA
  - Download from sourceforge.net/projects/sniadedupertest
  - Used for de-duplication and compression
- Taxonomy dependent
## Metrics

### Active (Primary)

- Ratio of operations rate over average power for the same measurement interval
  - $E_{PMW1}$ (IOP/S/W) of the 70% mixed workload at maximum response time
  - $E_{PMW2}$ (IOP/S/W) of the 25% of the IO used in MW1
  - $E_{PRR1}$ (IOP/S/W) of the random read workload at maximum response time
  - $E_{PRW1}$ (IOP/S/W) of the random write workload at maximum response time
  - $E_{PSR1}$ (MiB/S/W) of the sequential read workload at maximum throughput

### IO Profile

<table>
<thead>
<tr>
<th>IO Profile</th>
<th>IO Size (KiB)</th>
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<th>IO Intensity</th>
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<th>Access Pattern</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mixed Workload 1 (i=MW1)</td>
<td>8</td>
<td>70/30</td>
<td>100</td>
<td>8</td>
<td>Random</td>
</tr>
<tr>
<td>Mixed Workload 2 (i=MW2)</td>
<td>8</td>
<td>70/30</td>
<td>25</td>
<td>8</td>
<td>Random</td>
</tr>
<tr>
<td>Random Write (i=RW)</td>
<td>8</td>
<td>0/100</td>
<td>100</td>
<td>8</td>
<td>Random</td>
</tr>
<tr>
<td>Random Read (i=RR)</td>
<td>8</td>
<td>100/0</td>
<td>100</td>
<td>8</td>
<td>Random</td>
</tr>
<tr>
<td>Sequential Write (i=SW)</td>
<td>256</td>
<td>0/100</td>
<td>100</td>
<td>256</td>
<td>Sequential</td>
</tr>
<tr>
<td>Sequential Read (i=SR)</td>
<td>256</td>
<td>100/0</td>
<td>100</td>
<td>256</td>
<td>Sequential</td>
</tr>
</tbody>
</table>
Metrics (Continued)

- **Ready Idle (Primary)**
  - Ratio of raw capacity over average power measured in the defined measurement window (GB/W)

- **Capacity Optimization (Secondary)**
  - A yes/no for each Capacity Optimization Method tested
  - Do not have to test all COMs but if vendor declares to have a COM it must be tested and on during active test phase
Flow Needed for Valid Emerald Measurement

**General timeline**
- Tune the system
- A day to run test
- A day to generate the required data and review it
- A few hours to submit the data
Best Foot Forward (BFF) (Sweet Spot testing)

- Test configuration challenges
- Best Foot Forward Approach 1
  - Scale up system
- Best Foot Forward Approach 2
  - Scale out system
- Best Foot Forward Approach 3
  - Rough approximation
Test Configuration Challenges

- Wide Spectrum of Storage-Oriented Products
  - Created a taxonomy to narrow scope
  - Categories: On-Line, Near-Line, etc.
  - Classifications: Further granularity of each Category

- Still too Broad in Scope
  - Vendors may have multiple products in a particular Category/Classification
  - Each product may have many configuration variables

- Requirement/Challenge: Select Appropriate Test Configurations
  - Comprehensive and usable results for customer
  - Minimized, lower cost, but effective testing methods for vendor
Best Foot Forward Approach - 1

- **BFF Looks Holistically at Storage System Product/Family**
  - Allows vendor to select and test one product/family configuration
    - Or more if desired
  - At operating points near the Measurement Spec metric peak values
    - I.e. the “sweet spot”
  - Results reasonably representative of the entire family
    - Easier and less expensive for the vendor
    - Simple and understandable results for the potential customer

- **Scale Up Example on Following Slide**
  - Based on notion that Measurement Spec active metrics have peak values
  - Peaks typically located at points well below maximum configurations
"Typical" Performance vs. Capacity (Cache, End Storage)

Selected region of "best" or peak Performance/W and Capacity/W

Base Performance/W and Capacity/W

Varying roll-off behaviors by product.
Previous Slide is a Rough Approximation
- Capacity increases are actually more stepwise
- Performance roll-off can vary by product
  - Dashed lines attempt to show one (of possibly many) changes due to different storage technology tiers, e.g. scaling capacity w/large SATA drives
- Regardless, example depicts a smaller test configuration

What About Other Test Points?
- Could also test at base (entry point) but not required
- Key is no requirement to test beyond the peak point

Scale Out Example on Following Slide
- What if there is no clearly discernable peak?
Best Foot Forward Approach
Scale-Out System

- Theoretical homogeneous scale-out
- Theoretical heterogeneous scale-out

Selected region of “best” or peak Performance/W and Capacity/W

Base Performance/W and Capacity/W

Power

Typical Performance

Capacity (Cache, End Storage)
Again a Rough Approximation

- Capacity increases are actually more stepwise
- Dashed lines attempt to show one (of possibly many) changes due homogeneous vs heterogeneous scale-out configurations
- Can still select a smaller test configuration
Summary and Next Steps

- **Given Known Taxonomy Category and Classification**
  - Vendor determines one or more family representative configurations
  - Vendor locates Measurement Spec active metric peak points
  - Tests are performed on this reduced configuration (set)
    - Note: For smaller systems, the BFF may in fact be the maximum configuration

- **Where is the Performance/W Peak?**
  - Depends on numerical increase of numerator vs denominator with capacity
  - If numerator initially increases more than denominator, a clear peak
  - Else it becomes harder – Just pick a point before it rolls off?
  - Selection of the peak point(s) is the subject of the next slides
Other associations work on storage efficiency

- SPC
- Green Grid
Other Associations Green Storage Efforts

- **SPC**
  - Storage Performance Council mainly oriented to disk subsystems was the first industry association to add power to their benchmark

- **The Green Grid**
  - Data Center Maturity Model
  - Design guide in progress
  - Working on a usage metrics
    - Measure the IOP/s/W, MiBs/W, GB/W in the datacenter
The SNIA Education Committee would like to thank the following individuals for their contributions to this Tutorial.

**Authorship History**

Between 2009 and 2011
Erik Ridel
Carlos Pratt
Patrick Stanko
Patrick Chu
Matthew Brisse
David Reinsel
Edgar St. Pierre
Alan Yoder
Wayne Adams
SW Worth

Updates:
Carlos Pratt/August – September 2012

**Additional Contributors**

Herb Tanzer
David Thiel
Jim Espy

ALL SNIA GSI and TWG members

Please send any questions or comments regarding this SNIA Tutorial to tracktutorials@snia.org
SO, Where is the power?

Thank you