Radian®
MEMORY SYSTEMS

Symphonic™ Zones

Cooperative Flash Zones

Based upon Radian's award winning Symphonic™ CFM technology, Symphonic Cooperative Flash Zones provides a simple interface for highly efficient and deterministic Flash management in an *'All Firmware'* SSD implementation.

Like earlier versions of Symphonic, these Cooperative Zones abstract vendor specific NAND attributes but present host systems with sequential write zones of *'Idealized Flash'*. Routine Flash management processes are simplified, but still cooperative between the device and the host to provide determinism, parallelism and tail latencies that cannot be achieved with conventional Flash Translation Layers (FTL).

In addition to zone sizes being user configurable, these Cooperative Zones can be factory configured to support different types of memory, ranging from NV-RAM to SLC and TLC today, and for SCM and QLC in the future.

Cooperative & Configurable Zones of *'Idealized Flash'*

***'All Firmware'* SSD implementation is less OS dependent and optimal for SPDK**

Optional factory configurations for mixing zones of different memory types (NV-RAM, SCM, SLC, TLC, QLC, etc.) on the same SSD

Comprised of NAND Erase Units (blocks), Symphonic Cooperative Zones are subsets of physically, performance-isolated regions of memory, where these regions are configurable in size and can be associated with namespaces. Cooperative Zones appear as a range of contiguous LBAs accessible via conventional addressing through the NVMe command set. Certain SMR zone commands, such as 'Zone Report' and 'Zone Reset', are supported as part of extensions to the conventional NVMe command set.

Iso-boxes & Namespaces
Iso-boxes are user configurable, discrete performance-isolated regions based upon NAND dies and channels that can be associated with namespaces.

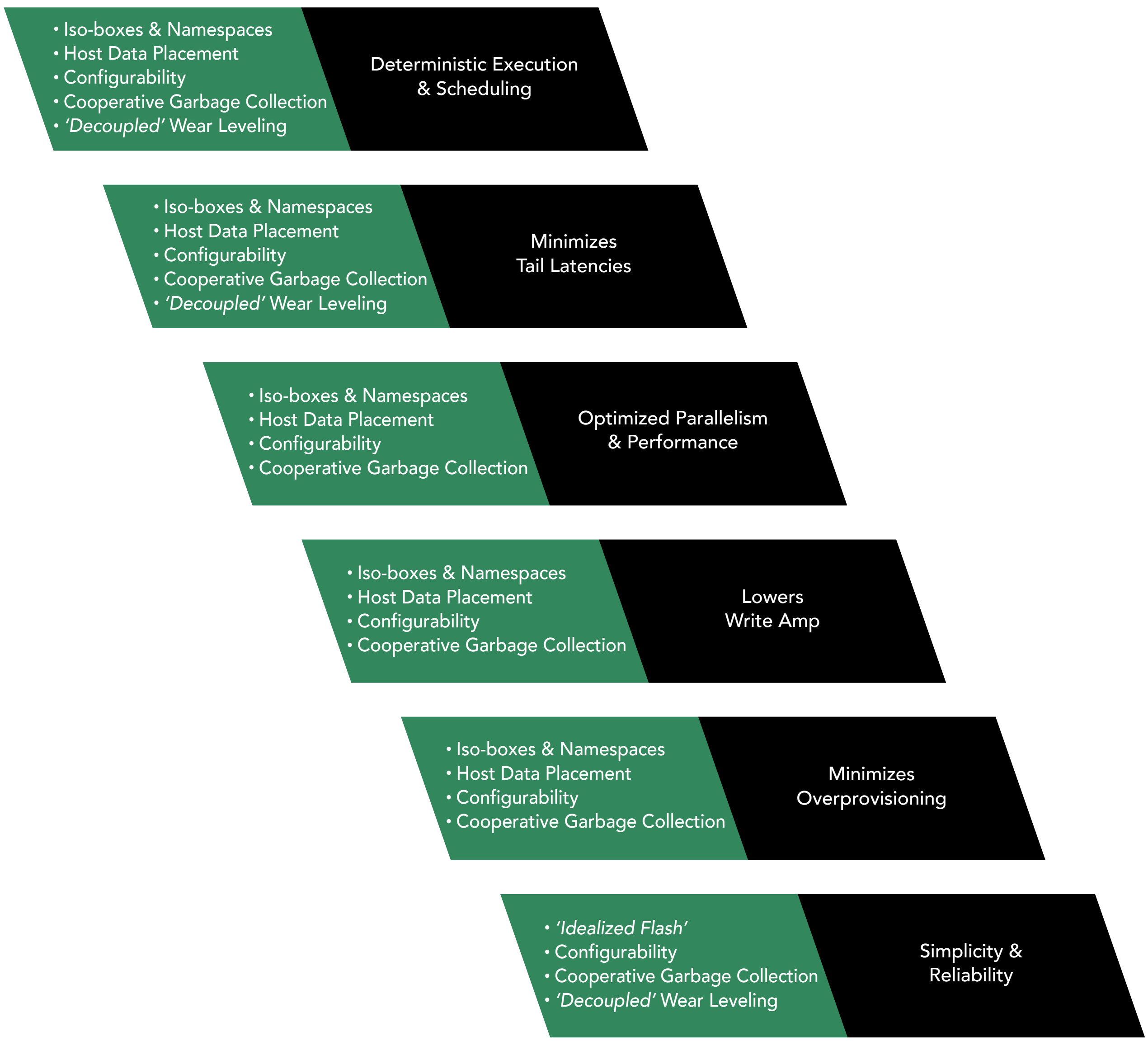
'Idealized Flash'
Cooperative zones are comprised of NAND Erase Units (blocks) that come from the same iso-boxes. Geometry emulation abstracts NAND geometry and vendor-specific attributes, presenting the host with zones of *'Idealized Flash'*.

Host Data Placement
Sequential write zones are presented to the host as a contiguous range of LBAs and host data placement is preserved through to the media in that zone. An optional Delegated Move operation enables the host to command the device to transfer data between zones.

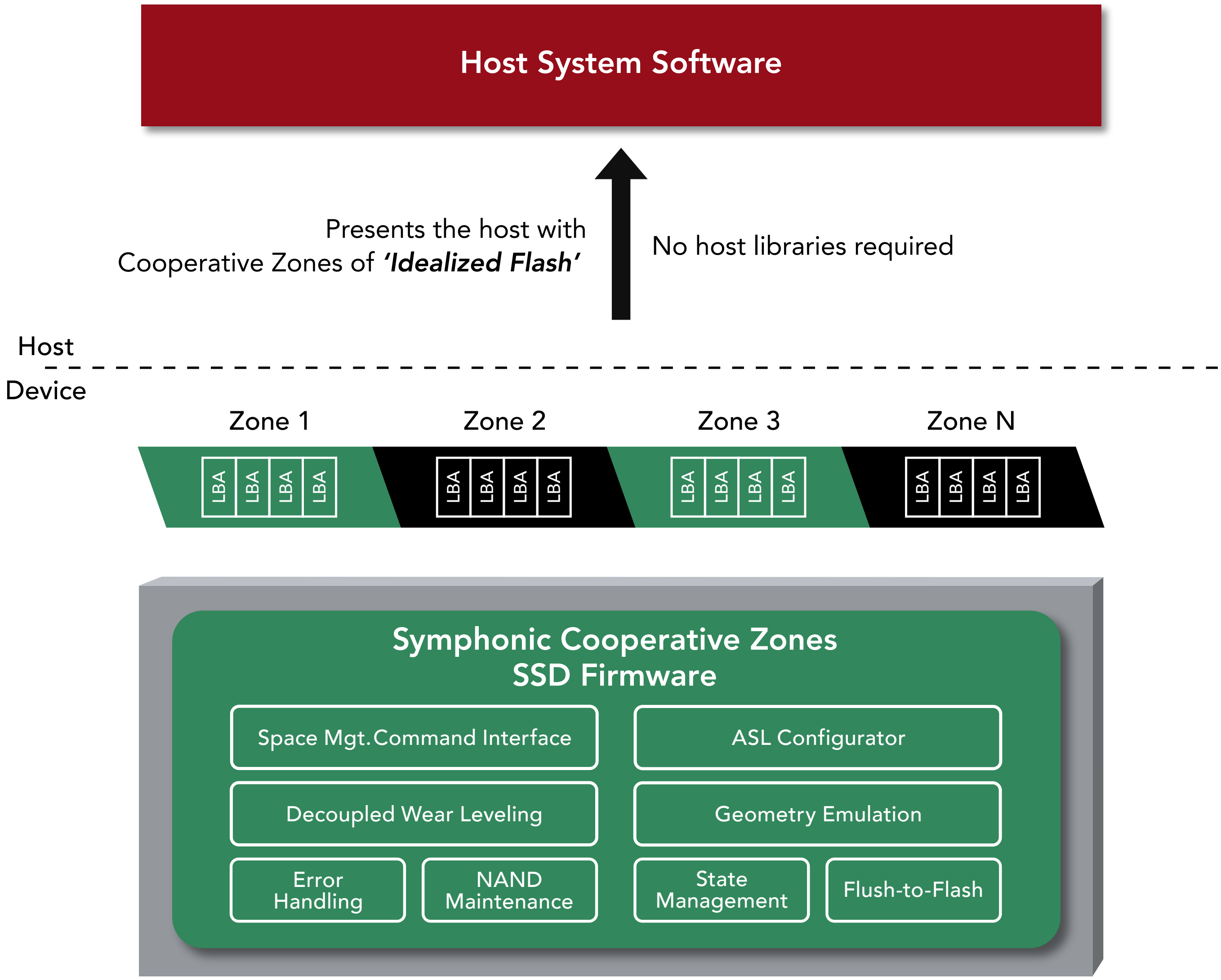
Configurability
Cooperative zones, iso-boxes, and write stripes are all user configurable.

Cooperative Garbage Collection
After relocating valid data, zones are erased by the host issuing a 'Zone Reset' command to the SSD for the target zone, whereby the device immediately erases that zone.

'Decoupled' Wear Leveling
Routine wear leveling and NAND maintenance are performed internally by the SSD in a coherently aligned manner, where the device only initiates cooperative requests to the host if required data movement could conflict with other I/O access.



Accessing a Symphonic Cooperative Zoned SSD follows the same host/device model as earlier Symphonic SSDs. This enables the host to control data placement while the SSD abstracts lower level media management, including geometry and vendor-specific NAND attributes (*'Idealized Flash'*). Flash management processes such as garbage collection, wear leveling, and NAND maintenance are executed by the device, under cooperative host control, and hence performed deterministically.



- Configurable, Cooperative Zones of *'Idealized Flash'* are presented to the host as contiguous LBAs and discovered through the 'Zone Report' command (NVMe vendor extension).
- As part of garbage collection, hosts are responsible for selecting valid data and a relocation destination on a different zone, either performing a copy/write operation directly or using Radian's optional Delegated Move command (NVMe vendor extension) that delegates the data transfer to the device.
- Zones are cleaned (erased) through the use of a 'Zone Reset' command (NVMe vendor extension) that is issued by the host to the device, or via a zone aligned NVMe deallocate command.
- By default, routine wear leveling and NAND maintenance (data retention, scrubbing, error handling) are performed internally by the device without requiring host involvement or interfering with host latencies.
- The device initiates a cooperative request to the host if additional wear leveling or other NAND maintenance is required that could conflict with host I/O access latencies.

Configurable Zones = Minimum Write Amp

Minimizing write amplification is becoming more critical with each new generation of NAND Flash. As NAND die capacities continue to grow larger, unnecessary traffic from write amp has a greater impact on latencies. And as process nodes shrink and bits per cell increase, such as with QLC, endurance is further diminished, potentially to a point where excess write amp prevents use of the technology for many applications.

Most modern host systems are non-overwriting, and many are based on log structured architectures where a contiguous address range, known as a segment, is cleaned as part of the space reclamation process. Typical SSDs have FTLs, which are also log structured and have the equivalent of a segment that is cleaned as part of garbage collection. At the system level, this creates a challenge known as 'log on log', where each layer is independently, redundantly cleaning and likely on different segment lengths and distributions. The result is additional write amp and unpredictable latency spikes.

With Symphonic Cooperative Zones, the host continues to be responsible for cleaning but the SSD does not have a redundant cleaning log, eliminating the 'log on log' write amplification. Of equal importance, Symphonic Zones are user configurable. Radian's ***Address Space Layout (ASL) configurator*** enables users to configure the SSD zones to match the host file system's segment size. This configurability minimizes modifications to host system software and associated integration efforts, while also eliminating the write amplification that would otherwise occur if the host segments and SSD zones were not aligned.

Deterministic Performance

Cooperative Garbage Collection

Unlike conventional FTL SSDs that clean (garbage collect) random address ranges without warning, Symphonic Zones are cleaned deterministically.

As part of its normal space reclamation process, the host selects which zones (segments) to clean. Relocation of valid data is either performed directly by the host with a copy/write operation, or using Radian's optional Delegated Move operation where the host specifies the destination address and commands the device to perform the data transfer. Then the host simply issues a 'Zone Reset' command to the device, and the device immediately erases the associated zone without introducing any new or complex scheduling requirements. This enables SSD garbage collection to be deterministic and prevents unforeseen latency spikes.

'Decoupled' Wear Leveling NAND Maintenance

In conventional FTLs, the wear leveling process is often integrated with garbage collection processes and algorithms. In the default option, a Symphonic Cooperative Zoned SSD performs *'Decoupled'* Wear Leveling and *'Decoupled'* NAND maintenance. These modes are cooperative, memory controller-owned processes performed by the device and effectively decoupled from the host's garbage collection algorithm.

When the host issues a 'Zone Reset' as part of its aforementioned space reclamation and cleaning process, the Symphonic Cooperative Zoned SSD will internally, concurrently perform wear leveling and data scrubbing on that same zone in a coherently aligned manner that does not interfere with other host-directed I/O accesses.

Because the host, or a host FTL, is in control of garbage collection and likely to be log structured, writes will inherently tend to level wear. When this is not adequate and the device determines that additional wear leveling or NAND maintenance data scrubbing is required, the Cooperative Zoned SSD will use its Back Channel, an out of band communication path, to initiate a request to the host that certain ranges of data be moved or refreshed.

The device continues to escalate these requests until the host responds. If the host does not respond, the device will eventually proceed with the necessary data movement which may briefly interfere with other I/O, but the latency conflict is one that has been forecasted to the host and is hence deterministic. The host can also poll the device to request this information in advance, taking it into account as part of its routine cleaning and data relocation processes.

Similarly, the Symphonic Cooperative Zoned SSD performs bad block management by transparently remapping erase units (bad blocks) from erase units held in reserve. This swapping of erase units is again handled deterministically and typically without impacting host latencies.

ASL Configurator = Optimized Scheduling

ASL Configurator

Radian's Address Space Layout (ASL) configurator enables user configuration of iso-boxes, Cooperative Zones, and write stripes. An iso-box is a physically discrete, performance-isolated region based upon NAND dies and channels that can be associated with namespaces. In addition to being based upon capacity, these iso-boxes can be configured based upon characteristics in terms of endurance and I/O bandwidth, predictable I/O latency, cleaning policies, deterministic scheduling or other combinations of desired metrics via parameterized descriptions. Cooperative Zones are comprised of NAND Erase Units (blocks) that come from the same iso-boxes. And write stripes are formed from a number of NAND pages from within that Cooperative Zone.

Radian's ***Geometry Emulation*** virtualizes the topology of the NAND, including geometry and vendor-specific attributes, to present the host with zones of *'Idealized Flash'* while maintaining symmetric alignment through to the physical memory. The ASL configurator utilizes hierarchical address virtualization to enable users to configure those zones to best match their system requirements.

Zones, Write Stripes, & Scheduling

NAND Flash arrays have an inherent tradeoff between performance and efficiency constraints. Configuring zones and write stripes to be wide and shallow will increase bandwidth, but will also increase write amplification and collisions that induce latency spikes. Alternatively, configuring zones and write stripes to be narrow and deep will reduce write amplification and latency spikes, but will also reduce frontier bandwidth.

Beyond performance and efficiency constraints, optimized system scheduling should be taken into consideration. While presenting 4TB, 8TB, or more as a single SSD creates challenges around deterministic performance, configuring a single SSD as hundreds of individual block devices or namespaces can create other challenges, including significant complexities in terms of optimizing host scheduling.

Radian's ASL Configurator provides different parameterized profiles that optimize Address Space Layout to help address the challenges of complex scheduling, along with the sizing tradeoffs associated with zones and write stripes. This includes the ability to configure iso-boxes of variable sizes, with different ASL profiles, within a Radian SSD to obtain the configuration that best matches the application requirements.

Tiered Zones

Symphonic Cooperative Zones offer a simple, logical model to access different memory types as different zones on the same SSD, from NV-RAM to Storage Class Memory to NAND Flash, and different classes of NAND Flash. Variations of SLC NAND can provide very low latency and high endurance, while TLC NAND provides better capacity and cost efficiencies. The architecture can support factory configured zones designated as SLC, or TLC, or NV-RAM zones today, and other memory types such as QLC, SCM, and specialized ultra low latency SLC variations in the future. Combined with Radian's Delegated Move technology, this enables hosts to readily apply tiering between zones based upon different memory technologies to optimize efficiency trade-offs for cost, performance, capacity and endurance.

'All Firmware' SDF SSD & SPDK

Until now, Software-Defined Flash (SDF) SSDs have either not offered *"Idealized Flash"* or *"Configurable Addressing"*, or, in the case of Radian's SDF SSDs, required proprietary host resident libraries to provide this functionality. The Symphonic Cooperative Zoned SSD is the first SDF SSD to provide this functionality completely in device firmware, without requiring any host libraries. This obviates the issues of having to integrate proprietary vendor libraries into host system software and minimizes OS compatibility requirements. The *'All Firmware'* implementation is especially advantageous in SPDK environments which do not require NVMe device drivers or use of the kernel block layer, as existing targets can access the Cooperative Zoned SSD directly without transitioning through intermediary libraries.

ZBD to NVMe Bridge

Radian offers an optional host library to customers utilizing a zone block device (ZBD) interface. Providing a protocol translation from the zone block device interface to NVMe, this bridge enables system software to access the Symphonic Cooperative Zoned SSD as a NVMe block device using a subset of the SMR zone block device commands.

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