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Lustre Features and Future

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Upcoming Release Feature Highlights

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- 2.13 feature complete, ETA November, 2019
  - **Persistent Client Cache (PCC)** – store file data in client-local NVMe/NVRAM
  - **LNet Multi-Rail Routing** – extend MR to/through routers, handle mixed interfaces
  - **DNE space balanced remote directory** – improve load/space balance across MDTs
  - **Layout OST overstriping** – allow multiple objects from one OST in a striped file
  - **Self-Extending Layouts (SEL)** – better handle OST out-of-space in the middle of a file
- 2.14 has a number of features under active development
  - **DNE directory auto-split** – improve usability and performance with multiple MDTs
  - **File Level Redundancy Erasure Coding (EC)** – efficiently store striped file redundancy
  - **OST Pool Quotas** – manage space on tiered storage targets using OST pools
- 2.15 plans continued functional and performance improvements
  - **Metadata Writeback Cache (WBC)** – low latency file operations in client RAM
  - **Client-side data encryption** – persistent encryption from client to disk

Persistent Client Cache (PCC, LU-10092) (2.13)

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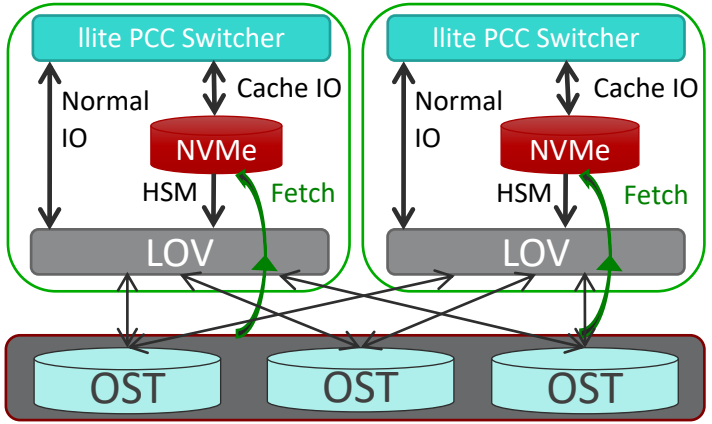
- **Reduce latency**, improve small/unaligned IOPS, reduce network traffic
- PCC integrates Lustre with a persistent per-client **local cache storage**
  - **A local filesystem** (e.g. `ext4` or `ldiskfs`) is created on client device (SSD/NVMe/NVRAM)
  - **Data is local to client**, no global/visible namespace is provided by PCC
  - **HSM POSIX copytool** fetches whole files into PCC by user command, job script, or policy
  - New files created in PCC are *also* created on Lustre MDS
- Lustre uses local data if in PCC, or normal OST RPCs
  - Further file read/write access "directly" to cache file
  - No data/IOPS/attributes off client while file in PCC
  - File migrated out of PCC via HSM upon remote access

2.13

2.14

- Separate **shared read** vs. **exclusive write** cache
- Integrate with DAX for NVRAM cache device



DNE Improvements (2.13+)

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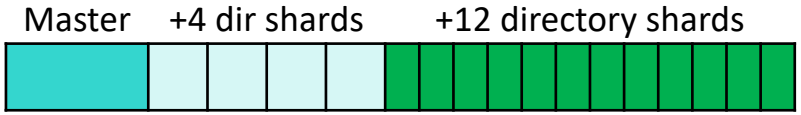
- **Space balance new directories** on "best" MDT based on available inodes/space
  - Simplifies multiple MDTs without overhead of striping all directories, similar to OST balance
  - 2.12 Explicitly when creating a new directory with "`lfs mkdir -i -1`" (LU-10277)
  - Transparently with normal `mkdir()` based on parent policy (LU-10784, LU-11213)
    - Set "**space**" hash policy on parent via "`lfs setdirstripe -H space dir`"
    - Most useful for root directory and top-level user directories
- 2.13 **Improved DNE file create performance** for clients (LU-11999, Uber)
- 2.14 **Automatic directory restriping** as directory size grows (LU-11025)
  - Create one-stripe directory for low overhead, scale shards/capacity/performance with size
  - Add extra directory shards when master directory grows large enough (e.g. 10k entries)
  - Move existing dirents to new directory shards
  - New dirents and inodes created on new MDTs



Data-on-MDT Improvements (2.13+)

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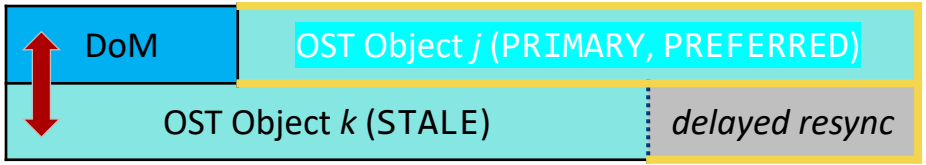
- Convert write locks to read locks w/o cache flush (LU-10175)
- General usability and stability improvements
- FLR mirror/migrate DoM file (LU-11421)
  - Mirror DoM data to OST object
  - Migrate DoM data to/from OST object
  - No MDT-MDT mirroring yet



- Performance and functional improvements
  - Target IO-500 `mdtest-hard-{write,read}` (3901-byte parallel file create in shared dir)

2.13

2.14

- Dynamic DoM component size by MDT free space (LU-12785)
- Merge data write with `MDS_CLOSE` RPC (LU-11428)
- Cross-file data prefetch via statahead (LU-10280)
- Allow MDT-only filesystem (LU-10995)

LNet Multi-Rail Selection Policy (2.13+)

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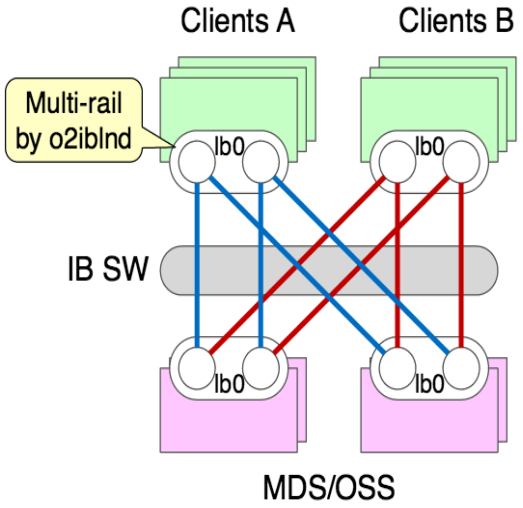
- Multi-Rail routing (LU-11299)
  - Extend LNet Multi-Rail to router nodes
  - Improve handling of mixed MR/single networks

2.13

2.14

- User Defined Selection Policy (LU-9121)
  - Fine grained control of interface selection
    - TCP vs. IB networks, primary vs. backup
  - Optimize RAM/CPU/PCI data transfers
  - Useful for large NUMA machines



Improved Client Efficiency (2.13+)

- **Single thread create** performance on **DNE** (LU-11999 Uber)
  - Reduce locking overhead/latency *for single-threaded* workloads (**780/sec -> 2044/sec**)
- **Parallel client readahead** performance (LU-8709, LU-12043)
  - Optimize *single-threaded readahead* using multiple async prefetch threads
  - Improved read for "`dd if=file of=/dev/null bs=1M`" from **1.9GB/s -> 4.0GB/s**
- **Overstriping OST objects** better utilizes large/fast OSTs from fewer clients (LU-9846)
  - "`lfs setstripe -C|--overstripe-count stripe_count`" for multiple objects per OST
- **Improved small file handling** (IO-500 `mdtest-hard-{write,read}` performance)
  - Cache small files after create (LU-11623, LU-12325, LU-10948, ...)
- **Improved strided read/write** (IO-500 `ior-hard-{write,read}` performance)

2.13
  - Detect and handle page-unaligned strided reads (LU-12644)

2.14
  - Kernel `lockahead` for strided writes (LU-12550)
  - Allow readahead to continue for slightly "imprecise" strides
- **Local client mount on OST/MDT** for data mover/resync (LU-10191)
  - Beginning of optimization for local IO path to avoid RPC + data copy

Performance Improvements for Flash (2.12+)

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- **Reduce server CPU** overhead to improve small flash IOPS (LU-11164)
  - Reduced CPU usage translates directly to improved IOPS
- **Avoid page cache** on ldiskfs flash OSS (LU-11347)
  - Avoids CPU/lock overhead/lock for page eviction

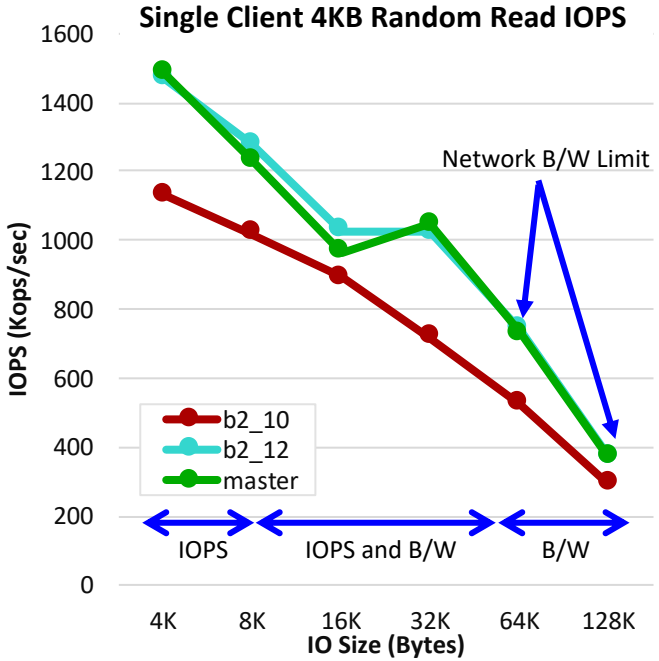
2.12

- **TRIM flash storage** on ldiskfs (LU-11355)
  - Release unused blocks of filesystem via `fstrim`
- **Self Extending Layouts** (LU-10070, Cray)
  - Avoids out-of-space in the middle of files
  - Good for PFL with smaller flash OSTs than disk OSTs

2.13

2.14

- Continued reductions of overhead and latency
  - Improve small, unaligned and interleaved writes



Ongoing ldiskfs Improvements (2.13+)

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- Major `ldiskfs` features merged into upstream `ext4/e2fsprogs`
  - Large xattrs (up to 64KB/xattr) stored in separate inode (**`ea_inode`**)
  - Large directories over 10M entries/2GB (**`large_dir`**)

2.13
  - Project quota accounting/enforcement (**`project`**)

2.14
- One more Lustre-specific feature remains to be merged to `ext4/e2fsprogs`
  - Extended data in directory (**`dirdata`**) - needs unit test interface before merge
- Existing `ext4` features available that could be used by Lustre on `ldiskfs`
  - Efficient block allocation for large OSTs (**`bigalloc`**)
  - Tiny files (1-600/3800ish bytes) stored directly in the MDT 1KB/4KB inode (**`inline_data`**)

2.15
  - Metadata integrity checksums (**`metadata_csum`**)
- New `ext4` features currently under development
  - **Data Verity** – Merkle tree of data checksums stored persistently on *read-only* files
  - **Directory shrink** – reduce directory block allocation as files deleted

File Level Redundancy (FLR) Enhancements (2.13+)

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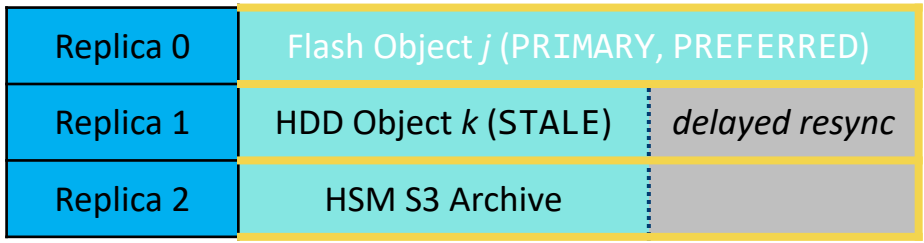
- **Lustre-level mirroring for files**, configured arbitrarily per file/directory
- **Mirror NOSYNC flag** + timestamp to allow *file version/snapshot* (LU-11400)
- Mount client directly on OSS without impacting recovery (LU-12722)

2.13
- **`lfs mirror resync/delete --pool`** to simplify tiering (LU-11022)

2.14
- **Erasure coding** adds redundancy without 2x/3x mirror overhead (LU-10911)
  - Add erasure coding to new/old striped files *after* write done
  - Leverage CPU-optimized EC code (Intel ISA-L) for best performance
  - For striped files - add N parity per M data *stripes* (e.g. 16d+3p)
  - **Fixed RAID-4 parity** layout *per file,* **declustered Parity** across files to avoid IO bottlenecks

2.15
- HSM in composite layout (LU-10606)
  - Allow multiple archives per file (S3, tape, ...)
  - Allow partial file restore from archive

TBD
- File version/reflink within namespace?
  - Access like VAX/VMS using "`filename,1`"?



Miscellaneous Improvements (2.13/2.14)

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- **Foreign Layout** file/directory in namespace (DAOS, CCI) (LU-11376 Intel)
- **Overstriping** allows multiple file stripes per OST (LU-9846 Cray/WC)
  - Useful for shared-file workloads or very large OSTs
- **`statfs()`** optimization for specific workloads (LU-12368, LU-12025)
- **`lfs find`** integration with Lazy Size-on-MDT (LU-11367)

2.13
- **Upstream kernel client cleanups** still under active development/merge (ORNL/Suse)

2.14
- **Pool Selection Policy** by extension, NID, UID/GID (LU-11234)
- **Dynamic OSS page cache** based on RPC IO size (LU-12071)
- **`fallocate()`** for file preallocation (ldiskfs only), hole punch (LU-3606)
- **`statx()`** for lightweight attribute fetching (LU-10934)
- **`O_TMPFILE`** for creating temporary files outside namespace (LU-9512)

Pool Quotas for OSTs (LU-11023)

(2.14+ Cray)

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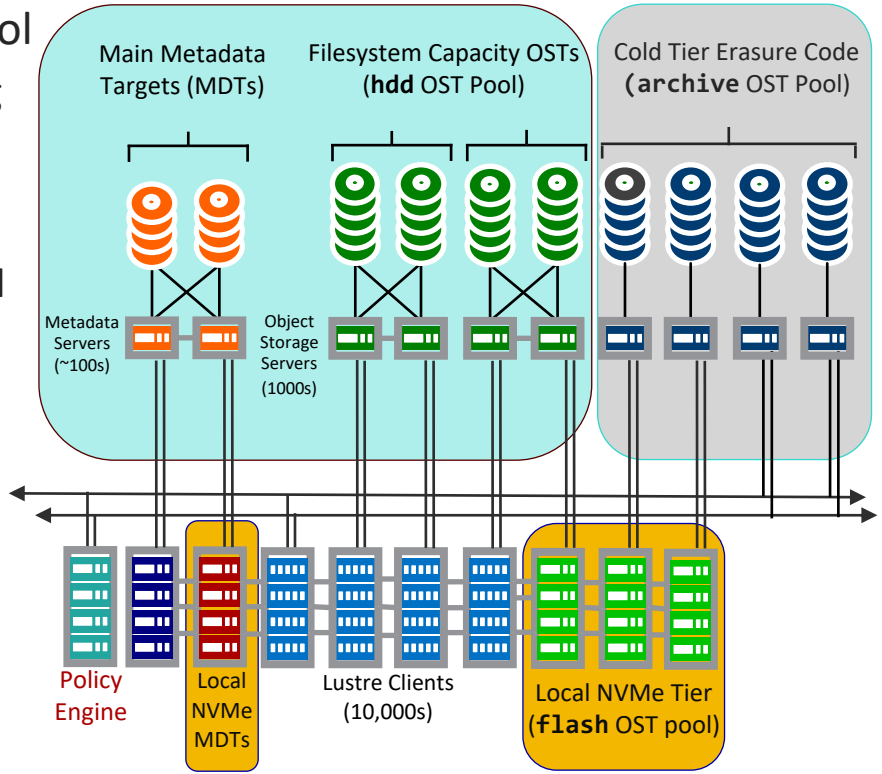
- Account/limit space for OSTs in a specific pool
  - Control usage of small flash OSTs in tiered config
- Use existing Lustre quota infrastructure
  - OST already tracks space per UID/GID/ProjID
  - Pool usage based on sum of current OSTs in pool
- Add pool quota limits per UID/GID/ProjID
  - No extra accounting on the OSTs

2.14
  - Only new aggregation/reporting by MDS

TBD
- Add MDT pools after OST pools complete
  - Manage DoM space usage
  - Allow different MDT storage classes



Client-side Data Encryption at Rest (LU-12755) (2.15)

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- Protect from storage theft/mistakes network/admin snooping
- **Encryption on Lustre client** down to storage
  - Applications see clear text in client cache
  - Data is **encrypted before sending** to servers
  - Data is **decrypted after receiving** from servers
  - Servers/storage only see encrypted data/filenames
  - Only client nodes need access to user encryption keys
  - Transparent to backend filesystem/storage (ldiskfs/ZFS)
  - Utilize larger client CPU/accelerator capacity
- **Ext4/f2fs `fscrypt` library/tools base** (don't invent it!)
  - Tunable encryption setting/key(s) per directory tree
  - **Per-file encryption key(s)**, itself encrypted by user key
    - **Fast and secure deletion** of file once per-file key is erased
  - Filenames encrypted in MDT directory entries

Metadata Writeback Cache (WBC, LU-10983) (2.15+)

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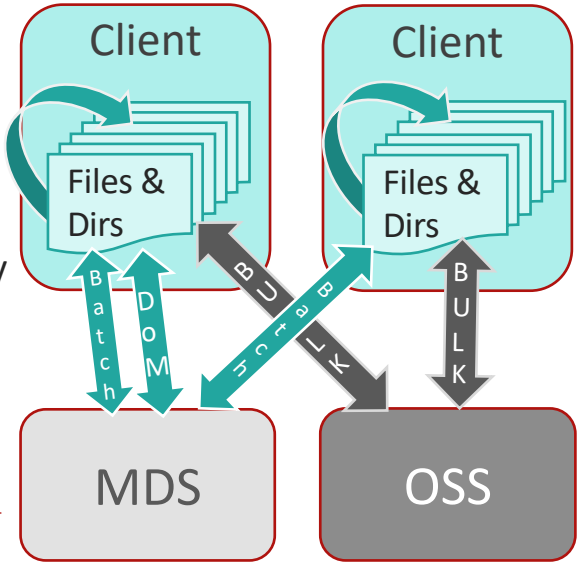
- Create new dirs/files **without RPCs in client RAM** (or local NVMe)
  - Lock new directory exclusively at mkdir time
  - Cache new files/dirs/data only in RAM/local NVMe until cache flush
- **No RPC round-trips** for file modifications in new directory
- **Files globally visible on flush** to MDS, *normal usage thereafter*
  - Flush top dir to MDS upon other client access, lock conflict
    - Create top-level entries, exclusively lock new subdirs, release parent
    - Repeat as needed for portion of namespace being accessed remotely
  - Flush rest of tree in background to MDS/OSS by age or size limits
- Basic WBC prototype developed to test concept
  - No cache/quota/space limits, no background flushing, no batching, ...
  - **10-20x *single-client*** speedup in early testing (`untar`, `make`, …)

2.15

2.16

- **Aggregate operations to server** to improve performance
  - Batch operations in one RCP to reduce network traffic/handling
  - Batch operations to filesystem to reduce disk IOPS



Client Container Image (CCI) (TBD)

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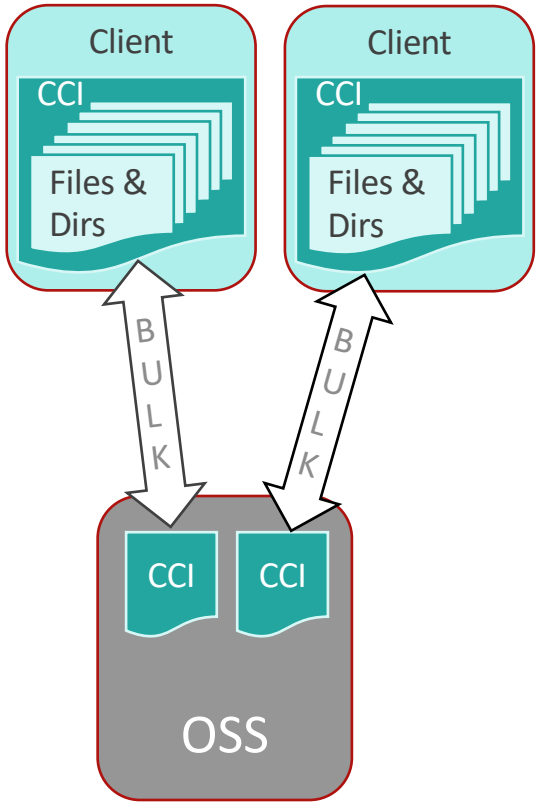
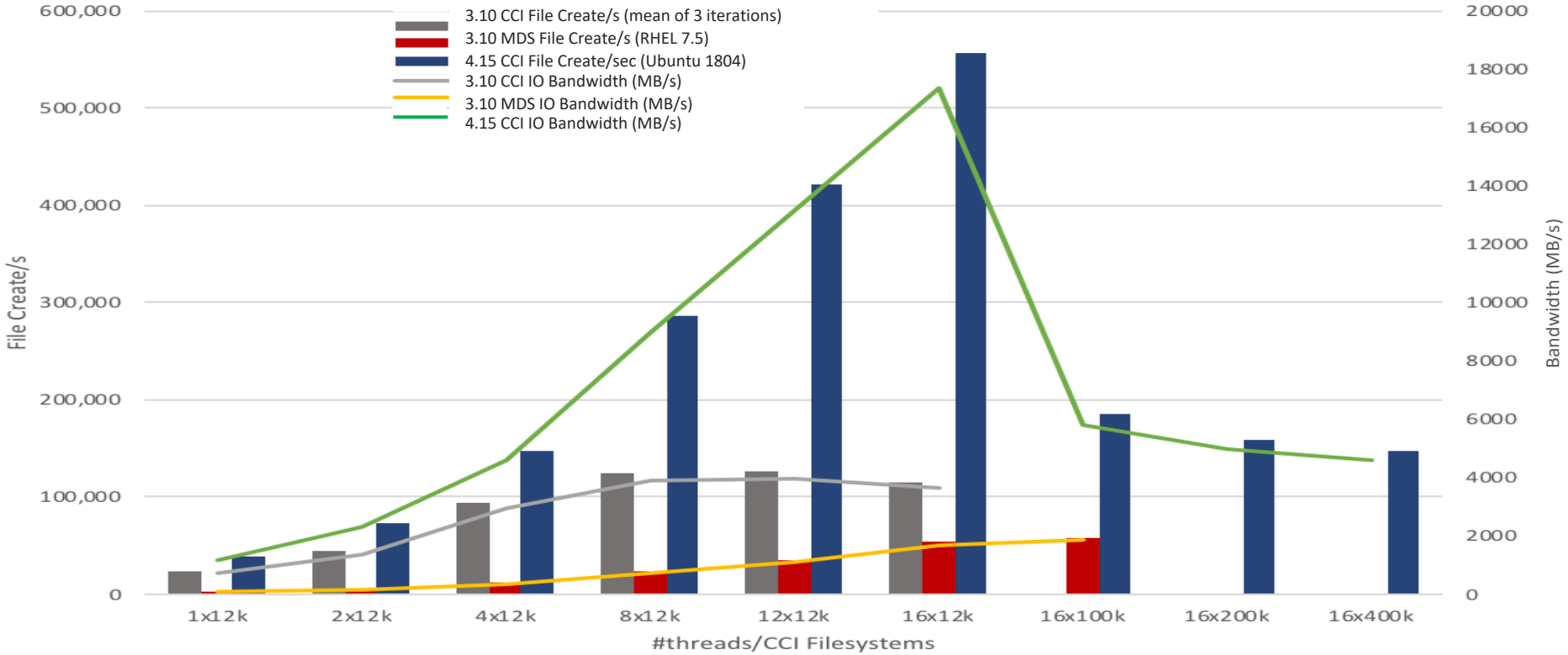


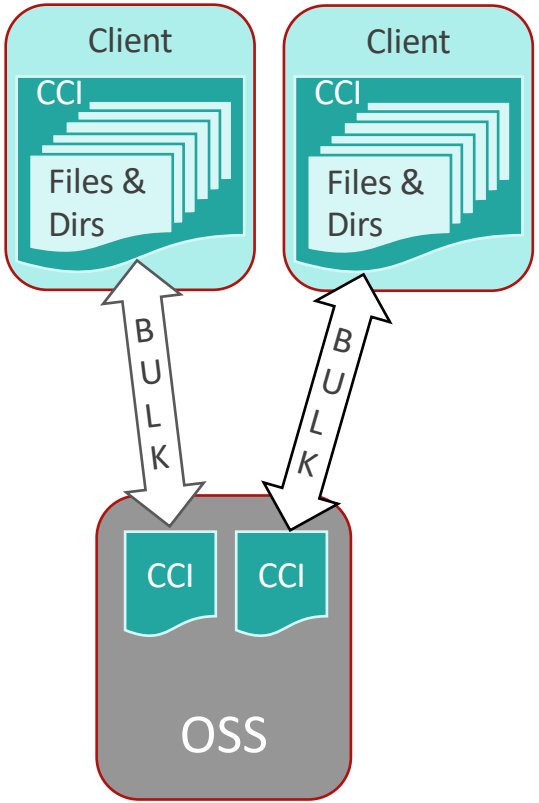
- Ext4 filesystem images used ad-hoc with Lustre in the past
  - **Read-only cache** of many small files manually mounted on clients
  - **Root filesystem images** for diskless clients/VMs
- ***Container Image* is loopback `ldiskfs` mount** on client
  - Whole directory tree (maybe millions of files) in **one Lustre image file**
  - **Best for self-contained workloads** (e.g. embarrassingly parallel)
  - **Optimize common AI, Genomics** workloads
- CCI *integrates* container image handling with Lustre
  - Image is registered to Lustre directory to automate future access
  - **Transparently mounts** registered image at client on directory access
  - Image data blocks read on demand from OST(s) and/or client cache
  - Images still part of namespace, allow some sharing between clients

Single Client **32KB File Create** Performance (MDS vs. CCI)

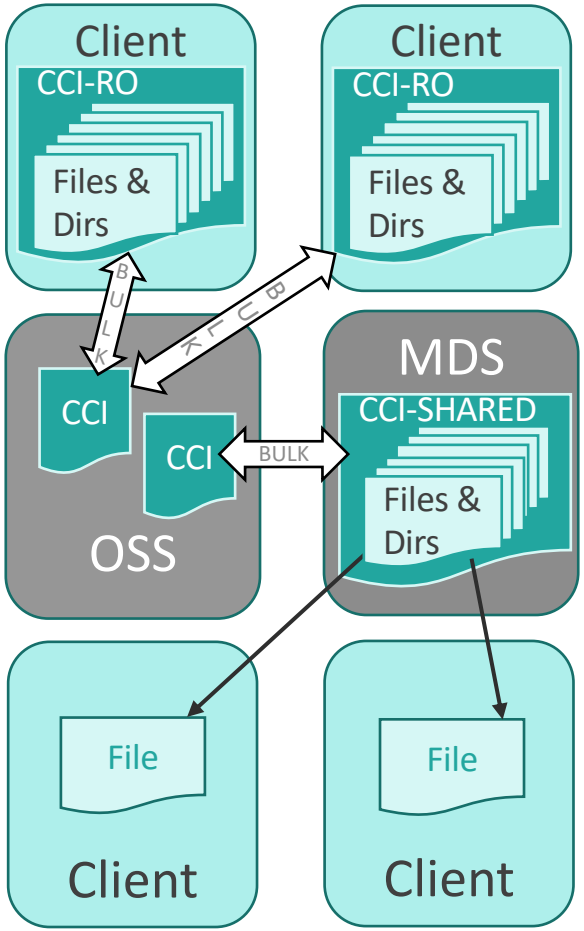


- Kernel 4.15 CCI improvement due to improved kernel loopback driver
- Early testing of CCI prototype shows promise

CCI Performance Optimization Areas



- **Low I/O overhead, few file lock(s), high IOPS per client**
  - Readahead and write merging for data and metadata
  - Client-local in-RAM filesystem operations with very low latency
- Access, migrate, replicate image with large bulk OSS RPCs
  - Thousands of files aggregated with MB-sized network transfers
  - Leverage existing high throughput OSS bulk transfer rates
  - **1GB/s** OSS read/write provides about **30,000 32KB files/sec**
- Unregister+delete CCI to **remove all its files with a few RPCs**
  - Simplifies user data management, accounting, job cleanup
  - Avoid MDS overhead dealing with large groups of related files



CCI Access Models

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- Need to integrate image handling on Lustre client/MDS
  - Integrate CCI creation with job workflow is easiest
  - CCI layout type on parent directory creates CCI upon `mkdir`
  - Improve `ldiskfs` online resize to manage image size
- One client ***exclusively*** mounts CCI(s) and modifies locally
  - For initial image creation/import from directory tree
  - For workloads that run independently per directory tree
- Multiple clients ***read-only*** mount single image
  - Shared input datasets (e.g. gene sequence, AI training)
- MDS exports ***shared read-write*** image to many clients
  - Internal mount at MDS attaches image to namespace
  - Use Data-on-MDT to transparently export image tree to clients
- Process whole tree of small files for HSM/tiering
  - Efficiently migrate tree to/from flash tier, to/from archive

Comparison and Summary of WBC vs. CCI

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Metadata Writeback Cache

- Keep normal namespace
- **Fully transparent to users and apps**
- Very low latency metadata operations
- **Faster single client performance**
- Network **batch RPCs** improves other ops
- **Lower total overhead** due to fewer layers

Client Container Image

- **Segregated directory subtree**
- Needs directive from user/job to create
- Not for all usage patterns
- **Faster aggregate system performance**
- Network **bulk IO** reduces MDS workload
- Aggregation simplifies dataset handling
  - Fast unlink, dataset prefetch
- **Usable for metadata tiering/HSM**

- Significant improvements for evolving HPC workloads
- Leverages substantial functionality that already exists

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