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End-to-end Data Integrity for NFS

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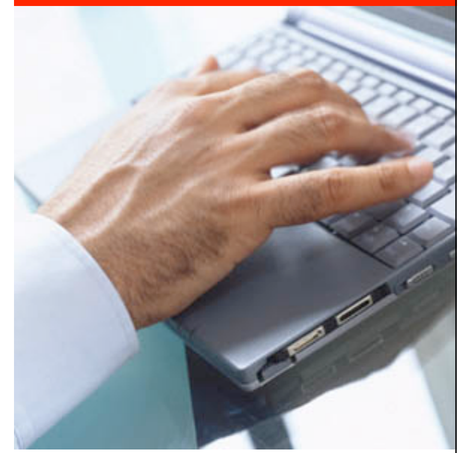
Today's Discussion



- What is end-to-end data integrity?
- T10 PI overview
- Adapting T10 PI for byte-stream files
- Provisional feature requirements
- Protocol considerations

End-to-end Data Integrity Protection

- Prevent the storage or use of corrupted data
  - “Protection Information” allows detection and/or correction of data corruption (*e.g.*, CRC)
  - *Application provides PI*, which is stored with data on permanent storage
    - Storage stack generates PI if application does not provide
  - *Data integrity can be verified at every node in I/O path* during both writes and reads

T10 PI Overview

- Defined in T10 SBC-2 and enhanced in SBC-3
- Data integrity for block storage
- “Type 1” defines contents of eight bytes of PI for every logical block
  - 16-bit CRC
  - 16-bit application tag
  - 32-bit reference tag (low order 32-bits of LBA)
- This is an open standard: allows any node in I/O path to verify that data and PI match

Data Integrity eXtensions

- Proposed by Oracle, not a standard
- T10 PI protects path between O/S buffer and block storage
- DIX extends protection up to applications
- Data and PI specified in separate buffers
- A lower-overhead guard tag is used
- Still block-oriented

Protecting Byte-Stream Files

- What API do applications use to specify reads and writes with accompanying PI?
- How is integrity of memory mapped data protected?
- Can an advanced file system store protected and unprotected data in the same volume?
- How does an advanced file system treat replicated blocks (snapshots or de-duplication)?

Protecting Byte-Stream Files

Application API

- Applications form the PI and submit it with the data
  - Apps need to know which protection mechanism is in use
- Protected reads and writes are logical block-aligned
  - Apps need to know size of logical block
- PI can be specified via ioctl(), scatter/gather, or other separate system call
- Data integrity failure can be reported via new errno
  - Application knows to employ a special system call to retrieve extended information

Protecting Byte-Stream Files

Advanced File System considerations

- File systems may alter application-specified PI during I/O on complex device types (*e.g.*, RAID)
  - But, all devices backing an FS use same protection type
- All files on a particular volume are either protected or unprotected
  - Applications may choose not to supply PI; file system can generate it appropriately
- File system may choose to protect blocks storing its metadata

Protecting Byte-Stream Files

NFS client considerations

- Clients need to know which protection mechanism is in use on each FSID on a server
  - Can then advertise this to local applications
- Clients can use integrity-protecting transports along with PI
- Need to protect against write-re-ordering due to network or server instability

Provisional Feature Requirements

- End-to-end
  - Must allow protection from application write to read
  - Must permit verification at all nodes in path
  - Like RPCSEC, MUST implement, but deployment optional
  - File system operation must appear the same whether or not application is using or is even aware of data integrity
- Based on existing data integrity standards
  - IETF has no purview over physical storage
  - Better adoption if we expose existing standards on wire
  - Open standard means every node can participate

Provisional Feature Requirements

- Allow co-existence with other mechanisms
  - Should not interfere with serial or concurrent use of other data integrity verification mechanisms
  - Extensible: we want to allow other types of data protection
  - Mechanism must not interfere with access to data that is not protected by an end-to-end data integrity mechanism
- Agnostic to access method
  - Should work with any layout type
  - Non-pNFS access should also work
  - Should allow local access on file server, if appropriate

Provisional Feature Requirements

- Agnostic to server file system
  - No mandate for how a server's file system supports data integrity protection, only how it looks to NFS clients
- Protection for NFS metadata operations not mandatory
  - So far I have not considered metadata operation protection
  - Partially accomplished using an integrity-protecting transport
- Minimal performance impact
  - We know there will be some, let's try to keep it minimal

Protecting NFS Files

Example Protection Envelopes

- **NFS server-only**
  - Server does not advertise data integrity capabilities
  - Or client does not utilize data integrity capabilities
  - Data integrity failures appear to client as I/O errors
- **NFS client-server**
  - Client uses data integrity capability when communicating with server
  - Client does not advertise capability to applications
  - Client can accesses extended failure data, but apps can't
- **Application-client-server**
  - Application can use data integrity on some or all of its files
  - Application can extract extended integrity failure data

Protecting NFS Files

Detecting Protection Types

- Server advertises protection type in use for an FSID
  - Can introduce a GETATTR per-filesystem attribute
  - Protection type MUST NOT change during FSID's lifetime
  - FSIDs can use different protection types
  - Not all FSIDs protected
    - Pseudo-root
    - FedFS domain root
- Client advertises FSIDs protection type to applications
  - Applications may not use data integrity protection
  - Clients can choose not to use it, or generate it themselves

Protecting NFS Files

Possibilities for Reading and Writing PI

- New operations included in same compound as READ_PLUS, WRITE, or INITIALIZE
  - Works like GETATTR
- New enumerators for NFS4_DATA_CONTENT
- New arguments to READ_PLUS, WRITE, INITIALIZE
- New pNFS layout types

Protecting NFS Files

Asynchronicity

- Disk I/O can fail after a WRITE(UNSTABLE) operation completes
  - Failure MUST be reported at COMMIT time
  - Client then retries failing WRITE(UNSTABLE) via a WRITE(FILE_SYNC) to gather extended information about the failure
- Disk I/O can occur well before client reads data, due to server-side pre-fetch
  - Failure MUST be reported when specific block is read, not before

Protecting NFS Files

Generating PI

- T10 type 1 protection data
  - Application tag: Arbitrary or blank
  - Guard tag: 16-bit CRC
  - Reference tag: Lowest 32-bits of LBA
  - Protection envelope: I/O controller to block device

- Possible NFS protection data
  - Application tag: Arbitrary or blank
  - Guard tag: IP checksum
  - Reference tag: Middle 32-bits of file offset
  - Protection envelope: Application to NFS server

Protecting NFS Files

Reporting and Interpreting Failures

- T10 Type 1 failure report
  - Which tag failed to verify correctly
  - LBA of failure
  - Reporting node in I/O path
- Possible NFS failure report
  - Which tag failed to verify correctly
  - File offset of failure
  - Reporting layer
    - May be virtualized for simplicity

Protecting NFS Files

Multi-server Considerations

- Each DS participating in a layout MUST use the same protection type
- Each replica of an FSID listed in fs-locations MUST use the same protection type
- Destination server MUST support the same protection type as Source server
  - And, an FSID after migration MUST use the same protection type it was using before

Forthcoming Personal Draft

- Propose an architecture for end-to-end byte-stream data integrity protection based on T10 PI
- Enumerate and justify high-level requirements for NFS data integrity
- Provide enough meat to allow prototype implementations

Next Steps

- Complete and publish requirements document
- Build a prototype or two
- Consider support for other types of data integrity protection
  - Lustre
  - Native ZFS checksums