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A Multilevel Secure MapReduce Framework for Cross-Domain Information Sharing in the Cloud

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A Multilevel Secure MapReduce Framework for Cross-Domain Information Sharing in the Cloud

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Introduction

- Motivation

- Develop a cross-domain MapReduce framework for a multilevel secure (MLS) cloud, allowing users to analyze data at different security classifications

- Topics

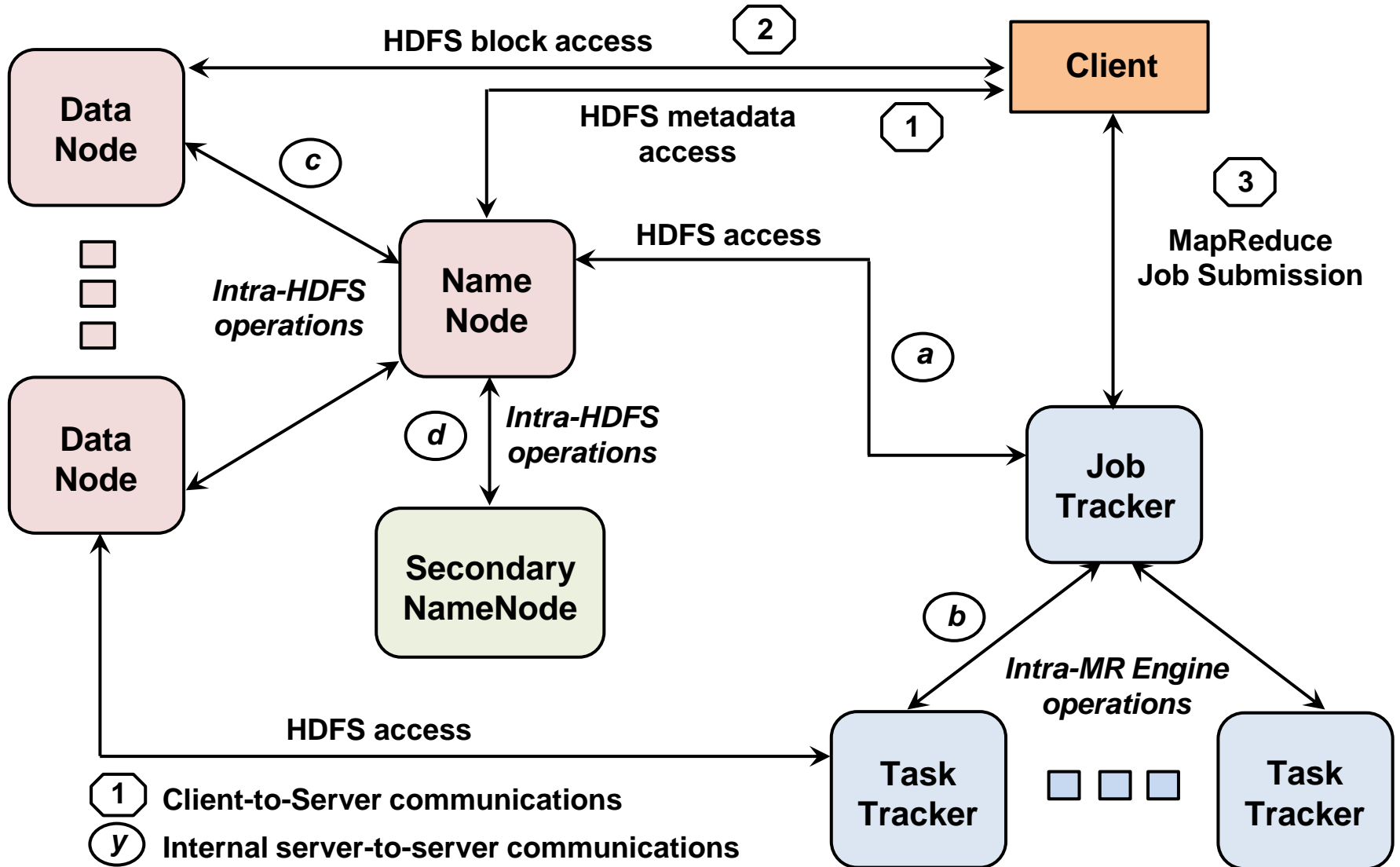
- Apache Hadoop framework
- MLS-aware Hadoop Distributed File System
 - Concept of operations
 - Requirements, design, implementation
- Future work and conclusion



Apache Hadoop

- Open source software framework for reliable, scalable, distributed computing
- Inspired by Google's MapReduce computational paradigm and Google File System (GFS)
- Two main subprojects:
 - Hadoop Distributed File System, Hadoop MapReduce
- Support distributed computing on massive data sets on clusters of commodity computers
- Common usage patterns
 - ETL (Extract → Transform → Load) replacement
 - Data analytics, machine learning
 - Parallel processing platforms (Map without Reduce)

Hadoop Architecture





MLS-Aware: A Definition

A component is considered MLS-aware if it executes without privileges in an MLS environment, and yet takes advantage of that environment to provide useful functionality.

Examples:

- Reading from resources labeled at the same or lower security levels
- Making access decisions based on the security level of the data
- Returning the security level of the data



Objective and Approach

- Objective
 - Extend Hadoop to provide a cross-domain read-down capability without requiring the Hadoop server components to be trustworthy
- Approach
 - Modify Hadoop to run on a trusted platform that enforces an MLS policy on local file system
 - Use Security Enhanced Linux (SELinux) for initial prototype
 - Modify HDFS to be MLS-aware
 - Multiple single-level HDFS instances – each is cognizant of HDFS namespaces at lower security levels
 - HDFS servers running at a security level can access file objects at lower levels as permitted by underlying trusted computing base (TCB)
 - No trusted processes outside TCB boundary

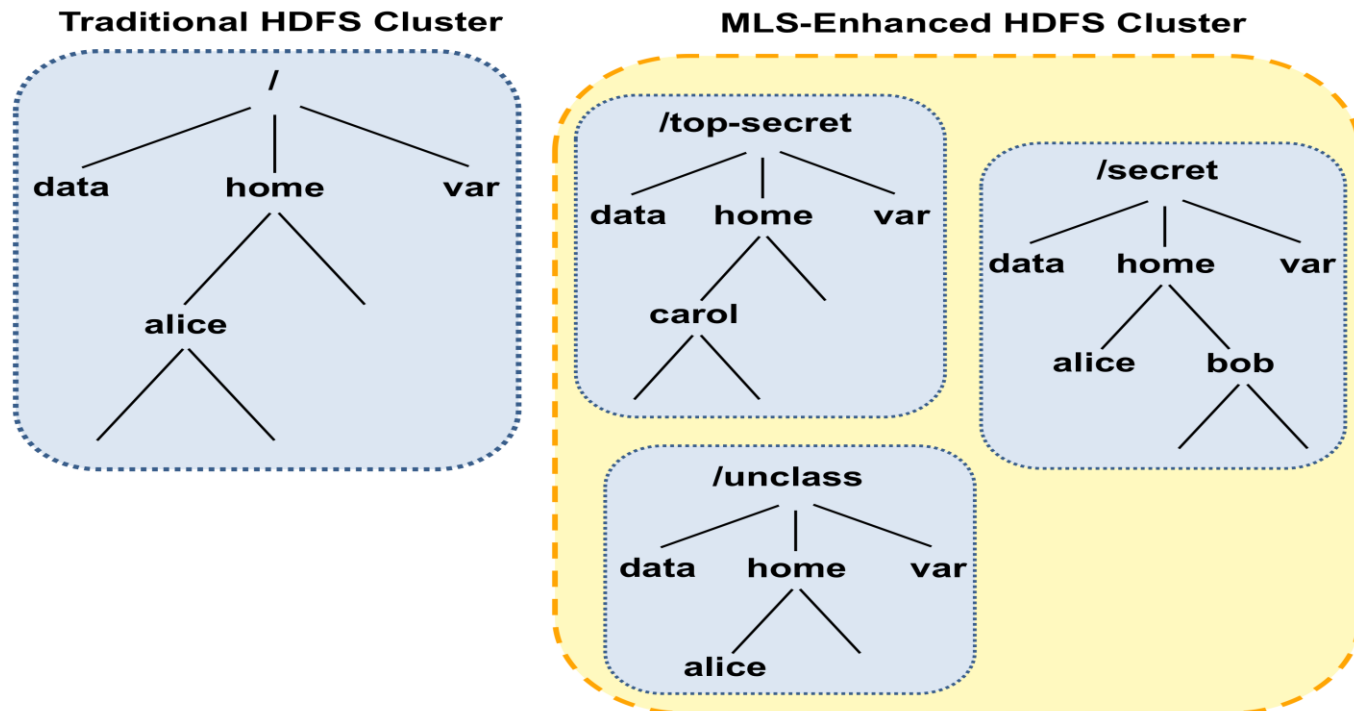


HDFS Concept of Operation

- User session level
 - Implicitly established by security level of receiving network interface and TCP/IP ports
- File access policy rules
 - A user can read and write file objects at user's session level
 - A user can read file objects if the user's session level dominates the level of the requested object
- File system abstraction
 - HDFS interface is similar to UNIX file system
 - Traditional Hadoop cluster: one file system
 - MLS-enhanced cluster: multiple file systems, one per security level

HDFS File Organization

- Root directory at a particular level is expressed as
 /*<user-defined security-level-indicator>*
- Security-level-indicator is administratively assigned to an SELinux sensitivity level
- Traditional root directory (/) is root at the user's session level





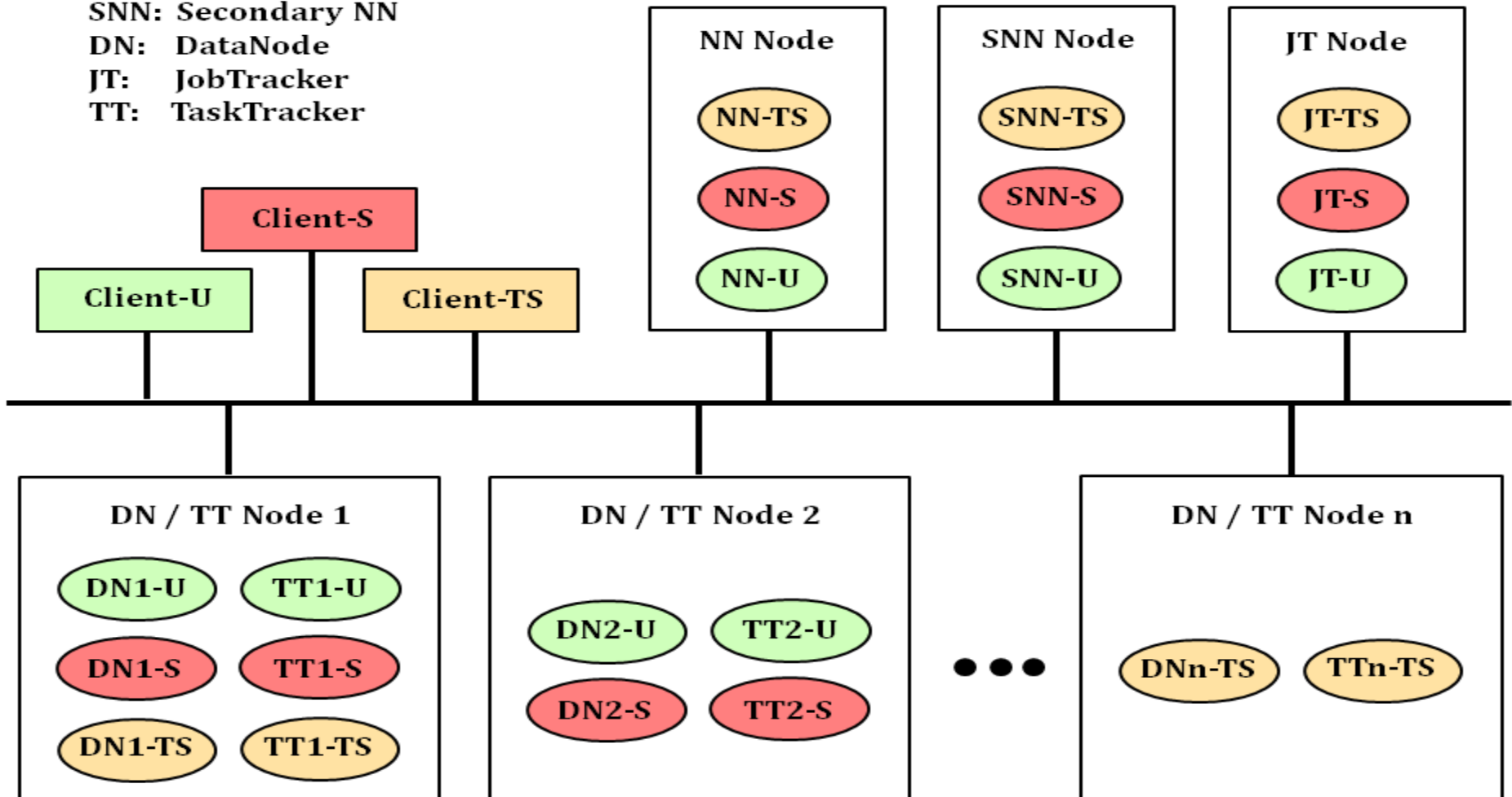
MLS-aware Hadoop Design

- Multiple single-level HDFS server instances co-locate on same physical node
- All NameNode instances run on same physical node
- DataNode instances are distributed across multiple physical nodes
 - *Authoritative DataNode* instance: owner of local files used to store HDFS blocks
 - *Surrogate DataNode* instance: handles read-down requests on behalf of an authoritative DataNode instance running at a lower level
- Configuration file defines allocation of authoritative and surrogate DataNode instances on different physical nodes
- Design does not impact MapReduce subsystem
 - JobTracker and TaskTracker only interact with NameNode and DataNode as HDFS clients

MLS-enhanced Hadoop Cluster

○ Process □ Physical node

NN: NameNode
 SNN: Secondary NN
 DN: DataNode
 JT: JobTracker
 TT: TaskTracker





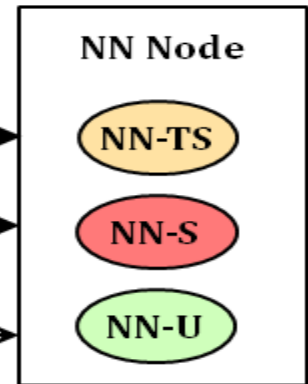
Cross-domain Read-down

- Client running at user's session level
 - Contact NameNode at same level to request a file at a lower level
- NameNode instance at session level
 - Obtain metadata of requested file and storage locations of associated blocks from NameNode instance running at lower security level
 - Direct client to contact surrogate DataNode instances that co-locate with the file's primary DataNode instances
- Surrogate DataNode instance at session level
 - Look up locations of local files used to store requested blocks
 - Read local files and return requested blocks
 - Security level of local files is lower than session level

Read-down Example

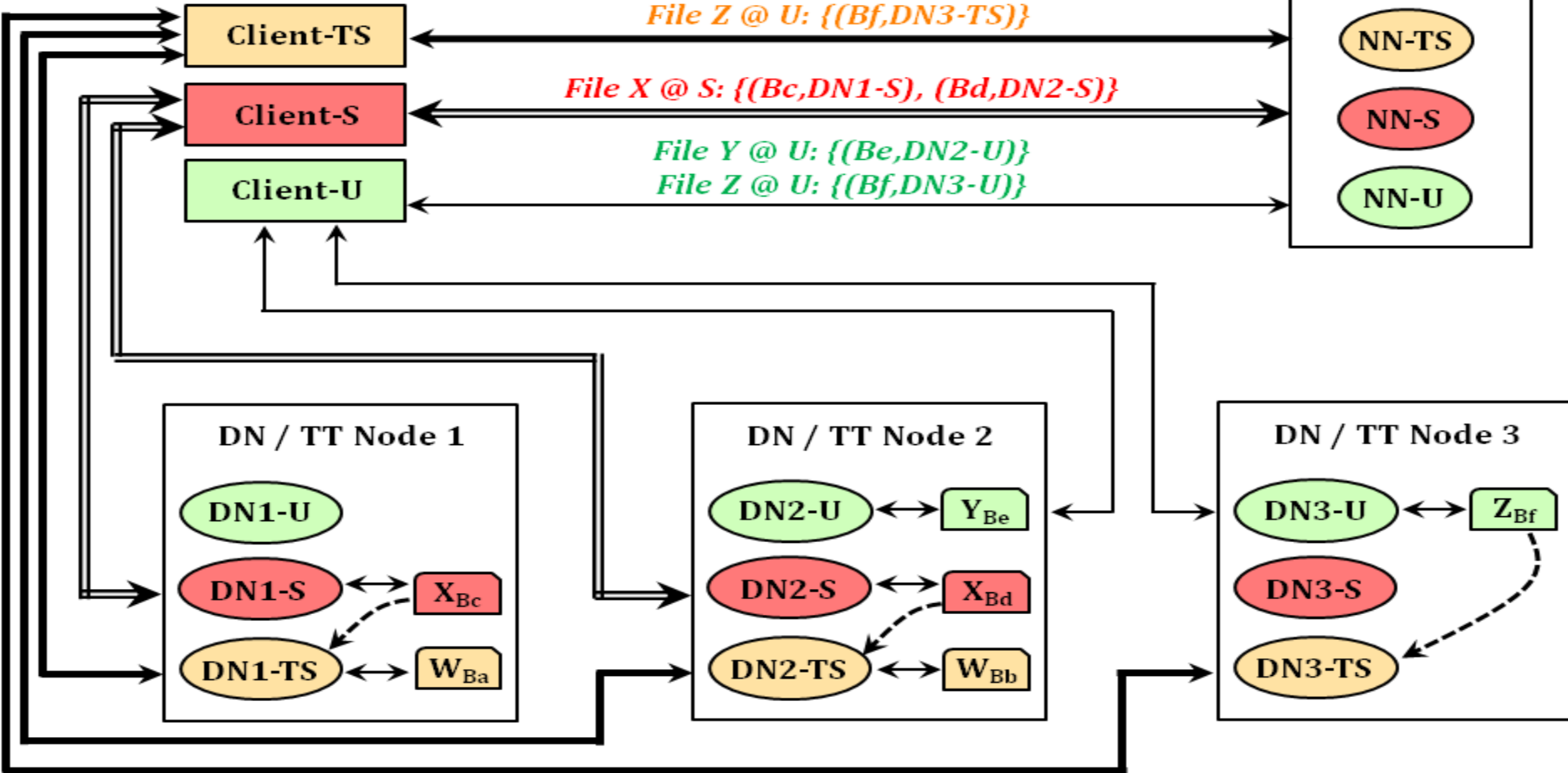
Bn: Block n

File W @ TS: {(Ba, DN1-TS), (Bb, DN2-TS)}
File X @ S: {(Bc, DN1-TS), (Bd, DN2-TS)}
File Z @ U: {(Bf, DN3-TS)}



File X @ S: {(Bc, DN1-S), (Bd, DN2-S)}

File Y @ U: {(Be, DN2-U)}
File Z @ U: {(Bf, DN3-U)}



TS operations
 S operations
 U operations

Read-down operations



Source Lines of Code (SLOC) Metric

- Use open source Count Lines of Code (CLOC) tool
 - Can calculate differences in blank, comment, and source lines
- Summary of code modification
 - Delta value is the sum of addition, removal, and modification of source lines
 - Overall change is less than 5%

	SLOC		Delta	Percentage Increase
	Original Hadoop	MLS-aware Hadoop		
NameNode (NN) only	14373	15974	1890	13.15%
DataNode (DN) only	6914	7399	692	10.01%
Misc (other than NN, DN)	68328	68890	732	1.07%
<i>Total HDFS related modules</i>	89615	92263	3314	3.70%



Future Work and Conclusions

- Future work
 - Adding read-down support to HDFS Federation
 - Implementing an external Cache Manager
 - Investigating Hadoop's use of Kerberos for establishing user sessions at different security levels
 - Performing benchmark testing with larger datasets
- Prototype is the first step towards developing a highly secure MapReduce platform
 - Does not introduce any trusted processes outside the pre-existing TCB boundary
 - Only affects HDFS servers



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