Security of Cloud Computing

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Syllabus

- Cloud Computing Introduction
  - Definitions
  - Economic Reasons
  - Service Model
  - Deployment Model
- Supporting Technologies
  - Virtualization Technology
  - Scalable Computing = Elasticity
- Security
  - New Threat Model
  - New Attack
  - Countermeasures ← Attestation

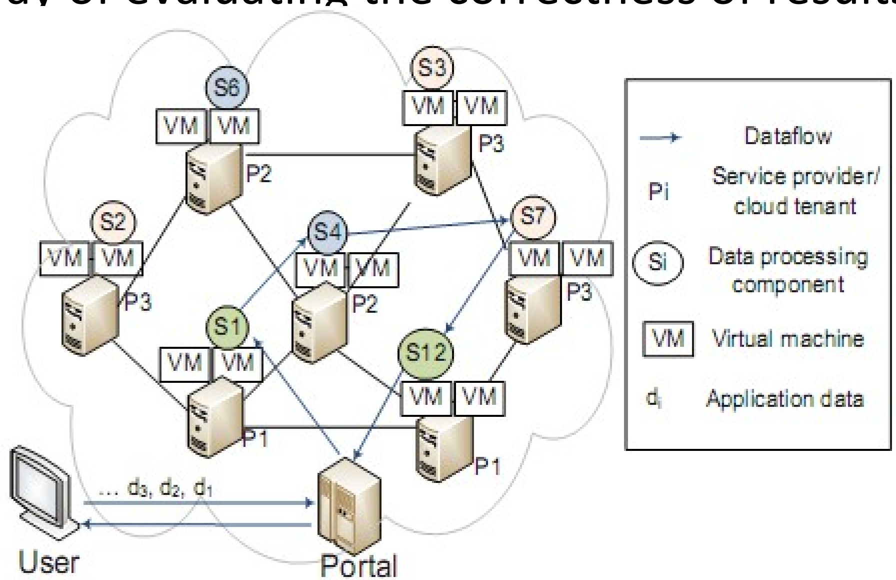
Verifying Computations in a Cloud

Scenario

User sends her data processing job to the cloud.

Clouds provide dataflow operation as a service (e.g., MapReduce, Hadoop etc.)

Problem: Users have no way of evaluating the correctness of results

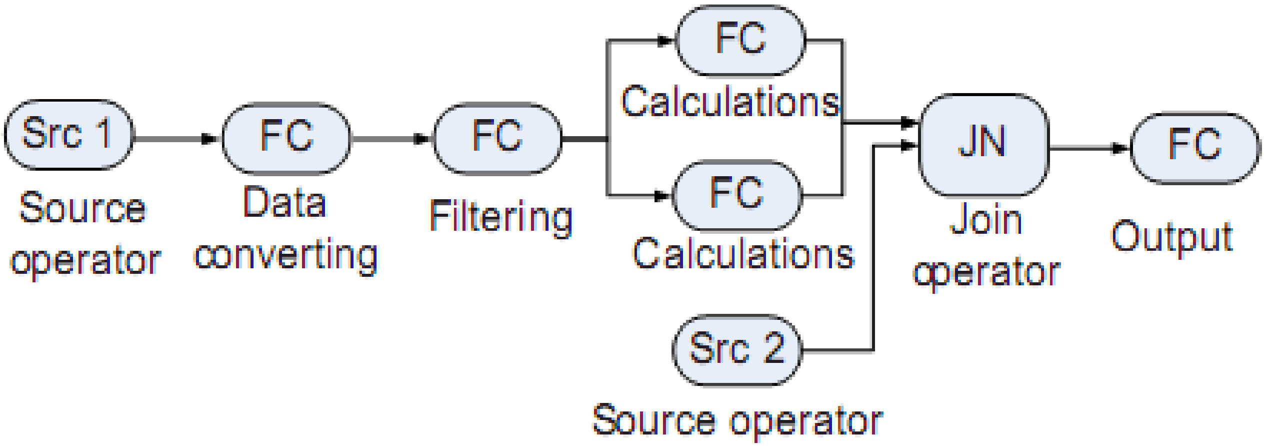


Why another attestation?

- The attestation that may be enabled by a TPM is static = it guarantees that the software that a VM runs is not malicious when it is loaded
- But the software can become malicious if it is successfully attacked
- Hence some form of dynamic attestation is required

Juan Du, Wei Wei, Xiaohui Gu, and Ting Yu. 2010. RunTest: assuring integrity of dataflow processing in cloud computing infrastructures. In *Proceedings of the 5th ACM Symposium on Information, Computer and Communications Security* (ASIACCS '10)

DataFlow Operations



Properties

High performance, in-memory data processing

Each node performs a particular function

Nodes are mostly independent of each other

Examples

MapReduce, Hadoop, System S, Dryad

How do we ensure DataFlow operation results are correct?

Goals

- To determine the malicious nodes in a DataFlow system
- To determine the nature of their malicious action
- To evaluate the quality of output data

Du et al., **RunTest: Assuring Integrity of Dataflow Processing in Cloud Computing Infrastructures**, AsiaCCS 2010

Possible Approaches

Re-do the computation

Check memory footprint of code execution

Majority voting

Hardware-based attestation

Run-time attestation

RunTest: Randomized Data Attestation

Idea

- For some data inputs, send it along multiple dataflow paths that all provide the same functionalities
- Record and match all intermediate results from the matching nodes in the paths
- Build an attestation graph using node agreement
- Over time, the graph shows which node misbehave (always or time-to-time)

Attack Model

Data model:

- Input deterministic DataFlow (i.e., same input to a function will always produce the same output)
- Data processing is stateless (e.g., selection, filtering)

Attacker:

- Malicious or compromised cloud nodes
- Can produce bad results always or some time
- Can collude with other malicious nodes to provide same bad result

Attack Model (scenarios)

Parameters

b_i = probability of providing bad result

c_i = probability of providing the same bad result as another malicious node = probability of providing the same bad result as another malicious node when a bad result is returned

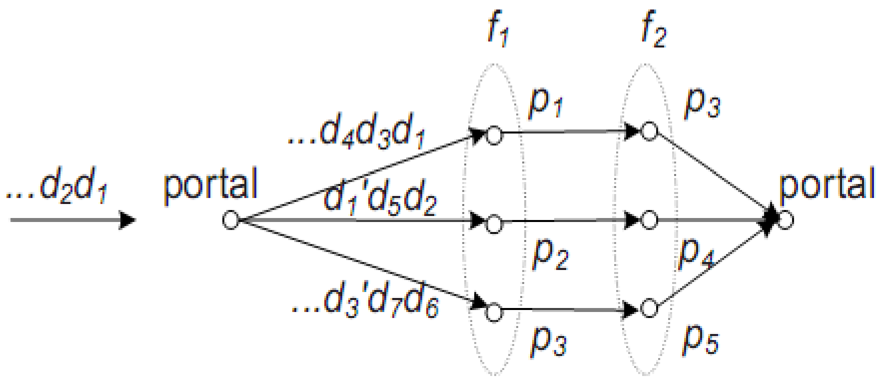
Attack scenarios

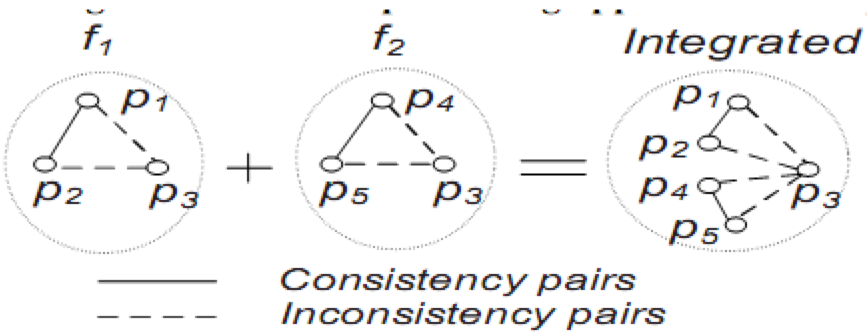
- **NCAM**: $b_i = 1$, $c_i = 0$ Non Collusion, Always Misbehaving
- **NCPM**: $0 < b_i < 1$, $c_i = 0$ Non Collusion, Partially Misbehaving
- **FTFC**: $b_i = 1$, $c_i = 1$ Full Time, Full Collusion
- **PTFC**: $0 < b_i < 1$, $c_i = 1$ Partial Time, Full Collusion
- **PTPC**: $0 < b_i < 1$, $0 < c_i < 1$ Partial Time, Partial Collusion

Integrity Attestation Graph

Definition:

- Vertices: Nodes in the DataFlow paths
- Edges: Consistency relationships.
- Edge weight: fraction of consistent output of all outputs generated from same data items

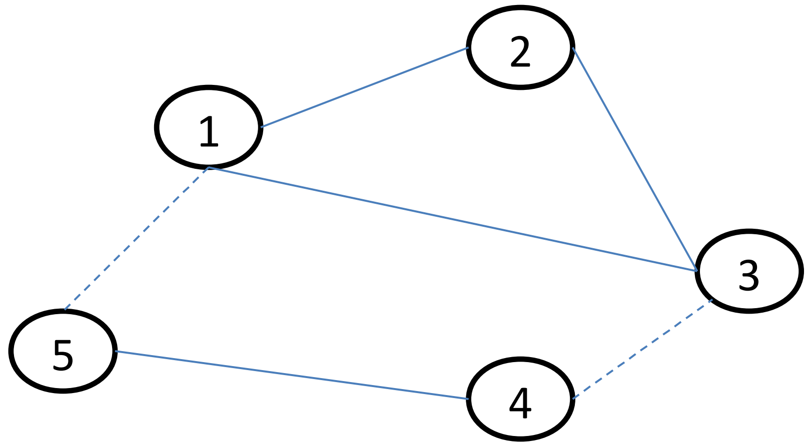




Consistency Clique

Complete subgraph of an attestation graph which has

- 2 or more nodes
- All nodes always agree with each other (i.e., all edge weights are 1)



How to find malicious nodes

Intuitions

Honest nodes will always agree with each other to produce the same outputs, given the same data

Number of malicious nodes is less than half of all nodes

Finding Consistency Cliques: BK Algorithm

Goal: find the **maximal clique** in the attestation graph

In an undirected graph a clique is a subset of its vertices such that every two vertices in the subset are connected by an edge.

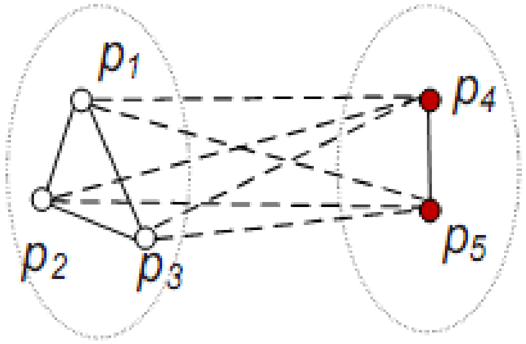
Technique:

Apply Bron-Kerbosch algorithm to find the maximal clique(s) (see better example at Wikipedia)

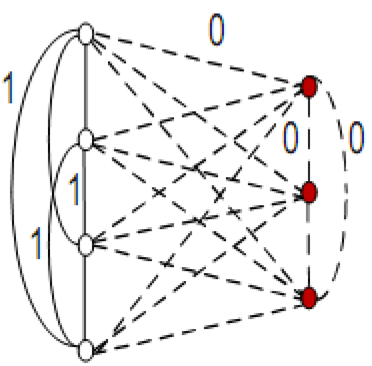
Any node not in a maximal clique of size k/2 is a malicious

Note: BK algorithm is NP-Hard

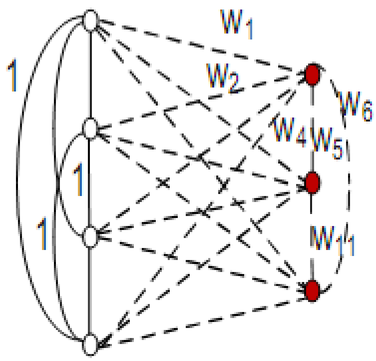
Authors proposed 2 optimizations to make it run quicker



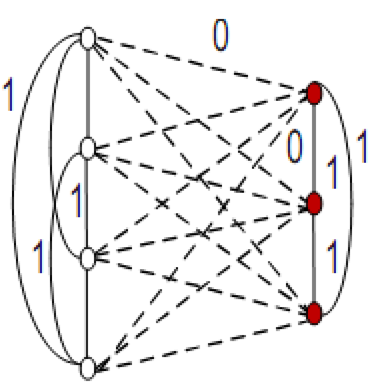
Identifying attack patterns



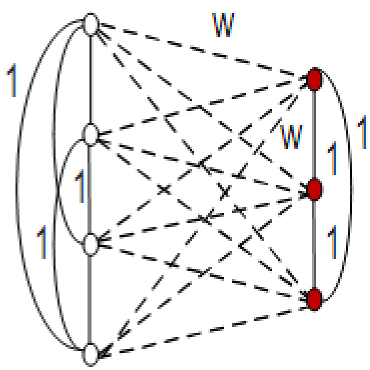
Non-Collusion Always
Misbehave



Partial Time Full
Collusion /
Non Collusion
Probabilistically
Misbehave



Full Time Full Collusion



Partial Time
Full Collusion

Inferring data quality

$$\text{Quality} = 1 - (c/n)$$

where

n = total number of unique data items

c = total number of duplicated data with inconsistent results

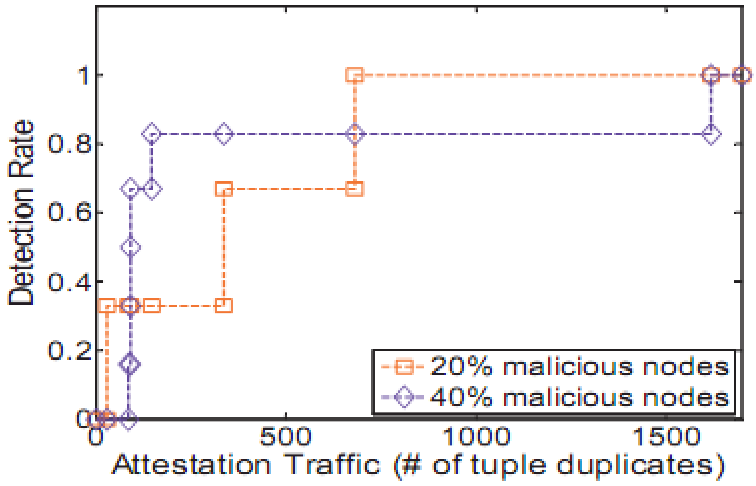
Evaluation

Extended IBM System S

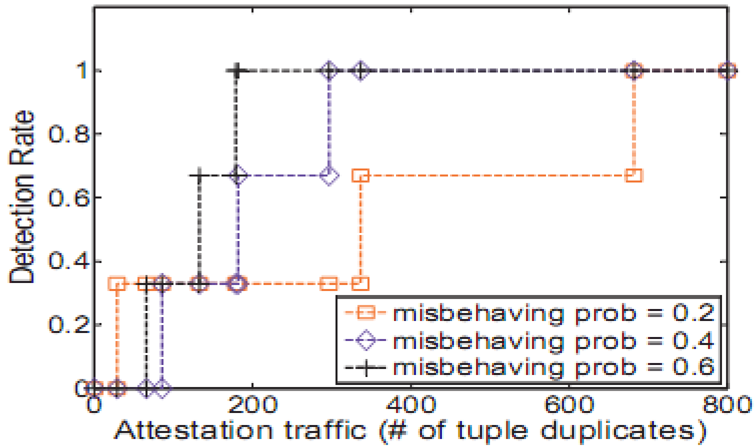
Experiments:

- Detection rate
- Sensitivity to parameters
- Comparison with majority voting

Evaluation



NCPM (b=0.2, c=0)



Different misbehavior probabilities

Discussion

Threat model

High cost of Bron-Kerbosch algorithm ($O(3^{n/3})$)

Results are for building attestation graphs per function

Scalability

Experimental evaluation