AN MTD-BASED SELF-ADAPTIVE RESILIENCE APPROACH FOR CLOUD SYSTEMS

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MOTIVATION

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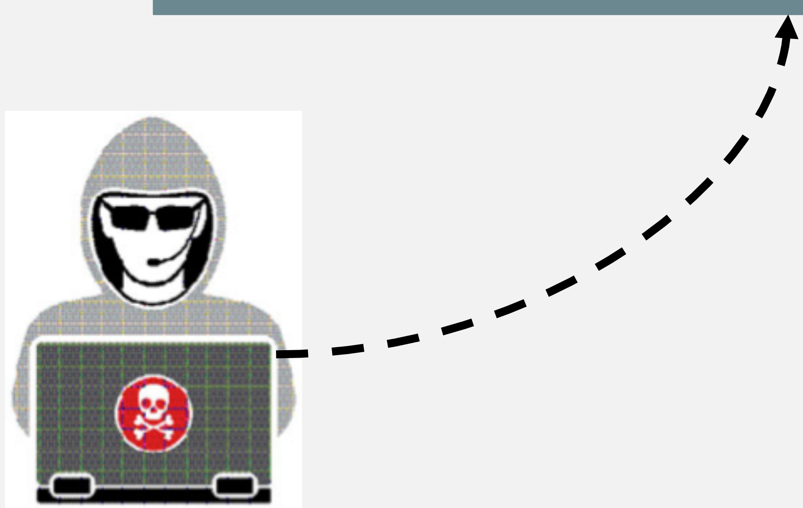


- Replication approaches in cloud computing increase the attack surface
- We need resilient/self-healing systems that can accurately detect anomalies and dynamically adapt themselves to keep performing mission-critical functions even under attacks and failures.

RESEARCH QUESTION

- Is it possible to construct a generic attack-resilient framework for distributed cloud systems with a combination of dynamic network configuration and continuous replacement of virtual machines?

MOVING TARGET DEFENSE (MTD)

Attack Vectors

- Data
- Code
- Infrastructure
- Communications
- People

Resilient Approaches

- Moving Target Defense (MTD)
- Proactive Restore/C2
- Least Privilege Enforcement
- Trust Zone Segmentation
- Identity Attribution
- Encryption
- Root Trust

MOVING TARGET DEFENSE (MTD)

- The proposed **Moving Target Defense (MTD)** solution introduces resiliency and adaptability to the system through live monitoring, which transforms systems to be able to adapt and self-heal when ongoing attacks are detected

MOVING TARGET DEFENSE (MTD)

- **Adversaries have an asymmetric advantage**: They have the time to study a system, identify its vulnerabilities, and choose the time and place of attack to gain the maximum benefit
- **The idea of moving-target defense (MTD):** Imposing the same asymmetric disadvantage on attackers by making systems dynamic and therefore harder to explore and predict

Threat Avoidance Techniques!

STATE OF THE ART AND LIMITATIONS

REPLICATION/REDUNDANCY

Fault-Tolerance Systems

- **Solution**: Replication/ Redundancy:
- **Examples**: Quorum, Chain
- **Limitation**: Gives fault resiliency but increases attack surface at application level (common code base)

DIVERSIFICATION/RANDOMIZATION

Fault-Tolerance Systems

- **Solution**: MTD
- **Examples**: ASLR [9], NVersion [10] & IP-Hopping [11]
- **Limitation**: Do not protect the entire host

STATE OF THE ART AND LIMITATIONS

- The traditional defensive security strategy for distributed systems is to prevent attackers from gaining control of the system using well established techniques: Replication/Redundancy, Encryption, etc.
  - **Limitation**: Given sufficient time and resources, existing defensive methods can be defeated

STATE OF THE ART AND LIMITATIONS

- The state of the art of MTD solutions focus on randomization and diversification in particular layers of the system
  - **Limitation**: Do not protect the entire host

PROPOSED APPROACH

- **“Stay one-step ahead” of sophisticated attack**
  - Protect the entire stack through dynamic interval-based spatial randomization
  - Avoid threats in-time intervals rather than defending the entire runtime of systems through Mobility and Direction
  - System will start secure, stay secure and return secure
  - Increase agility, anti-fragility and adaptability of the system
  - Unified generic MTD framework that enables reasoning about behavior of deployed systems on cloud platforms

OBJECTIVES OF THE MTD SOLUTION

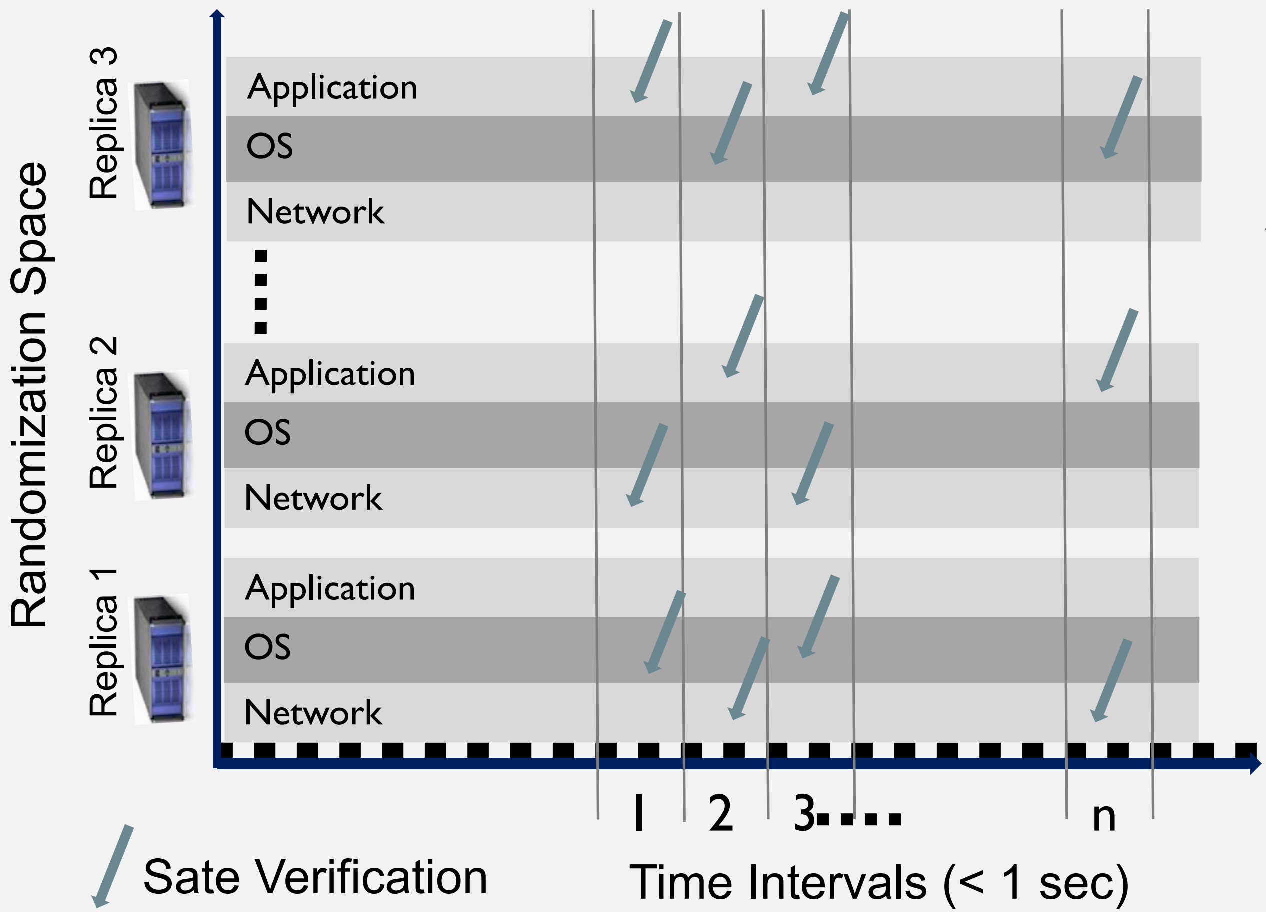
- Aims to **reduce** the need to continuously **fight against attacks** by decreasing the gain-loss balance perception of attackers.
- **Narrows the exposure window of a node to attacks**, which increases the cost of attacks on a system and lowers the likelihood of success and the perceived benefit of compromising it.

OBJECTIVES OF THE MTD SOLUTION

- The **reduction in the vulnerability window** of nodes is mainly achieved **through three steps**:
  - Partitioning the runtime execution of nodes in time intervals
  - Allowing nodes to run only with a predefined lifespan (as low as a minute) on heterogeneous platforms (i.e. different OSs)
  - Proactively monitoring their runtime below the OS

BENEFITS OF THE PROPOSED SOLUTION

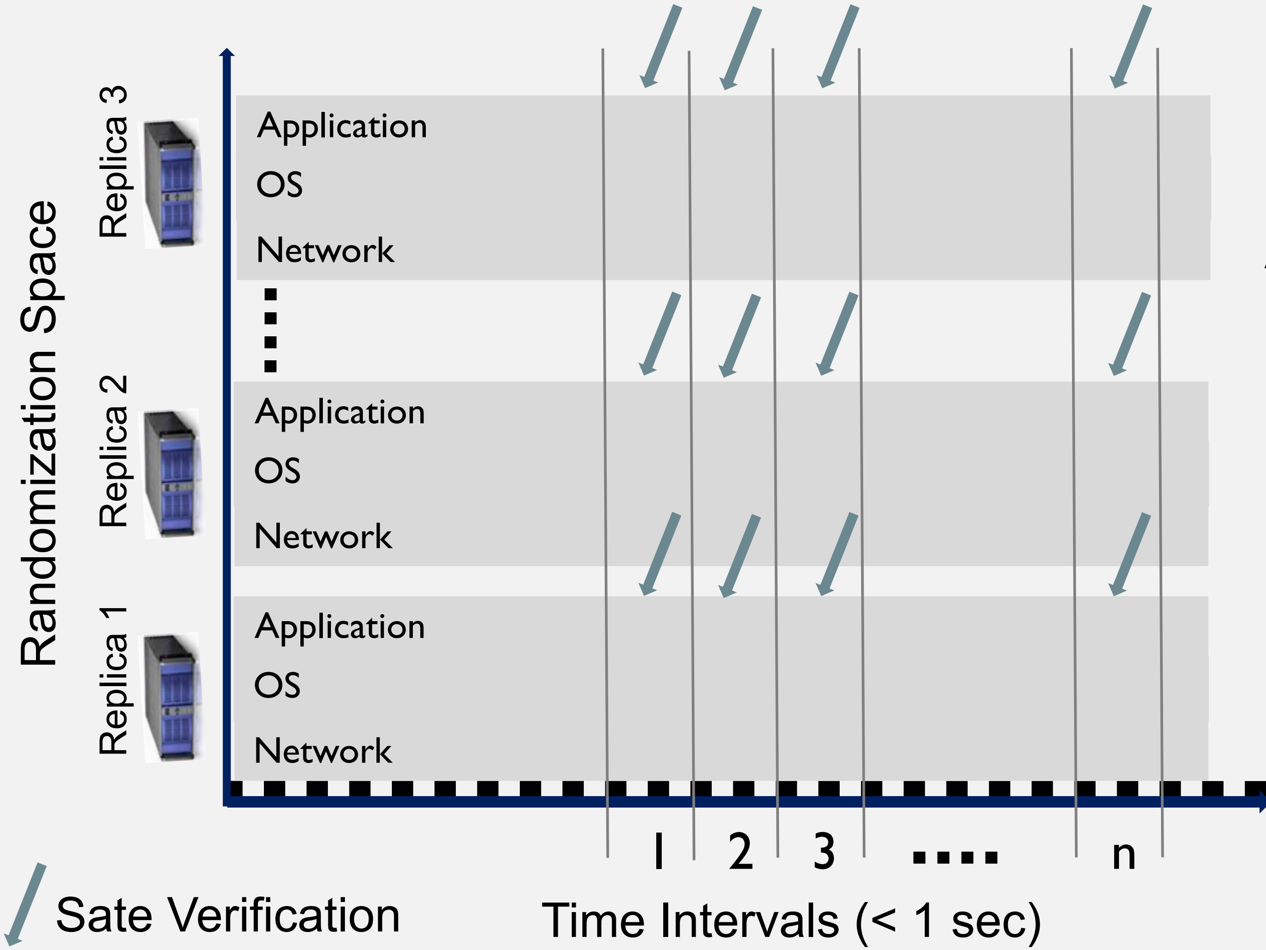
- **State of the Art System View:**



At a given time only **some** layers of the stack (Application, OS or Network) are checked/ protected

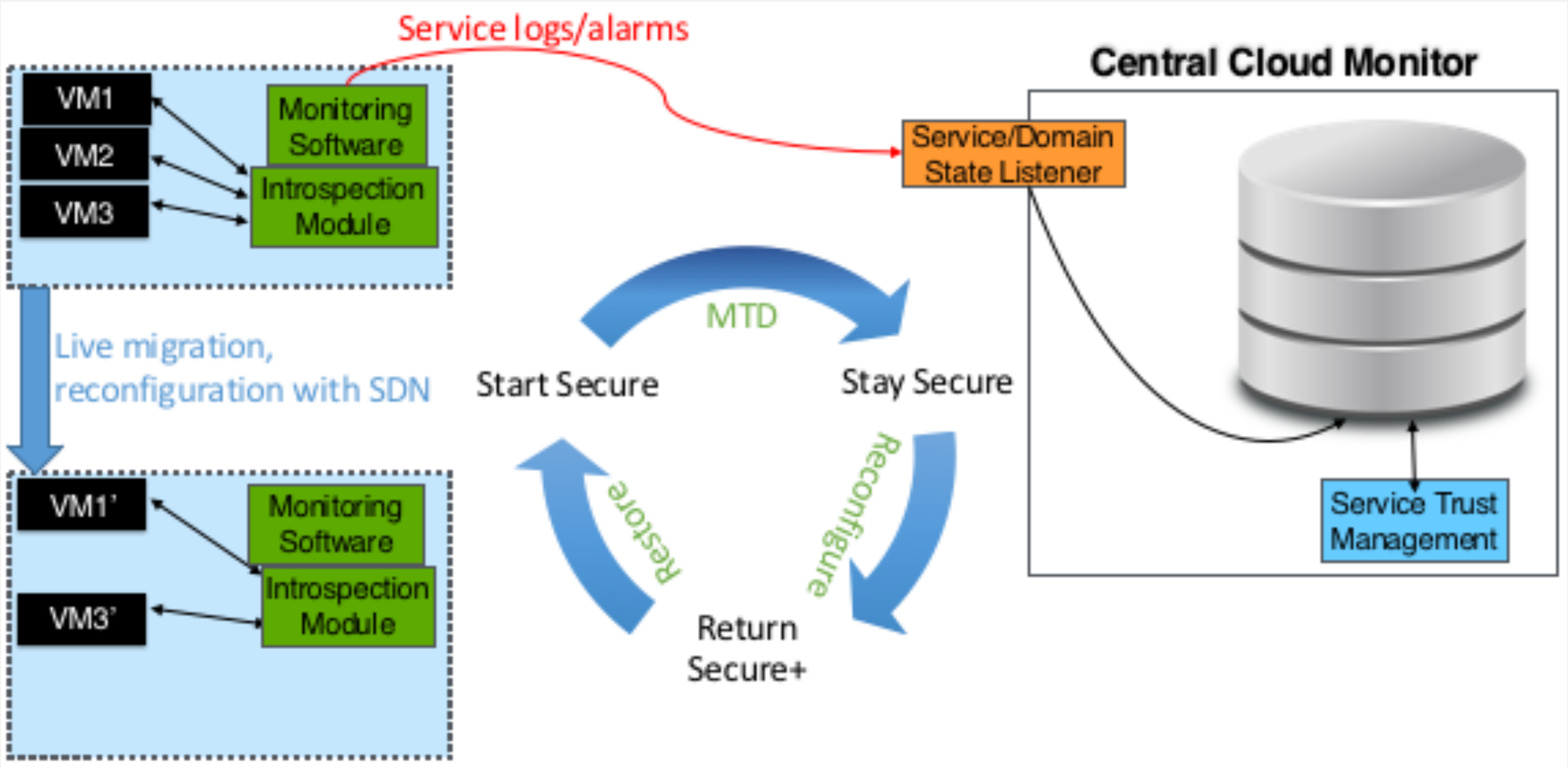
BENEFITS OF THE PROPOSED SOLUTION

- **Proposed Solution System View:**

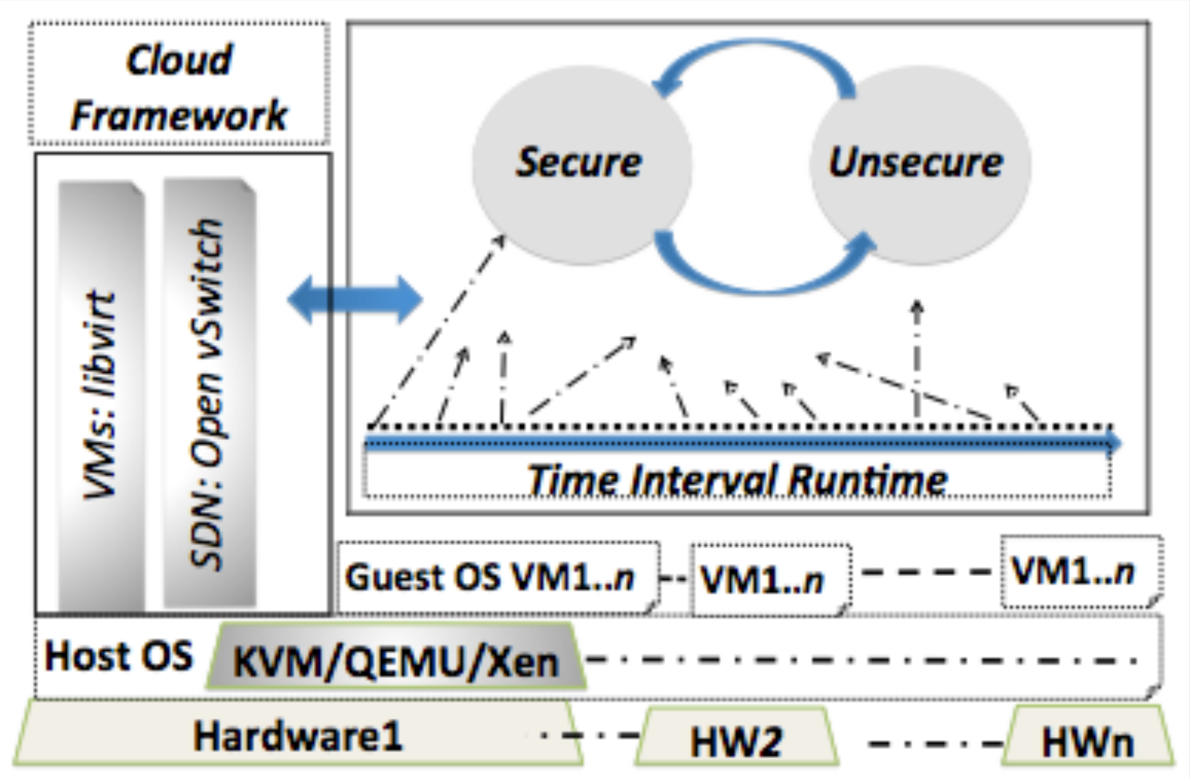


At a given time **all** layers of the stack (Application, OS or Network) are checked/protected.

APPROACH OVERVIEW



MTD ARCHITECUTRE



Components:

(1) Virtual Reincarnation (ViRA)

(2) Proactive Monitoring

(3) SDN Network Dynamics

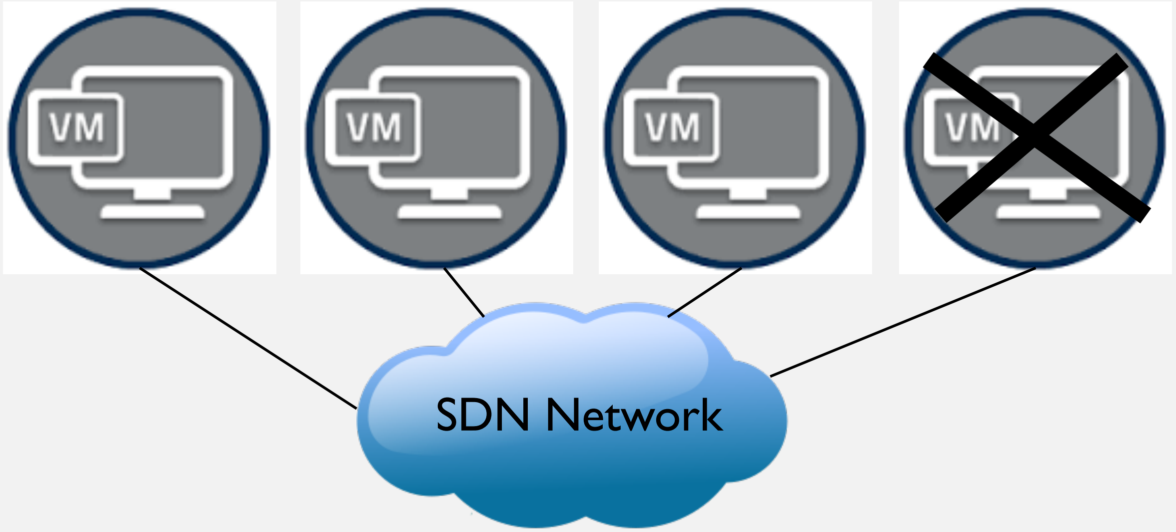
(4) Systems States and Application Runtime

MTD ARCHITECUTRE

- The MTD framework consists of the following four components:
  - Virtual Machine Reincarnation (ViRA)
  - Proactive Monitoring
  - SDN Network Dynamics
  - Systems States and Application Runtime
- The framework will protect the whole stack; not only particular layers

APPROACH DETAILS

- Nodes run a distributed application on a given platform for a controlled period of time
- The running time is chosen in a way that successful ongoing attacks become ineffective
- The new fresh machine will integrate to the system and continue running the application after its data is updated



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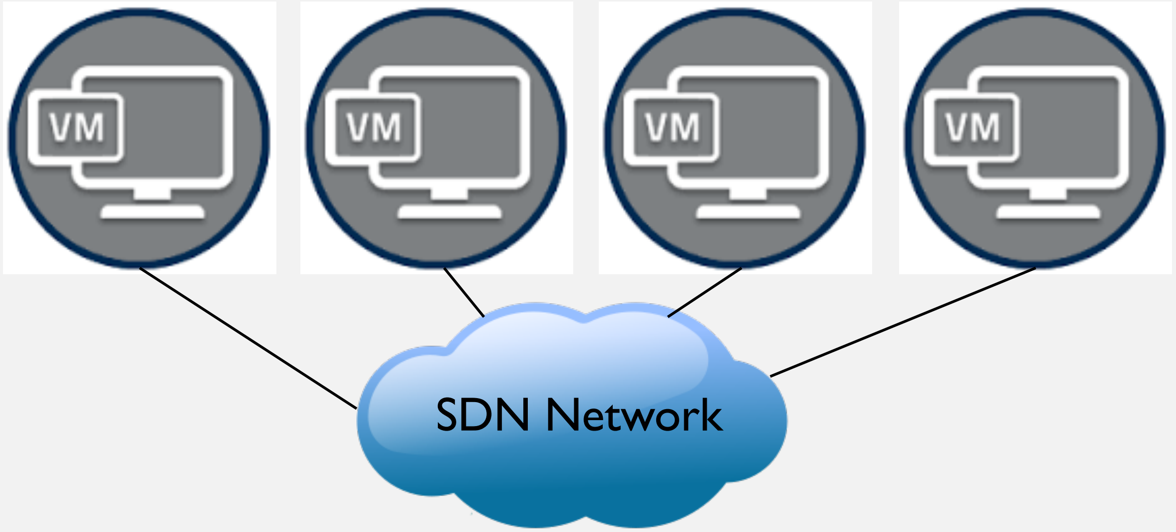


VIRTUAL REINCARNATION

- Randomization and diversification technique where nodes (virtual machines) running a distributed application vanish and reappear on a different virtual state with different guest OS, Host OS, hypervisor, and hardware .

Improve Resiliency

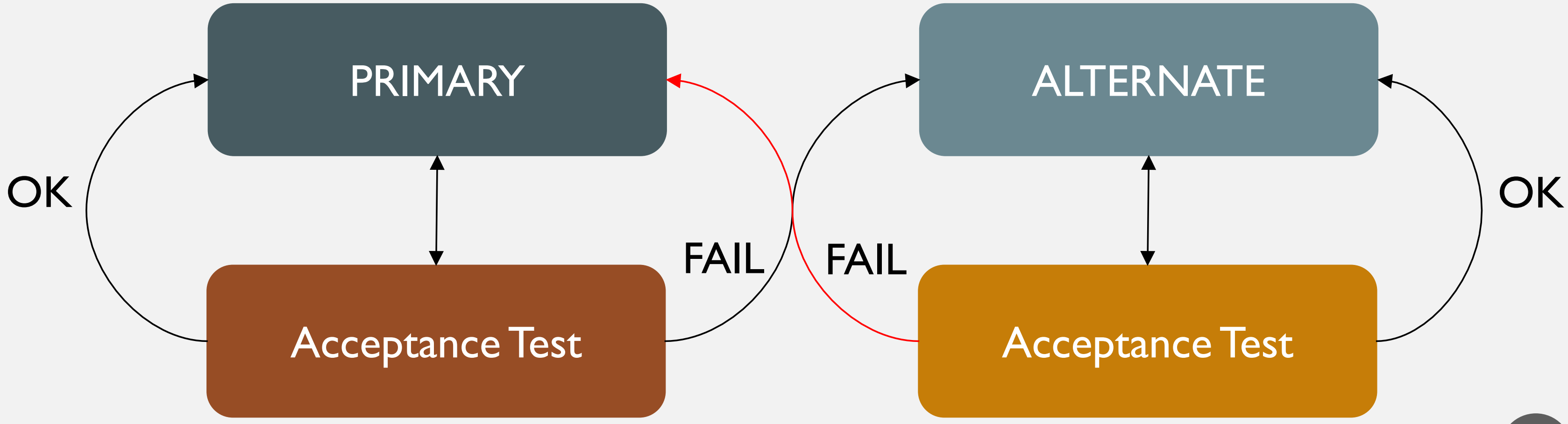
Improve Anti-Fragility

Virtualized Environment

CREATION OF REPLICAS

How do we create replicas?

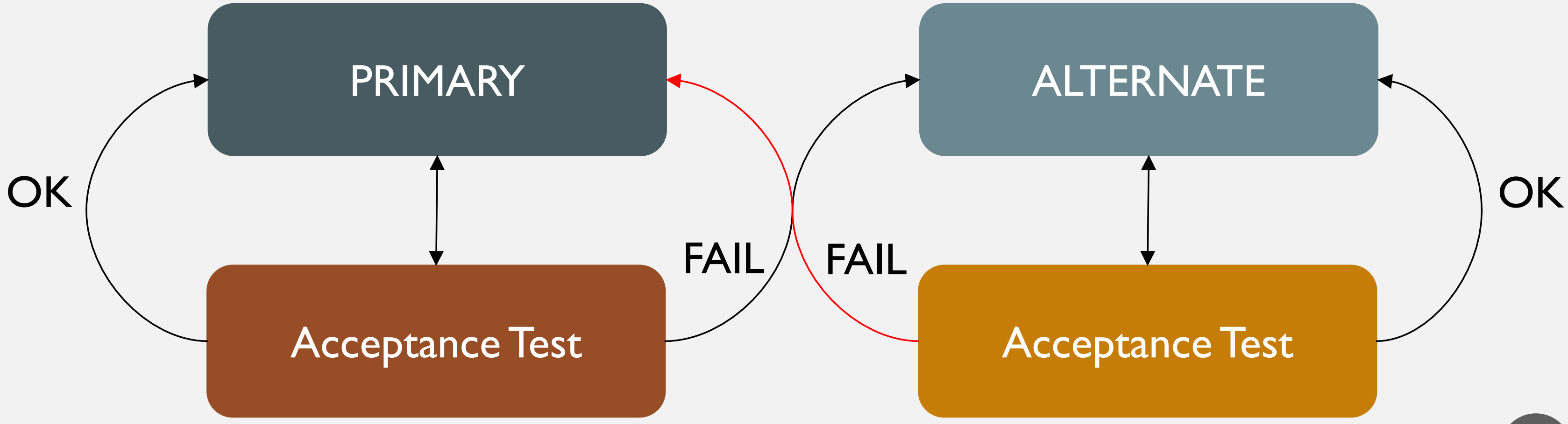
- Primary VM runs as no failures are detected.
- Alternate VM takes place when a failure occurs
- Acceptance tests are adjusted independently to guarantee system operation
- Alternate learn from Primary and become more robust to failures/attacks experimented by primary



CREATION OF REPLICAS

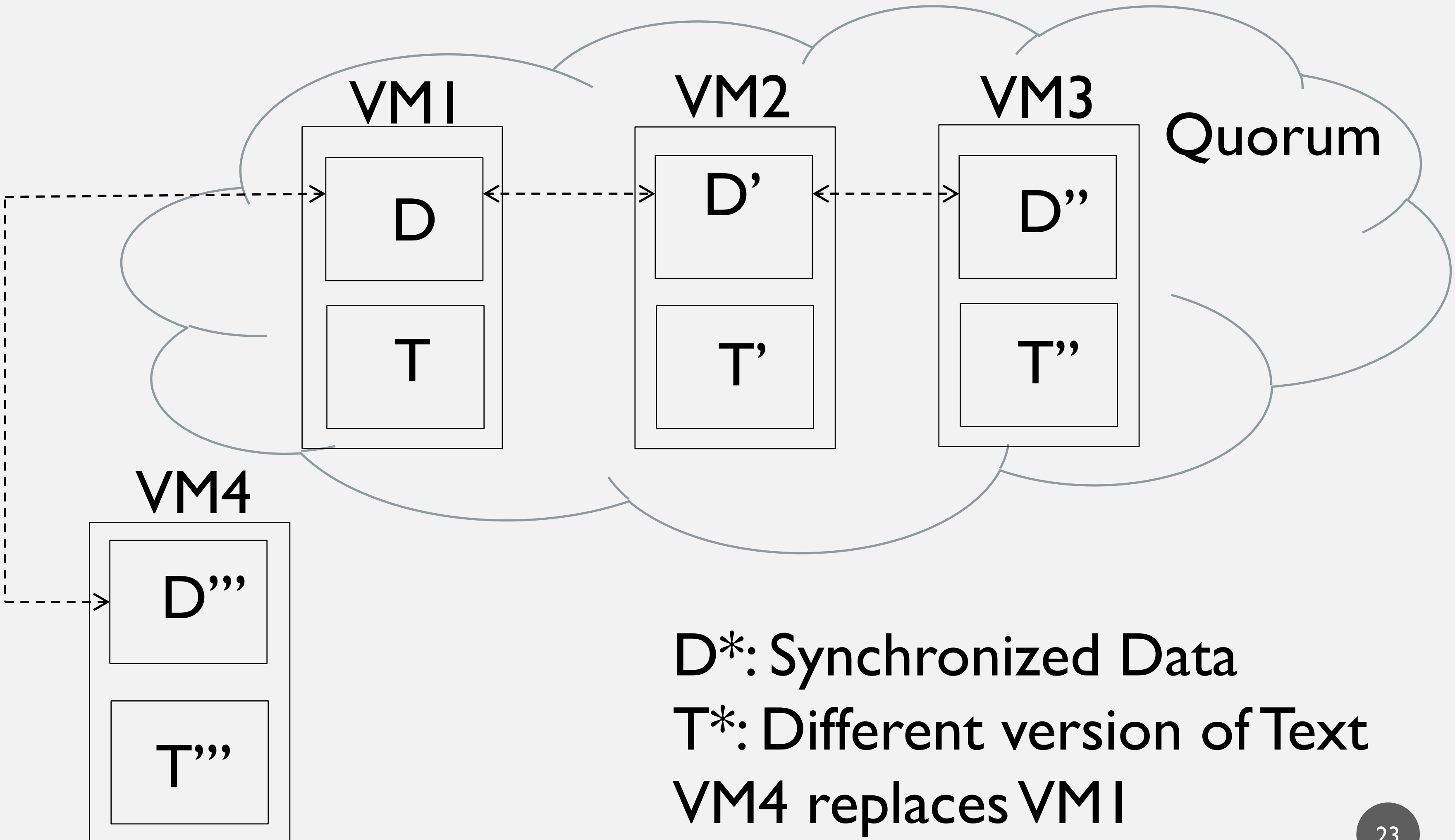
Challenges:

- Reduce downtime when Primary is replaced by Alternate and vice versa
- Keep the state of the machine (either Primary or Alternate) after the replacement to achieve uninterrupted operation
- Keeping the state (stateful reincarnation) allows the system to be application-agnostic



CREATION OF REPLICAS

Stateful Reincarnation Ideas:



D*: Synchronized Data

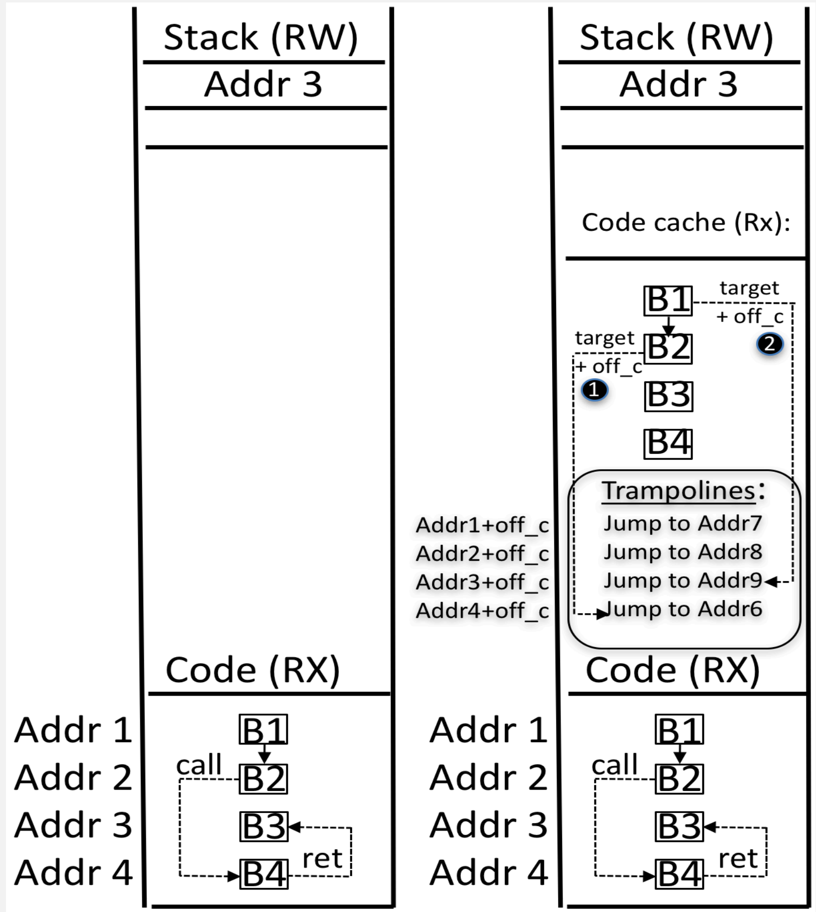
T*: Different version of Text

VM4 replaces VM1

CREATION OF REPLICAS

Stateful Reincarnation Ideas:

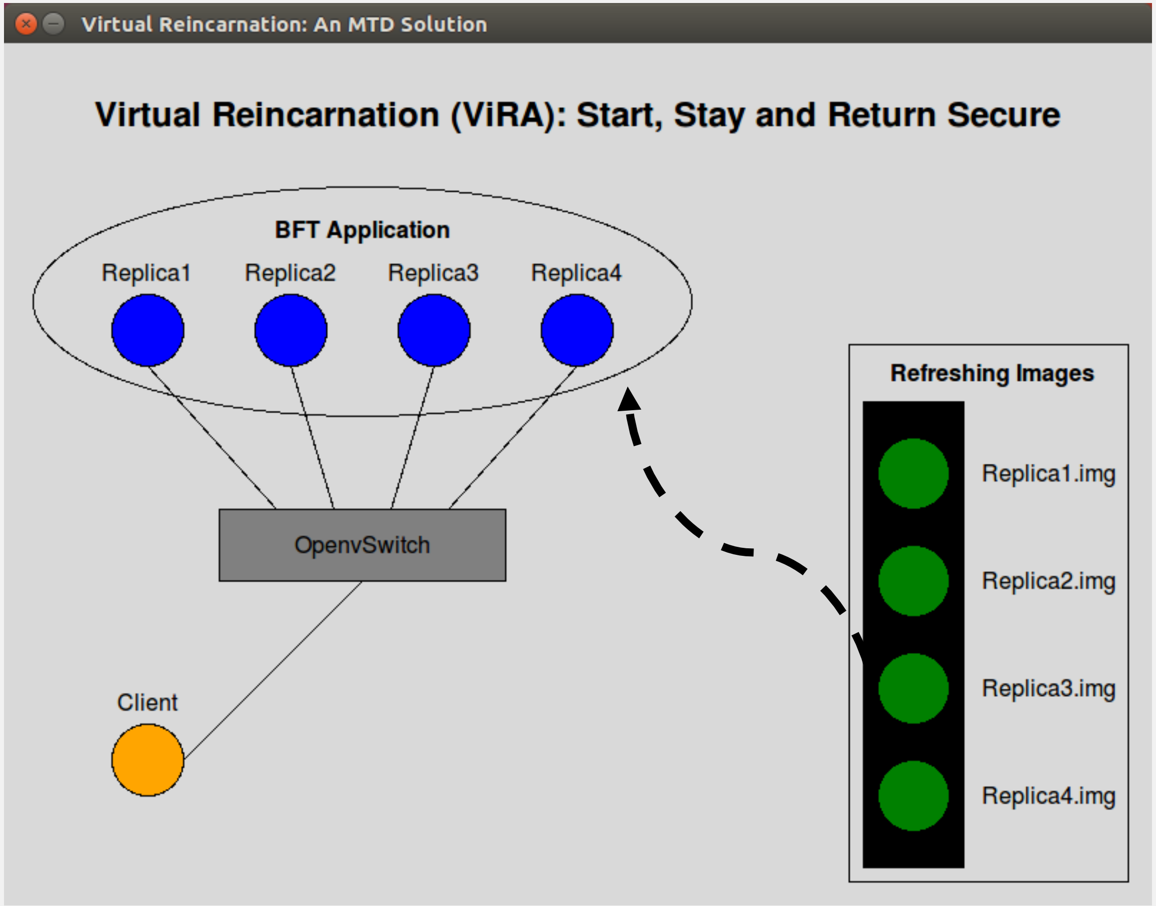
- Create different versions of binaries
- The original code is kept and set with read-only permission so that it can be used as part of the reference to the new locations of the blocks in the re-randomized version.
- We avoid identifying and updating code position pointers in each randomization process by keeping a table of trampolines as shown in (b). Each block is located at a fixed offset (i.e., **off_c**) with respect to the trampoline table.
- The pointers (in the original code space) are dynamically redirected to its respective address in the code variant when it is de-referenced



(a) (b)

Z. Wang, C. Wu, J. Li, Y. Lai, X. Zhang, W. Hsu and Y. Cheng. ReRANZ: A Ligh-Weight Virtual Machine to Mitigate Memory Disclosure Attacks. To appear in VEE2017.

VIRTUAL REINCARNATION



"Active machines are replaced by new ones with a totally new image"

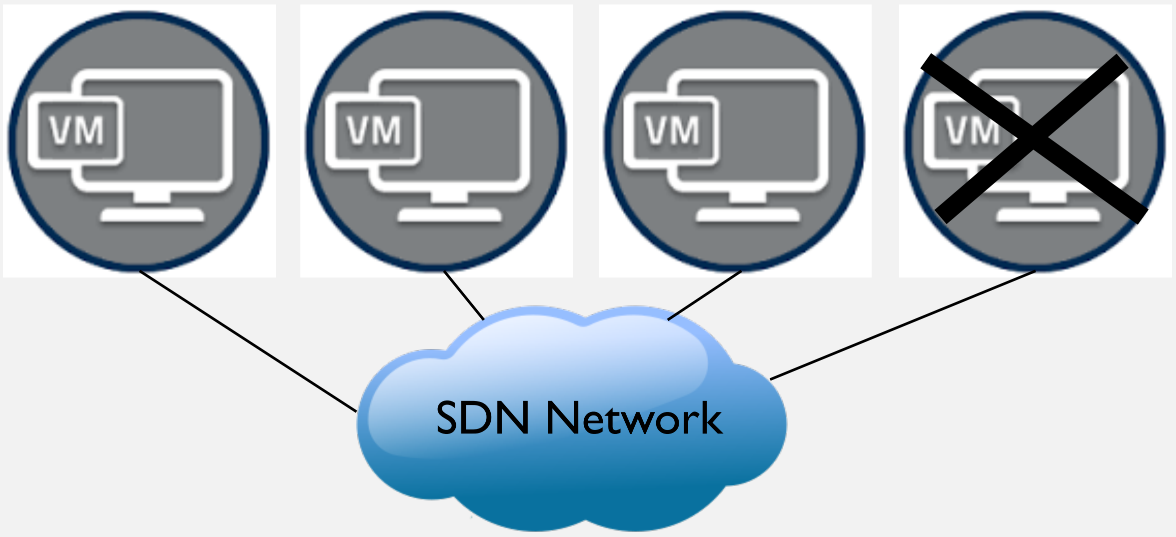
https://www.dropbox.com/s/fqjh75su0p908ic/NGCRC-2017-Bhargava-DEMO2.mp4?dl=0

PROACTIVE MONITORING

- Operates at the hypervisor level
- Helps for performing node reincarnation effectively rather than blindly
- *Based on Virtual Machine Introspection* (VMI)
- Proactively gathers live memory data (at host OS) in intervals and reacts if anomalous behavior is detected
- Use libvmi library for introspection with negligible performance overhead
  - When application is hijacked, address offsets show new entries for injected code
  - When application is terminated and a new malicious one created, it could end up with a different process ID or memory address offset

SDN NETWORK DYNAMICS

- Network devices are reconfigured via OpenFlow on-the-fly
- New added flows redirect traffic intended for the old machine to the new machine



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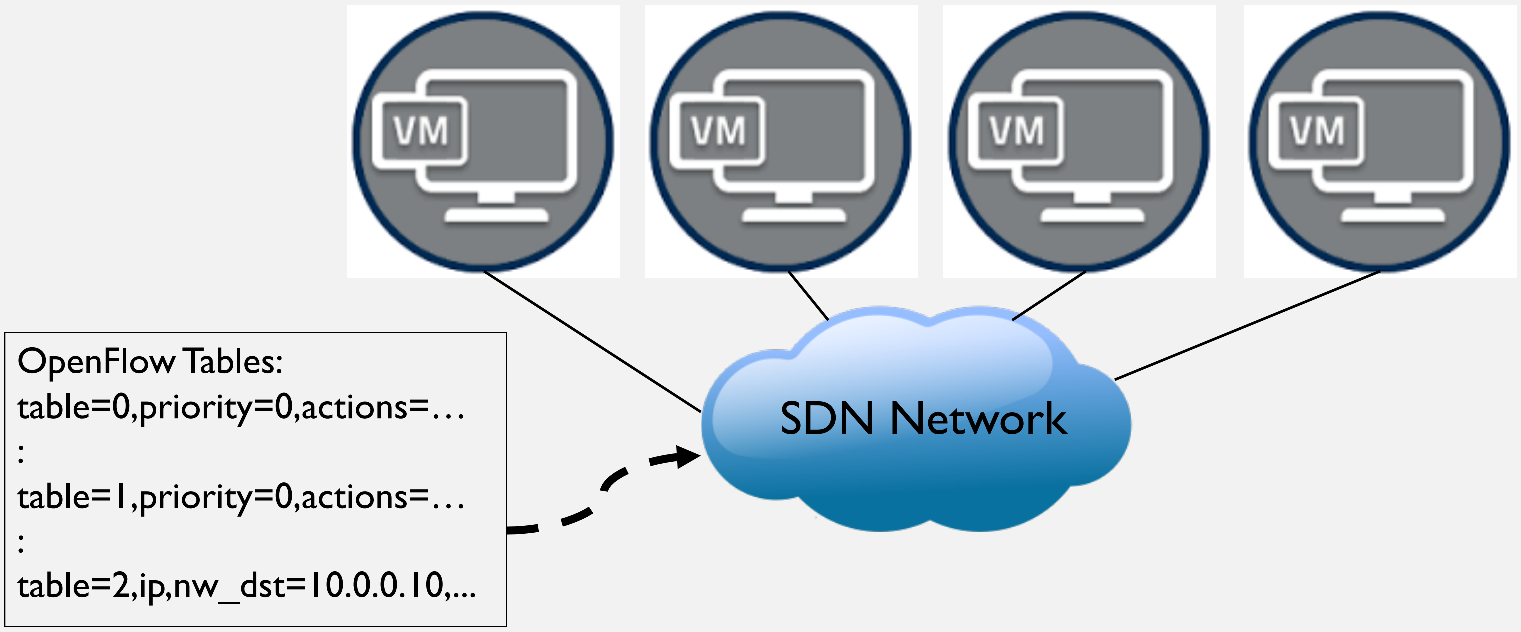
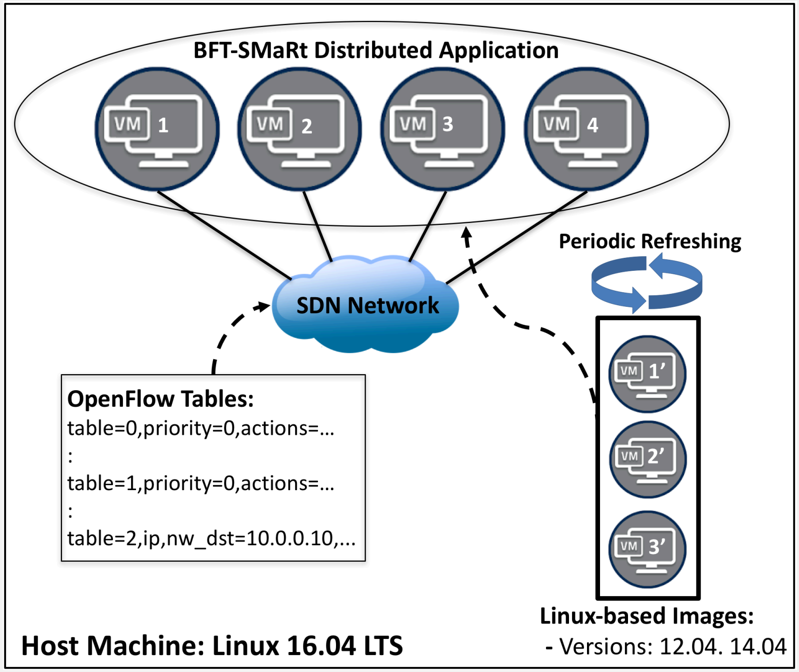


SDN NETWORK DYNAMICS

- New machines can be integrated to the system with their own IP addresses
- No waiting for the IP address of the old machine
- Downtime is reduced

MEASUREMENTS

- A Byzantine fault tolerant (BFT-SMaRt) distributed application was run on a set of Ubuntu (either 12.04 or 14.04 randomly selected).
- VMs run in a private cloud, and are connected with an SDN network using Open vSwitch
- The reincarnation is stateless, i.e. the new node (e.g. VM1') does not inherit the state of the replaced node (e.g. VM1).
- The set of new VMs are periodically refreshed to start clean and the network is reconfigured using OpenFlow when a VM is reincarnated to provide continued access to the application.



MEASUREMENTS

1. **VM restart time**: Time it takes the machine to respond to be full operational since it is started.
2. **Virtual creation time**: Time to create the new image of the VM.
3. **Open vSwitch flow injection time**: Time it takes to inject new flows to Open vSwitch

Measurements	Times
VM restart time	$\sim 7s$
VM creation time	$\sim 11s$
Open vSwitch flow injection time	$\sim 250ms$

Note: that the important factor for system downtime here is the Open vSwitch flow injection time, as VM creation and restart take place before the reincarnation process

MEASUREMENTS

- Aim to estimate the time it takes the new machine to be full operational.
- VM creation and restart take place before the reincarnation process
- The important factor for system downtime here is the Open vSwitch flow injection time

FUTURE WORK

- Enhanced live monitoring techniques
- Instrumentation to measure overhead more accurately
- Test other stateless applications on the MTD framework
  - E.g.: Upright (Public and Subscribe System)

FUTURE WORK

- Stateful Virtual Reincarnation Support:
  - Can we preserve the state of the virtual machine during the reincarnation process to make the solution application-agnostic?
  - Test the framework with Secure SOA Services (stateful reincarnation)

PRESENTATION AND PUBLICATIONS

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