I Heard It through the Firewall: Exploiting Cloud Management Services as an Information Leakage Channel

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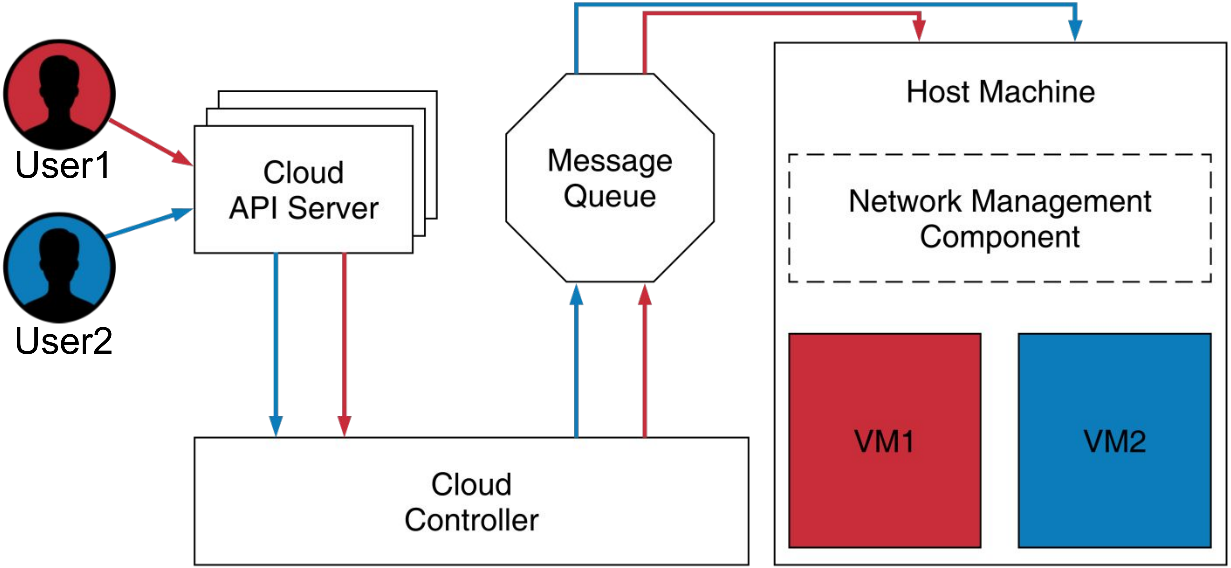
Motivation

- Information leakage in cloud has concerned cloud users from the beginning of cloud computing.
- Existing cloud information leakage channels:
  - Cache [Ristenpart et al. 2009, Liu et al. 2015]
  - Memory [Zhang et al. 2011, Meltdown, Spectre]
  - Network device [Bates et al. 2012]

  → **Hardware-level Shared Resources**

- **How about Software-level Shared Resources?**

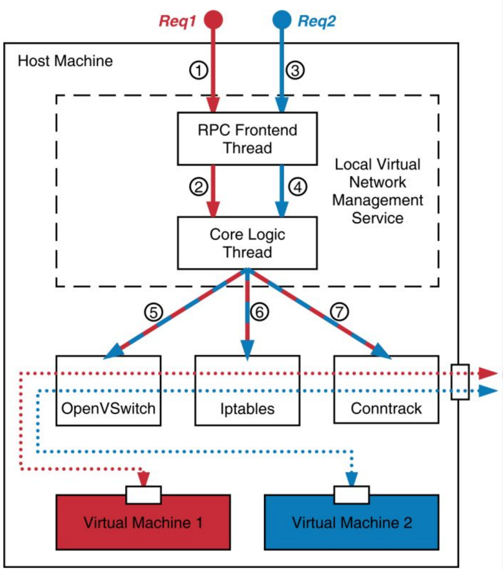
Motivation


User1
User2
Cloud
API Server
Message
Queue
Host Machine
Network Management
Component
VM1
VM2
Cloud
Controller

Motivation

The two users' requests shared:

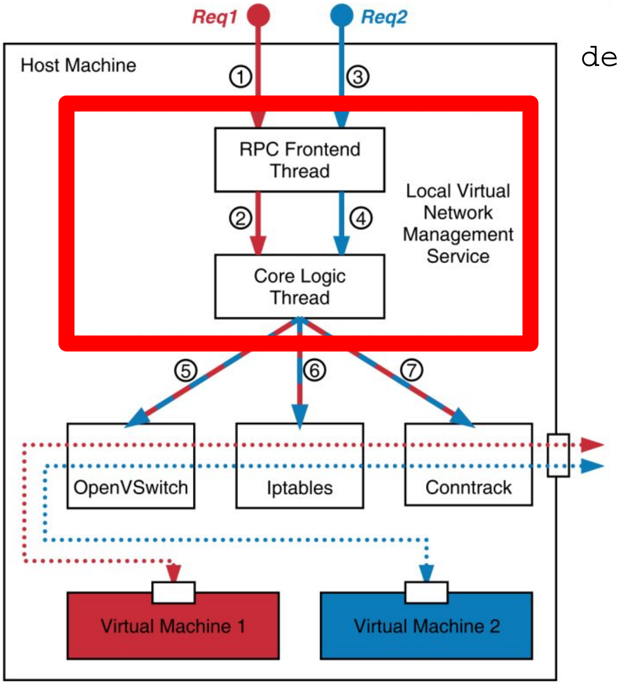
- Processes
- Threads
- Variables
- Queues
- Execution paths
- ...



Goal

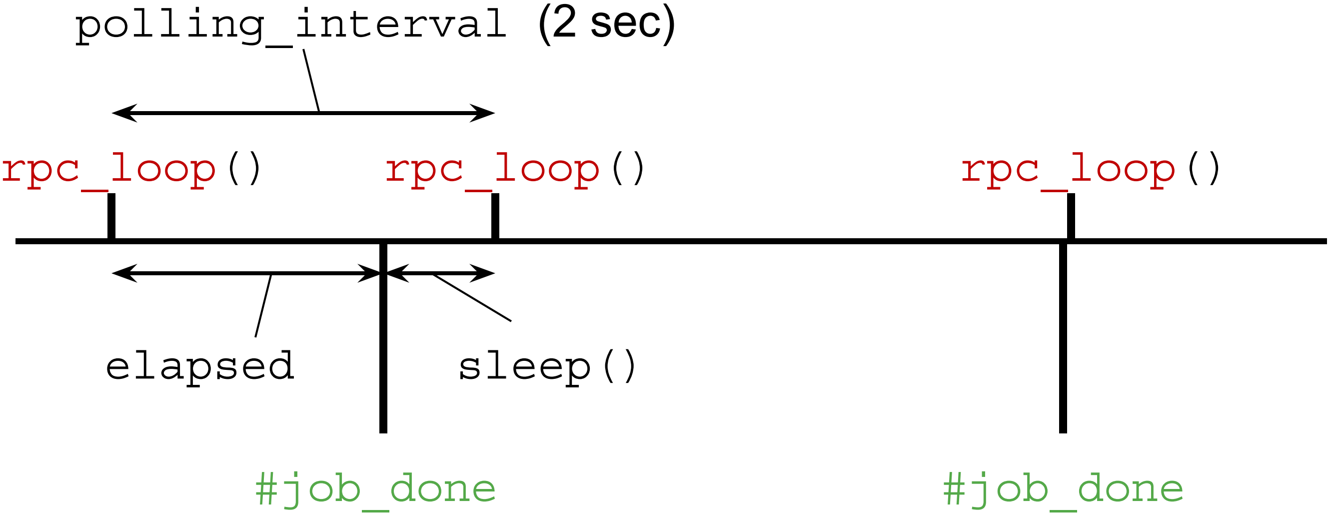
- Demonstrating exploitability of software-level shared resources as an information leakage channel
- Especially, focusing on Shared Execution Paths (i.e., cross-tenant batch-processing)
- Using OpenStack Network Management Service (similar mechanism can be applied to other systems)

Background: `polling_interval`

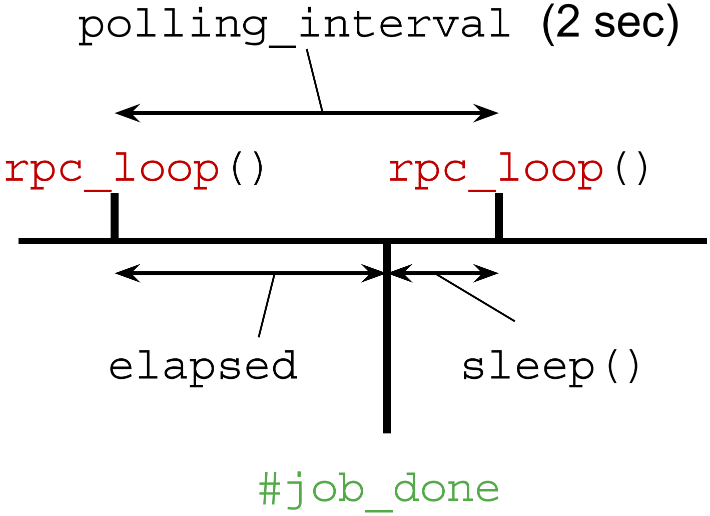


```
def rpc_loop(self):
    while True:
        start = now()
        # update OVS changes
        # update Iptables changes
        # update conntrack changes
        elapsed = now() - start # job_done
        if elapsed < polling_interval:
            sleep(polling_interval - elapsed)
```

Background: `polling_interval`

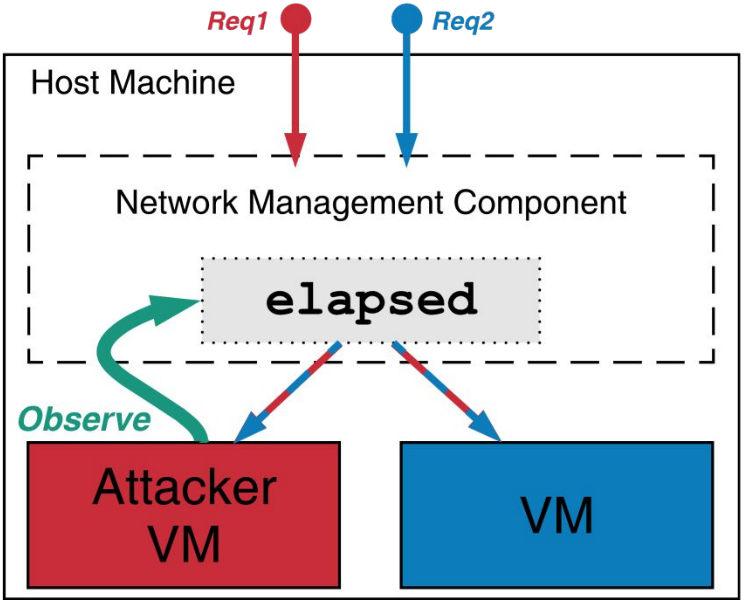


Basic Idea



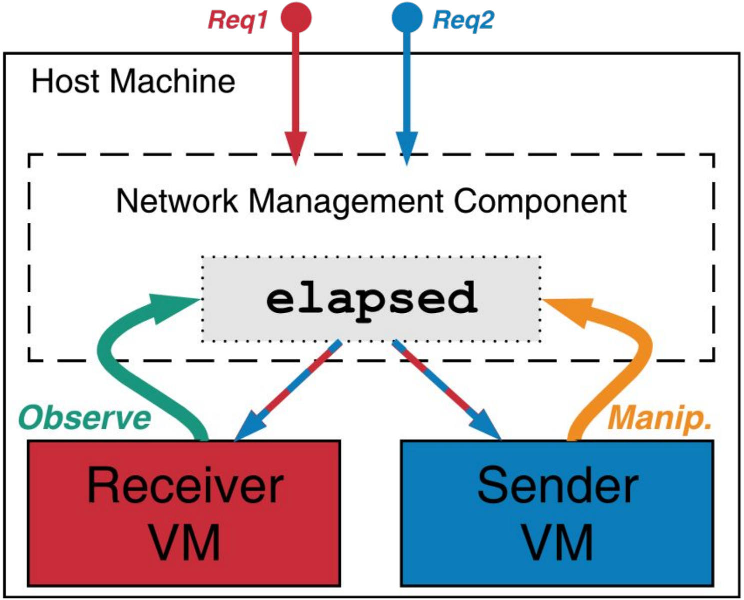
- The `rpc_loop()` is shared by requests of VMs running in the host.
- The total size of the load of requests $\propto$ `elapsed`.

Basic Idea



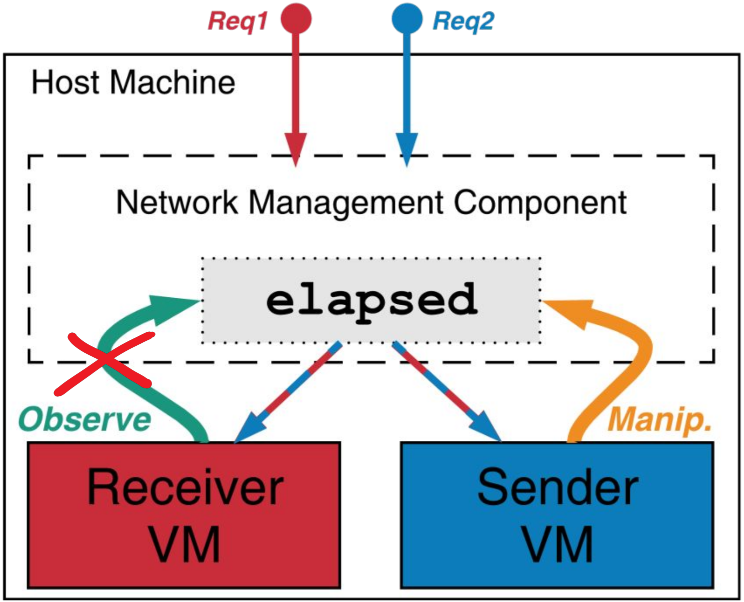
- Observing `elapsed` times to distinguish infrastructure level events
  - Side Channel

Basic Idea



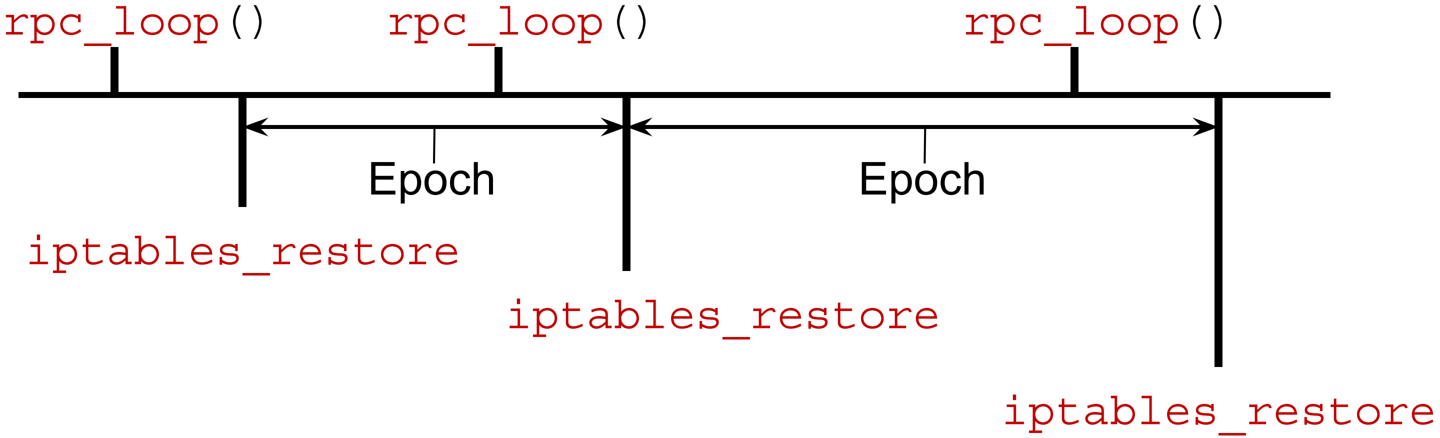
- Manipulating `elapsed` times to send messages
  - Covert Channel

Problem



- Cloud users (and VMs) cannot directly observe the `elapsed` times
- Something ≈ `elapsed` and observable by users?
  → **Virtual Firewall Epoch**

Epoch



`rpc_loop()`

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Epoch

Epoch

`iptables_restore`

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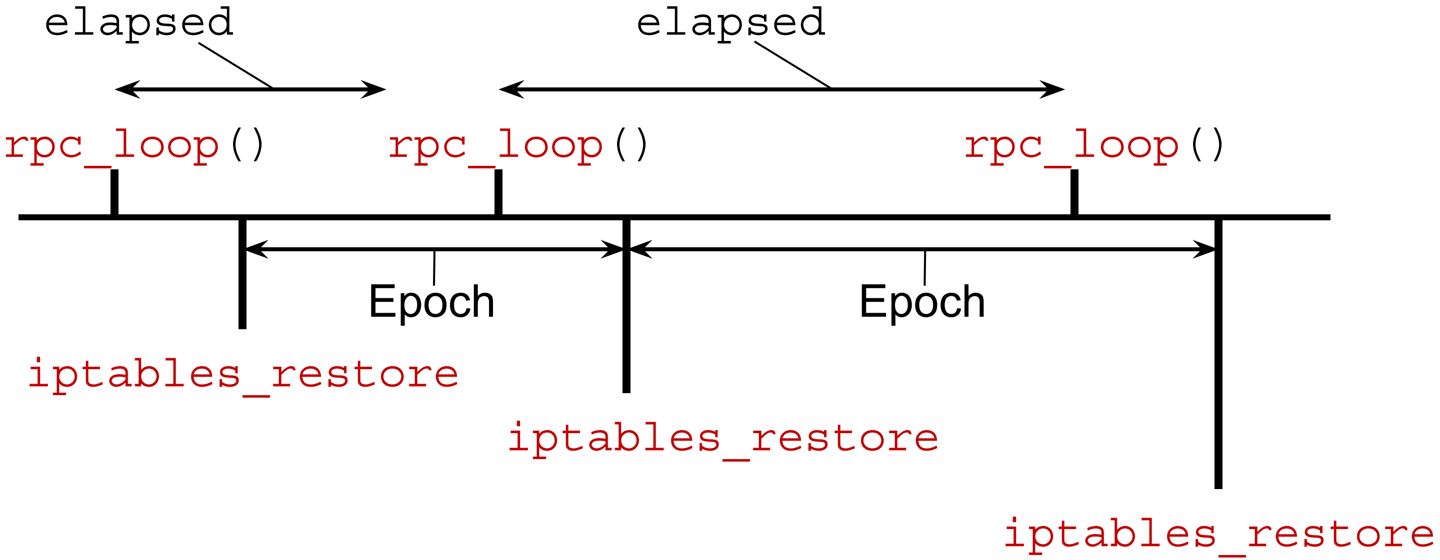
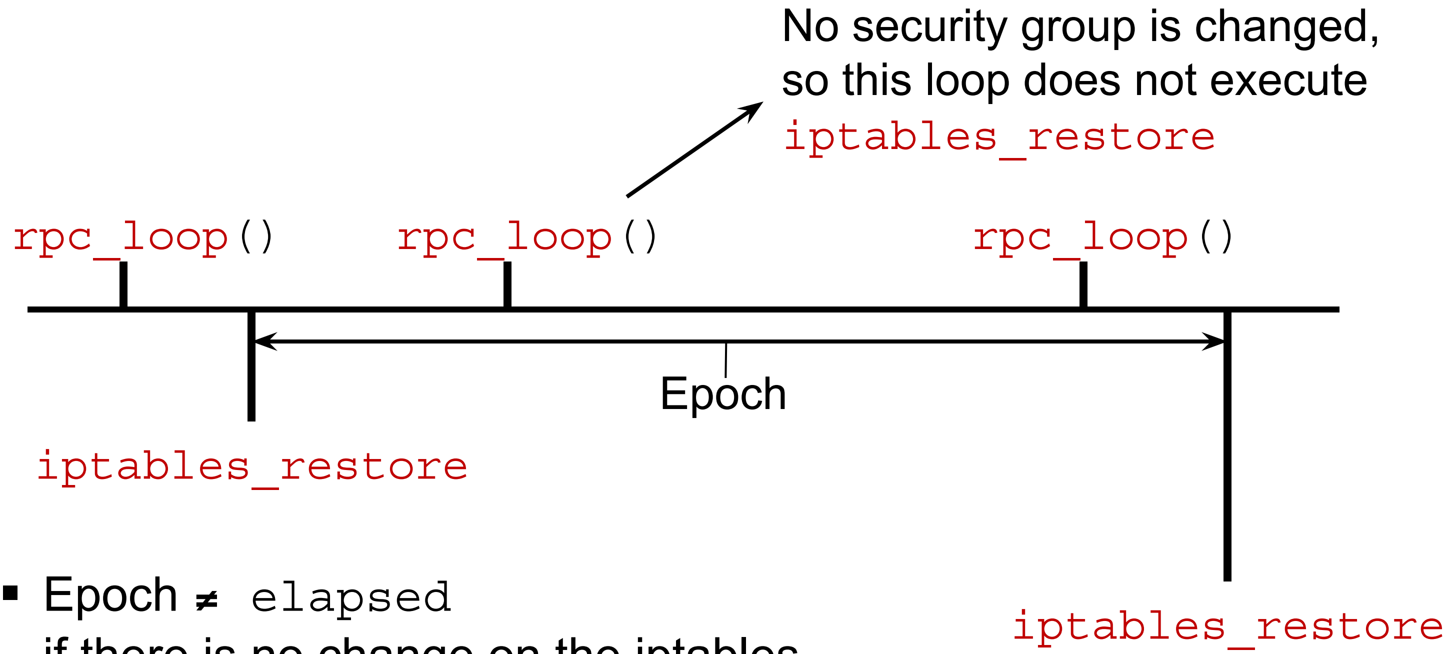
Epoch



- Epoch ≈ `max(elapsed, polling_interval)`

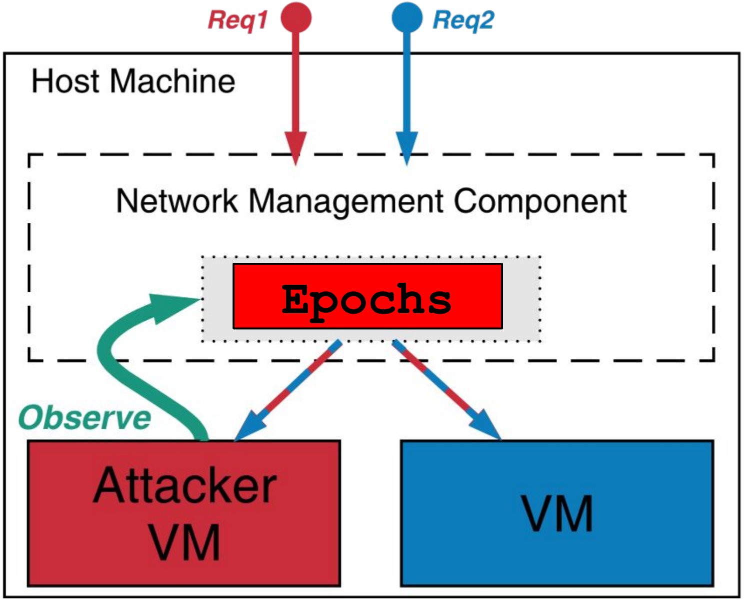
Epoch



No security group is changed, so this loop does not execute `iptables_restore`

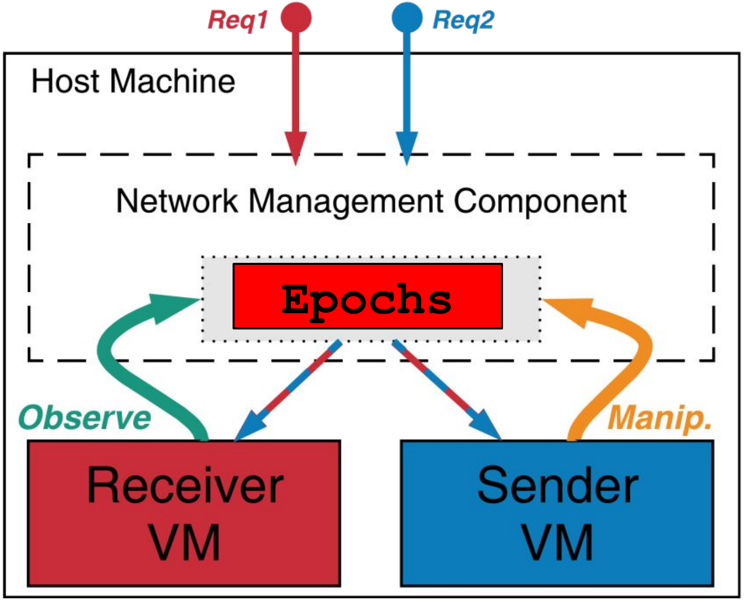
- Epoch ≠ `elapsed`
  if there is no change on the iptables.

Solution



- Observing **`Epochs`** to distinguish infrastructure level events
  - Side Channel

Solution



- Manipulating **`Epochs`** to send messages
  - Covert Channel

Epoch

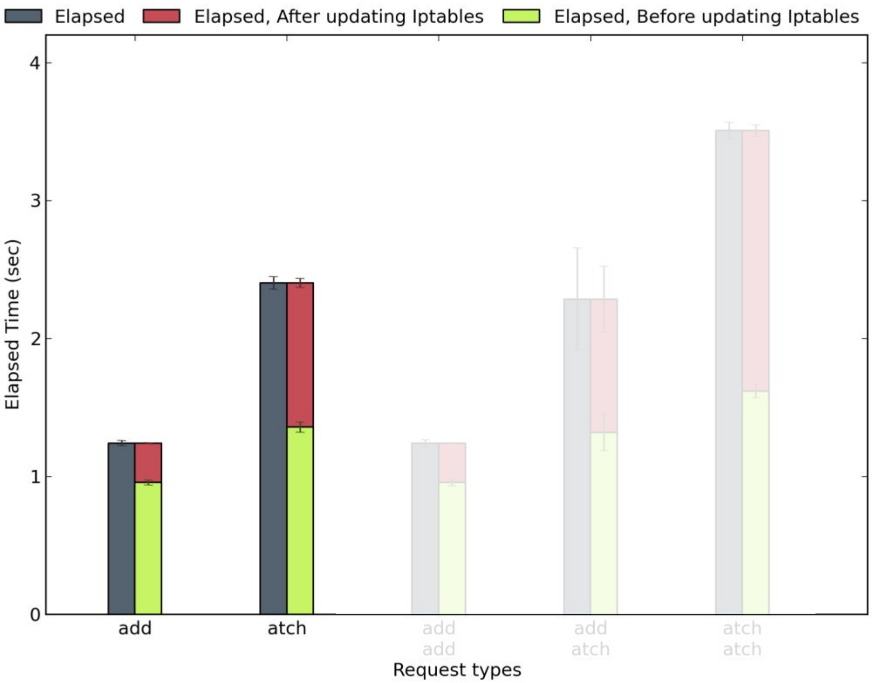
- To monitor Epochs:
  1. The virtual firewall should be **updated** in every RPC loop iteration so that the Iptables is also updated.
  2. The update result should be **observable** by the attacker.
  3. The update request should have small impact on the `elapsed` to minimize noise.

Epoch

- To manipulate Epochs:
  1. There should be a request that can make a clearly distinguishable impact on `elapsed`.
  2. The request should be processed at the targeted RPC loop iteration.

Impact of Requests: One-time Impact

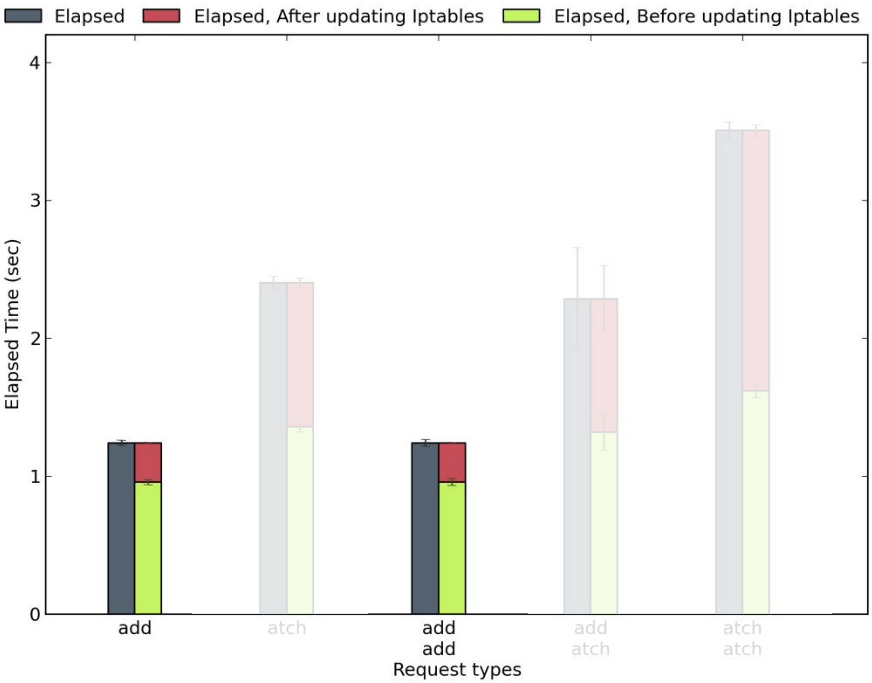
- Property 0)
  Some requests bring the same result but their load sizes are different



Impact of Requests: One-time Impact

- Property 1) Some requests introduce nearly no additional load

- Useful for monitoring Epochs



Impact of Requests: One-time Impact

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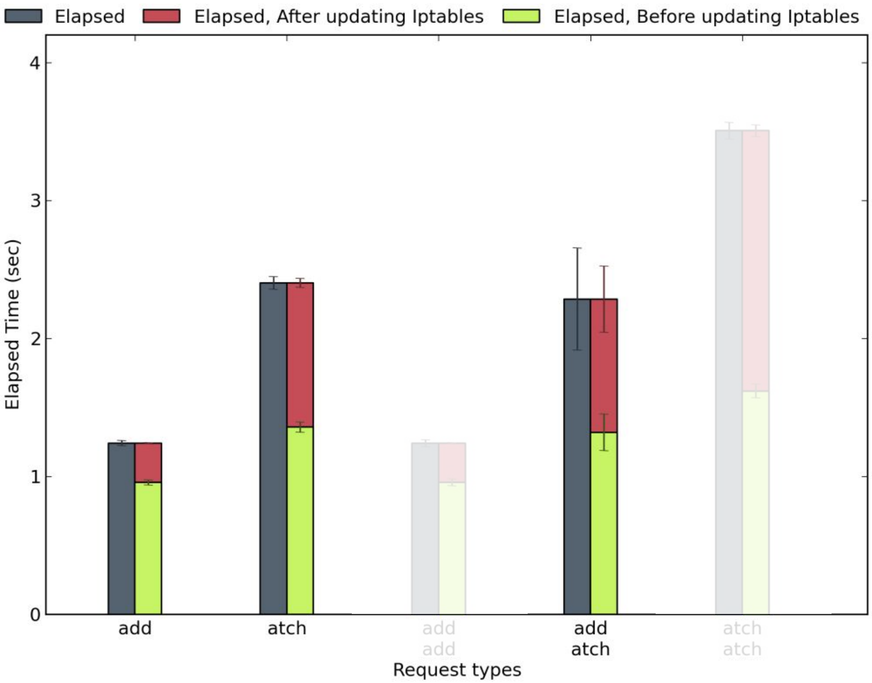
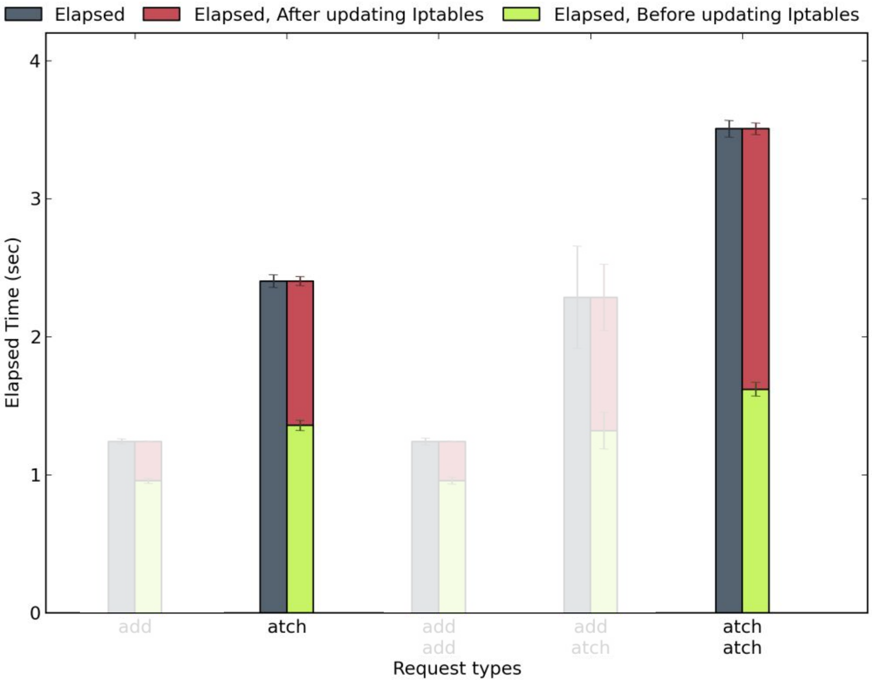


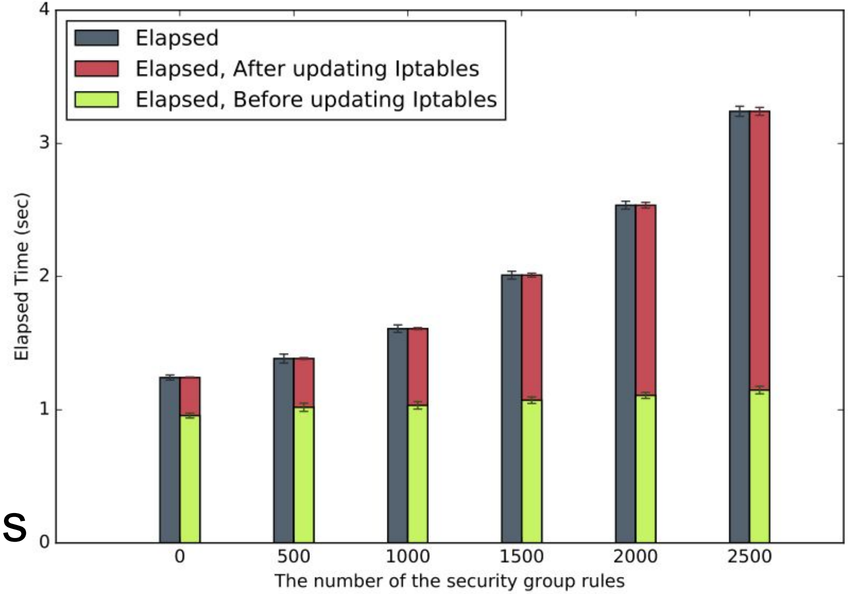
Impact of Requests: One-time Impact

- Property 2) Some other requests introduce clearly distinguishable additional load
- Useful for manipulating Epochs

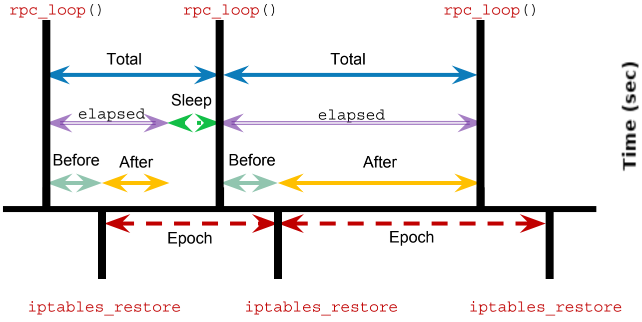


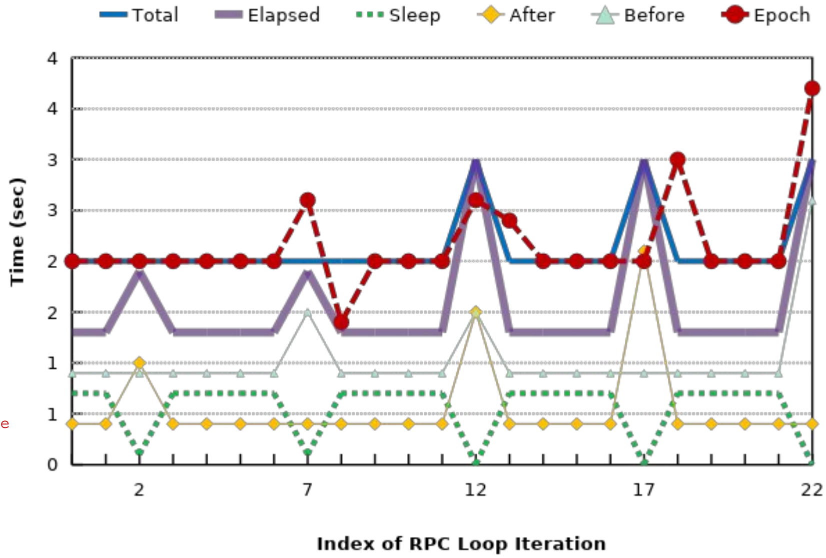
Impact of Requests: Long-term Impact

- Property 3)
  Some requests may permanently increase the loads of **<u>other requests</u>**.
- Useful for manipulating Epochs



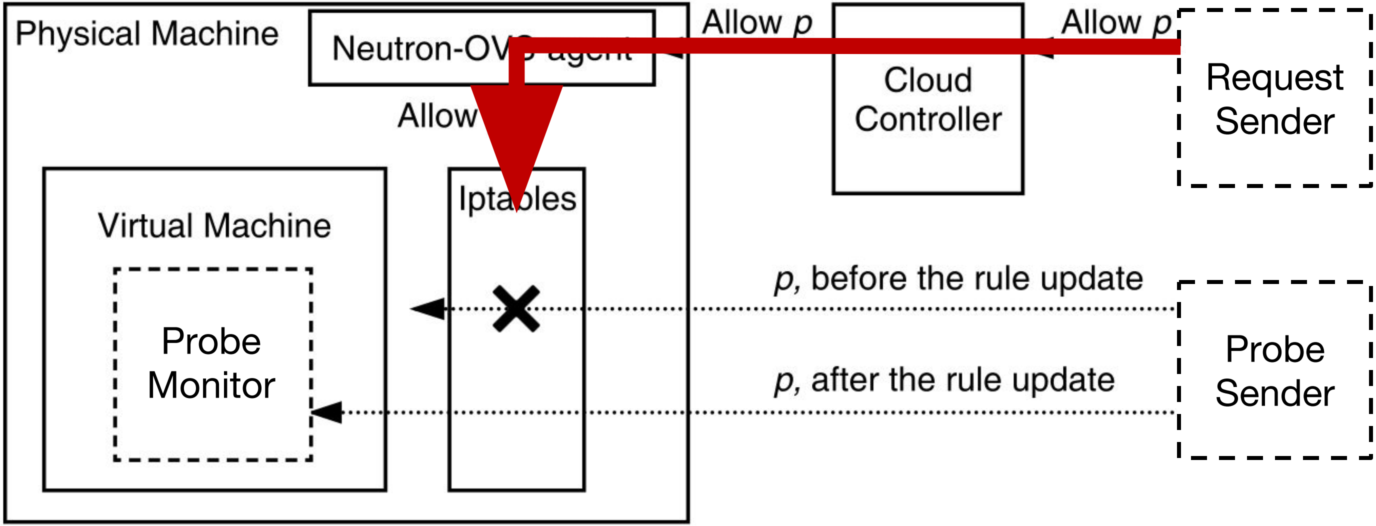
Epoch Patterns



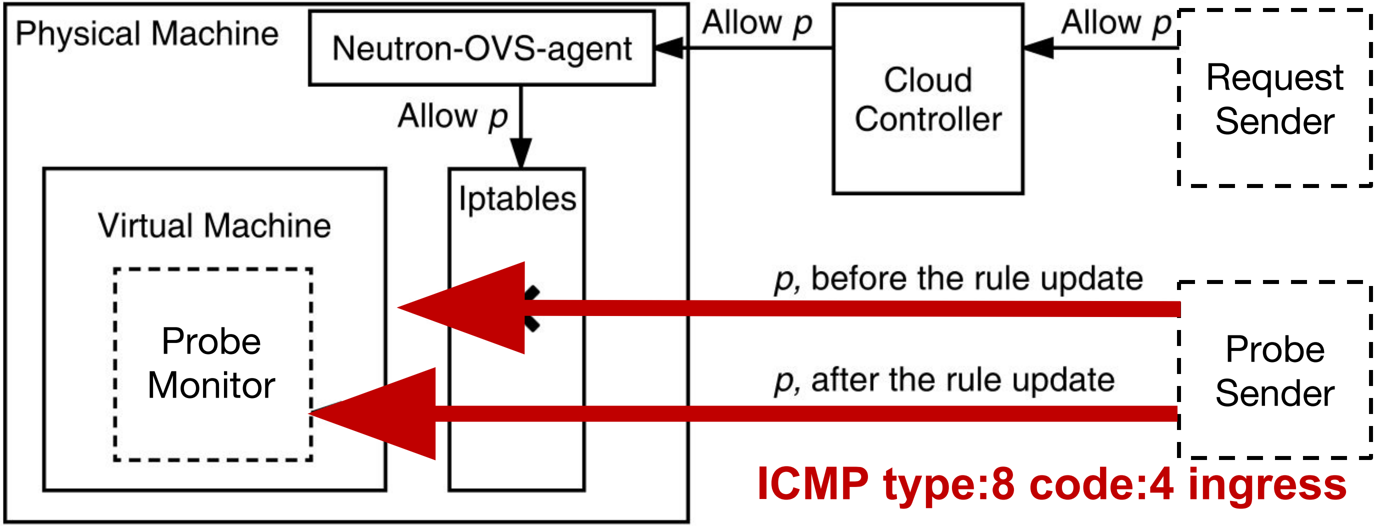


Monitoring Epoch: UPDATE+PROBE

Update: add a new rule to its virtual firewall.
E.g., Allow ICMP type:8 code:4 ingress



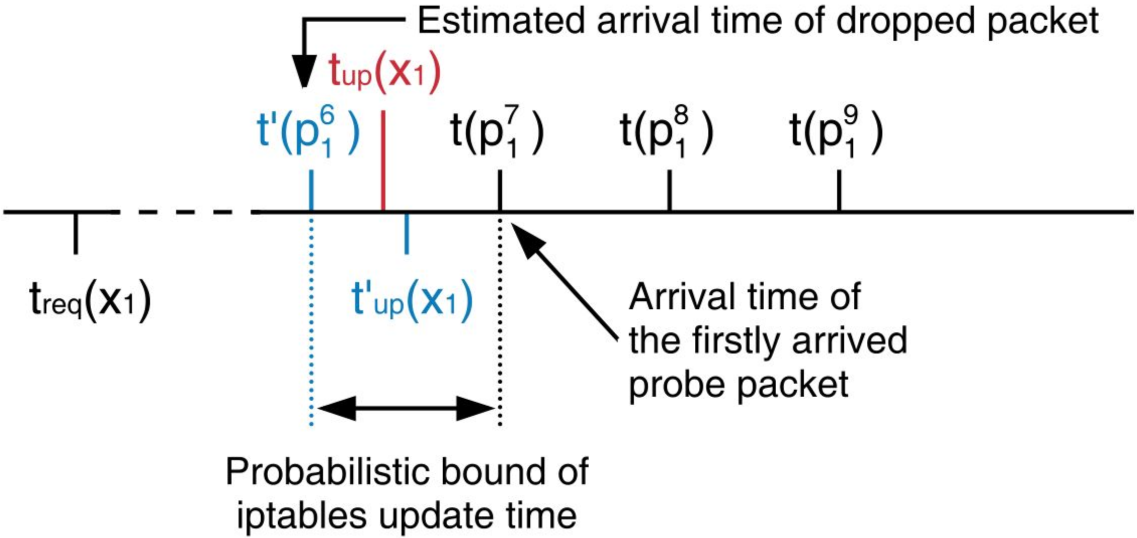
Monitoring Epoch: UPDATE+PROBE



ICMP type:8 code:4 ingress

Probe: generate a series of probe packets

Monitoring Epoch: UPDATE+PROBE

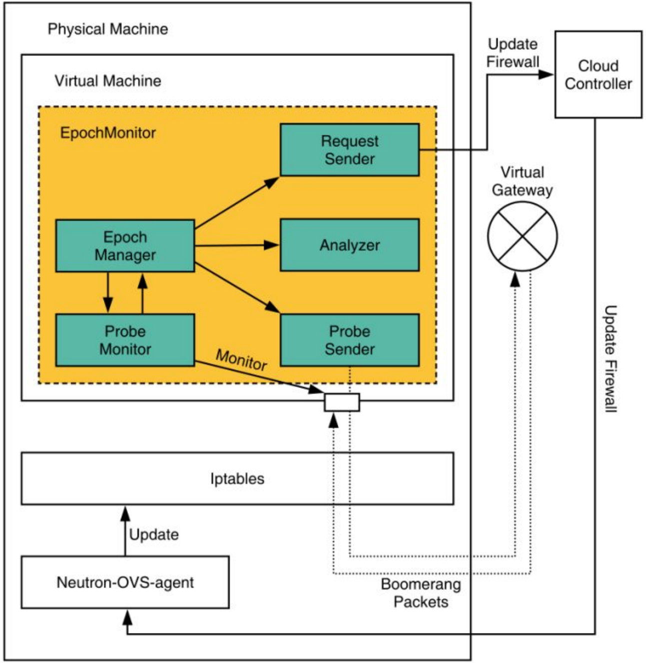


Continuous Monitoring

- Iterative UPDATE+PROBE method
  - Monitoring modules are independent
- Reactive UPDATE+PROBE method
  - The number of requests: 1 / epoch
- *n*-Reactive UPDATE+PROBE method
  - can dynamically adjust the number of requests

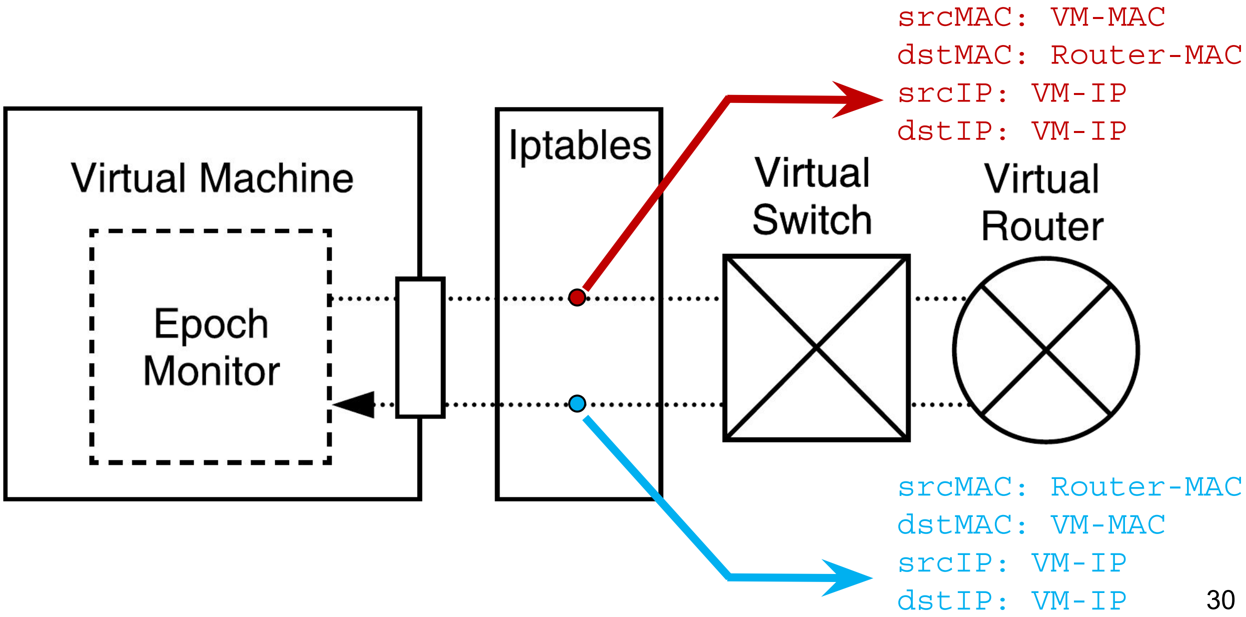
Practical Epoch Monitor

- *EpochMonitor*
  - A stand-alone architecture for epoch monitoring.
  - Can easily support any of the previously introduced methods



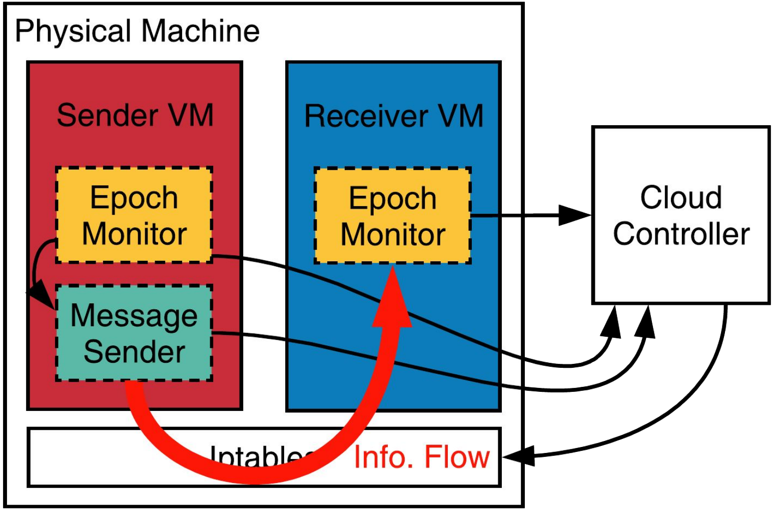
Deployment: Boomerang Packets

- Layer 3 Boomerang with Single Interfaces

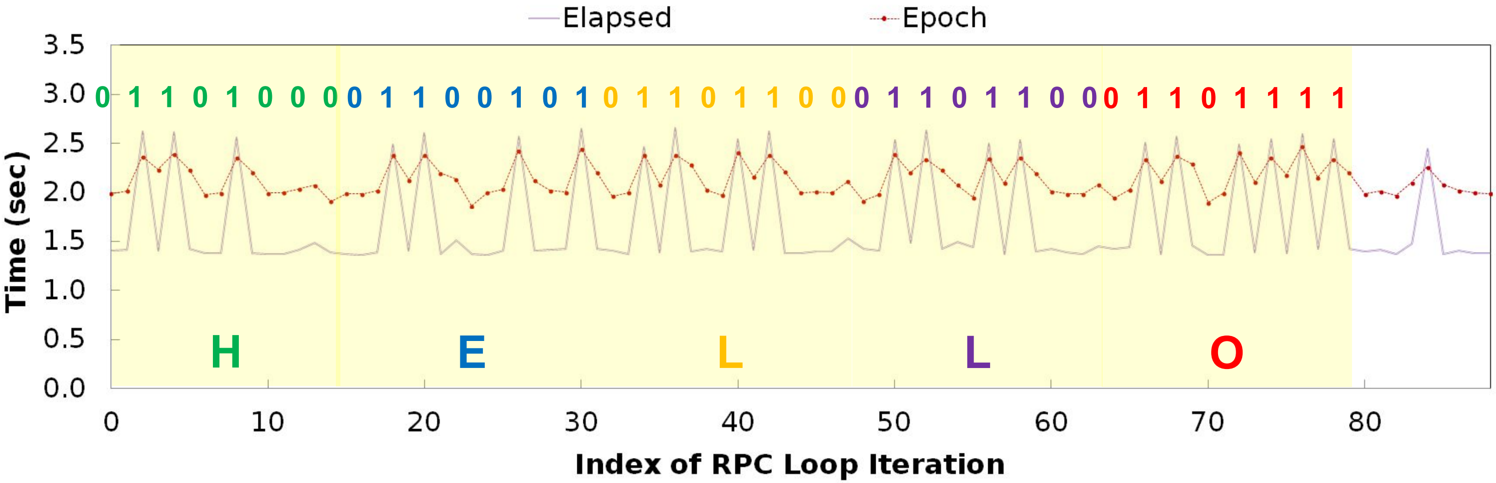


Single-node Covert Channel

- Covert Channel
  - Both VMs keep monitoring the epochs using EpochMonitor.
  - SVM also reactively send message to RVM by manipulating the duration of epochs.
  - E.g., to send `0`: do nothing
    to send `1`: attach/detach SG



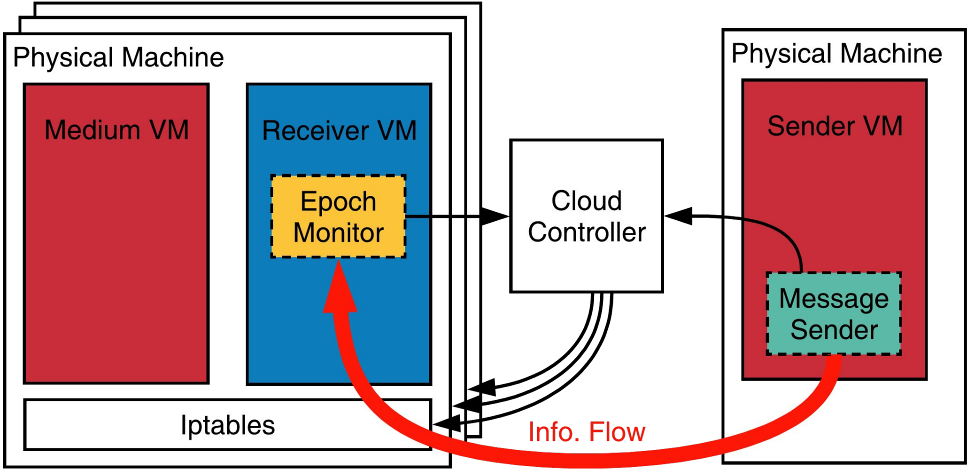
Single-node Covert Channel – Evaluation



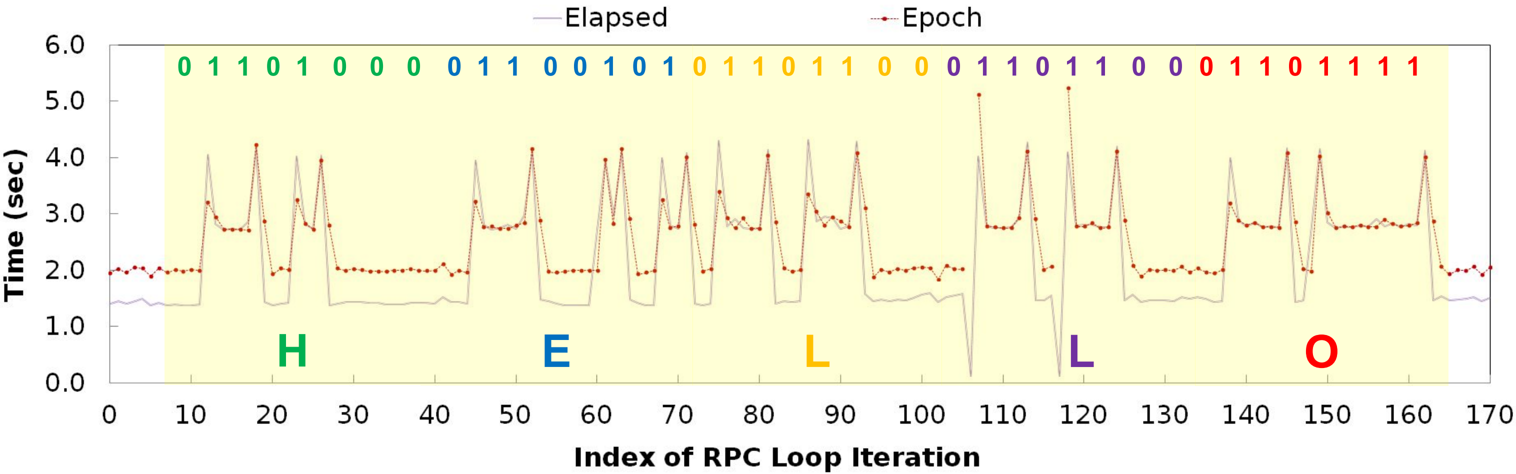
- Error rate: 0
- Bandwidth: 0.21 bps

Multi-node Covert Channel

- Covert Channel
  - SVM send message by sending the same message for *n* seconds.
  - This can be done by manipulating the duration of epoch of medium VMs, using the long-term impacting requests.



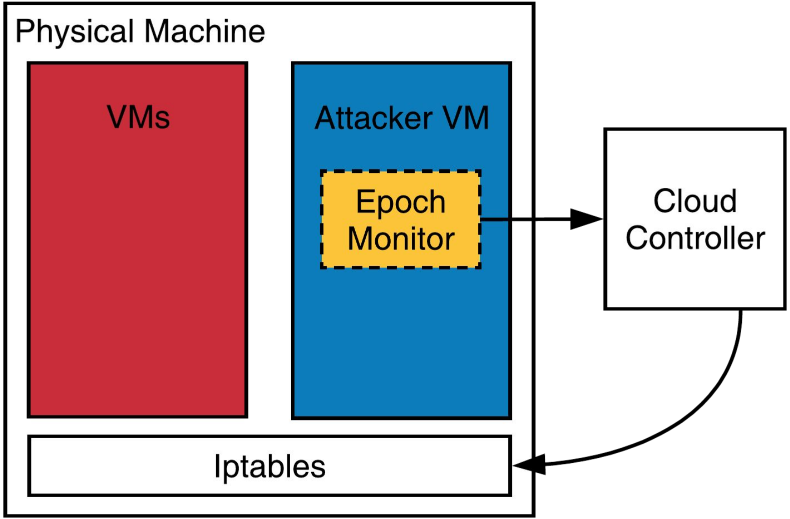
Multi-node Covert Channel – Evaluation



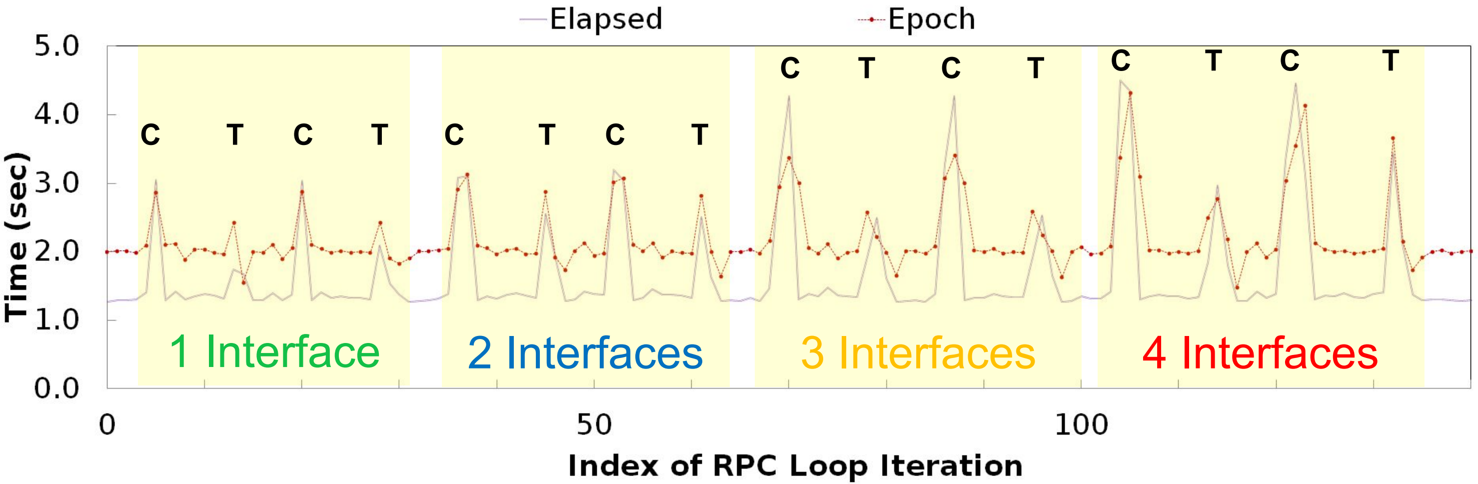
- Error rate: 0
- Bandwidth: 0.1 bps

Infrastructure Event Snooper

- Snooping on the host level events
- Any network-related requests can leave their mark on Epoch
- The attacker keep monitoring Epochs and extract event information



Infrastructure Event Snooper



- VM creation / termination
- # of virtual interfaces per VM

Infrastructure Event Snooper

- Continuously monitor Epochs
- Classify events using LSTM Model
- Output:
  - If any VM was created / terminated during an Epoch
  - The number of virtual NIC attached to the VM

Infrastructure Event Snooper – Evaluation

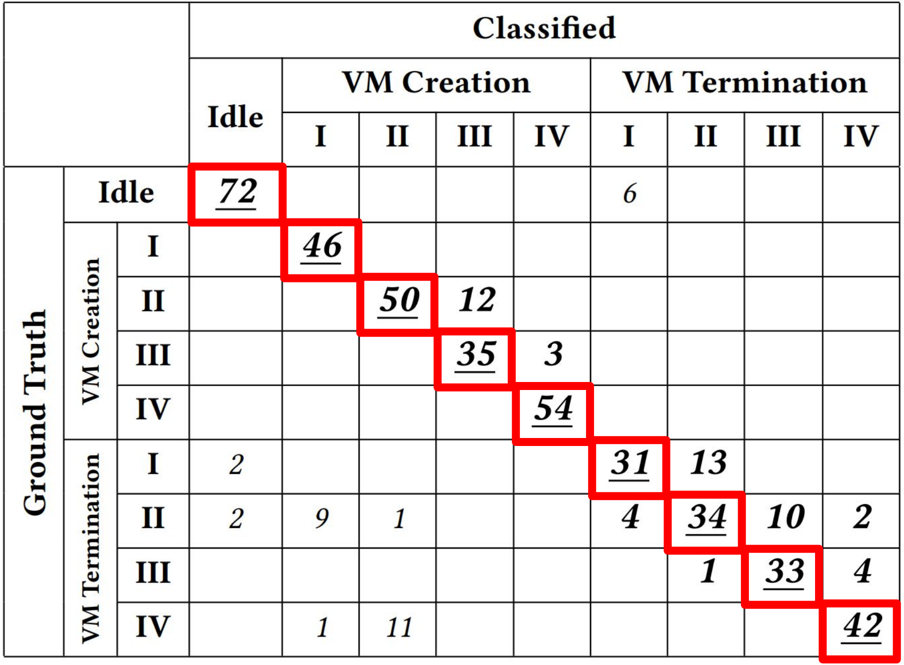
- Training Data
  - Two types of Host Machines
  - Four types of VMs

    each of which has different # of virtual NIC
  - Two types of events: VM creation / VM termination
  - 100 data points for each class
  - 75% for training, 25% for validation

Infrastructure Event Snooper – Evaluation

- Test Data
  - For each different type of Host Machine
  - Created and terminated 100 VMs in a random order
  - Each VM was configured to have random number of virtual NIC between 1 and 4
  - 478 labeled data points

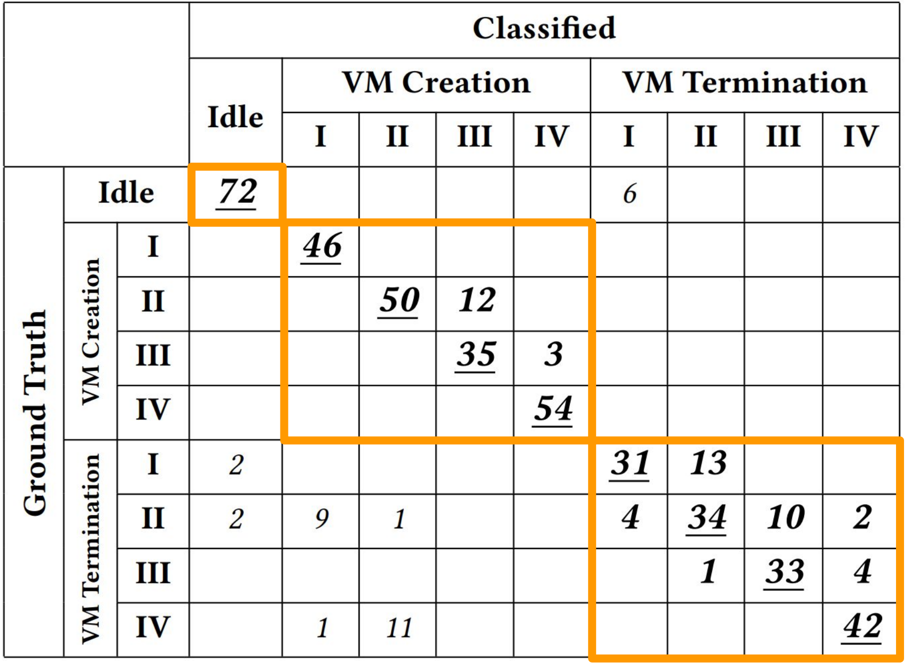
Infrastructure Event Snooper – Evaluation



			Classified								
			Idle	**VM Creation**				**VM Termination**			
				I	**II**	**III**	**IV**	**I**	**II**	**III**	**IV**
Ground Truth	**Idle**		***72***					*6*			
	VM Creation	**I**		***46***							
		II			***50***	***12***					
		III				***35***	***3***				
		IV					***54***				
	VM Termination	**I**	*2*					***31***	***13***		
		II	*2*	*9*	*1*			***4***	***34***	***10***	***2***
		III							***1***	***33***	***4***
		IV		*1*	*11*						***42***

- Accuracy:
  83.1%

Infrastructure Event Snooper – Evaluation



		Classified								
		Idle	VM Creation				VM Termination			
			I	II	III	IV	I	II	III	IV
Ground Truth	Idle	*72*					*6*			
VM Creation	I		*46*							
	II			*50*	*12*					
	III				*35*	*3*				
	IV					*54*				
VM Termination	I	*2*					*31*	*13*		
	II	*2*	*9*	*1*			*4*	*34*	*10*	*2*
	III							*1*	*33*	*4*
	IV		*1*	*11*						*42*

- Accuracy: 83.1%

- Accuracy ignoring vNIC: 93.3%

Evaluation – EpochMonitor

- Root Mean Square Error
  - 1.54 milliseconds
- Maximum Error
  - 25.5 milliseconds
  - Sufficient for distinguishing different requests (differences are larger than 100 milliseconds)

Mitigation – Refactoring

- Don’t use Cross-tenant Batch

```
...
req_batch = aggregate_requests()
...
update_something(req_batch) # observable event
...
```

Mitigation

- Increasing Polling Interval
  - Pros: simple and may work for some cases
  - Cons: increases the system delay by **order of seconds**

- Introducing Random Delay
  - The same as above...

Mitigation

- Rate Limiting (Request Delaying)
  - Request pattern is different from Dos-style attack
    - e.g., 0.5 request per second
  - If combined with a tailored policy,
    may effectively mitigate the probing.
    - e.g., if avg(# of requests for VM1 per sec) > 1 and
      std(# of requests for VM1 per sec) < 0.1 :
      delay future requests by 5 seconds

Conclusion

- Showed software-level shared resources can be exploited as an information leakage channel.
- Designed covert / side channels exploiting shared execution paths.
- Demonstrated attacks using OpenStack Network Management Service.

Possible Application

- Cooperative co-residency detection
  - Detecting co-residency of the attacker’s own VMs.
  - A VM keeps sending detectable signal through the control plane (e.g., keep creating/deleting SG with many rules)
  - If another VM successfully co-reside with the VM, it can read the signal through the Update+Probe
  - Trivially doable

Possible Application

- Un-cooperative co-residency detection
  - Detecting co-residency with victim VMs.
  - E.g., when load increases, the auto-scaling service launches new VMs in the same physical machine (e.g., affinity group in OpenStack)
  - The attacker change the load on the victim VM and monitors Epochs to detect when VMs come/leave

Possible Application

- Infrastructure Profiling
  - E.g., a cloud provider launches large number of ‘spot instances’ in night time for specific type of machines.
  - E.g., a cloud provider launches ‘High-end VMs’ with large number of virtual interfaces only in specific types of machines.