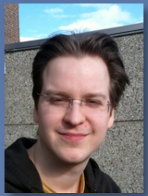
SliceTime

A platform for accurate and scalable network emulation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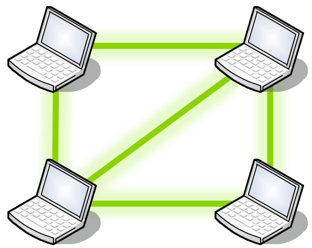
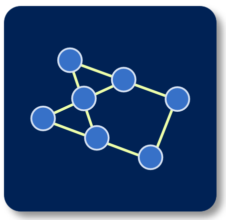
http://comsys.rwth-aachen.de/

NSDI 2011, Boston, MA

Motivation

How to evaluate networking software at large scale?



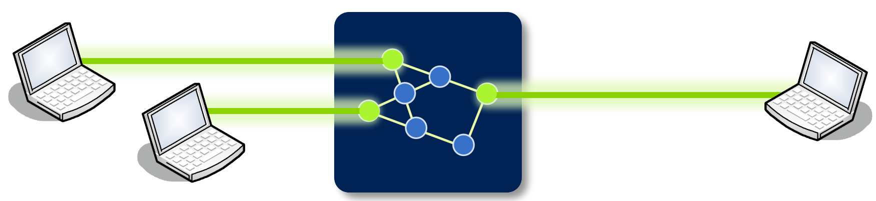


Network Testbeds

Drawbacks: Scalability and Cost

Network Simulation

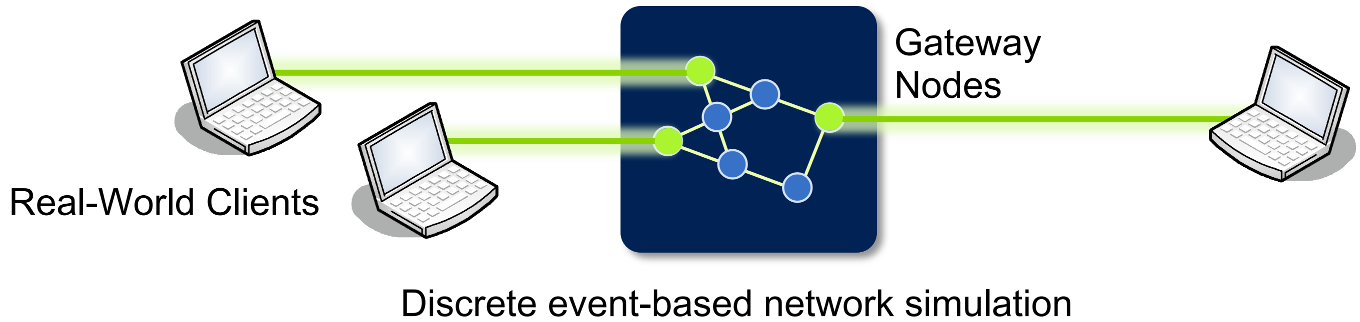
Models instead of software, no operating system…



Network Emulation

Requires real-time capable simulations

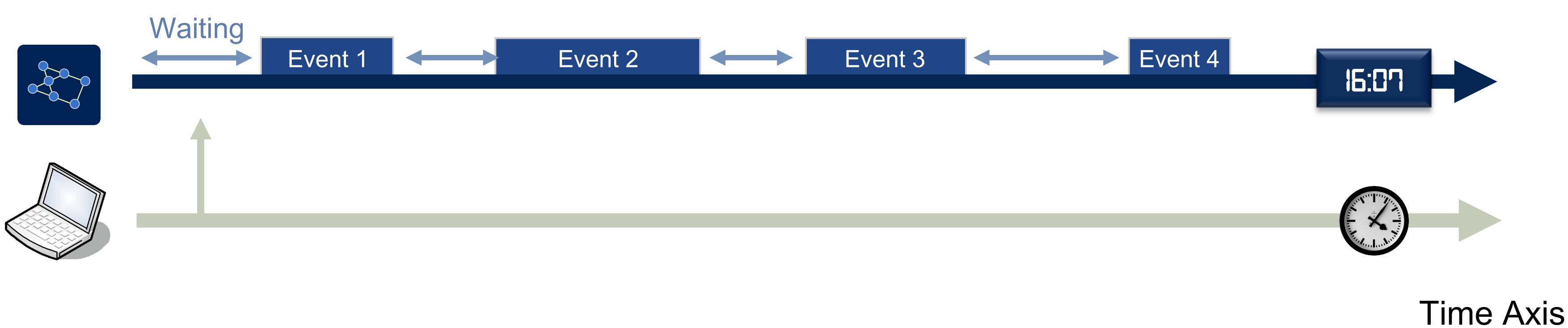
Network Emulation



- **Real-World clients**
  - Execute communications software & operating system
- **Discrete event-based network simulator**
  - Models interconnecting network
  - Examples: ns-2, OMNeT++
  - Also provides simulated hosts → scalability
  - Simulated environment: virtual mobility, radio propagation…

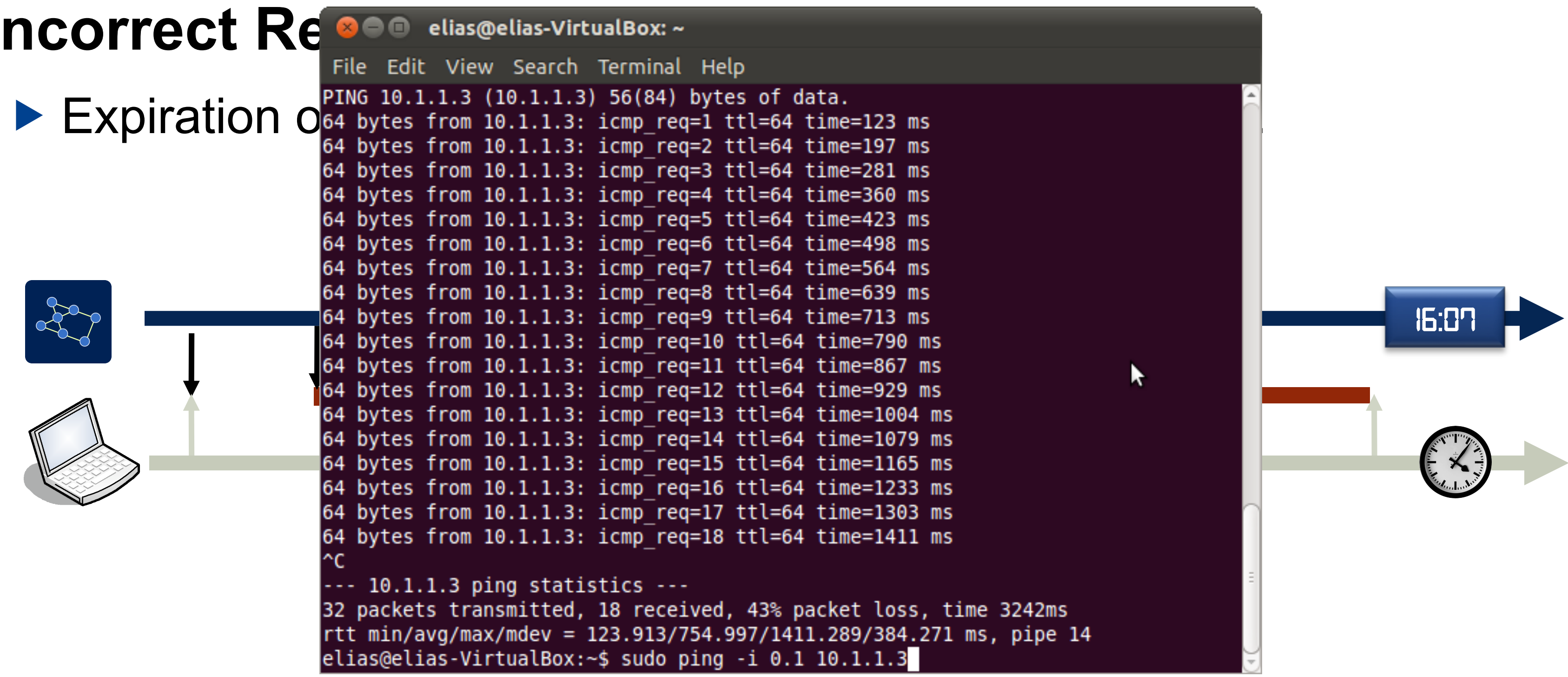
Network Emulation: Timing

- **Different timing concepts**
  - Network simulation: series of discrete events
  - Real-world clients: continuous wall-clock time
- **Current common solution**
  - Pin simulation events to wall-clock time
  - Wait between events



Time Drifting Issue

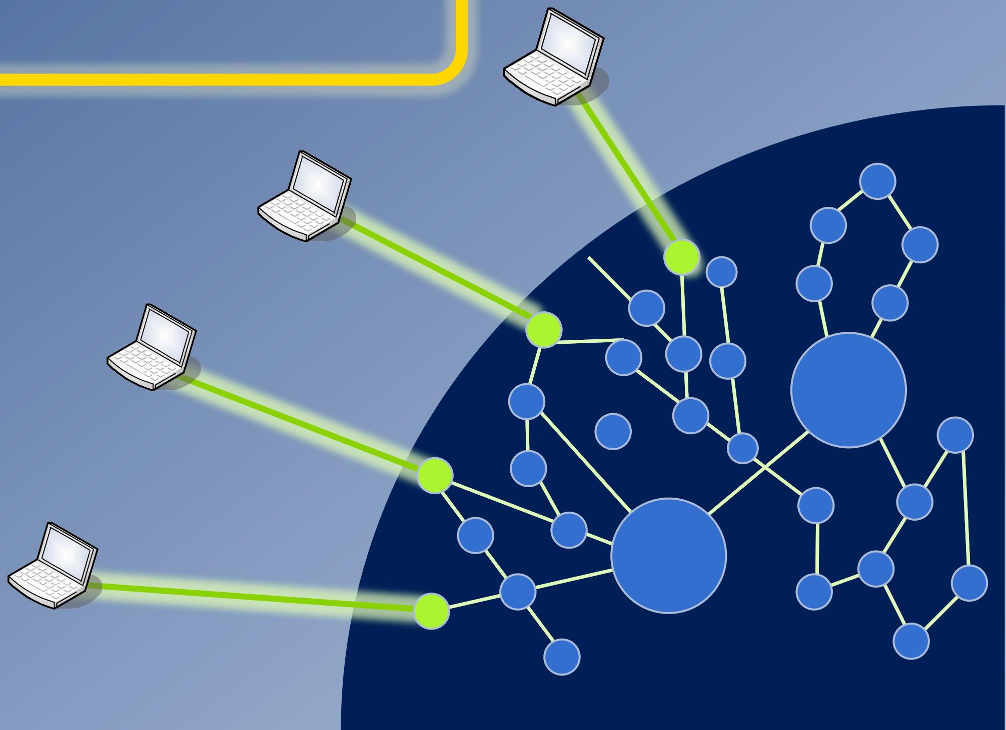
- **Problem: Many Simulations are not real-time capable**
  - Computationally complex models
  - Many simulated nodes
- **Simulation is overloaded → time drift**
- **Incorrect Re**
  - Expiration o



How can time drifting be prevented to enable large-scale and complex network emulation scenarios?

Two options:

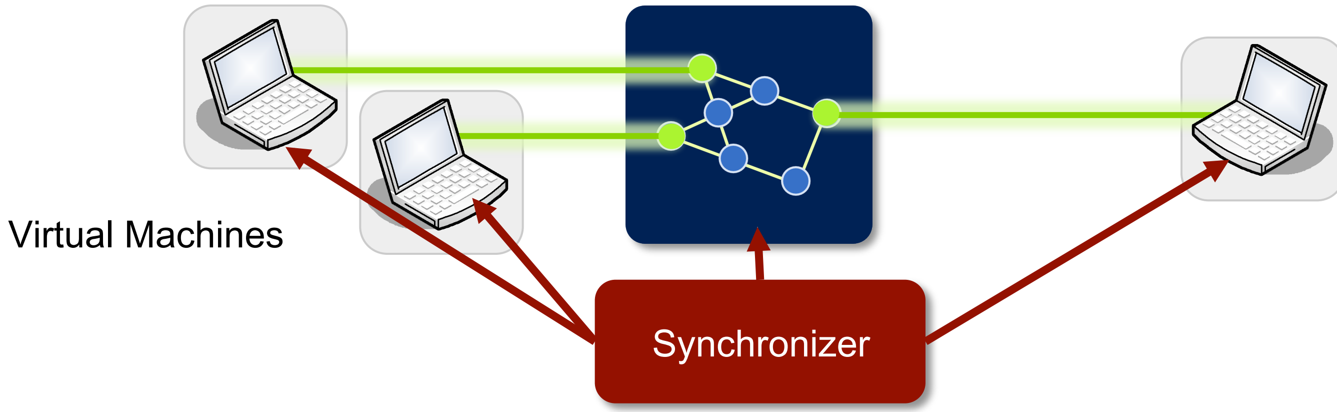
1. Make the simulation fast enough
2. Slow down the real clients to match the simulation's speed



Requirements

1. **We tightly need to synchronize clients and simulation**
   - Limit drifting to 1ms or less (for WAN scenarios)
2. **We need to slow down real-world software clients**
   - Unmodified communications software
   - Legacy operating systems (Linux or Windows)
   - Slow down must be transparent to the clients
     → provision of virtual time
3. **The synchronization should introduce little overhead**
   - Additional run-time
   - Additional delays or measurement artifacts

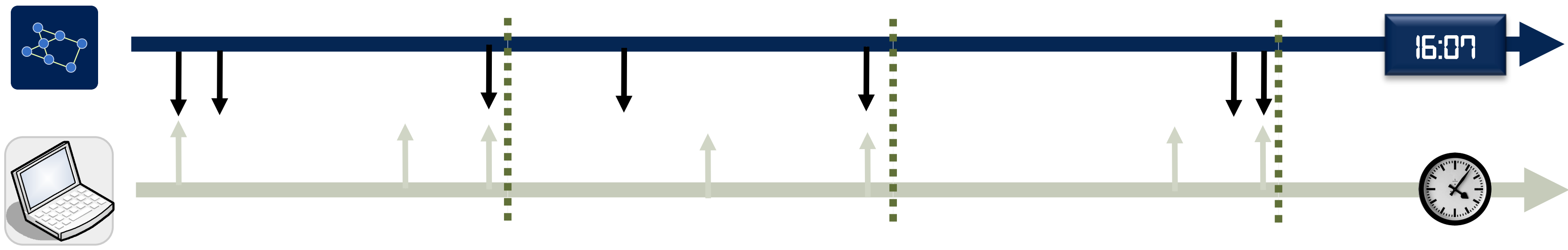
SliceTime: A Synchronized Network Emulation platform



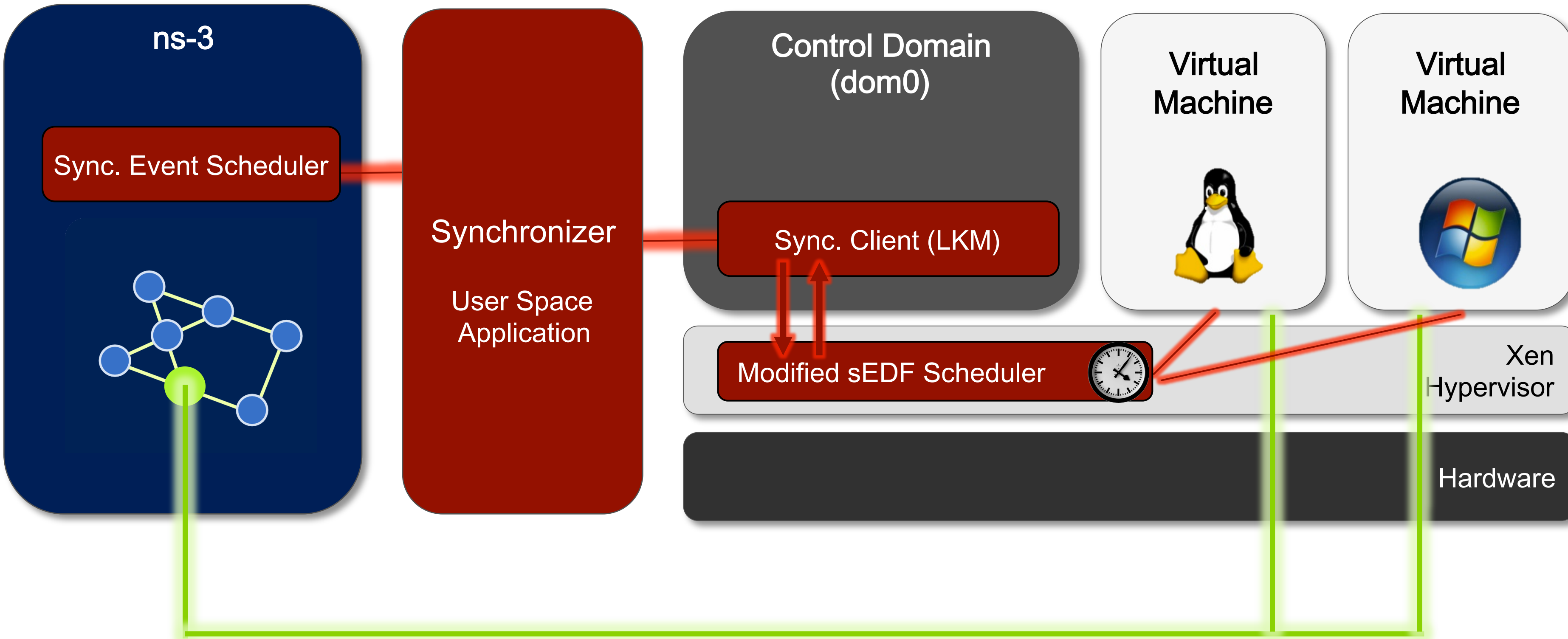
- **Synchronizer**
  - Synchronization algorithm aligns execution of clients and simulation
- **Virtual machines provide needed level of control**
  - Control over run-time behavior
  - Full control over system context/timers → provision of virtual continuous time

Synchronization Algorithm

- **Goal: Limit time drifting**
  - No assumptions about future run-time behavior
  - No snapshotting & rollbacks
- **Barrier Algorithm**
  - Assign slices of run-time
  - Blocking at end of time slice
  - Clients notify synchronizer after they have finished
- **Synchronization accuracy corresponds to time slice size**



SliceTime Implementation



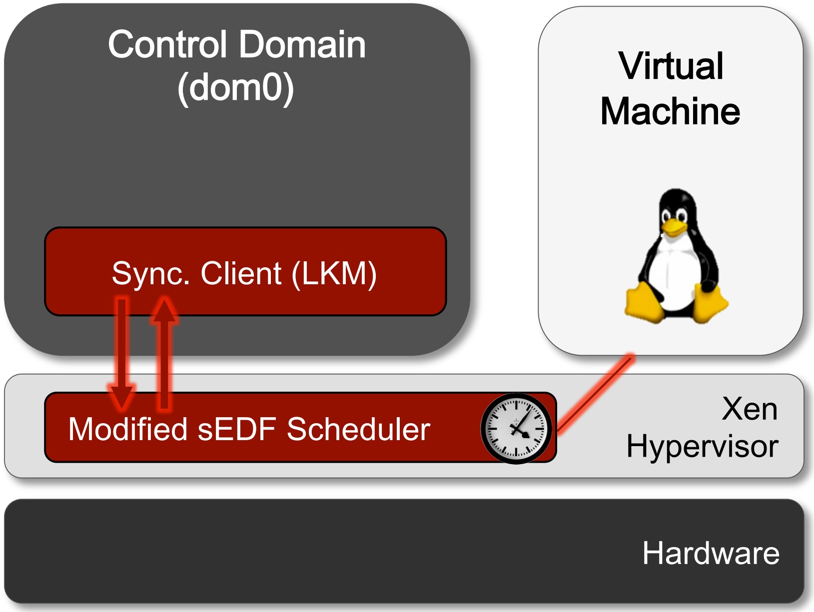
Data Communication Flow
- Tunneled EtherNet Frames
- 802.11 Frame Tunnel

Synchronizer

- **Implements barrier synchronization algorithm**
  - Assignment of time slices
  - Synchronizes multiple VMs with multiple simulations
- **User-space application**
  - Can run on VM, simulation slave or dedicated host
  - Lightweight signaling protocol
- **VMs and simulations may join sync. dynamically**
  - Allows VM bootstrapping out of synchronization

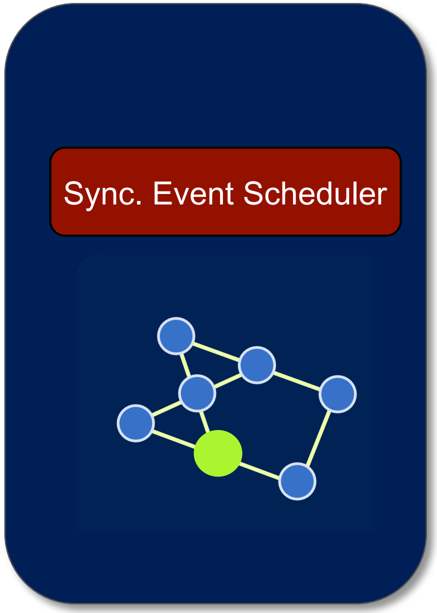
Implementation: Modified Xen environment

- **Synchronization Client**
  - Linux Kernel Module → save context switches
- **Modified sEDF scheduler**
  - Execute Xen domains for time slice duration
    - Extra scheduling queue for synchronized domains
    - Self-correction mechanism to overcome misattribution of run-time
  - Virtualizes time progression for synchronized domains
    - Calculates delta values for timers and clock sources



Network Simulation

- **Synchronized Event scheduler**
  - Synchronizes any ns-3 simulation with synchronizer/VMs
  - Checks if next event in queue resides in current time slice
- **Different ns-3 extensions**
  - Tunnel protocol → data exchange with VMs
  - WiFi emulation extensions
    - Provides VMs with wireless networking interface
    - Interface is intergrated with 802.11 model of ns-3



Evaluation

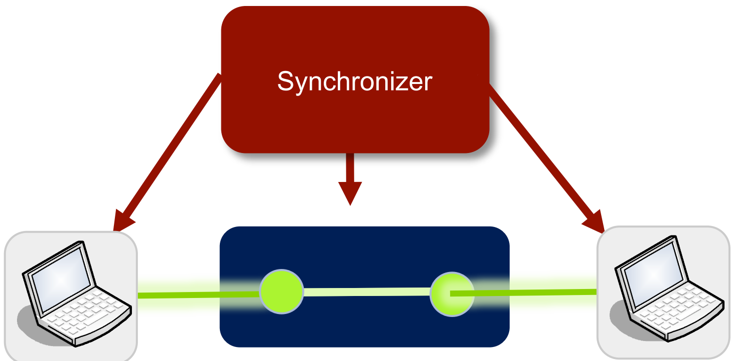
How accurate is SliceTime?

How much overhead is caused by the synchronization?

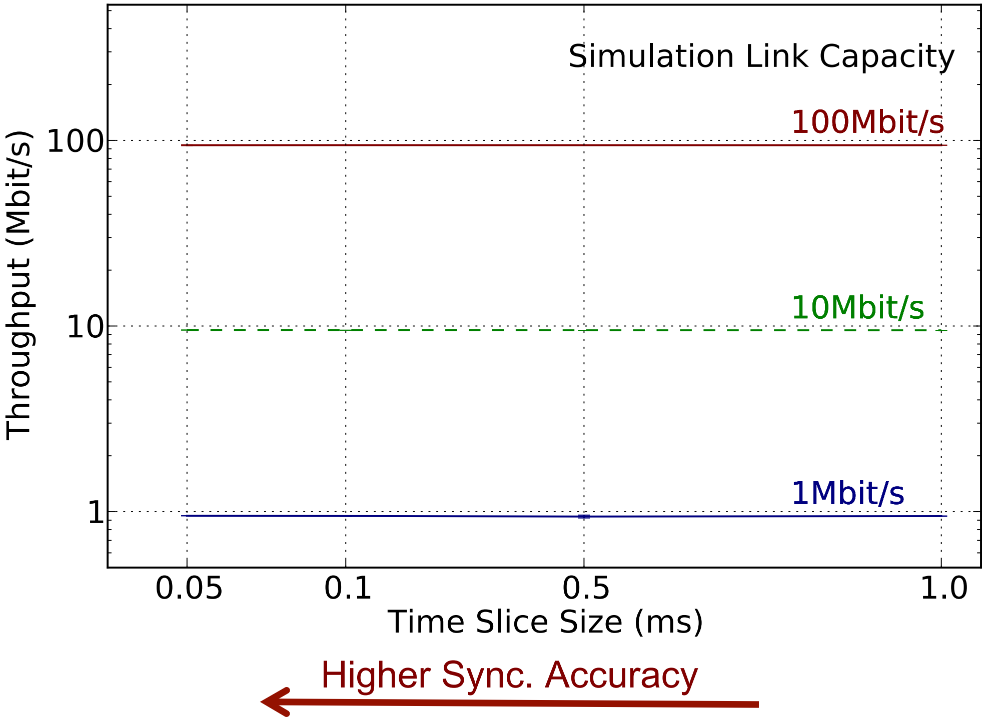
Is it applicable to complex network emulation scenarios?

Network Throughput

How is network throughput affected by time slice size?



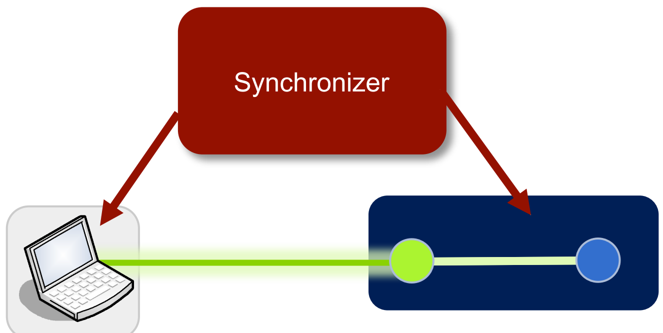
Measurement: netperf TCP_STREAM benchmark
Different levels of sync. accuracy



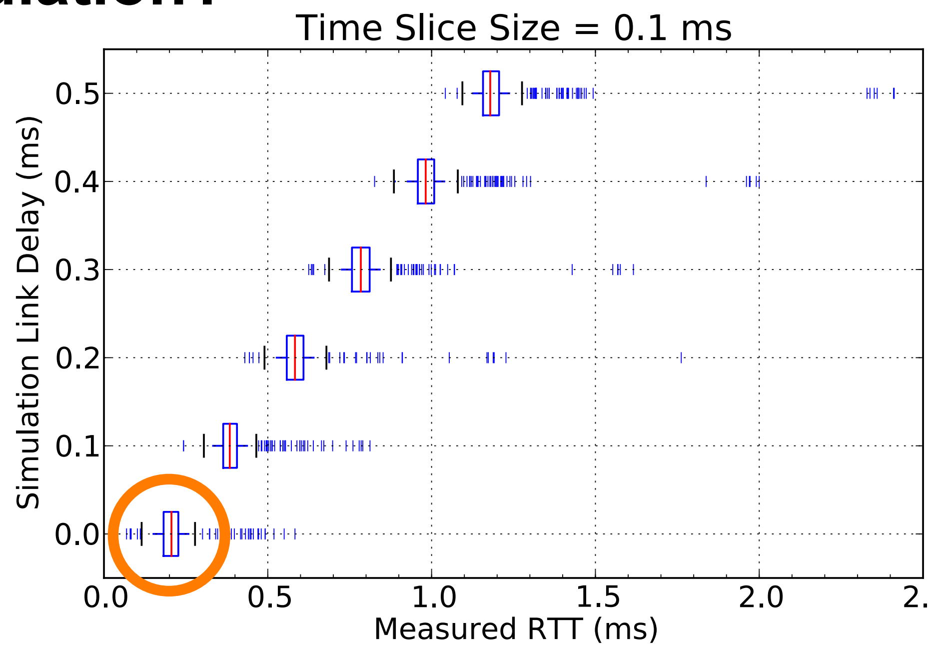
- **Perceived bandwidth is invariant to time slice size**

Evaluation: SliceTime Timing

How accurate is the time integration of VMs and the simulation?

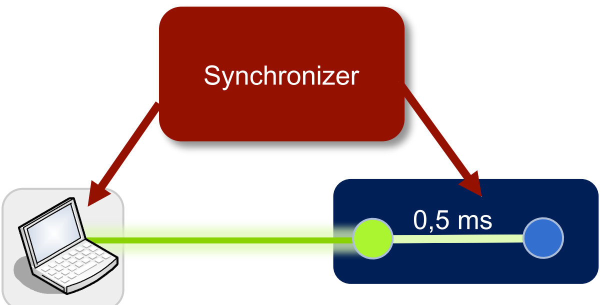


Measurement: 1500 RTTs (ICMP Echo Replies)
Simulated Link Delays between: 0,0 – 5ms
Static time slice size of 0.1ms

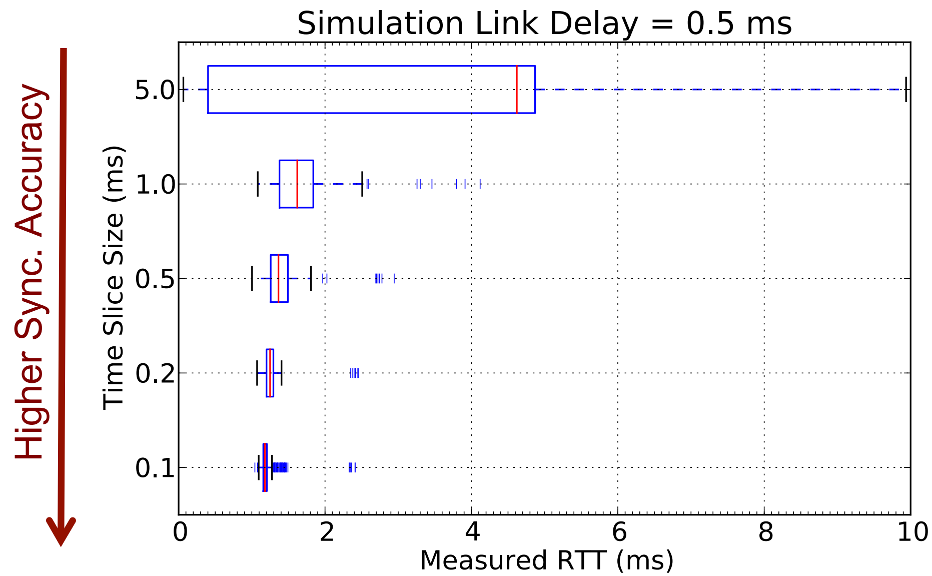


- **If no simulation delay is present → RTTs around ~ 0.2ms**
  - Base delay: Time needed for data exchange between VM & sync
- **RTT distributions shifted by twice simulation delay**

How do different time slice sizes influence the results?



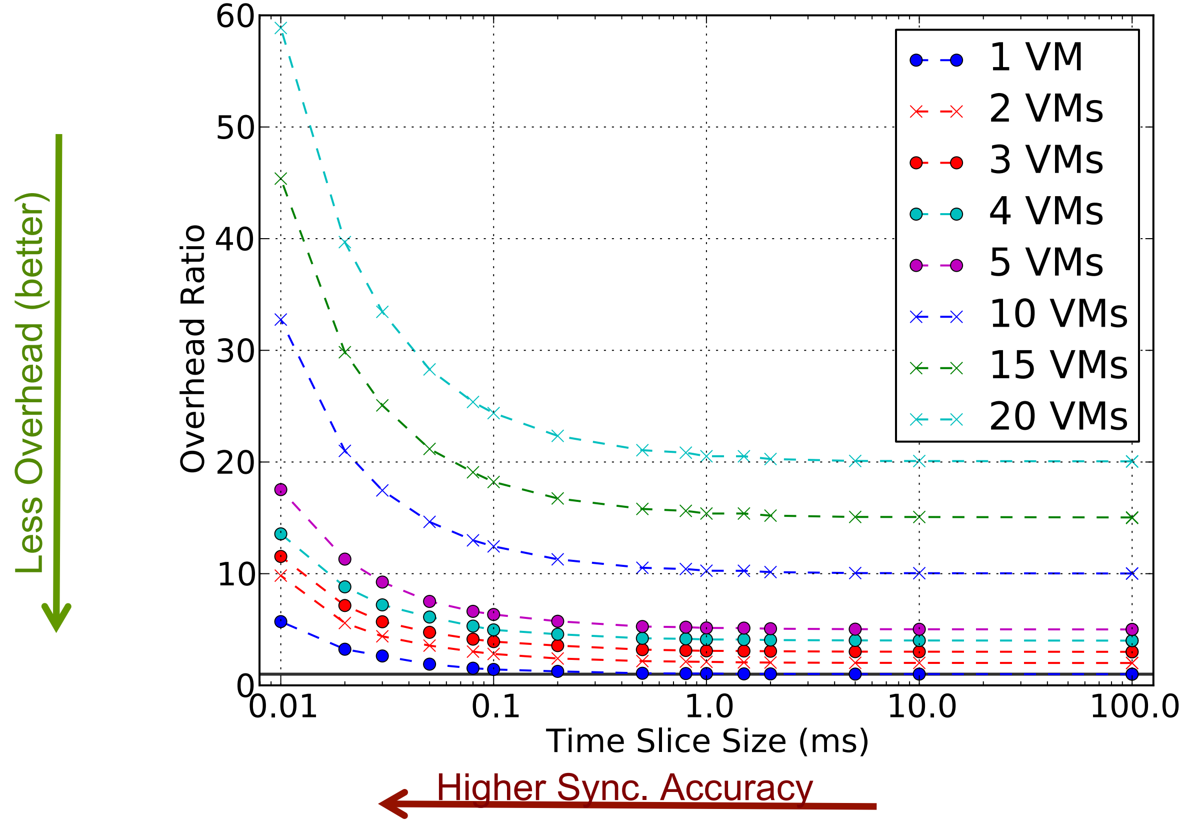
Measurement: 1500 RTTs (ICMP Echo Replies)
Variation: Time Slice Sizes



- **RTT distributions converge to base delay for smaller time slices (higher accuracies)**

Synchronization Overhead

How long does it take to execute 1s of virtual time?



- **Synchronization introduces additional run-time overhead**
  - Less than 5% for time slices > 0,5ms
  - Linear in the number of VMs

Can SliceTime ease the evaluation of networking software?

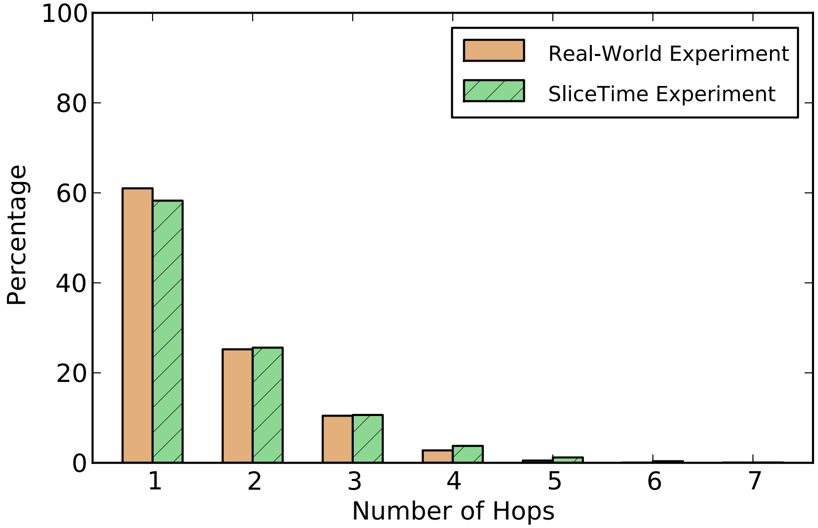
AODV Experiment
(Gray et al, 2003)

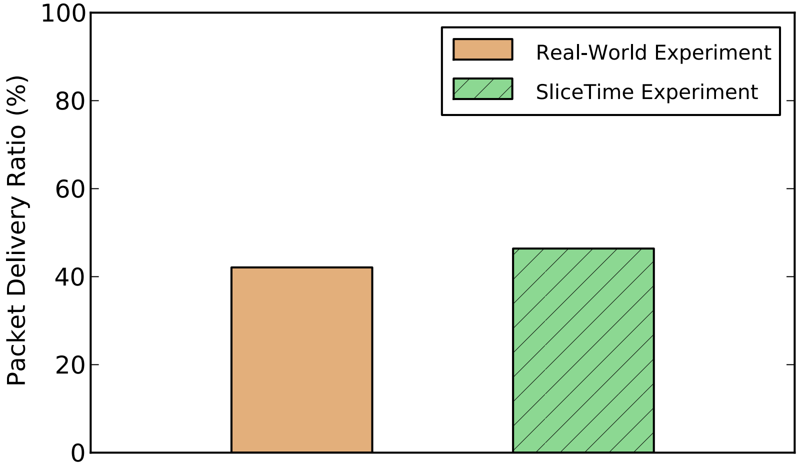
- 33 laptops running AODV
- 40 people carrying them around (on an athletic field)
- Random UDP traffic
- Laptops log traffic + position (GPS)
  - Logs available at CRAWDAD

The SliceTime equivalent

- 33 Xen HVM domains / AODV
- SliceTime 802.11 extensions
- 1 physical PC
- Ns-3 mobility model based on GPS traces
- Traffic generator

How do the results compare?





- **SliceTime produces results close to real-world measurements**
- **Always differences due to real-world/simulation disparity**

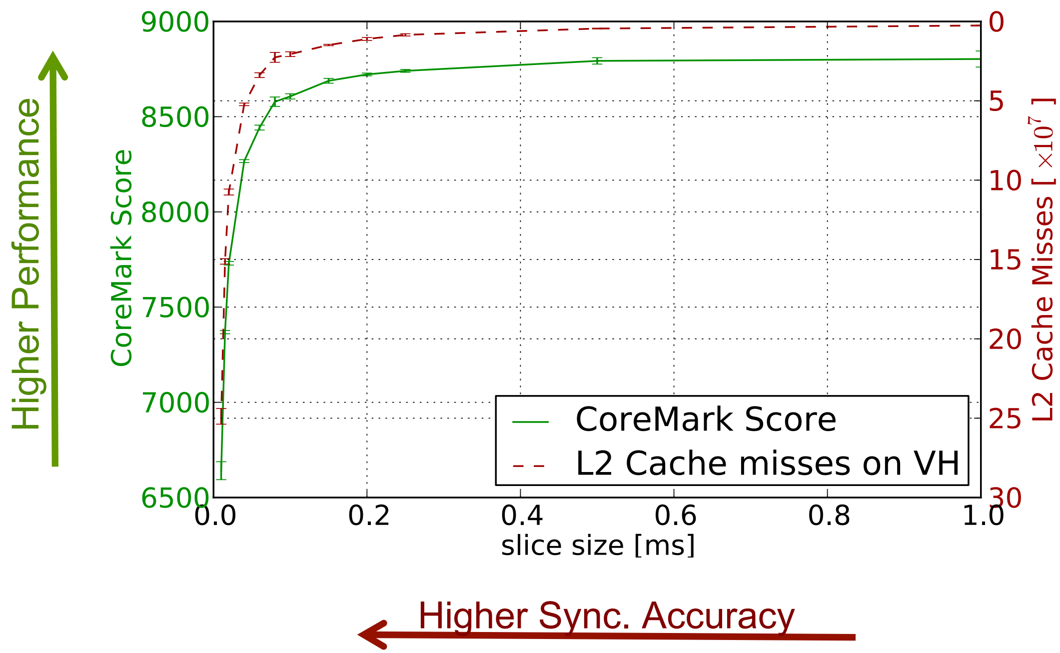
Conclusion

- **SliceTime allows network emulation scenarios with network simulations of any complexity**
- **SliceTime is accurate regarding timing and throughput**
- **SliceTime is resource efficient**
  - Low overhead even for time slices less 1ms
  - Saves physical hardware resources in comparison to real test beds
- **SliceTime is open source**
  - Get it at http://www.comsys.rwth-aachen.de/projects/slicetime
- **SliceTime extends the applicability of network emulation**

Questions?

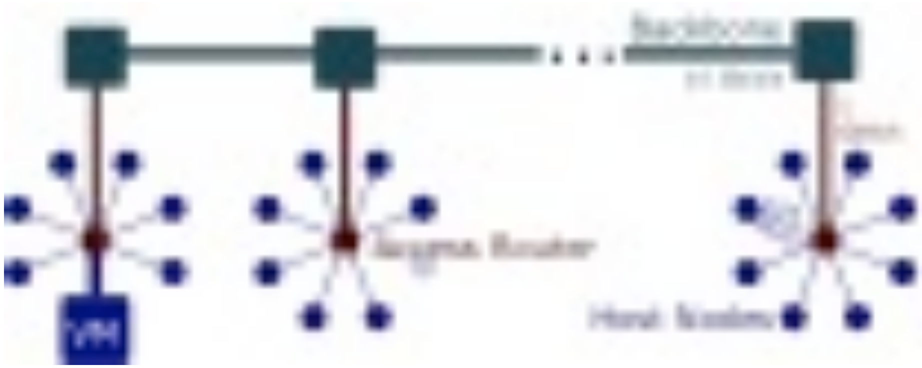
CPU Performance Impact

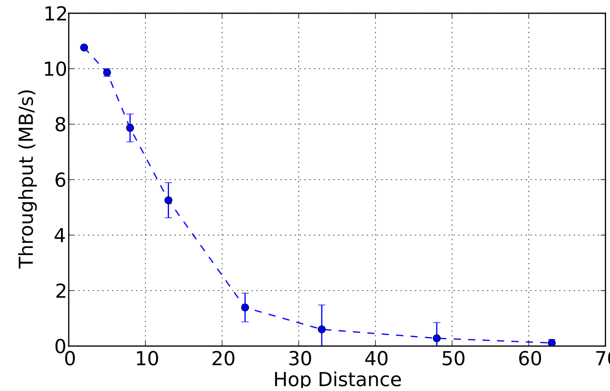
How about the CPU performance?
Doesn't the synchronization cause artifacts?



- **CoreMark score decreases for small time slices**
  - Almost no impact for slices greater than 0.1ms
  - Explanation: More L2 cache misses

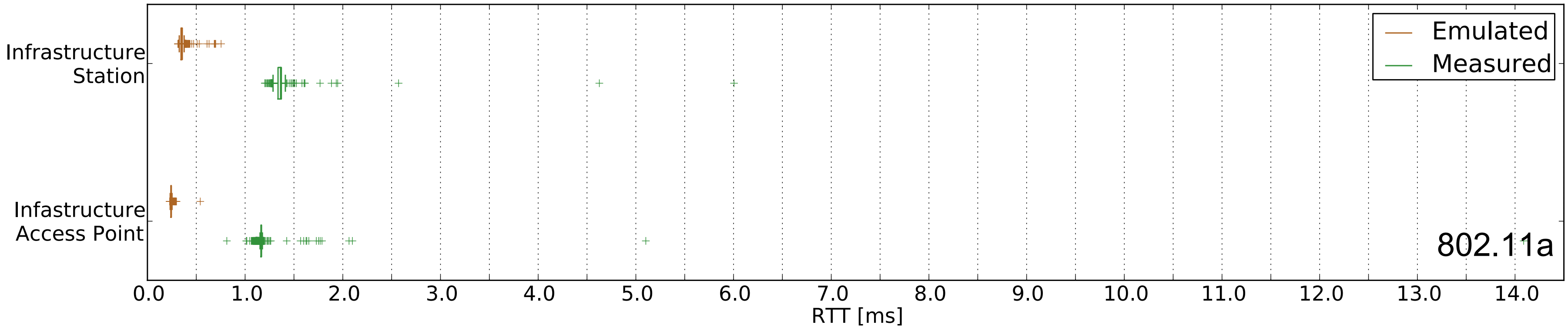
SliceTime Simulation scalability

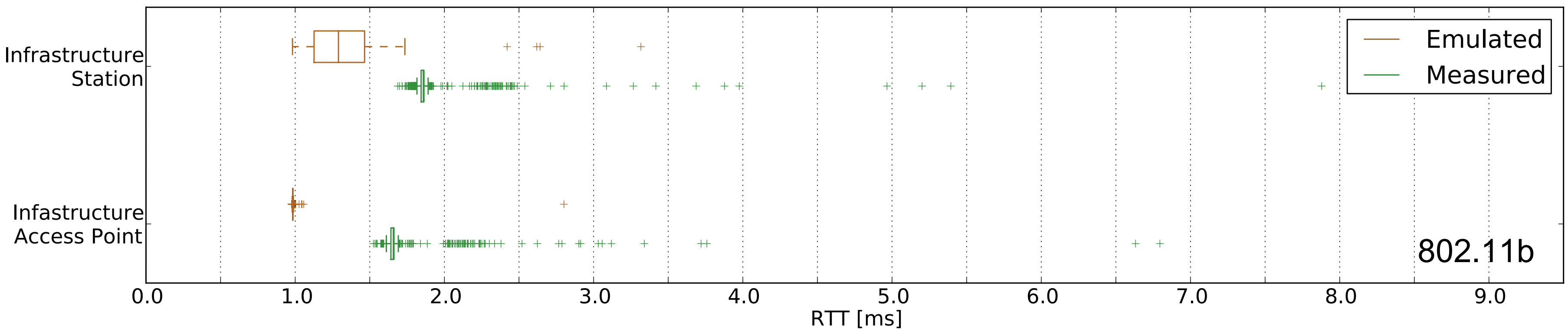




- **Setup: 15000 simulated nodes (60 stars with 250 nodes)**
  - Exchange data blocks among each other using HTTP
  - Executes~15 times slower than real-time
  - 1 VM attached to backbone
- **HTTP perormance measured with curl**
  - Expected result

How do round trip times compare to real world 802.11?

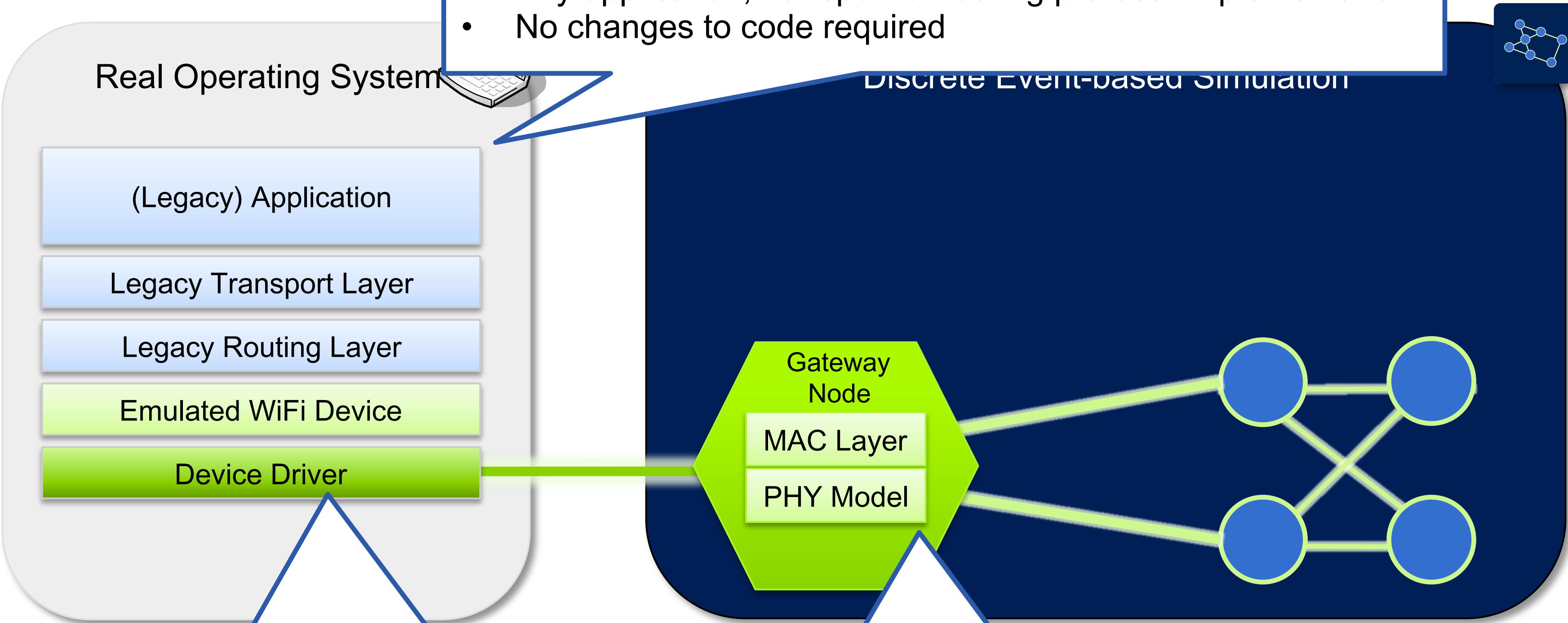




- **Emulated RTTs are lower than real world measurements**
  - ns-3 only approximations for link-level delays; no system delays

Device Driver-enabled Wireless Network Emulation

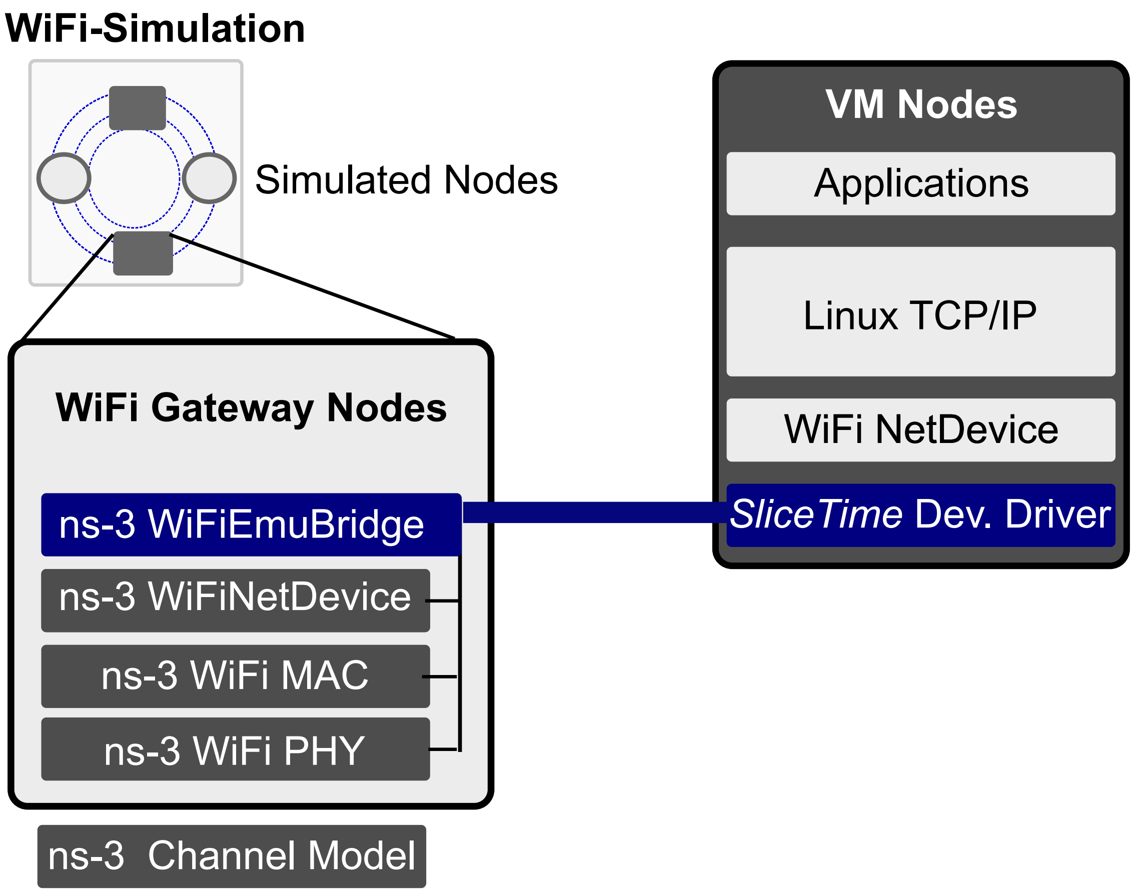
- Any application, transport or routing protocol implementation
- No changes to code required



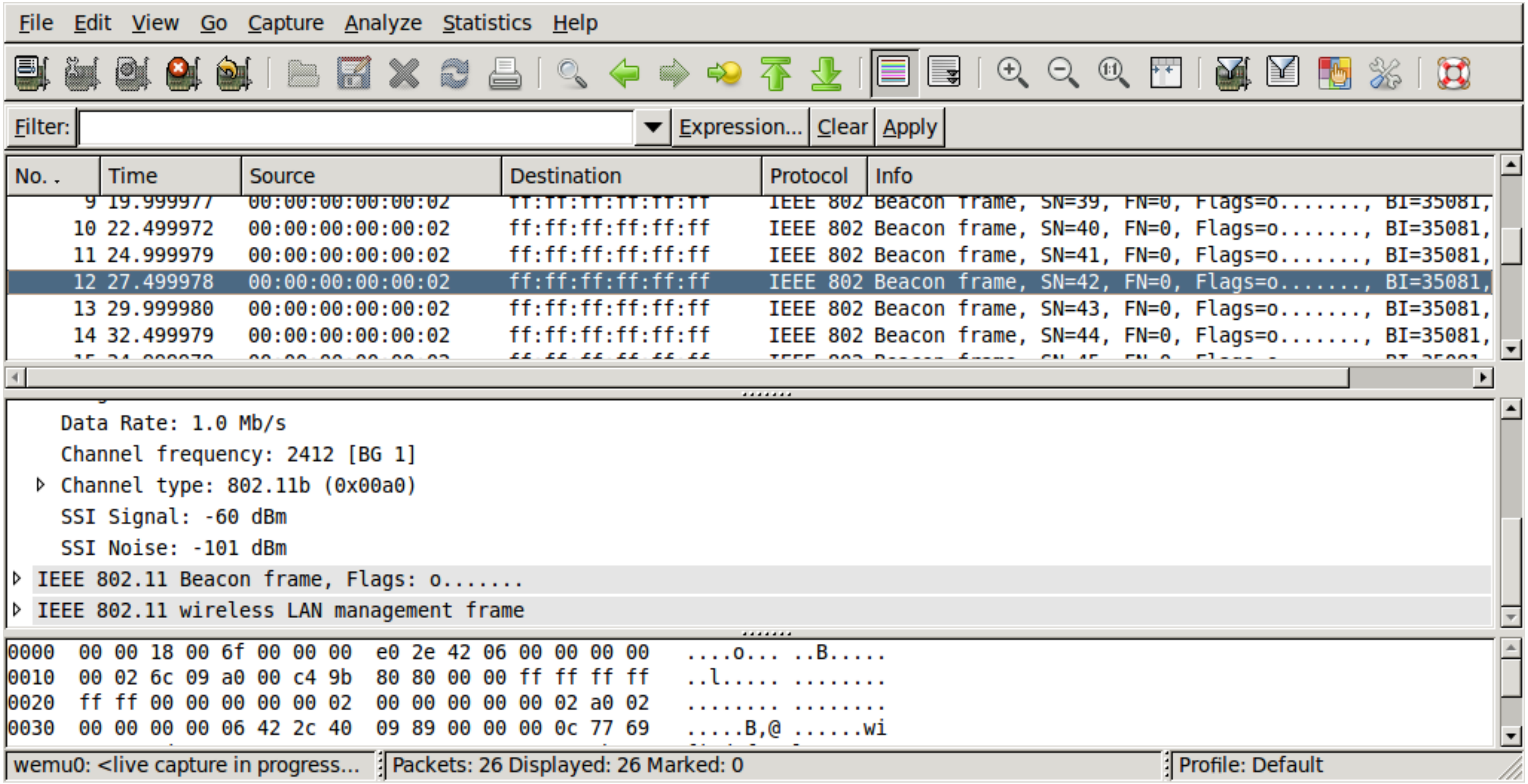
- Emulated Wifi Device: Mimics interface
- Device driver: Exchange of data and s

- Feeds data from real systems into simulated network
- Exchanges simulation properties (e.g. RSSI) with driver
- Acknowledgements/low-level 802.11 operations remain in simulation domain

SliceTime WiFi extensions

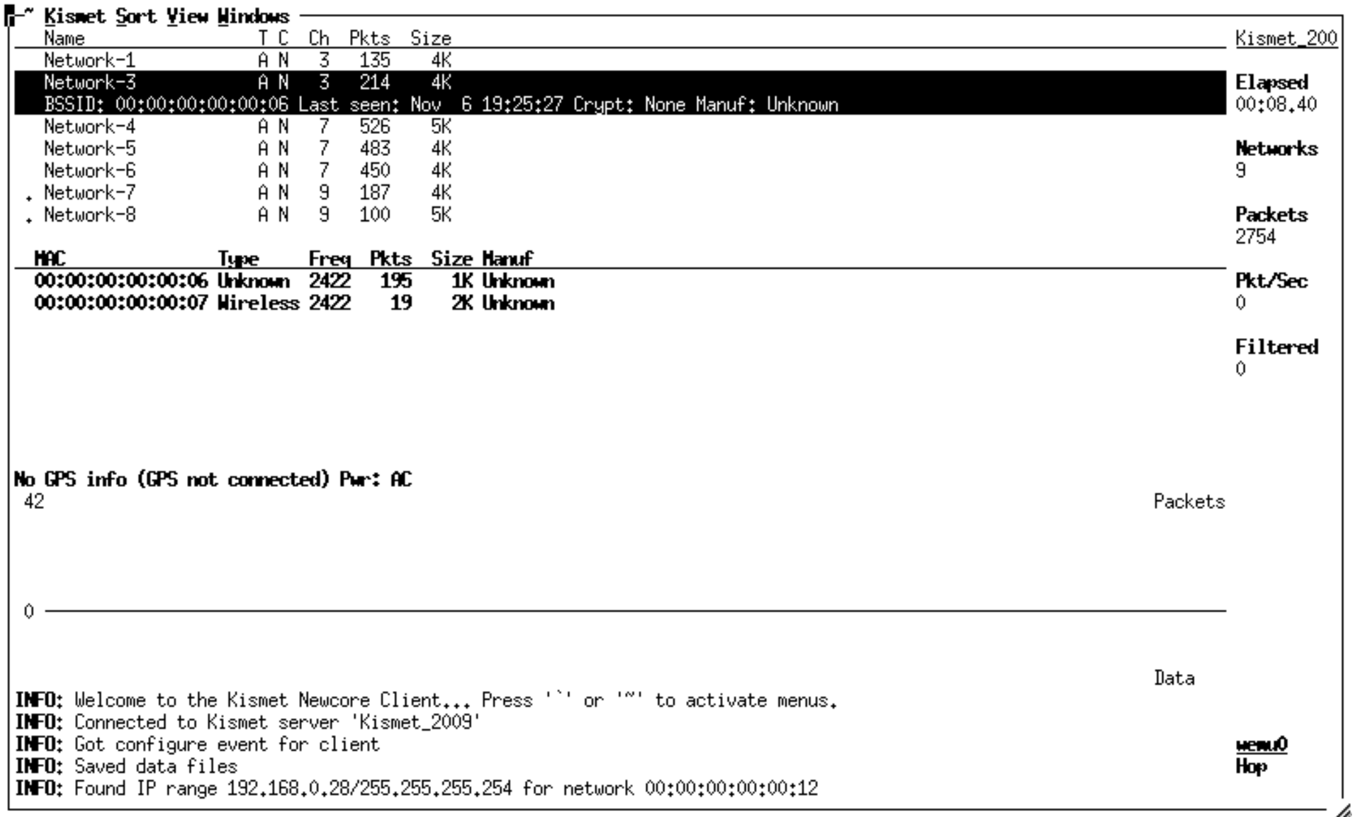


Legacy Applications



- **Wireshark for live monitoring of simulated WiFi networks**
  - Inspection of low-level 802.11 properties using Radiotap headers

Legacy Applications



- **Kismet being executed in simulated network**
  - Allows the execution of unmodified legacy applications that make use of Linux Wireless Extensions