Virtual WiFi: Bring Virtualization from Wired to Wireless

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This work was done in Intel Labs during Xia's internship

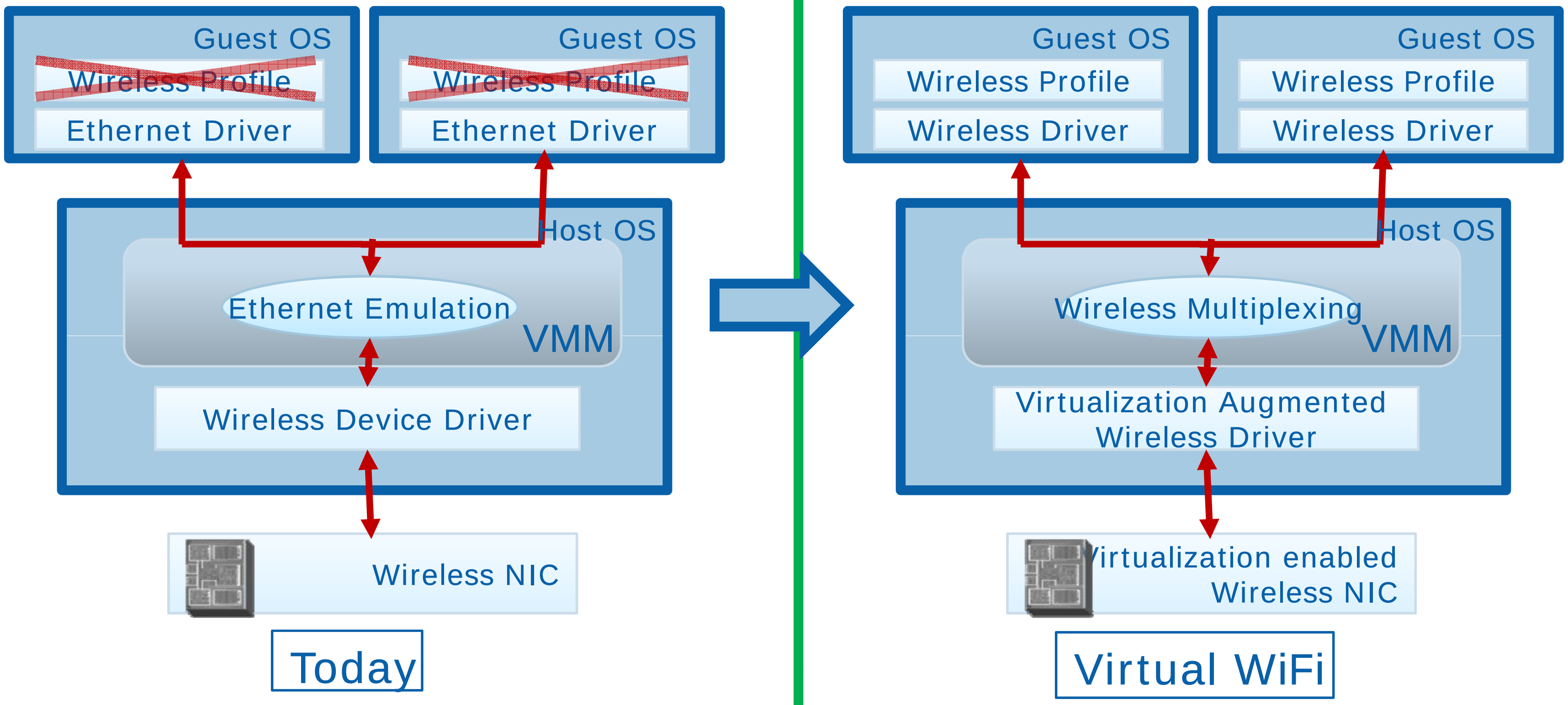
Virtual WiFi

- New virtualization approach suitable for wireless LAN virtualization
  - Full wireless LAN functionalities are supported inside VMs
  - Multiple separate wireless LAN connections are supported through one physical wireless LAN network interface

Wireless Virtualization

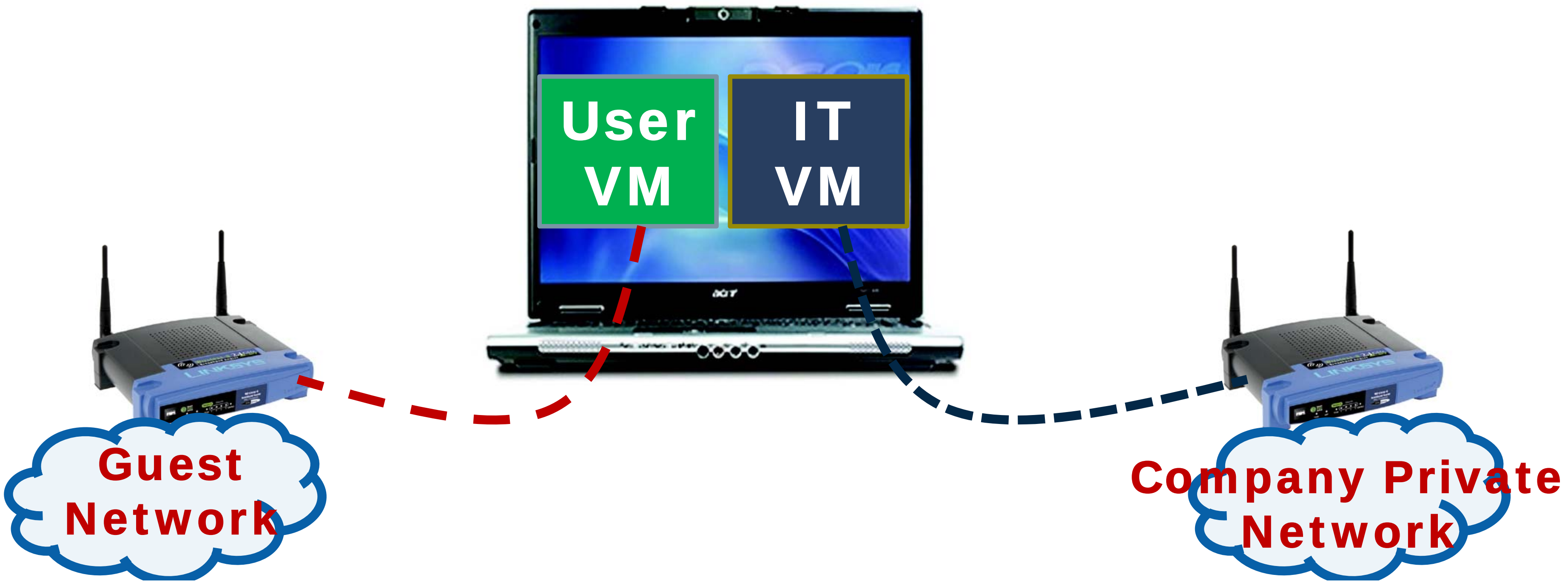
- Wireless driver stack sits in Host OS only
- VMs see only wired NIC
- Wireless functionality invisible to Guest

- Wireless driver stack runs inside the Guest as well
- Providing rich wireless functionalities to Guest



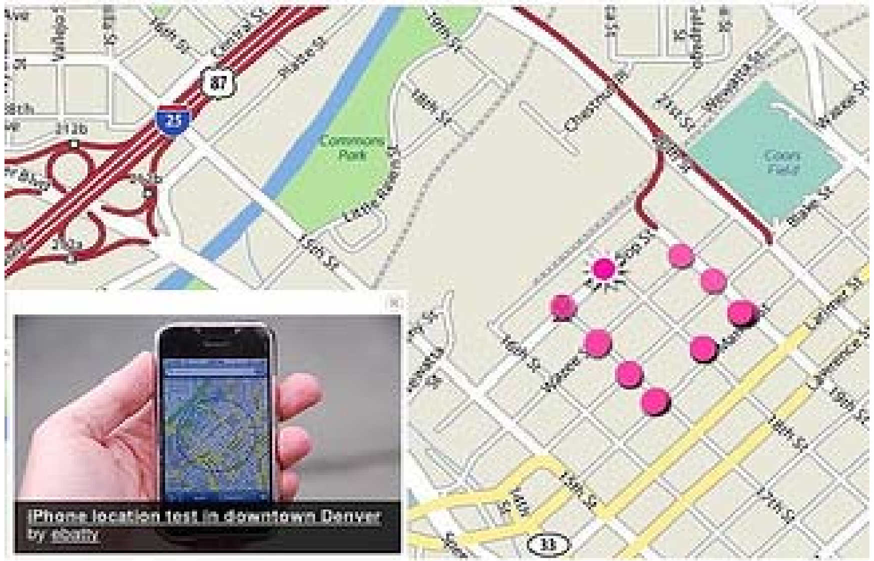
Why we need *virtual WiFi*?

- Client Virtualization
  - Enterprise IT: Separate enterprise & personal applications, data and configurations



Why we need *virtual WiFi*?

- Mobile and ultra-mobile devices
  - Separate work from play
  - User connect exclusively through wireless
  - Software tools depend on WiFi connectivity
    - **WiFi-based Location-Aware System**
      - Maps WiFi hotspots to determine location



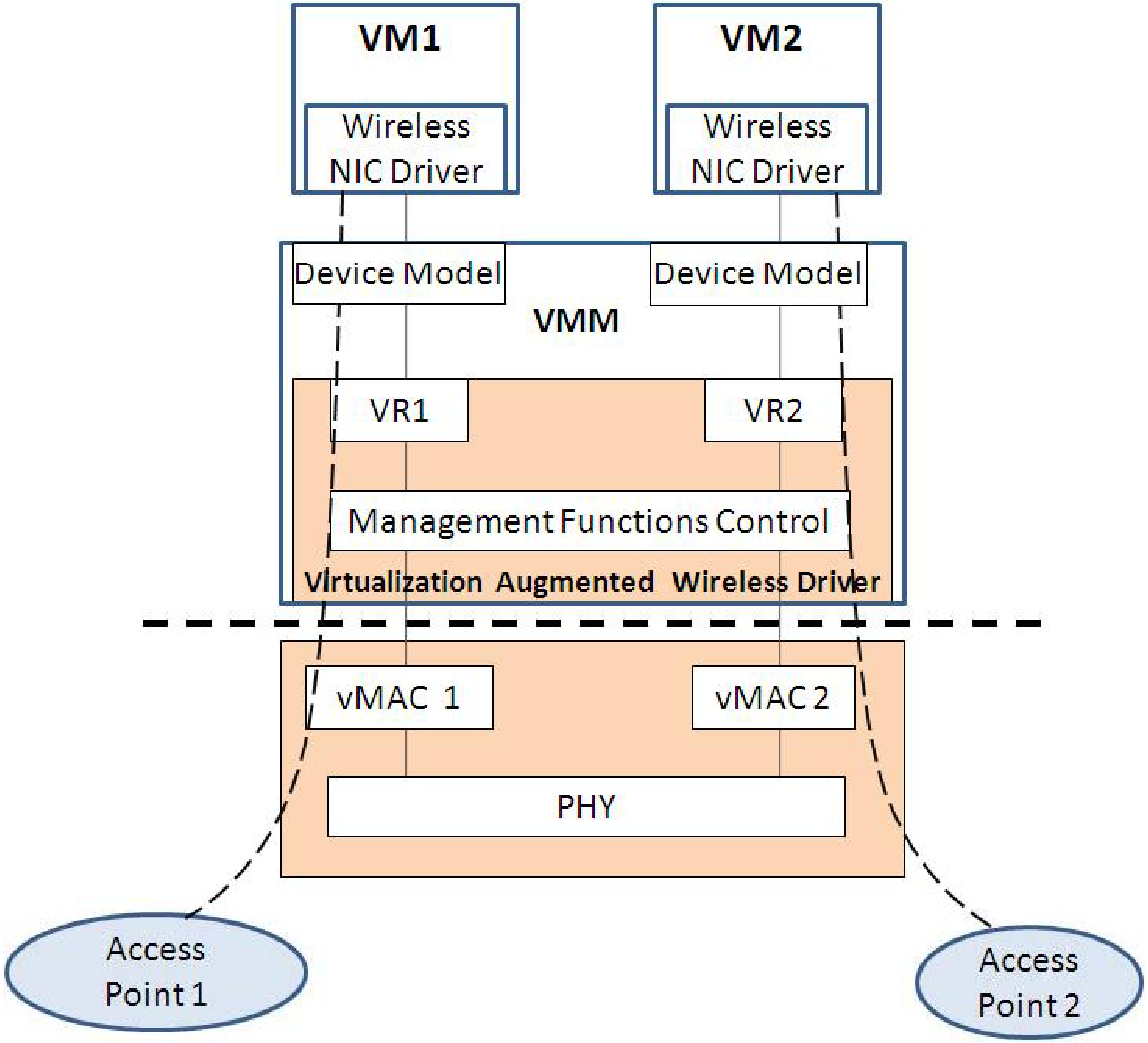
Wireless LAN Specific Features

- Complex management functions that affect the functionalities of WLAN devices.
  - Scan/Associate to specific access point
  - Rate adaption
    - Dynamic switching data rates to match the channel conditions
  - Power management
    - Device driver can control how long and how often the radio needs to be on to save battery
  - ……
- **Device driver has to be involved in many of those management decisions**

Required Hardware Support

- **Multiple virtual MACs in wireless NIC**
  - Available on most of commercial WiFi devices, For example, used in Intel MyWiFi technology
  - ***Virtual WiFi extends such technology***
    - To support wireless virtualization, multiple MAC entities maintain their independent associations with corresponding APs
    - Number of independent associations dependent on number of vMACs

Virtual WiFi: System Architecture



Virtual WiFi: Architecture

- VMs run native Intel WiFi device driver
  - Using WiFi features from device driver
  - Guest manage its own WiFi connections

Virtual WiFi: Architecture

- VMs run native Intel WiFi device driver
- Device Model exposes same virtual WiFi device to VM as physical device
  - Commands from guest can be pass to physical device without translation
  - Device model (VMM) knows few about device-specific knowledge
  - Wireless vendor minimally dependent of VMM vendor

Virtual WiFi: Architecture

- VMs run native Intel WiFi device driver
- Expose same virtual WiFi device to VM as physical device
- Virtualization *Augmented* host Wireless device driver
  - Management functions of virtualized wireless interfaces
  - Logically assigns vMAC to a VM
  - Processing commands from device model
    - Forwarding them directly or with consolidation or
    - Emulated some locally
  - Forwarding receive network packet to VMs
  - Mapping table between vMAC and VM
    - Configuration/connection status/state machine for each vMAC/VM pair

Virtual WiFi: Architecture

- Address Translation
  - Commands from guest: GPA->HPA
    - Avoids extra memory copy for TX packets
    - Either Software/Hardware IOMMU
    - Enable VT-d table to support multi-domain for single device
      - Collapse multiple page tables to single address translation table in VT-d

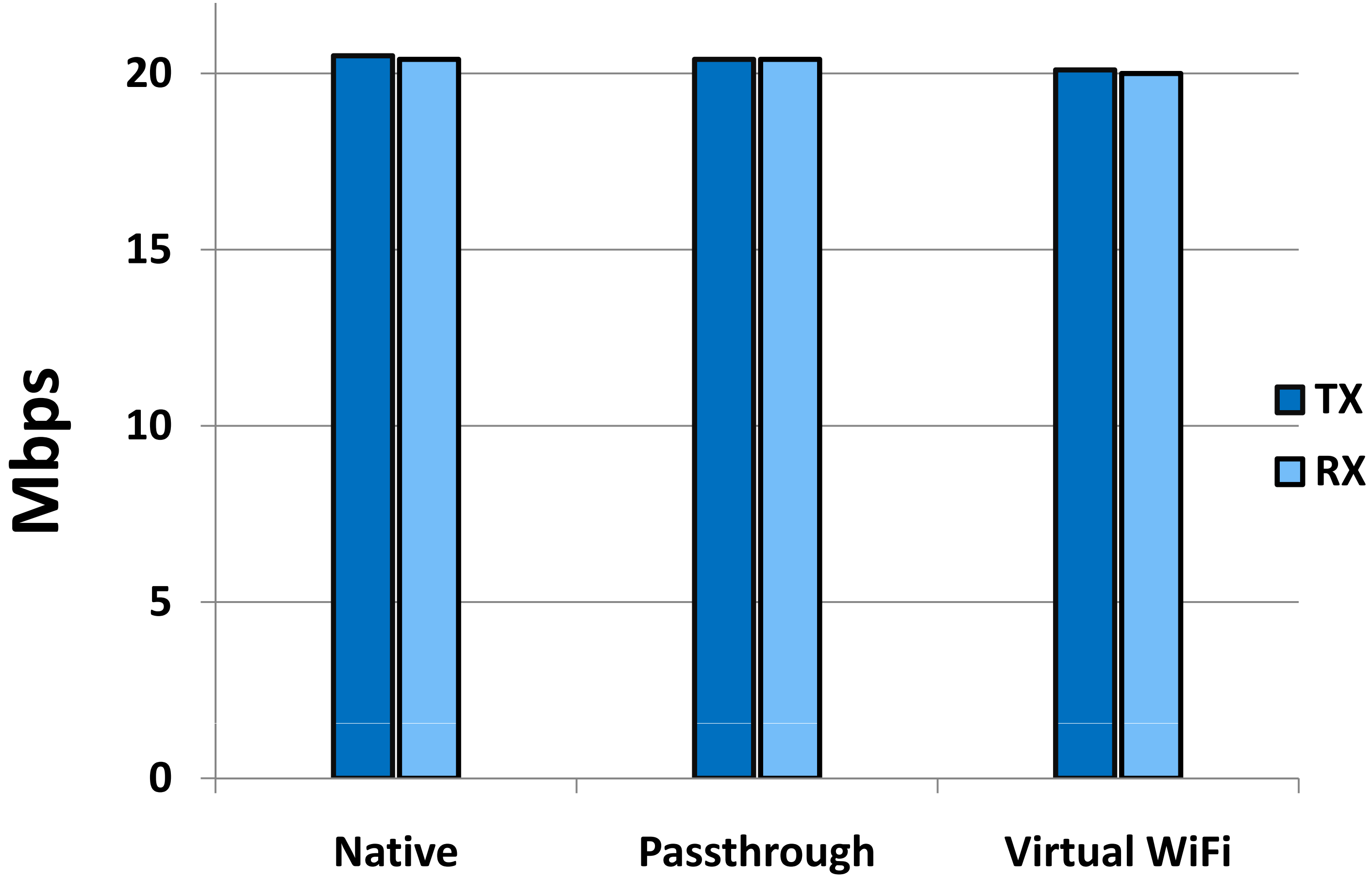
Augmented Host Device Driver Commands Handling

- TX command
  - Pass it directly to associated vMAC on WiFi NIC
- Rate Control Command
  - Only update the rate table associated with the specific VM-ID
- Device Initialization
  - Start a new vMAC, and starting state/information mapping to new vMAC
- Scan request
  - Consolidate properly of scan requests from different VMs
  - May return previous stored scan results to VMs
- And a lot more ......

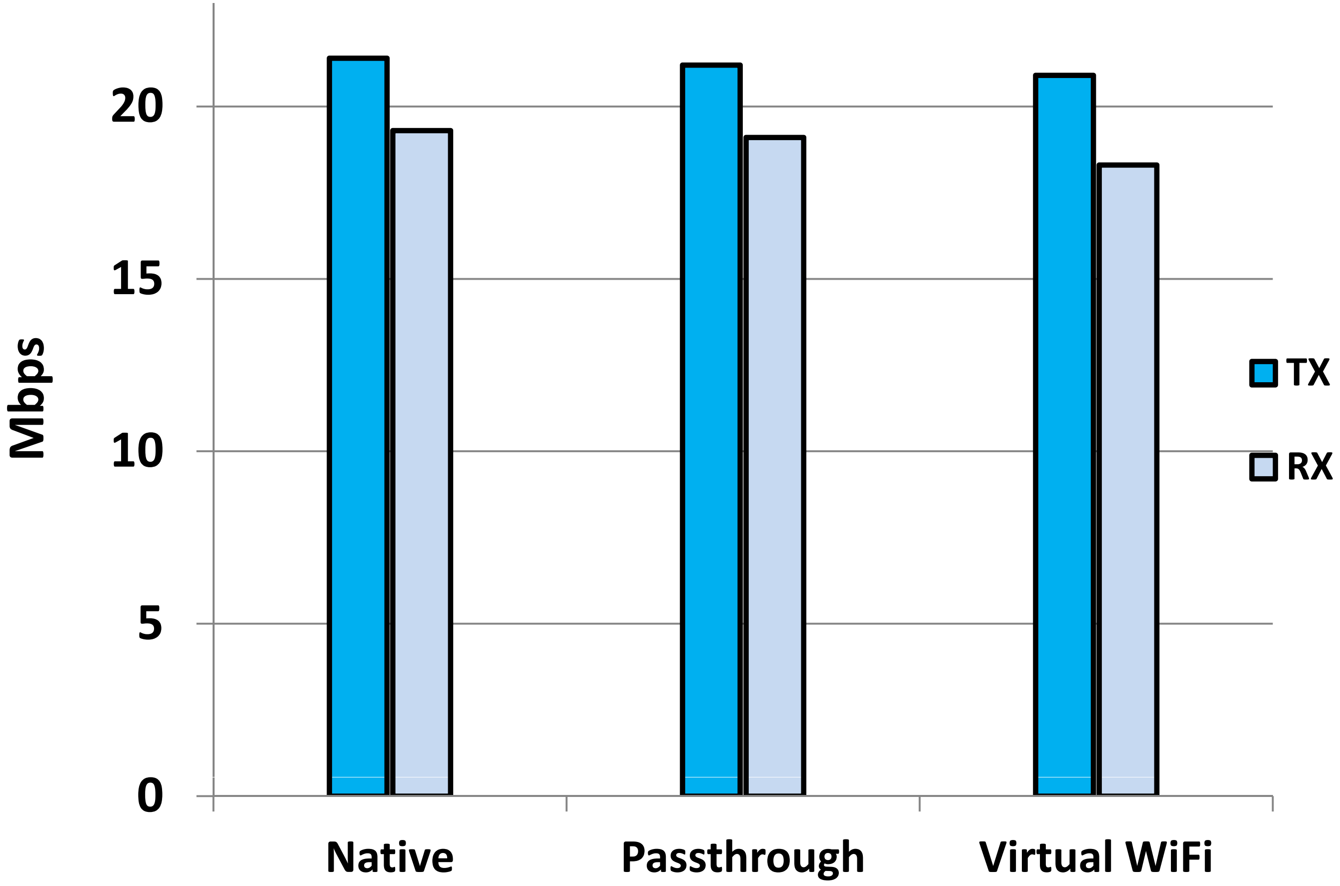
Performance

- **Benchmarks**
  - **Chariot** benchmark tool
  - *Metrics*: TCP & UDP throughputs,
  - Ping round-trip latency
- **Setup**
  - HP EliteBook 6930p Laptop with Intel Core2 Duo CPU 2.53GHz (one core used), 4GB RAM, 80GB HD
  - Intel WiFi 5300 AGN Card + Cisco WAP410N AP
  - KVM + Qemu + Linux 2.6.33.1
- **Comparing Groups**
  - *Virtual WiFi*: VM with virtual WiFi system
  - *Native*: Linux with Native WiFi driver
  - *Passthrough*: VM with direct assigned WiFi device

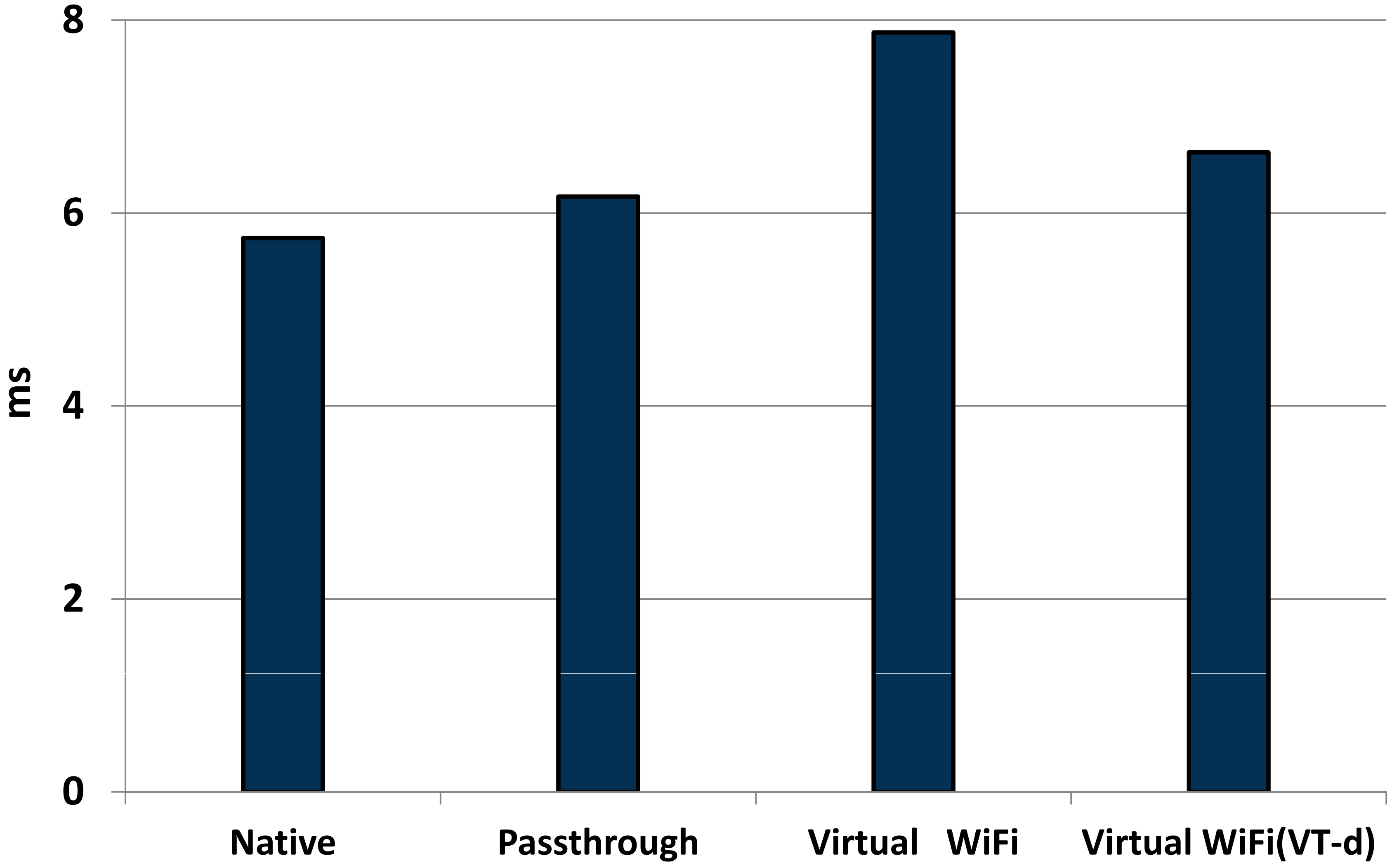
Performance – TCP Throughputs



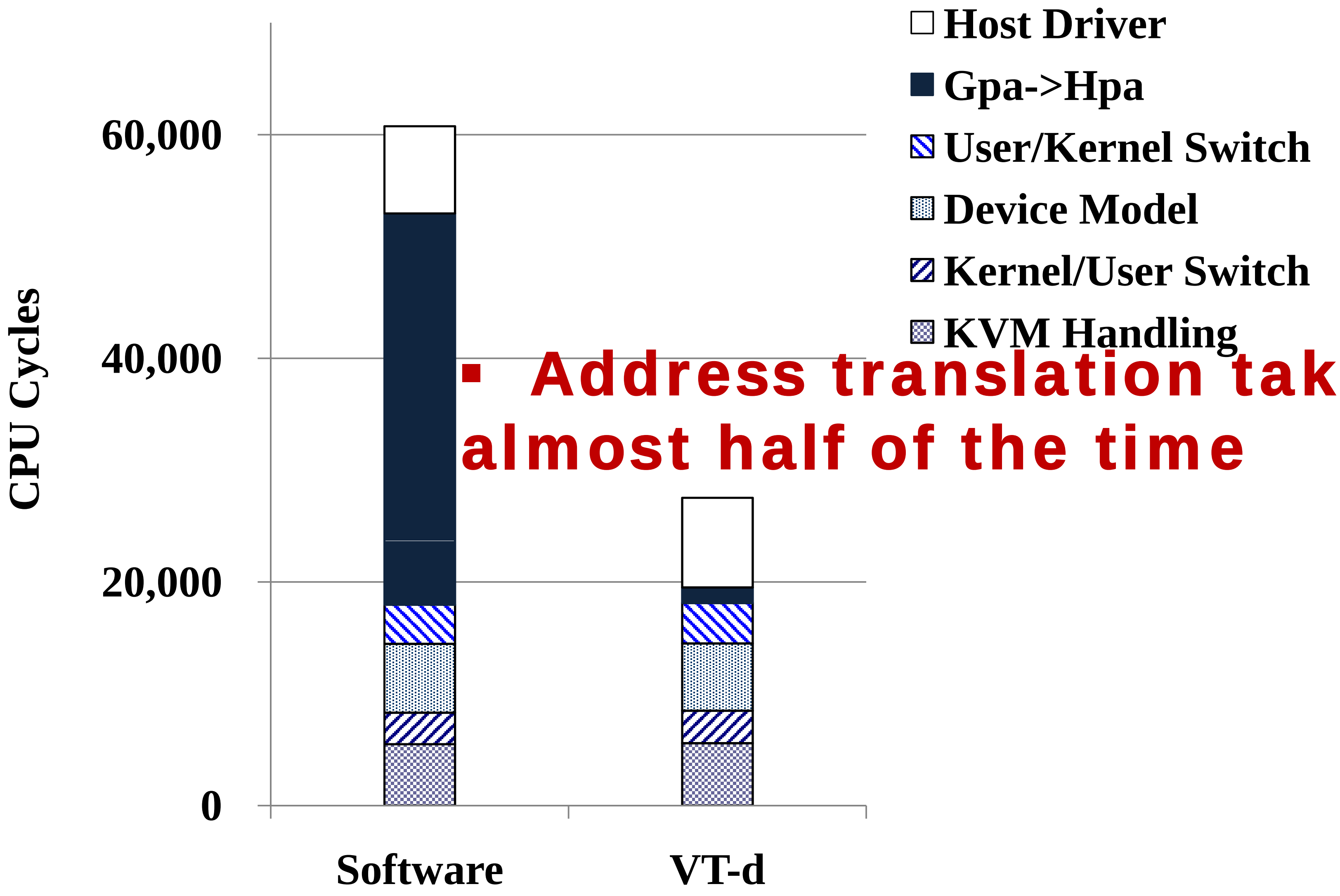
Performance - UDP Throughputs



Virtual WiFi: Performance - Latency



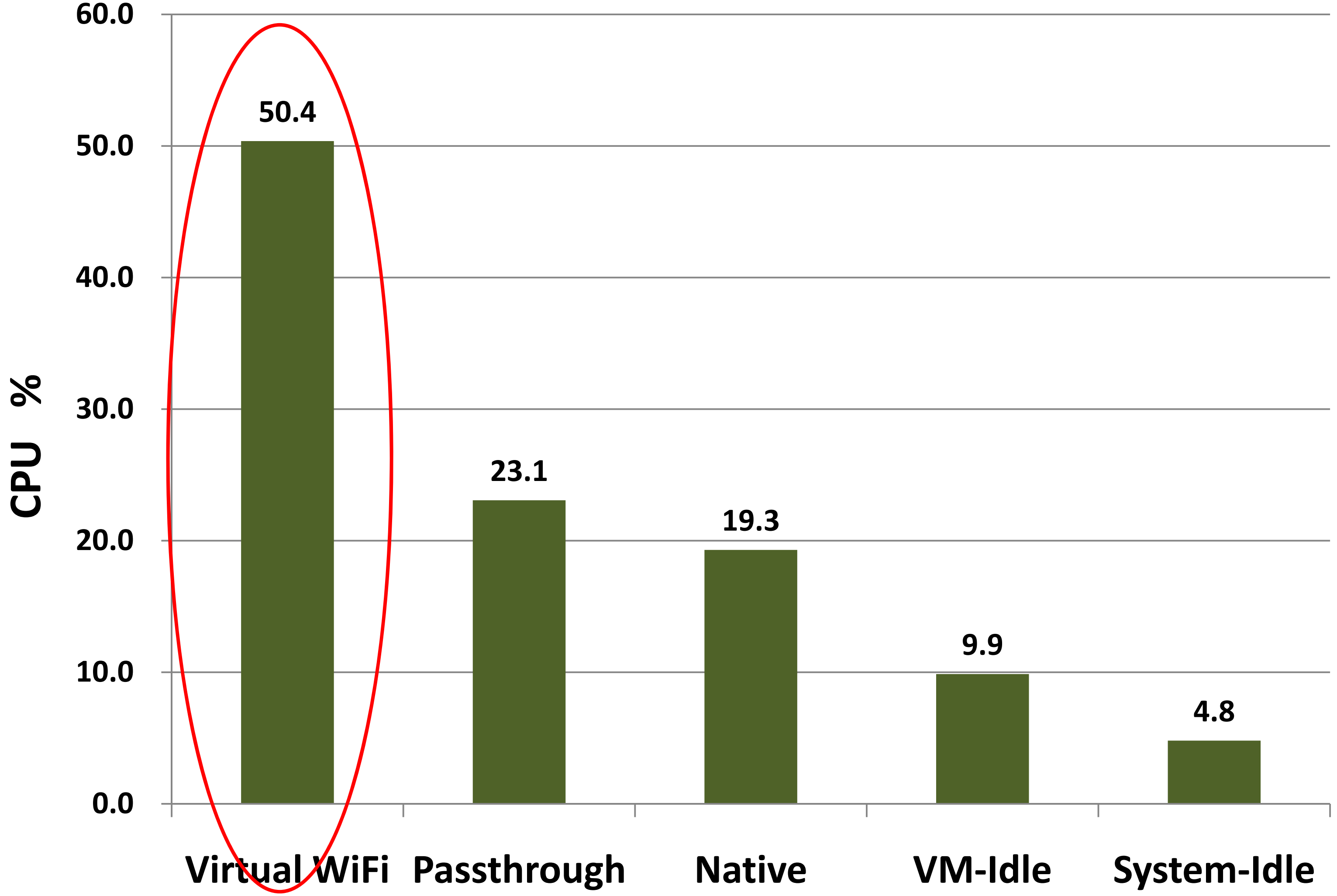
VM Additional Latency on TX-path



- Address translation takes almost half of the time

System Overall CPU Cost

(single core, 2.53GHz)



Major Virtualization Overheads

- **Address translation**
  - Solution: Hardware IOMMU
    - IOMMU hw do the address translation
    - Reduce the VM additional latency/CPU usage

Major Virtualization Overheads

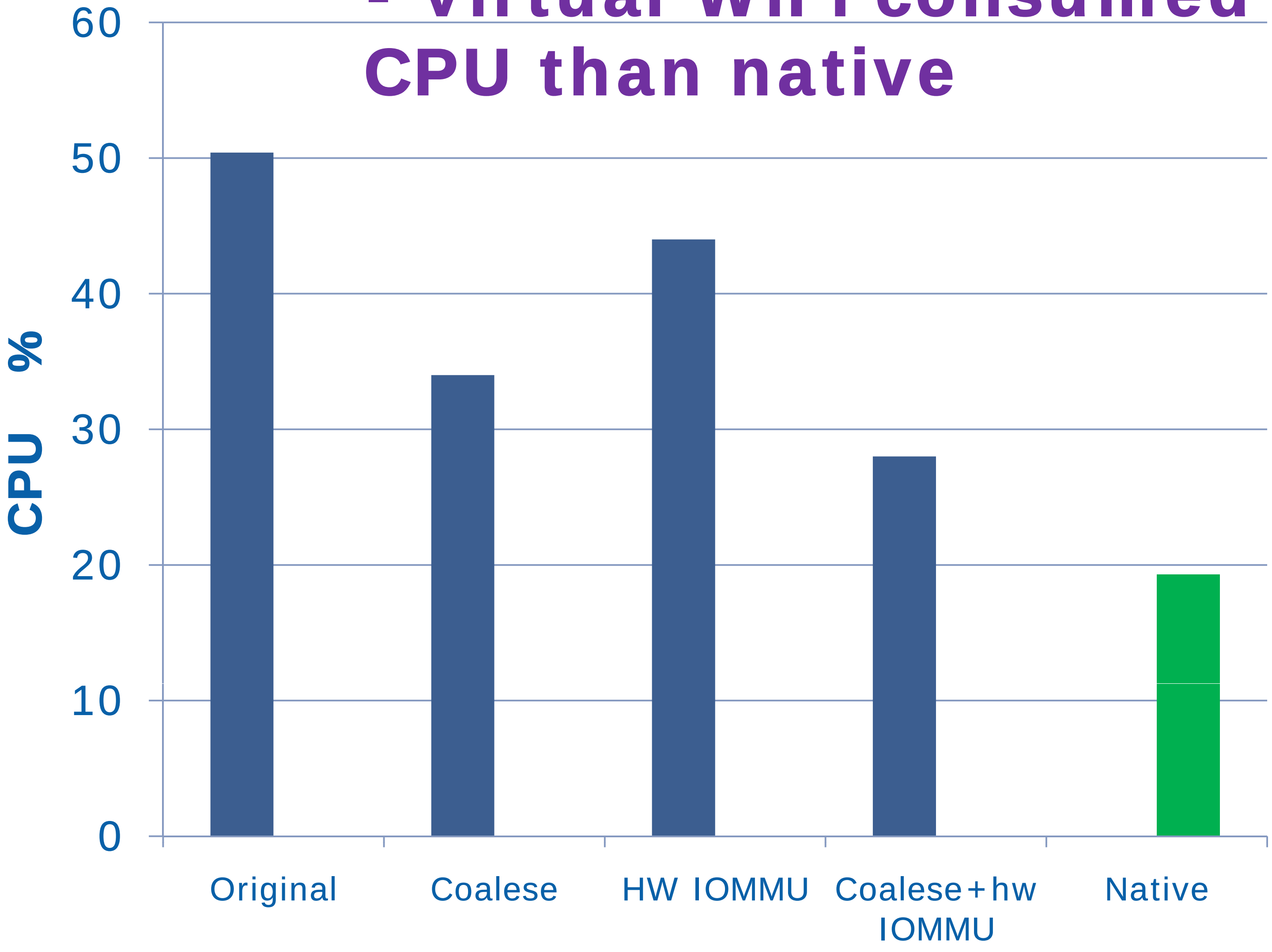
- **Address translation**
  - Solution: Hardware IOMMU
- **Interrupt Handling**
  - Coalesce interrupts disabled in host device driver
  - Each physical interrupt leads to more synchronization & signal VMs and kernel
  - Solution: Interrupt coalescing in device model

Major Virtualization Overheads

- **Address translation**
  - Solution: Hardware IOMMU
- **Interrupt Handling**
  - Solution: Interrupt coalescing in device model
- **I/O handling**
  - **MMIO handling**
    - Context switches, Threads synchronization overhead for each TX/RX packet
  - Solution: Fast data pass-through (***Future Work***)
    - Data traffic passthrough into physical device through separate queue

CPU Usage with Optimizations

- Virtual WiFi consumed 9% more CPU than native



Related Work

- **MultiNet (Microsoft vWiFi)**
    - A software layer that abstracts the wireless LAN card hardware into multiple virtual adapters
    - Continuously switch the wireless card across multiple wireless networks

- **Virtual Pass-through IO (VPIO)**
    - A modeling-based approach to high performance I/O virtualization
    - Device is directly assigned to guest
    - Most of IOs from a guest are directly applied on physical device, no VMM inventions.
    - VMM uses a behavior model to determine when IO has to be intercepted for security and device switching

Summary

- **Virtual WiFi: new virtualization approach for wireless LAN device**
  - Support fully wireless functionalities inside VMs
  - Separate wireless connections among VMs through one physical wireless interface
- **Prototype system using virtual WiFi**
  - Native throughputs with 7% extra latency
  - Less than 9% more CPU cost

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http://v3vee.org

Backup Slides

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Current Wireless virtualization

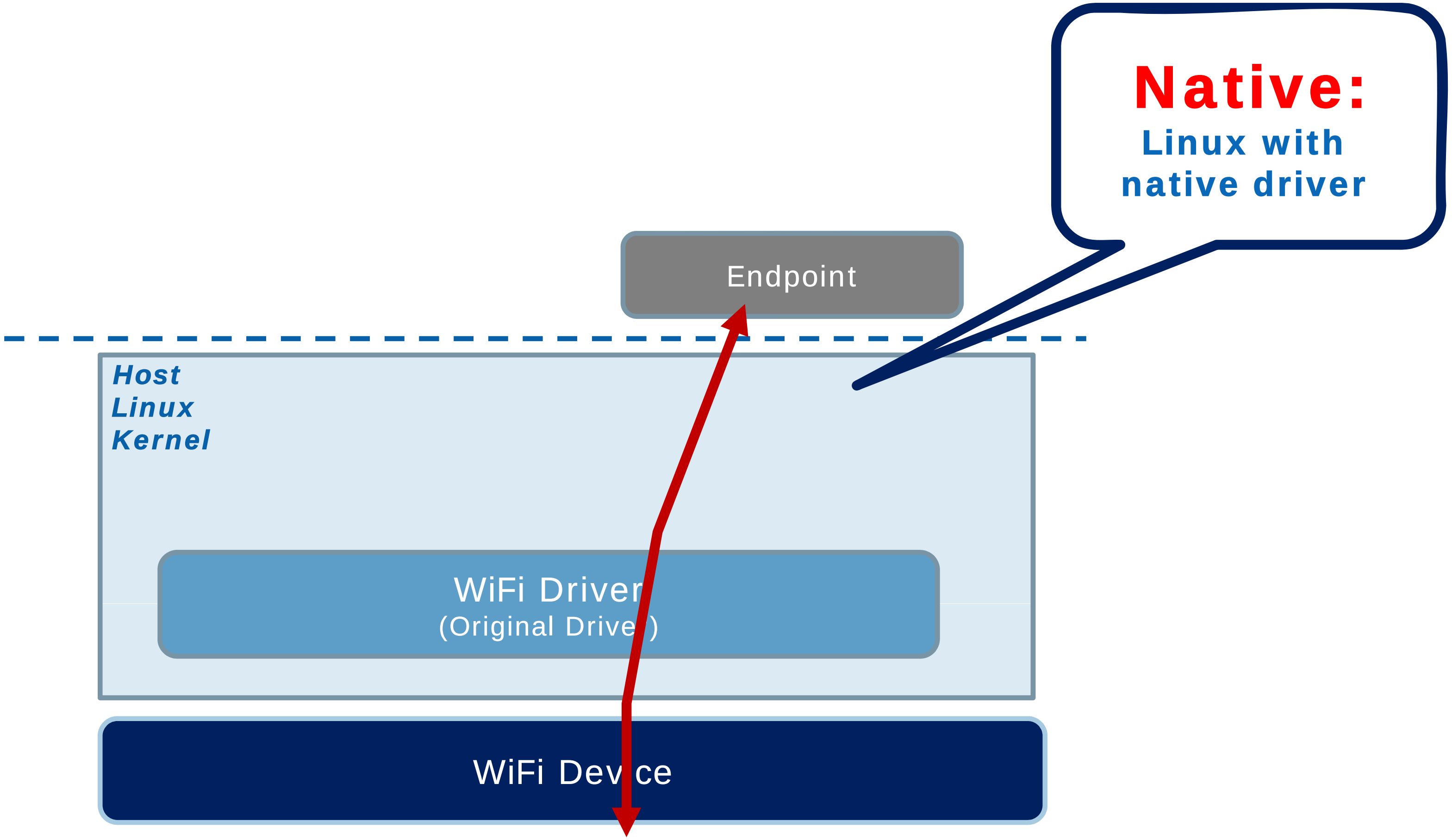
- Map network connections to virtual wired Ethernet device
    - Works well for data transfer
    - But downsides for wireless connection
        - Feature of network infrastructure can not be controlled from inside VM
        - Wireless NIC has to be configured and managed by VMM

System profiling setup

- Profiling Components for virtual WiFi system
  - Kernel: App-specific, kernel-general
  - Kernel modules: KVM, driver
  - Application-level: Endpoint, Qemu, Guest

- Presented test results based on KVM/QEMU; similar evaluations need to be performed for other VMM software, such as Xen.

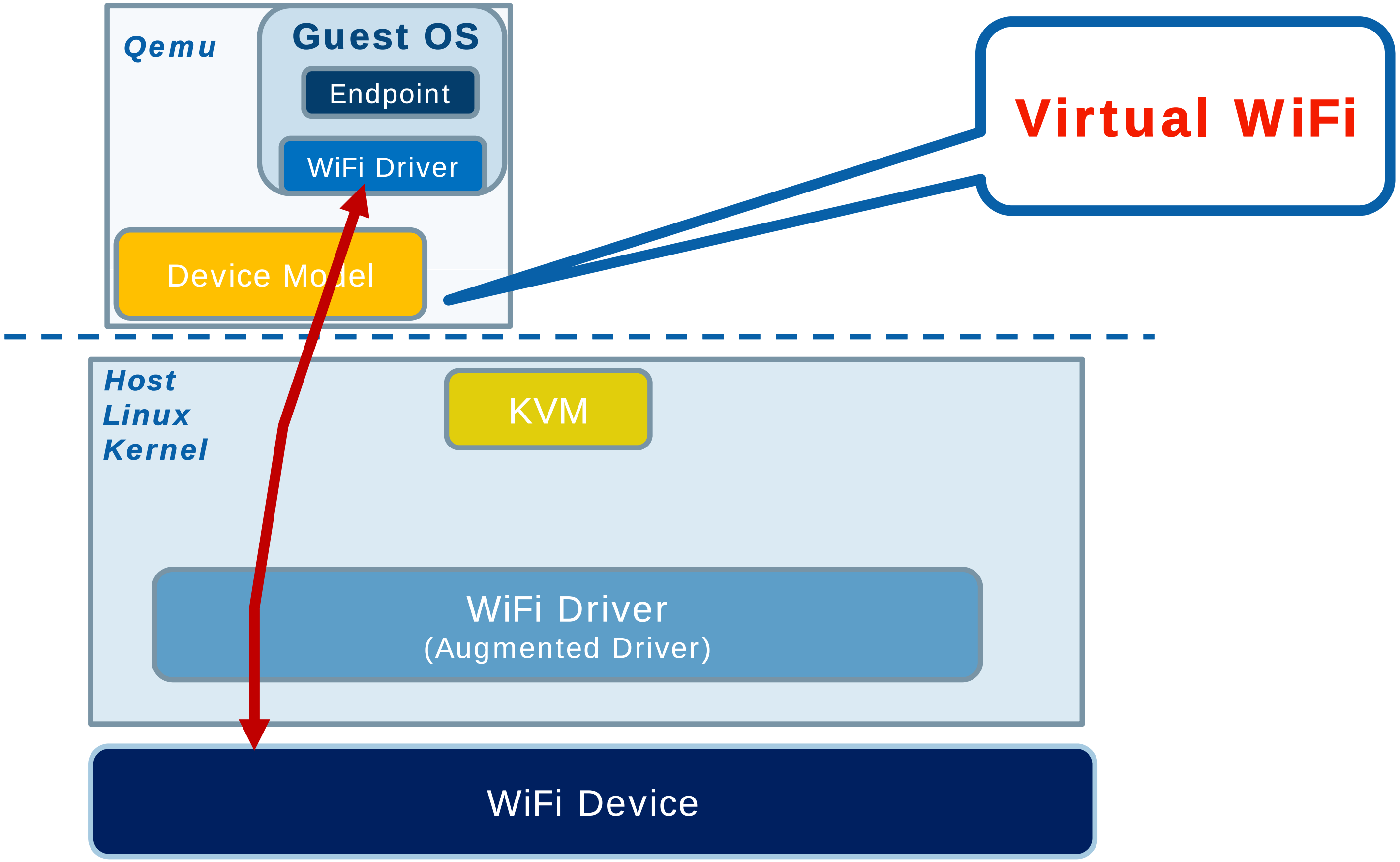
Comparing Groups



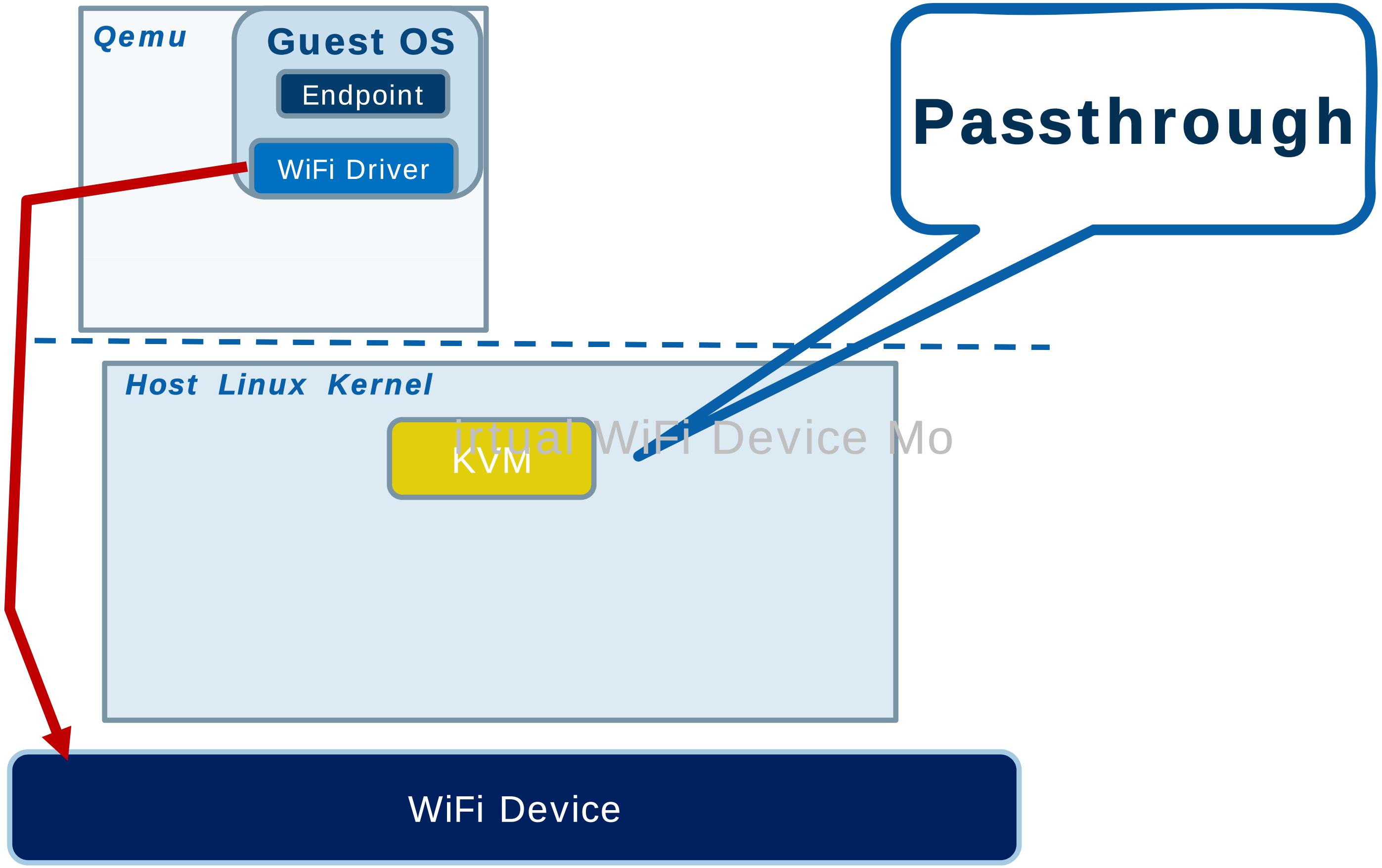
Native:

Linux with native driver

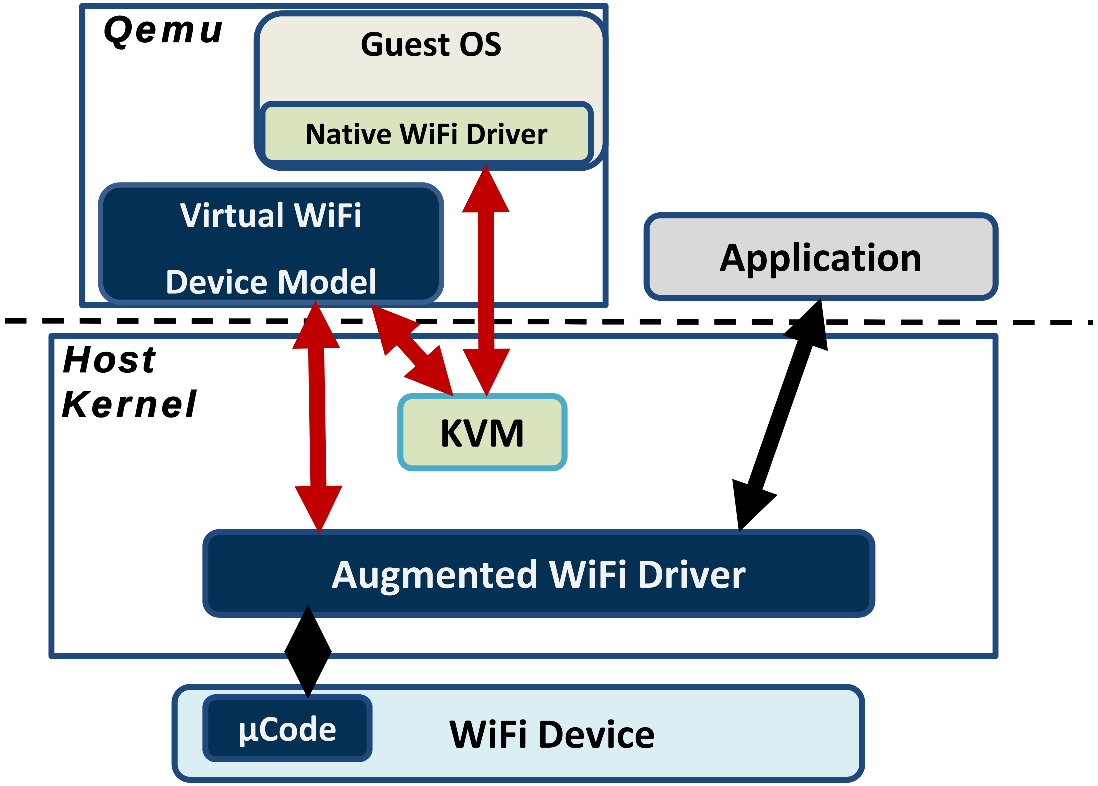
Comparing Groups



Comparing Groups



Virtual WiFi: Implementation



- Type II hosted VMM
- Can be easily ported to Type I bare metal VMM

Implementation

- Virtual WiFi Device Model
  - Expose only PCI config and MMIO mapping
  - Tag command with VM-ID, Injecting virtual interrupt to VMs.

Implementation

- Virtual WiFi Device Model
- Augmented WiFi Device driver
  - Forwarding commands directly to physical WiFi device, or Emulated some locally
  - Receive network packet from WiFi interface, Identify destination VM, signal device model

Implementation

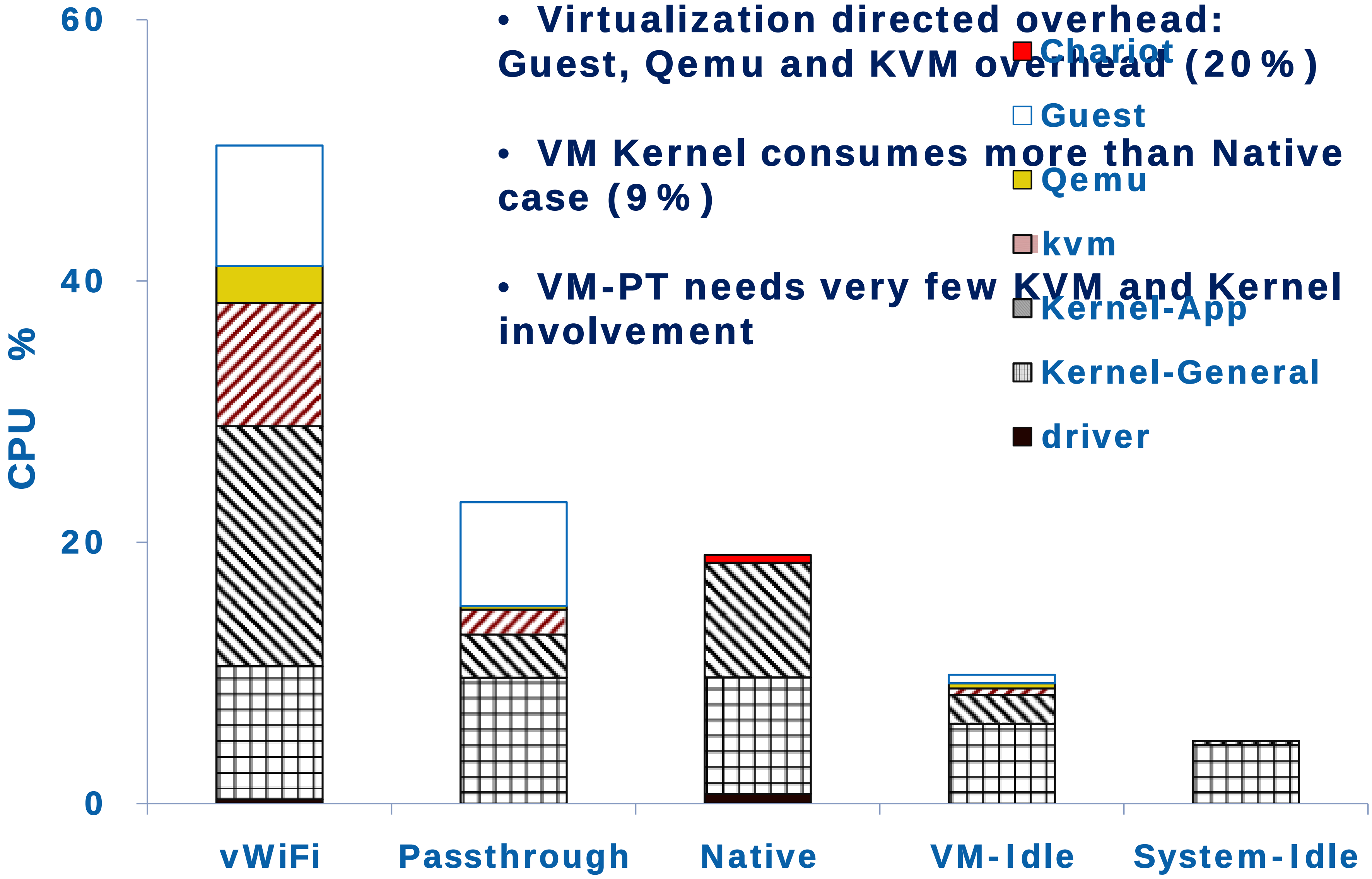
- Vdel
- Augmented WiFi Device driver
- Augmented NIC
  - Only uCode update needed
  - Virtualization extension added to uCode

The CPU Usage Matters!

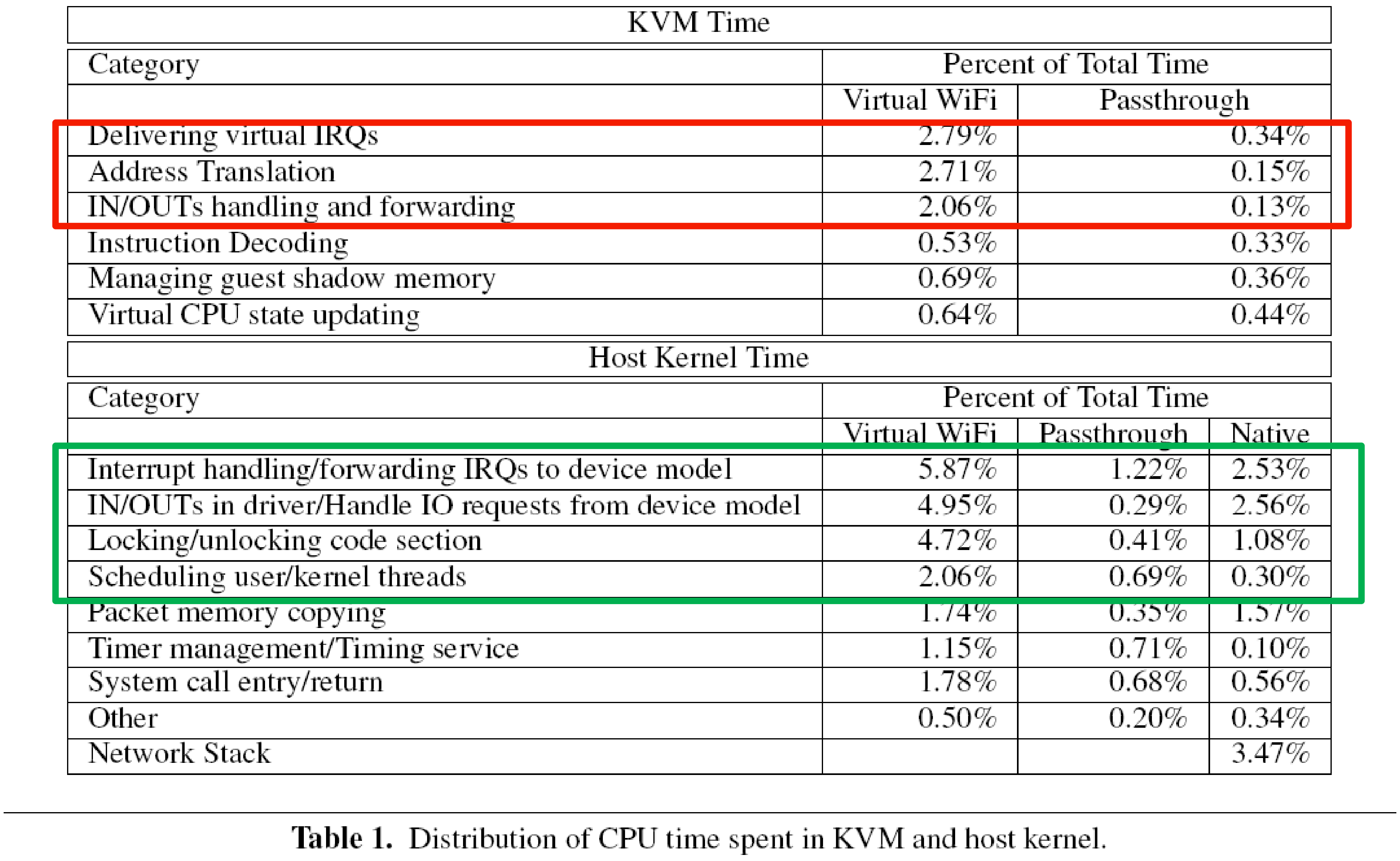
- **Scalability**
  - From 802.11g (50Mbps) to 802.11n (up to 500Mbps)
  - CPU usage grows with throughput
- **Mobile platform**
  - Limited processor resources
- **User experience**

CPU Usage breakdown (Chariot TX)

- Virtualization directed overhead: Guest, Qemu and KVM overhead (20%)
- VM Kernel consumes more than Native case (9%)
- VM-PT needs very few KVM and Kernel involvement



CPU Usage breakdown:
KVM and Host Kernel (by Oprofile)



KVM Time

Category	Percent of Total Time	
	Virtual WiFi	Passthrough
Delivering virtual IRQs	2.79%	0.34%
Address Translation	2.71%	0.15%
IN/OUTs handling and forwarding	2.06%	0.13%
Instruction Decoding	0.53%	0.33%
Managing guest shadow memory	0.69%	0.36%
Virtual CPU state updating	0.64%	0.44%

Host Kernel Time

Category	Percent of Total Time		
	Virtual WiFi	Passthrough	Native
Interrupt handling/forwarding IRQs to device model	5.87%	1.22%	2.53%
IN/OUTs in driver/Handle IO requests from device model	4.95%	0.29%	2.56%
Locking/unlocking code section	4.72%	0.41%	1.08%
Scheduling user/kernel threads	2.06%	0.69%	0.30%
Packet memory copying	1.74%	0.35%	1.57%
Timer management/Timing service	1.15%	0.71%	0.10%
System call entry/return	1.78%	0.68%	0.56%
Other	0.50%	0.20%	0.34%
Network Stack			3.47%

Table 1. Distribution of CPU time spent in KVM and host kernel.

Future Works

- **Data Pass-through**
  - Data traffic passthrough into physical device through separate queue
  - Control/management commands go through device model/augmented driver
- **Apply on next generation WiFi standards**
  - WiFi 802.11n
  - Expected throughput: ~500Mbps

Related Work

- **Full-virtualization** by emulating
  - Large performance overhead, Many development efforts, Lack of device datasheets
- **Para-virtualization**
  - Need guest modification/new para-virtualized device driver
  - WLAN device specific features are closed to VMM vendor for back-end driver
- **SR-IOV**: hardware support virtualization
  - Costly/complexity/Time line