

Project Maux Mk.II

"I Own the NIC, now I want a shell!"

Arrigo Triulzi
arrigo@sevenseas.org

“I have a Cunning Plan”

- Background concepts
- Last year's work (NIC takeover)
- Evolving Project Maux: Project Maux Mk.II
- Identification and defence
- Future work

How to read these slides

- This is **not** a funded project but personal curiosity-driven what-if research,
- Conceptually similar to the “nth Country Experiment” at LLNL in the 1960s: given open literature how quickly can two Physics PhD candidates develop a working nuke?
- Given no prior knowledge, “the Internet”, a cheap 10-pack of NICs and a PC can we develop the ultimate rootkit?

Background concepts

- NICs are becoming more intelligent:
 - firmware is becoming more sophisticated,
 - bugs creep into firmware leading to updates,
 - updates on a deployed card are desirable (especially WiFi...).
- So there must be a firmware loader..

Background concepts

- Video cards are becoming smarter:
 - gamers want a “better experience” therefore accelerated graphics,
 - the GPUs are becoming sophisticated,
 - there is plenty of RAM to play with,
 - a vendor ships a development toolkit..

Project Maux Mk. I (2006–2007)

- A particular PCI NIC (Broadcom “Tigon”-based):
 - MIPS CPU, very little on-board RAM,
 - SDK available on web,
 - Modified Linux drivers courtesy of CERN,
 - Cheap 10-pack available.

Project Maux Mk. I (2006–2007)

- SDK lead to development of “alternative” firmware (aka “Project Maux”):
 - hook to IP checksum routines,
 - add “sniffer” which copies packets into scratch RAM (circular buffer design).
- Only approximately 5s–30s sniffing on loaded NIC then circular buffer fills up.

Project Maux Mk. I (2006–2007)

- Major issues with project Maux:
 - lots of NICs blown in the process,
 - the circular buffer is ridiculously small,
 - loader requires Ring 0,
 - sniffing alone is not very useful.

So what?

- A bit like a ^{235}U device: easy to build but required lots of hardware,
- an excellent proof-of-concept strongly suggesting that the firmware avenue was worthwhile,
- it is an “obvious” entry point into the firmware hacking scenario,
- not that many players cover most hardware (Broadcom, RTL, Intel, Via, etc.).

Defences

- Security through obscurity? Forget it, Google will (eventually) find it,
- Assume your firmware SDK is in hostile hands,
- Think about drivers sanity-checking hardware (need Secure Computing to really work)...
- ...but don't assume PKI will save you...

Evolving Project Maux

- We cannot fix anything at all on the NIC!
 - Blowing NICs is an inevitable consequence of not having documentation,
 - We can't increase the RAM on the MIPS embedded controller,
 - The loader only runs in Ring 0,
 - No RAM means no extra functionality.

Evolving Project Maux

- Look elsewhere given the following constraints:
 - No OS support required,
 - Almost invisible to the CPU,
 - “Remote shell” capability,
 - Must be stealthy!
- This is where we go for the ^{239}Pu design.

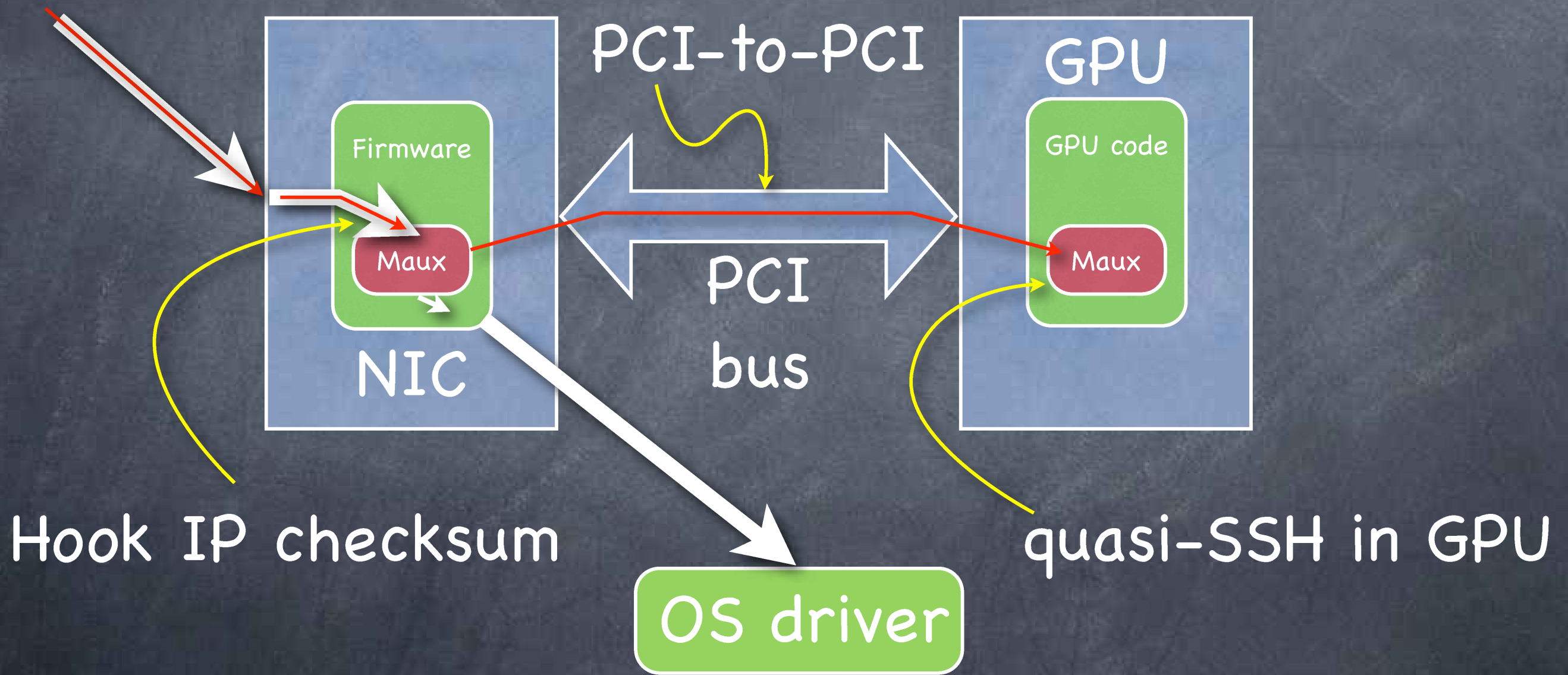
Project Maux Mk.II

- The solution is to look at another PCI board!
- nVidia GPU development kit:
 - not the "OpenGL/Direct X" stuff...
 - but the "GPU computing" kit (aka "CUDA")!
- This gives us access to a CPU with substantial amounts of RAM (128Mb at least)...

Project Maux Mk.II

- Overall design outline:
 - quasi-SSH communications with quasi-SSH daemon running in GPU,
 - NIC filters out “relevant” packets, forwards them to GPU via PCI-to-PCI transfer,
 - quasi-SSH interprets them.

Project Maux Mk.II



Project Maux Mk.II

- NIC firmware modification:
 - same technique as old “sniffer”: hook IP checksum (every IP packet triggers it),
 - grab packet, **check magic**,
 - pass “magic packet” to GPU via PCI-to-PCI transfer

Project Maux Mk.II

- check magic:

- if the IP ID is 0xbeef and

- the IP timestamp option has a flag value of 0x3, IP address of 0x50b1463d and a timestamp of 0x06026860.

- this causes the firmware to forward the packet off to the GPU.

Project Maux Mk.II

- GPU gets magic packet:
 - 1st packet seen from this IP? Then send back a “suitable” response to say we are a “Mauxed” system with details of OS and capabilities,
 - otherwise interpret as part of a session.

Project Moux Mk.II

- Introducing nicssh 1.0 (a quasi-SSH daemon):
 - no DH key exchange, in fact **no authentication!**
 - Blowfish with static 128-bit key (static as in "static in the GPU code being injected"),
 - basic command shell with readline and limited number of commands.

nicssh 1.0

- nicssh handshake:
 - ICMP Echo Request with "magic",
 - respond with **correct** ICMP Echo Reply, but with "magic" in the header,
 - nicssh waits for 1st session packet.
- **Note:** the OS is totally oblivious to the above and **never** sees the ICMP packets.

nicssh 1.0

- nicssh capabilities:
 - memory inspection (GPU RAM and system RAM),
 - sniffer on NIC sending data to VRAM,
 - sending of data via the network,
 - cleanup (**extremely** flaky),
 - readline (tab completion and history).

nicssh 1.0

- “Stealth” capabilities:
 - if **negotiated** then use special port for traffic, otherwise default is 80,
 - when using “web ports” (pre-defined to 80, 8080, 3128) then use rwwwshell GET method.
- More planned (Nushu, sniffing backdoor..).

nicssh 1.0

first "magic packet"

"magic packet" back

```
archimede:~/nicssh$ nicssh 10.4.4.233
Connecting to 10.4.4.233
ICMP Echo Reply from OS - no nicfw
archimede:~/nicssh$ nicssh 10.4.4.234
Connecting to 10.4.4.234
ICMP Echo Reply from nicfw (Windows system)
Requesting tcp/80 with cloaking
nicssh> ?
help memory* sniff* send* reboot cleanup quit
nicssh>
```

"stealth" mode

"shell" with basic help

Installation...

- Good question with no good answer at the time (March 2008). Some ideas:
 - fake driver update with phishing website to entice downloaders (think “enhanced driver for gamers”),
 - virus with injection payload,
 - infected Linux distribution.

Installation...

- Now for something more esoteric:
 - Broadcom firmware has traces of “remote update” functionality...
 - Drive-by injection via WiFi, WiFi driver exploit, PCI-to-PCI into the NIC?
- The second of the two would be lethal for laptops.

Uninstall?

- What if you wish to remove all traces of modification?
- Sorry, no (smart) answer at the moment (March 2008) for the NIC.
- GPU? Just reboot (cold boot perhaps).
- Should drivers always inject fresh firmware?

Is it worth it?

- Short answer: definitely **not** in 2008.
- In the longer term this is an ideal A-V evasion technique for bots:
 - install bot, zap firmware, disappear. New A-V signatures? Too late. OS reinstall? Irrelevant.
 - bot functionality **in VRAM and on GPU!** OS is pristine and irrelevant.

Is it worth it?

- What about virtualisation?
 - VM escape: working on something named the “Jedi packet trick”...
 - Smaller number of server NICs make it an attractive “market” from an ROI perspective,
 - Hypervisor is “Just Another OS”,
 - “A Hypervisor” allegedly runs “Not Linux”...

Is it worth it?

- What about firewalls?
 - 90+% of world's firewalls run on the PC architecture and therefore...
 - extension of "Jedi packet trick" to NIC-to-NIC transfers!
- This could also extend to IDS/IPS systems... one parser vulnerability, NIC takeover, game over!

Is it worth it?

- Get nastier: what about the highly integrated support chips on the motherboard?
 - MITM of PCI-to-PCI transfers,
 - crypto accelerators need data and key to be sent to them to “accelerate”...
 - grab data being written to SATA...
- Why? ROI for theft looks promising: keylogger++

Is it worth it?

- Two scenarios:
 - Government: exercise for the reader.
 - Criminal organisations:
 - Targeted attacks “for rent”,
 - “Transparent” bots,
 - Pre-loaded bots: how difficult is it to attack Dell’s pre-loaded **image loader**?

But we use PKI!

- PKI structure (assumed):
 - signed firmware with a public key embedded in “secure” area of the chip,
 - offer semi-custom parts to OEMs,
 - OEMs roll-out their own modified firmware,
 - so you have multiple public keys on chip.
- One question: how do you push a CRL?

PKI, an interesting note

- In the previous PKI scenario the problem is obviously pushing a CRL off to end-users.
- The scenario was thought up **independently** and then was discovered to match the concerns of a manufacturer...
- Think back to the Nth Country Experiment...
I might not be the only one thinking about it.

Identification

- On the network?
 - Currently as good as your detection of rwwwshell,
 - Can be improved due to “magic” needed for NIC firmware to redirect to GPU.
- On the system?
 - Anyone counting PCI-to-PCI transfers?

Defence

- The marketing defence: JIT manufacturing means different cards in different PCs **and** “same model different chipset” making targeting extremely difficult,
- Firmware verification during update (c.f. Intel’s microcode update vs. AMD microcode update),
- Trusted computing if extended to cover firmware verification (see John Heasman).

Defence

- Learn from OS/VM (now zVM) providing fine virtualisation services since 1968:
 - true hardware-aided virtualisation,
 - protection rings at the hypervisor level,
 - See IBM's research (Karger paper on alpha PALcode and virtualisation).
- "A virtualisation so good you can virtualise it"

Defence

- The Secure Computing Initiative:
 - currently does not appear to cover firmware! Obviously needs extending...
 - the PCI bus could well become the “new Internet” for malicious communications,
 - check all firmware, not just the obvious.
- Interesting question: how do you boot safely?

Project Maux Mk.II

unsolved issues

- Elegant installation process:
 - Currently **by hand** (!!), no automation...
- NIC long-term stability testing:
 - Never ran for more than a week.
- GPU code persistence:
 - Reboot kills us at the moment.

Project cost

- "Another year of Sundays":
 - approximately 100 man/hrs,
 - Project Maux was approx. 150 man/hrs,
 - \$0 hardware costs (Project Maux: \$100),
 - MVT: Google.

Future work

- GPU code persistence by using John Heasman's ACPI/BIOS work?
- GPU code persistence using hidden sectors on disk loaded at boot via NIC firmware BIOS initialisation routine?
- More sophisticated nicssh functionality (with authentication?)

Jedi packet trick™ spoiler

- Drivers (sometimes) assume hardware is badly designed, perhaps badly behaved, but **not** malicious...
- NIC takeover followed by driver takeover...
- Driver takeover means Ring 0...
- Ring 0 means kernel...
- Who says that there has to be a single TCP/IP stack in the kernel? "There is no packet here, you will let it through" 😊
- **You heard it here first™**

Thanks

- My family $\forall$ their ∞ patience while I play with my toys,
- Toby for keeping the hard questions coming,
- Maya for project naming,
- $C_8H_{10}N_4O_2$

Spoiler: the Nth Country Experiment nuke design by the PhDs would have gone “b00m!” and was indeed initially meant to be tested “for real” at the NTS to validate this.

References

- Michael Zalewski, "Silence on the Wire: A Field Guide to Passive Reconnaissance and Indirect Attacks", No Starch Press.
- Broadcom firmware development kit: http://www.broadcom.com/products/communications_processors_downloads.php
- The "GPU computing" kit (aka "CUDA"): http://www.nvidia.com/object/cuda_get.html
- Joanna Rutkowska, <http://theinvisiblethings.blogspot.com/atom.xml>
- "dailydave" mailing list VPC discussion, <http://archives.neohapsis.com/archives/dailydave/2008-q1/0083.html> (start of thread)
- Paul A. Karger, "Performance and Security Lessons Learned from Virtualising the Alpha Processor", ISCA '07

References

- Van Hauser (THC) rwwwshell, <http://freeworld.thc.org/papers/fw-backd.htm>
- Opteron Exposed: Reverse Engineering AMD K8 Microcode Updates, <http://www.securiteam.com/securityreviews/5FP0M1PDF0.html>
- Papers by John Heasman (ACPI, BIOS and PCI rootkits):
 - <http://www.blackhat.com/presentations/bh-federal-06/BH-Fed-06-Heasman.pdf>
 - http://www.nextgenss.com/research/papers/Implementing_And_Detecting_A_PCI_Rootkit.pdf
- nth country experiment, <http://www.gwu.edu/~nsarchiv/news/20030701/nth-country.pdf>
- Rowan Atkinson, "Blackadder", BBC TV series.