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ETHERNET POWERLINK

openPOWERLINK over Xenomai

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$ whoami

- French embedded Linux developer, writer and teacher
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POWERLINK

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Industrial bus

- Used to connect industrial devices in real time mode
- Main standards are both “serial” and/or Ethernet
  - CAN
  - MODBUS (-TCP)
  - Profinet
  - EtherCAT
  - AFDX (Avionics Full DupleX)
  - POWERLINK
- Ethernet is a standard
  - Easy to integrate, cheap hardware and good performances (standard CAN is 1 Mbps)
  - Homogeneous networking (routing, etc.)
  - No RT because of collision detection

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POWERLINK

- Deterministic Ethernet based industrial bus
- Originally created by B&R automation (Austria) in 2001
- Managed since 2003 by open organization EPSG (Ethernet POWERLINK Standardization Group)
- Leverage advantages of Ethernet for RT networking systems
- 1.8 M systems installed (2016)
- Min cycle time is 100 µs, 240 nodes on a single network
- Software only → works on standard Ethernet
- Avoid collisions thanks to a software only protocol :-)
- Open-source version (2.x) *openPOWERLINK* available from SourceForge
- Now used by B&R hardware (PLC)

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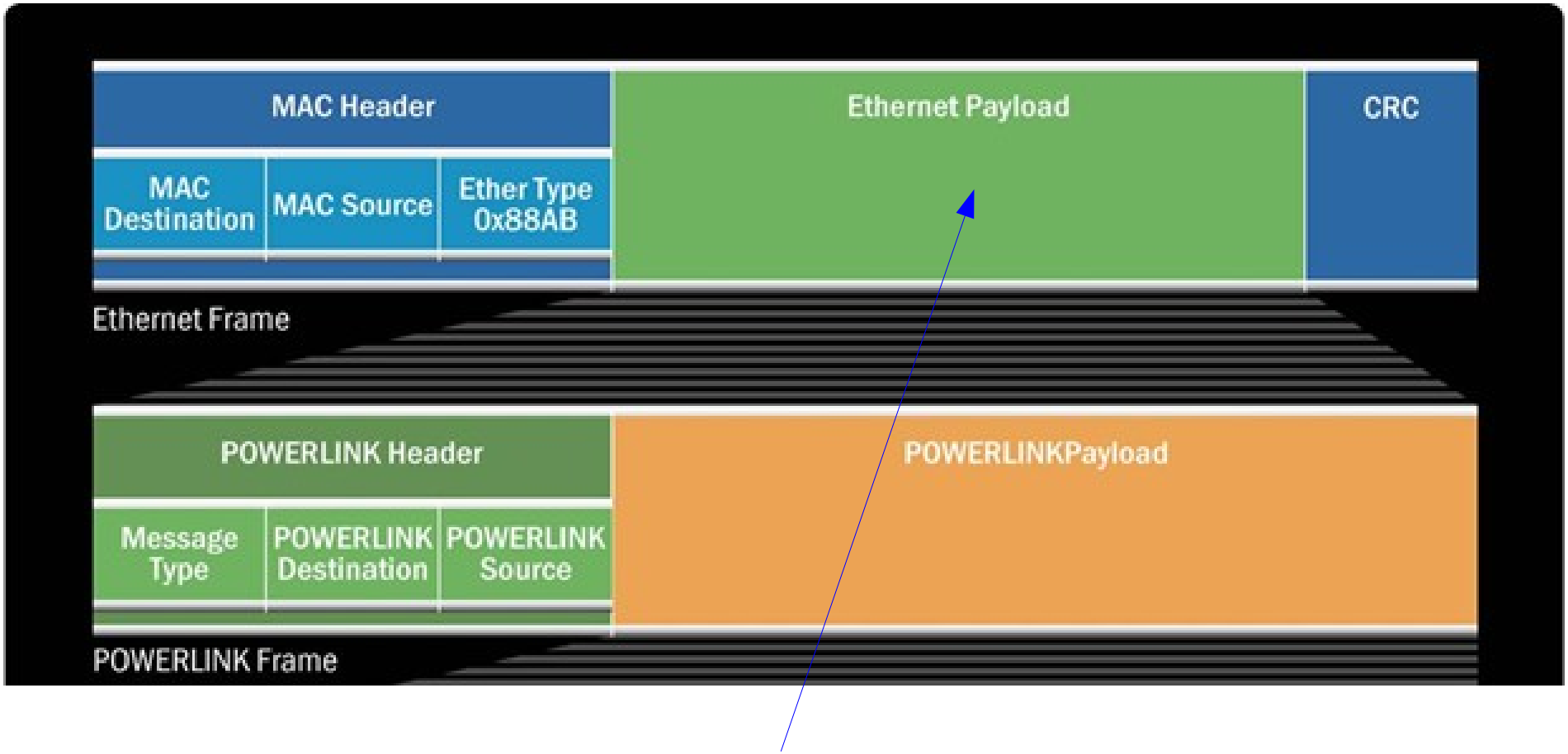
POWERLINK frame



Powerlink frame “inside” Ethernet payload

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POWERLINK protocol

- One “manager” node (MN) and several “controlled” nodes (CN)
- Cycle divided in 3 steps
  - MN synchronizes CNs with a *SoC* (Start of Cycle) frame which starts “isochronous phase” (RT)
  - CN receives *PReq* (Poll Request) from MN, and replies with *PRes* (Poll Response) and data (RT)
  - Last step is “asynchronous phase” (no RT) started with *SoA.* Addressed node should answer *ASnd*
- Standard IP-based protocols and addressing can be used during the asynchronous phase

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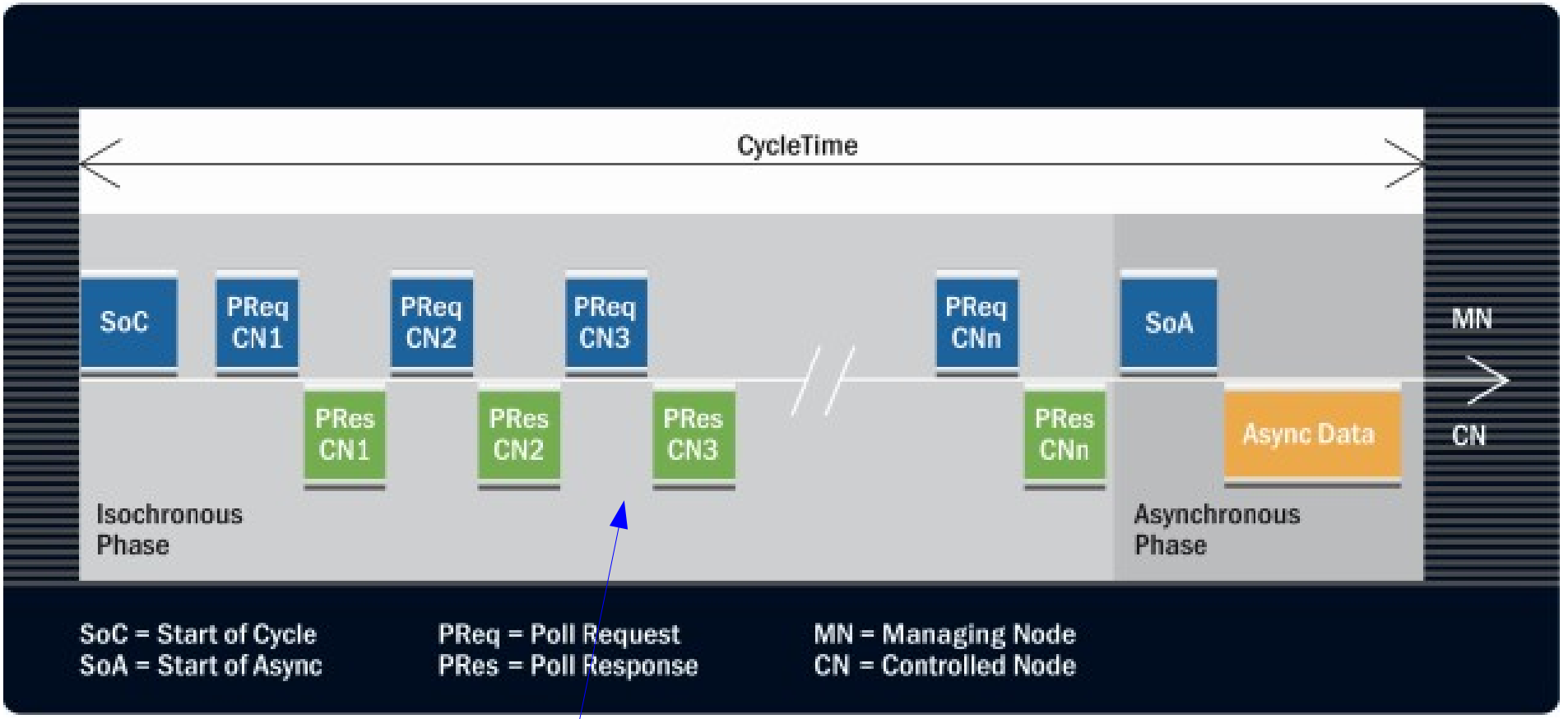
POWERLINK protocol



RT

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openPOWERLINK

- Open source implementation of POWERLINK stack
- BSD license
- Support for Linux, Windows, Xilinx/Altera FPGAs
- Official support for x86, ARM (Zynq)
- CMake based → `CMAKE_TOOLCHAIN_FILE` for cross-compilation
- Buildroot integration by Smile-ECS (latest stable 2.4.1)
- Building process :
  - Stack
  - Drivers (if necessary)
  - Demo applications MN/CN (console, Qt)

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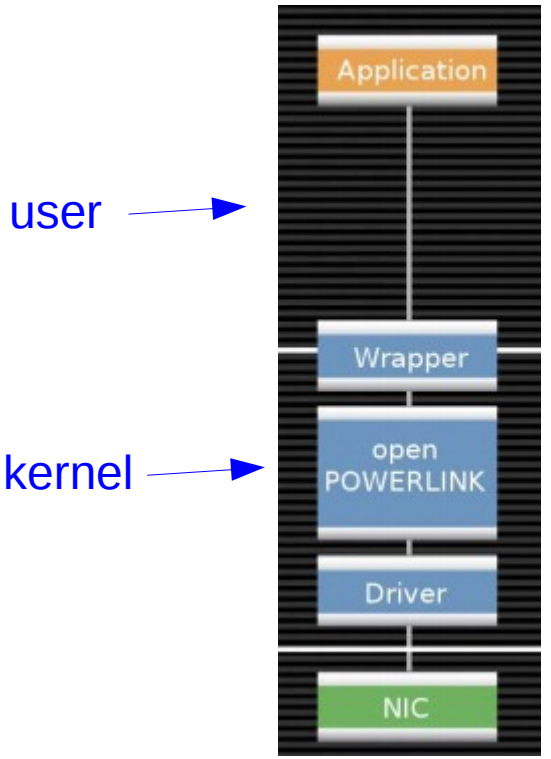
Architecture 1 (kernel)

- Application in user space
- Stack and drivers in kernel space
- High performance and precision
- Specific drivers (`stack/src/kernel/edrv` for Ethernet drivers)
  - About > 10 supported controllers
  - No Linux “mainlining”
- Hard to debug (kernel space)



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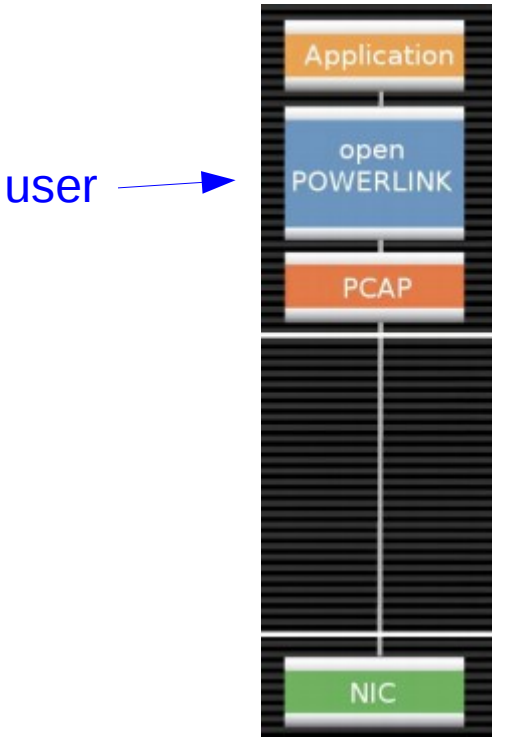
Architecture 2 (user)

- Move stack to user space
- Use *libpcap* library (tcpdump) to talk with standard Linux driver
- Proven solution
- Much easier to debug
- Based on Linux NIC drivers
- Better with PREEMPT_RT patch
- 100 µs jitter (only 40 µs in kernel)



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Xenomai

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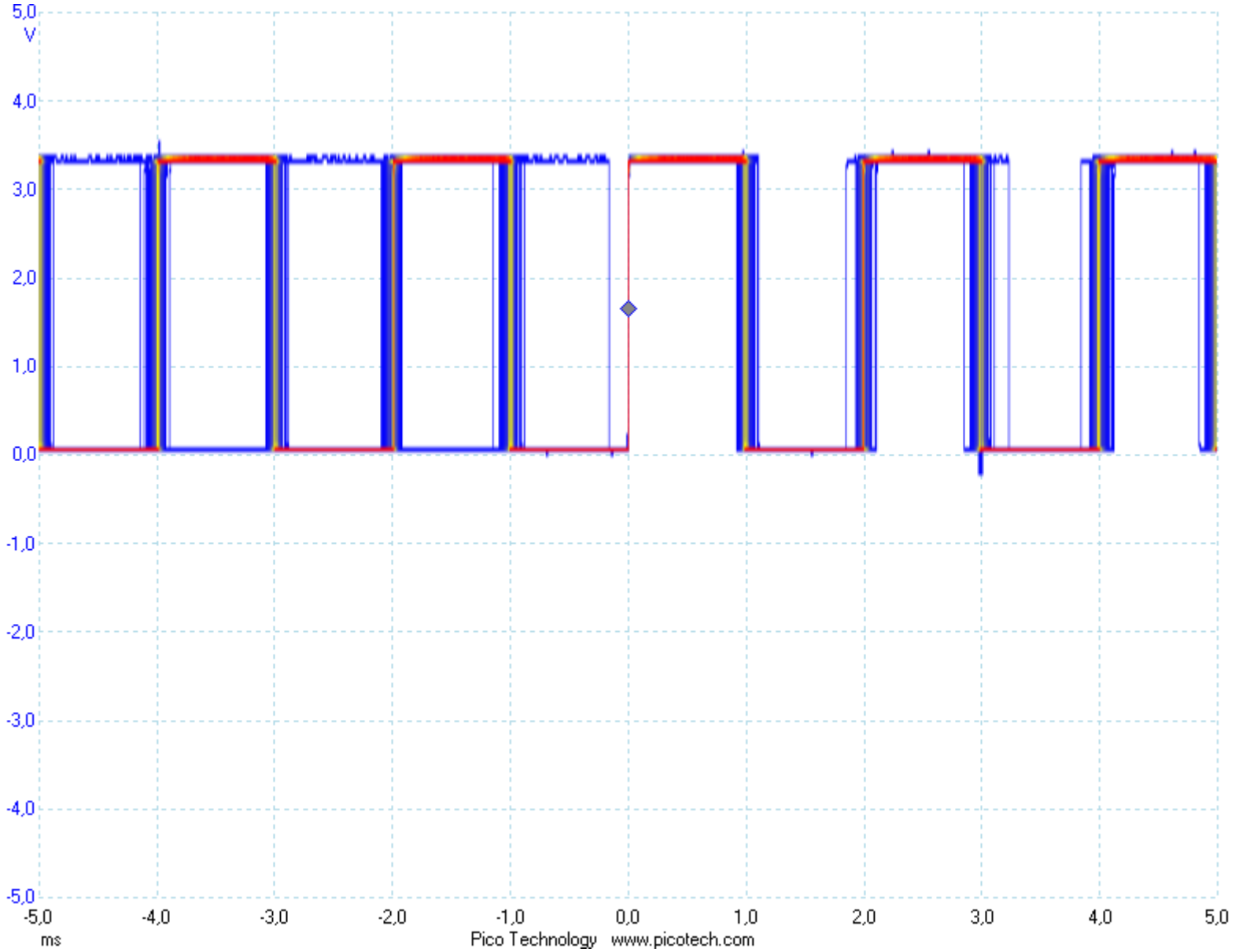
Standard Linux & RT :-(



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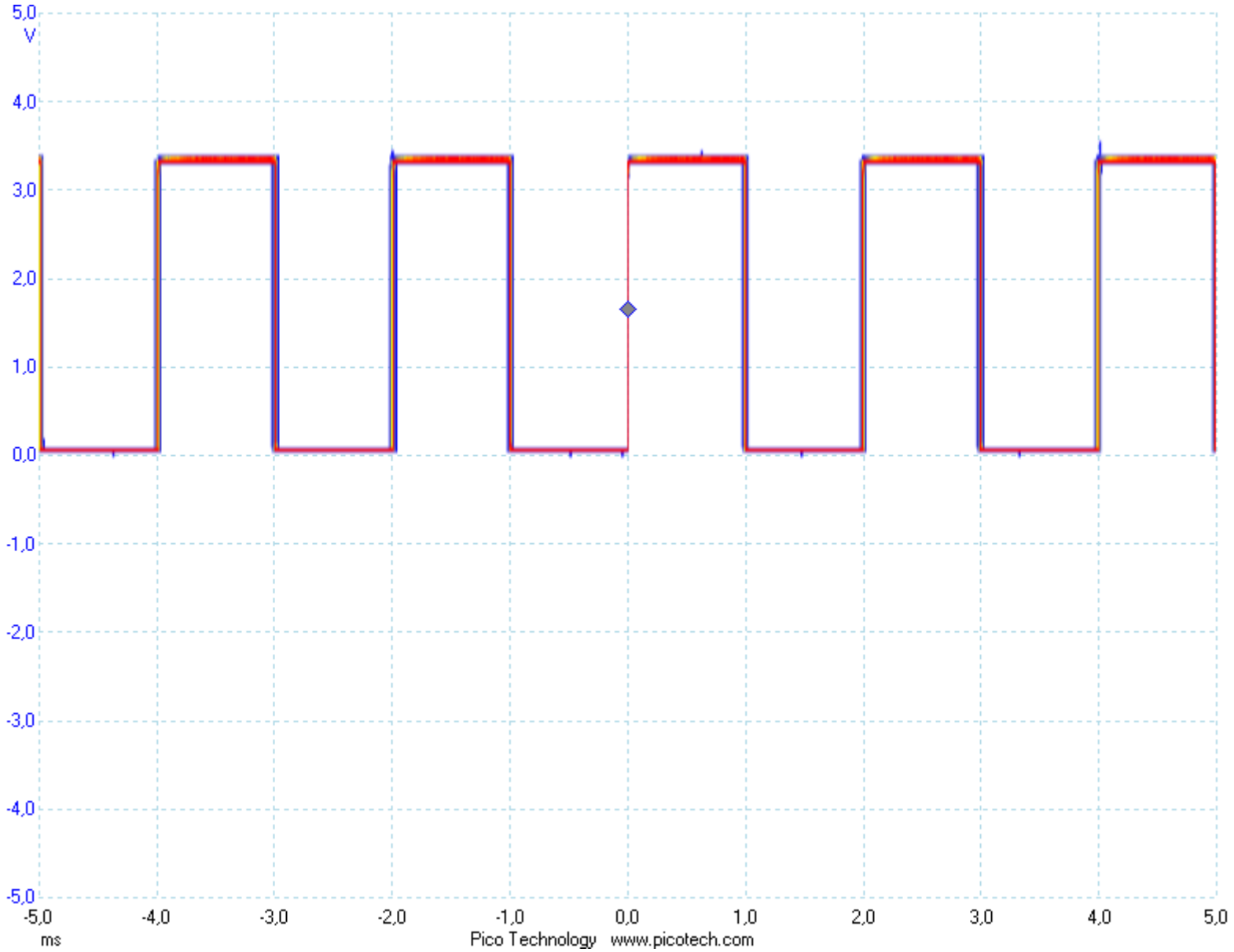
Linux/Xenomai & RT :-)



Linux & RT

- Using Linux as “RTOS” is very interesting
  - POSIX
  - Hybrid approach → UNIX + some RT tasks
  - Usable as a standard UNIX
- 2 solutions :
  - Upgrading Linux kernel RT performance (PREEMPT_RT, the “official” way)
  - Adding a RT “co-kernel” sharing hardware with Linux (RTLinux, RTAI, Xenomai)

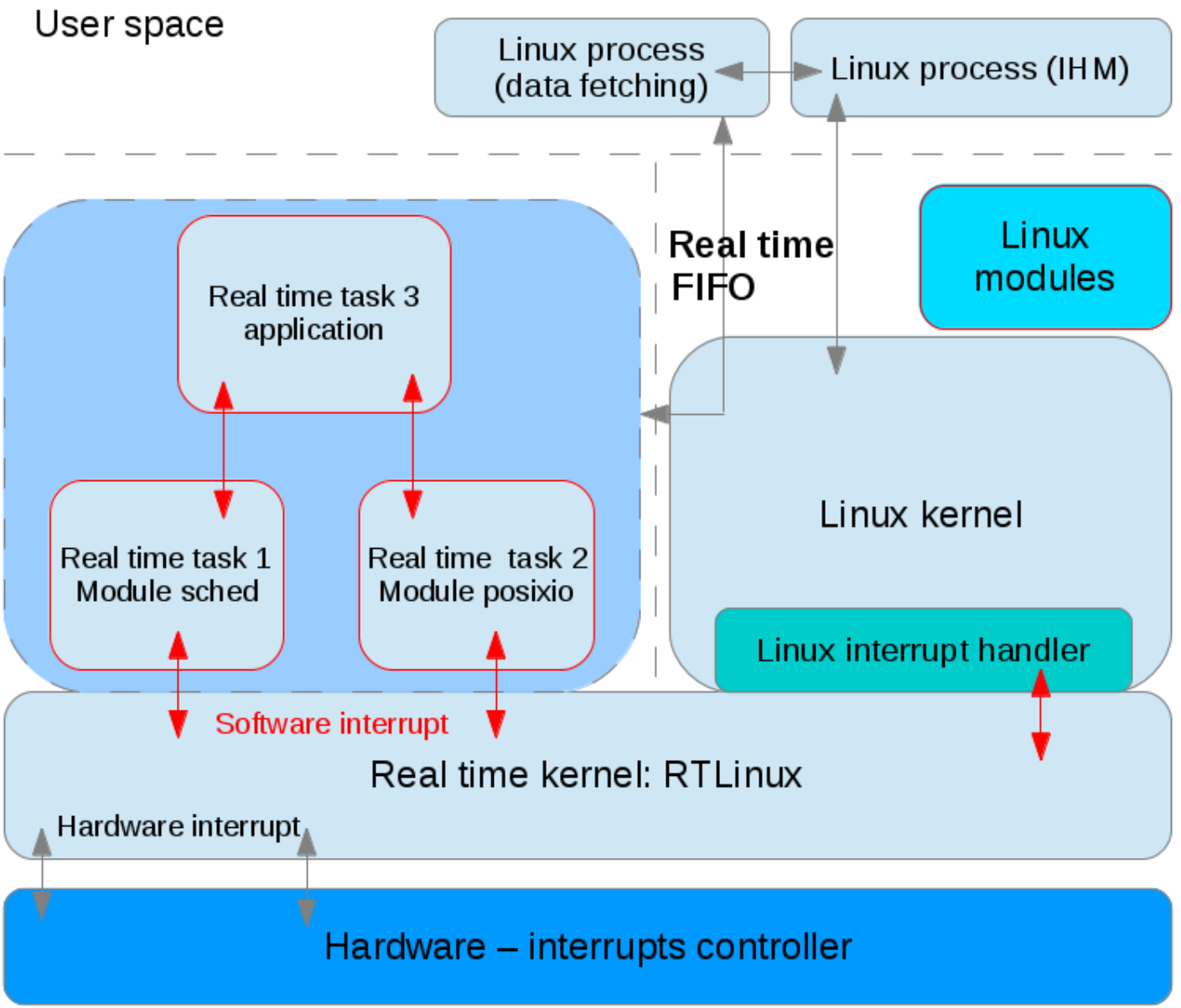
PREEMPT_RT

- Maintained by Thomas Gleixner
- Mostly used on x86 (but runs on most recent ARM, Nios2, Microblaze)
- Needs a mainline kernel (or something like)
- Very easy to install (just a kernel patch)
- Same programming API as standard kernel (user and kernel space)
- 50 µs jitter (x86/Atom), 150 µs on Raspberry Pi B+
- Currently used with openPOWERLINK
- Official project of Linux foundation since Oct. 2015 !

Co-kernel

- Adding co-kernel for RT tasks
  - RT subsystem inside kernel module(s)
  - Needs kernel patch for hardware resource (IRQ) virtualization
- Main projects
  - Kernel only (RTLinux, 1996) → “dead”
  - Kernel & (partially) user space (RTAI, 1998)
  - Full user space integration (Xenomai, 2001)
- 10 µs jitter on Atom/x86, 50 µs on Raspberry Pi B+

RTLinux architecture (kernel only)



Xenomai

- Created by Philippe Gerum
- Xenomai = realtime Linux subsystem
  - RT tasks in user space
  - RT driver API = RTDM for “Real Time Driver Model”
  - RT network stack = RTnet !
- Include “skins” for POSIX, VxWorks, VRTX, uITRON, pSOS+, etc.
- Runs on top of I-pipe (Interrupt pipeline)
  - Xenomai domain (RT)
  - Linux domain (No RT)
- Currently 2.6.5 and 3.0.3
- 3.0 uses co-kernel (Cobalt) or PREEMPT_RT (Mercury)
- GPL license (kernel), LGPL (user)

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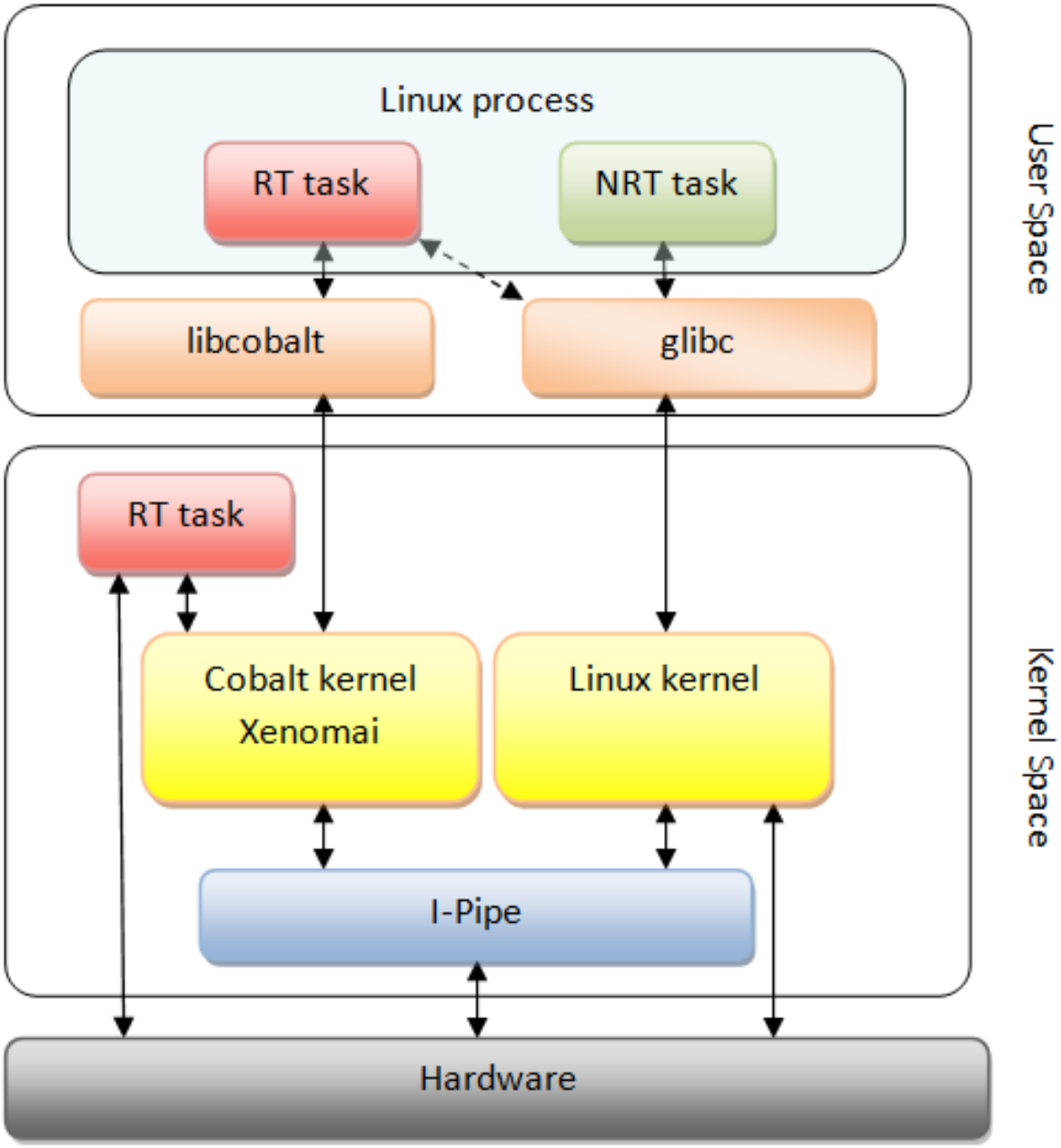
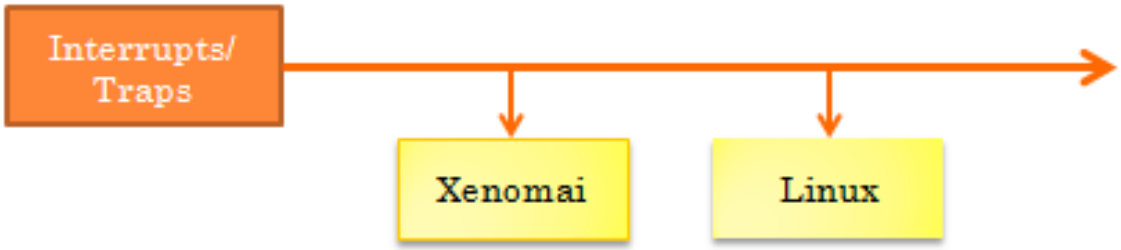
Xenomai 3 architecture (Cobalt)



I-pipe

- I-pipe = interrupt source for “domains” (Xenomai, Linux) based on ADEOS technology
- Highest priority to RT domain (Xenomai)
- Stalled/unstall domain instead of hardware CLI/STI



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Xenomai in industry

- CANFestival (CANopen stack)
- PEAK System CAN boards drivers
- EtherCAT master
- RTDM SPI driver (i.MX28)
- BEREMIZ, integrated development environment for machine automation
- And much more...

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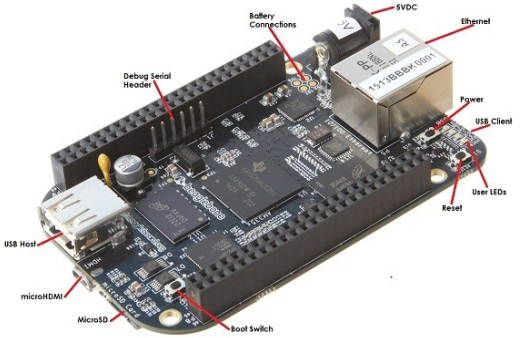
Proof of concept

- Started as 2 internships
  - Damien Lagneux for the first version on i.MX6 boards and Buildroot (Armadeus APF6, RIOTboard → RTnet support for “FEC” controller)
  - Geoffrey Bonneville for improvement and Android testing (AIOSP) on BeagleBone Black
- No Raspberry Pi because of USB based Ethernet (though there is Pi2 port for openPOWERLINK!)
- Using openPOWERLINK in Xenomai domain
- PREEMPT_RT / Xenomai comparison !



RTnet

- Xenomai v2 contribution, merged with v3
- Based on RTDM (protocol device)
- Limited hardware support (dedicated driver API)
  - FEC, AT91, AM335x (BB Black, external contrib)
  - RTL8139, Natsemi, PCnet32
  - MPC8xxx
- Example session (BB Black)

```
# insmod rtnet .ko
# insmod rt_smsc.ko
# insmod rt_davinci_mdio.ko
# insmod rt_ticpsw.ko
# insmod rtpacket.ko
# insmod rtipv4.ko
# rtifconfig rteth0 up 192.168.1.1
# rtroute add 192.168.1.2 00:22:15:80:D5:88 dev rteth0
# rtping 192.168.1.2
```

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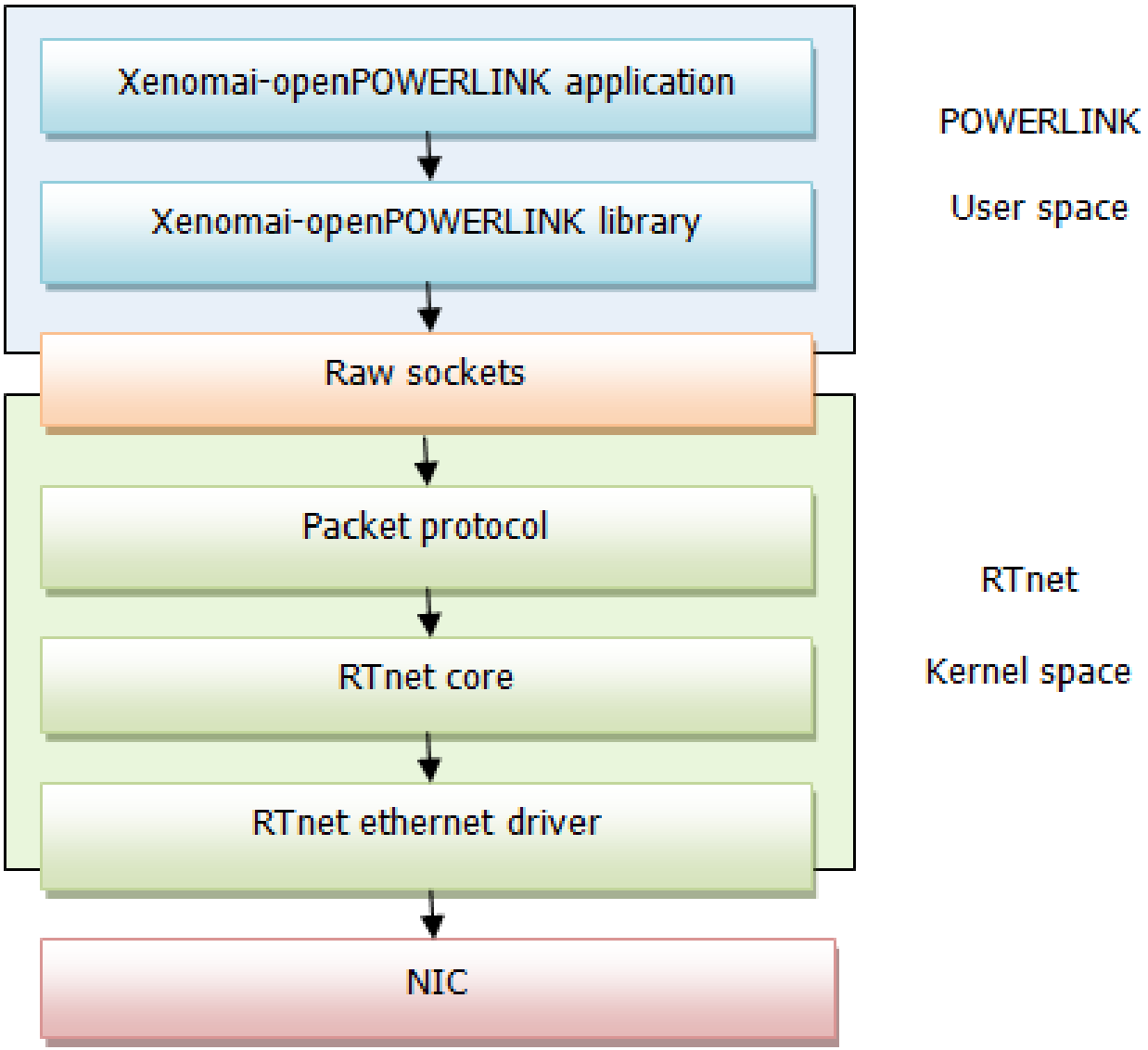
Architecture

- One openPOWERLINK architecture is based on libpcap
- Libpcap (Linux) is based on “packet” protocol
- Xenomai RTnet stack includes packet socket support (“rtpacket” module)
- Porting libpcap to Xenomai is quite difficult !
- Hardware is limited by RTnet driver availability (but it's just an POC !)

Architecture



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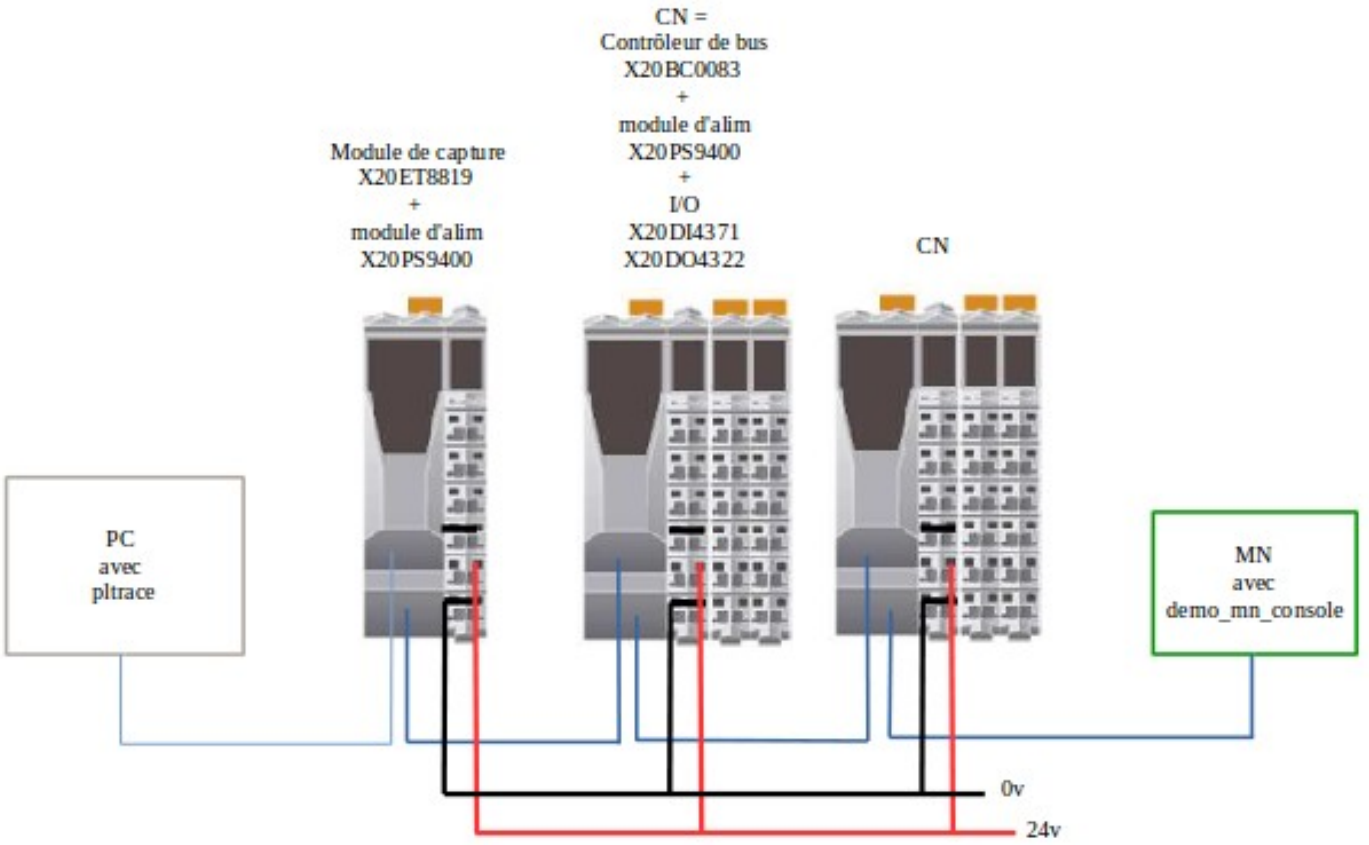
Architecture

- PCAP layer removed
- Sending / receiving packet (through packet socket) directly from/to the openPOWERLINK stack
- RTnet architecture is close to openPOWERLINK “kernel” architecture

Test configuration

- 1 i.MX6 board as MN
- 2 B&R modules as CN
- 1 B&R capture module (timestamping)
- 1 PC for saving frames



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Test and results

- Xenomai solution is close to Linux “kernel” version of openPOWERLINK (architecture 1)
- Based on Baumgartner/Schoenegger/Wallner papers (B&R)
- Stress with cpuburn, dd, hackbench
- Jitter for 500 µs cycle
- Better than PREEMPT_RT !

Xeno		Linux/RT		
-	+	-	+	
15	18	40	48	Idle
17	18	26	25	CPU -> cpuburn
24	24	49	52	HD I/O
24	26	57	56	USB HD I/O
20	22	53	53	SCHED -> hackbench

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Conclusion + future work

- Currently not stable enough for industrial use → stack debug and optimization
- Test with more CN
- Work to be done with B&R
  - mainlining in openPOWERLINK project
  - more test with available POWERLINK devices
- PREEMPT_RT version is fair enough for most projects
- Currently not a strategic market for Smile-ECS (except one customer)

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